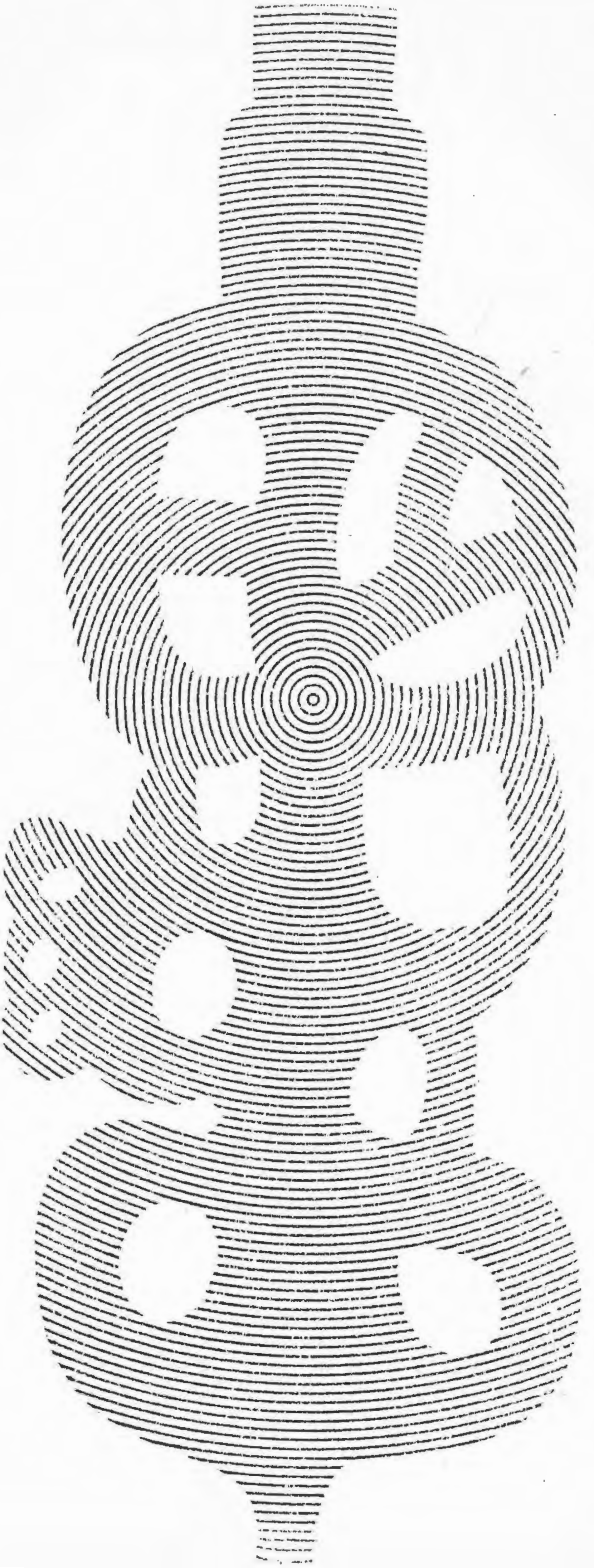

ABSTRACT

At the request of the Earthquake and War Damage Commission, the New Zealand National Society for Earthquake Engineering has assessed the order of loss of building value in the event of a large earthquake in the Wellington region.

Two sizes of earthquake were considered of average return period 250 years and 1100 years. Each event was centred in two different locations.

The study considered only the effect of earthquakes on buildings and their contents. Government owned buildings were assessed separately. Only the value of loss up to assumed indemnity value was calculated, this being the extent of liability of the Earthquake and War Damage Commission.

For the four scenario earthquakes studied, ranges of loss were calculated.

CONTENTS

1.0 INTRODUCTION

1.1 Background and Initial Objectives

On 8 February 1983 the Secretary of the Earthquake and War Damage Commission requested the New Zealand National Society for Earthquake Engineering to consider "setting up a working party to gauge the maximum probable loss the Commission may suffer by way of claims for insured tangible property in the event of a large earthquake hitting New Zealand with its epicentre being in Wellington".

By May 1983 a Study Group had been formed and the task described as follows:

"1 Determine the maximum cost of physical damage to buildings, structures and services which could credibly be expected to result from an earthquake in the Wellington region. Because of the difficulty of selecting any single event it is envisaged that the group would study two or three earthquakes selected for the combination of high cost of damage and probability of occurrence, assessing both the costs and probability of each event.

2 Separate the total cost into that which would be borne by

(a) the Earthquake and War Damage Fund;

(b) central government;

(c) all other parties (i.e., uninsured or unknown)."

Intermediate tasks envisaged were described as follows:

"- critically review available published information on assessment of seismic loss making any adjustment necessary for the New Zealand situation;

- describe envisaged earthquake(s) for study and assess return periods (possibly three, giving rise to MM X, IX and VIII in downtown Wellington);

- consider the effects of geological hazards, such as faulting, landslides, liquefaction and settlement;

- assess effects of microzones;

- estimate building stock and classify from structural point of view;

- assess cost of direct seismic damage to structures and non-structural elements to buildings by class and location;
- assess cost of fire, flood and other earthquake-induced risks;
- assess the reliability of the calculations;
- consider the effects of trends in replacement of existing structures."

1.2 Changes to Scope

During the course of the work, for a variety of reasons, some objectives listed in the brief of May 1983 were not pursued. The changes were as follows:

- Losses to structures and services other than buildings were not considered. Data on current value and the likely extent of damage to these were not readily available, and the Earthquake and War Damage Commission advised that they were not required to be included.
- Losses considered were limited to loss of current market value. Although the brief could have been interpreted as including extra costs of rebuilding or costs such as loss of production, the Study Group understood that this had not been intended.
- Because of the lack of data on the extent to which properties were insured to full indemnity value, it was not found possible to separate costs to the Earthquake and War Damage Commission from those to uninsured or under-insured building owners other than central government.
- The effects of geological hazards were not studied. A previous study by Dowrick(25) found that this aspect was insignificant.
- The specific costs of earthquake-induced flood or fire were not assessed as they were considered to be allowed for in the Mean Damage Ratios used.

2.0 OUTLINE OF STUDY

The following outline summarises the principal steps involved in the loss assessment. Greater detail of the process followed in each of these steps is provided in the corresponding sub-sections of section 4.

2.1 Review of Literature

An initial review was made of overseas and New Zealand literature thought likely to be relevant. The main thrusts of this were to consider approaches used in comparable studies, and to assemble data on which the relationships between building damage and intensity of ground shaking could be developed. Reference is made to many of these sources in the text of this report.

Specific study was also made of four previous estimates of damage due to a large earthquake in the Wellington region, referred to in section 4.1. The differences between the results of these studies confirmed the need for an independent review of their conclusions.

2.2 Selection of Earthquakes

Four scenario earthquakes, all with Modified Mercalli Intensity of MMX in the area near source, were selected for study as follows:

Event 1: Centred near Palmerston North with an intensity of MMIX in Wellington.

Event 2: Centred near Blenheim with an intensity of MMIX in Wellington.

Event 3: Centred near Palmerston North, with an intensity of MMX in Wellington.

Event 4: Centred near Blenheim with an intensity of MMX in Wellington.

Events 1 and 2 were assessed as having an average return period of about 250 years, and events 3 and 4 about 1100 years.

The basis of the selection of these events is described in section 4.2.

2.3 Distribution of Intensity of Ground Shaking

The assessment of distribution of seismic intensity for each of the events was based on the work of Dr W D Smith (22) for weakly-attenuated, or type B, earthquakes. From these were developed isoseismal maps of each of the four events. Figure 1 shows the distribution of intensity of shaking for each event.

For the Wellington metropolitan area only, the seismic intensities thus derived were further refined to take account of local variations of ground type. The adjustments made to the basic MM intensity levels for such microzone effects were as set out in Table 1.

TABLE 1: MICROZONE ADJUSTMENTS MADE FOR WELLINGTON METROPOLITAN AREA

Ground Description	Increment to Base MM Level
Basement rock	-1
Compact sediment (assumed "average ground")	0
High porosity sediment	+1
Deep alluvium	+2

These matters are examined in greater detail in section 4.3.

2.4 Valuation and Classification of Buildings

An attempt to obtain valuation and structural classification information from local authorities in the affected area had very limited success. Consequently, the current values of buildings in the study areas were obtained from Valuation Department data[24] updated to a common base date of March 1983. These valuations were taken to represent "indemnity value", which is the measure of maximum liability of the Earthquake and War Damage Commission. Different methods were used in the compilation of data for housing and for other buildings, as described in section 4.4.

Buildings were classified into five types based on Valuation Department data, as follows:

(a) houses
(b) unreinforced masonry
(c) pre 1936 reinforced concrete
(d) 1936-1977 reinforced concrete
(e) post 1977 reinforced concrete

For Wellington City, structural classifications prepared by the City Engineer's Department were used where available to confirm the classifications obtained from Valuation Department data.

2.5 Relationships between Intensity and Building Damage

The assessment of "mean damage ratio" for each building class and for each level of seismic intensity was based on a detailed survey of published information in earlier studies. The information derived from these sources was assessed for its appropriateness to New Zealand conditions, and for reliability. The figures derived in this study incorporated adjustment where considered necessary to retain consistency between building classes, using the method described in section 4.5.

The relationships between seismic intensity and building damage used in the study for each of the five building classes are summarised in Figure 2, section 4.5.

The large scatter in available data was used to produce a range of damage ratio for each building type and each level of intensity. Thus computation of a range of loss estimate resulted.

2.6 Building Contents

The cost of damage to building contents was assessed as a proportion of upper and lower values of estimate of damage to the building. The proportions used were as follows:

Housing	one third
Other buildings	60%

2.7 Computation of Damage Costs

Data described in sections 2.3 to 2.6 were assembled in the Ministry of Works and Development computer, and losses calculated for each event from

$$\text{Loss} = \sum (1 + C)(R \times V)$$

where "R" is the Damage Ratio for the building, dependent on both intensity of ground shaking and building classification and whether upper or lower end of range of estimate

"V" is the assessed indemnity value at March 1983

"C" is the proportionate value of contents lost.

This calculation was carried out for all listed buildings, and the loss incurred by Government-owned buildings separately assessed as a proportion of the total loss.

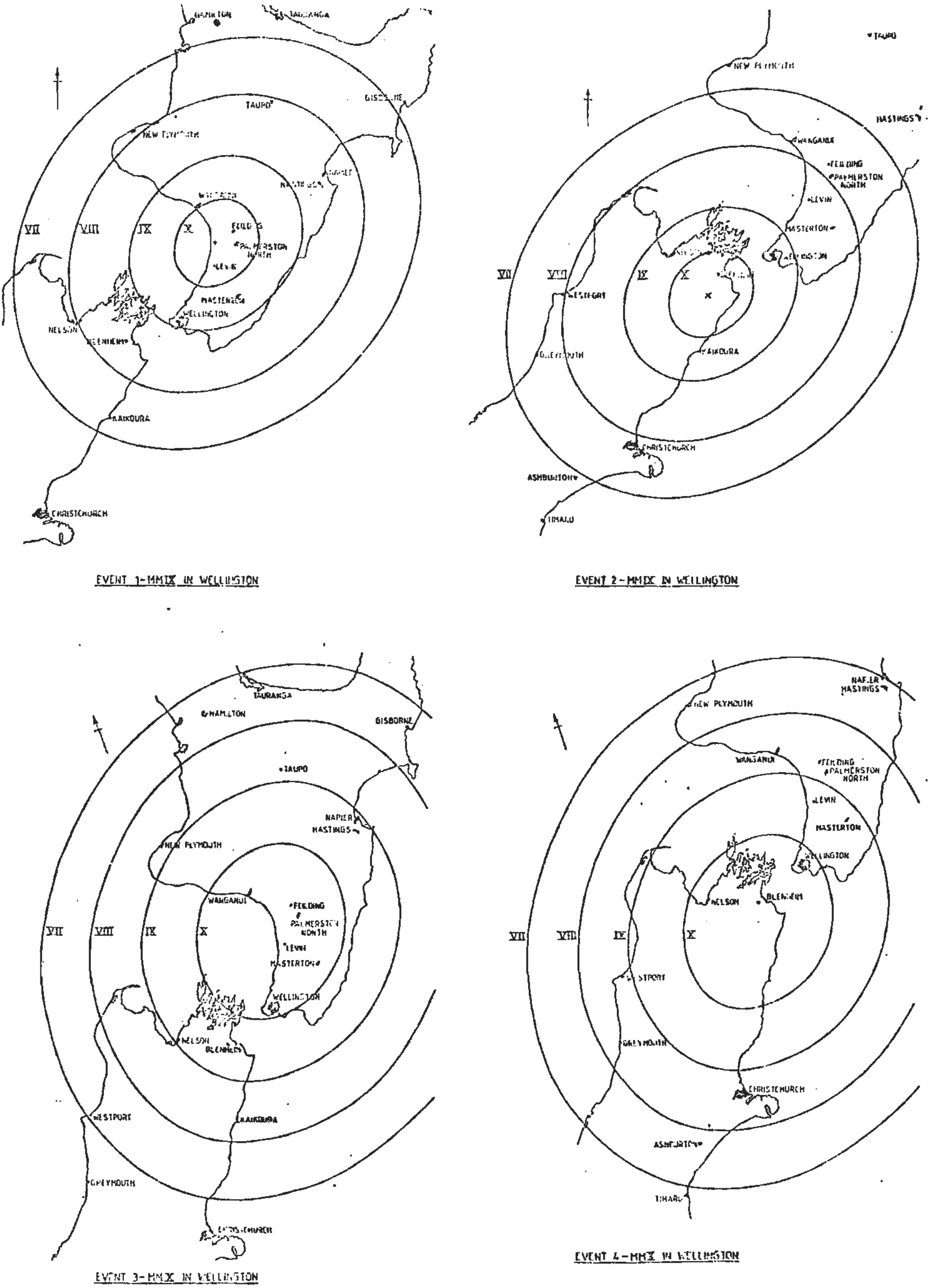

Fig. 1.

Earthquake Events Studied

TABLE 2 ESTIMATED LOSS OF CURRENT VALUE, BUILDINGS AND CONTENTS				
Category of Loss	Loss Range (note 1) $ million as at March 1983			
↓ Event →	EVENT 1	EVENT 2	EVENT 3	EVENT 4
Loss of Building Value				
Houses	840 to 1250	610 to 900	1160 to 1740	970 to 1440
Other Buildings	1550 to 3520	1120 to 2500	2840 to 5120	2380 to 4050
Loss of Contents Value				
Houses	280 to 420	200 to 300	390 to 570	320 to 480
Other Buildings	930 to 2110	670 to 1500	1710 to 3070	1430 to 2430
Total Loss of Value	3600 to 7300	2600 to 5200	6100 to 10500	5100 to 8400
Distribution of Loss				
Central Government	270 to 540	190 to 340	440 to 780	340 to 580
Balance (note 2)	3330 to 6760	2410 to 4860	5660 to 9720	4760 to 7820

Notes 1. For building losses the range shown is ± one standard deviation. For contents the range is as set out in section 4.6.

2. The balance of loss shown is the loss to the Earthquake and War Damage Commission, assuming all properties, other than those owned by Central Government, to be insured to full current market value.

3.0 RESULTS OF STUDY

3.1 Table of Losses

Table 2 sets out the range of losses estimated to result from each of the four scenario earthquake events. The losses are separated into houses and other structures, and contents of each of these. The total losses are then divided into those estimated to be borne by Central Government, and the balance which represents the liability of the Earthquake and War Damage Commission assuming all non-Government buildings to be insured to full current market value. In practice this loss will be partly borne by uninsured and under-insured building owners, but as the Study Group could get no access to data on the extent to which properties are fully insured, no division between these parties was possible.

Finally, it should be noted that these estimates relate only to losses of current market value of the buildings and contents. The total cost which the community may have to bear will include the difference between indemnity value and restoration/replacement cost, cost of loss of production and other costs, the determination of which is outside the scope of this study. These could increase the estimates by a very large margin.

3.2 Sources of Error

The principal source of doubt in the results of the study is considered to be the error in the Mean Damage Ratio versus Mercalli Intensity relationships (see section 4.5). This has been taken into account in the range of building losses shown, which allows for ± one standard deviation in the estimation of these factors. Other sources of error which contribute to the uncertainty of the final result include:

- distribution of earthquake intensities;
- the limited number of building classes used in the study;
- market value;
- indemnity value (in this study assumed equal to market value);
- assessment of damage to contents.

These sources are difficult to quantify and no estimation has been made of the error resulting from them.

3.3 Independent Check of Results

Based on data from studies for the New Zealand South British Insurance Group[9], some approximate independent checks were made on some of the findings of this report[25]. All of the components giving rise to loss estimate were determined independently, viz

- MDR/MM relationships,
- building values,
- contents values,

and the method of apportioning liabilities between the Commission and insurance companies. The following estimates were made for houses and other buildings including contents:

		(cf Present study - average values)
Total replacement value in affected zone	$24,000 m	
Total "market"* value in affected zone	$20,000 m	($25,000 m)
Earthquake and War Damage Commission liability (MM IX in Wellington)	$ 4,000 m	($ 4,340 m)**
Earthquake and War Damage Commission liability (MM X in Wellington)	$ 6,800 m	($ 6,990 m)**

The results are considered surprisingly close.

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* Market value for buildings, but the term "market" does not strictly apply to contents.

** Assuming non-Government buildings fully insured.

4.0 DETAILED ACCOUNT OF STUDY

4.1 Review of Literature

.1 Studies on four previous estimates of damage resulting from earthquake in the Wellington region were examined. The wide range of results detailed in subsection .5 confirmed the need for an independent study. The main thrust of subsequent literature review was concerned with obtaining relationships between value of damage for each class of building an intensity of ground shaking. In addition, published studies describing the spread of intensity zones as a result of the four scenario earthquakes were examined.

.2 Previous studies prepared for the Commission

In 1982 results of two studies commissioned by the Earthquake and War Damage Commission were presented to them.

The first, by Sedgwick Ltd, examined the effect of an earthquake of Richter magnitude 8.2 centred in Wellington. A total building value for the Wellington area was assessed and multiplied by an "average damage rate" of 28.4%, to give the "direct damage" cost. This product was multiplied by 19% to give the estimated value of damage to contents. It was assumed that 60% of the value of direct damage plus loss of contents would further result from fire and allied effects. A small figure was added for automobile damage and "all other damage" was assumed to amount to 10% of the direct damage cost.

The sum of these components gave a total estimate of loss of $1,654 million.

The second study, by a consortium of four insurance brokers is less clear in its statement of method. However, they considered the occurrence of a earthquake of modified Mercalli Intensity of IX or higher occurring in Wellington.

This study gave a total estimate of loss of $2,800 million.

However, the two studies give less comparable results than the values indicate. This is because a Richter magnitude 8.2 event could lead to a modified Mercalli Intensity of X or XI, rather than IX. A doubling of the loss estimated from the second study is therefore possible when the results is scaled up to reflect the event described in the first study. A threefold difference in result between the two studies is therefore apparent.

.3 Darwin study

In 1980 Darwin[7] estimated the total building and dwelling loss as a result of two envisaged earthquakes in Wellington giving rise to values of modified Mercalli intensity of VIII and X in Wellington City. Buildings were divided into pre- and post-1968. Two areas containing half the commercial floor area in Wellington City were examined and the balance of building floor area for the two building classes in both Wellington City and surrounding affected communities assessed on a pro rata basis. Darwin assessed damage versus Mercalli Intensity relationships for the two building types as well as for dwellings and asserted that his total loss estimates could be doubled to take into account the loss of "fittings and facilities" and thus final loss estimates of $590 million and $1,120 million result.

The value of dwelling loss was about half the loss of commercial buildings in both events.

.4 Dowrick study

Dowrick[8] carried out an estimate of loss to properties insured with the NZ South British Insurance Group as a result of two earthquakes in turn, giving rise to modified Mercalli intensity volumes of IX and X in Wellington City. The former event gave rise to 39% of the damage cost predicted for the latter event. General estimates of the level of damage were refined by detailed surveys of the most valuable properties insured and assessing the damageability of the structure, architectural components, building services and equipment.

.5 Summary of results of previous studies

The results of three of these studies may be compared by inflating estimates to March 1983 values, the values used in the present study, using the Ministry of Works and Development Construction Cost Index:

Sedgwick (MMX+)	$1,700 million
Insurance broker consortium (MMIX+)	$2,800 million
Darwin (MMX)	$1,710 million

As indicated previously, the figure of $2,800 million is calculated for a seismic event less severe than the events considered for the other two studies. Hence the scatter of results for equivalent events is considerably wider than is immediately apparent.

4.2 Selection of Earthquakes

.1 Events selected for previous studies

Both Darwin[7] and Dowrick[8] have undertaken studies in recent years using a selection of scenario seismic events centred in Wellington. The earthquakes used are summarised below.

Darwin[7]

1 Richter magnitude 7.5, epicentral intensity MM X, epicentre Ngauranga:
   - the "largest likely earthquake".

2 Richter magnitude 6.5, epicentral intensity IX, but intensity VIII in Wellington City having a return period of 50 years, epicentre Ohariu Valley:
   - a "frequent medium sized earthquake".

Dowrick[8]

1 Richter magnitude 7.9, epicentral intensity IX, return period 1000 years.

2 Richter magnitude 8.0, epicentral intensity X, return period 9000 years.

.2 Events selected for this study

While, as Steinbrugge[13] points out, both potential monetary losses from a large disaster and the average annual loss from all earthquakes over long periods of time are of interest, the present study was directed to concentrate on the former problem. The latter is clearly of interest in setting insurance premiums but was not considered for this study.

For the present study Dr W Smith, Superintendent of the DSIR Seismological Observatory, kindly provided us with his latest estimates of seismicity parameters which have since been published[21]. It was decided to look at events resulting in modified Mercalli intensity values of IX and X in Wellington City.

Because Smith's seismicity model does not require epicentres to be located on known faults but rather models the diffuse nature of epicentral location, we did not feel constrained to set the epicentres of our scenario events on faults. Epicentral locations were selected for the two events chosen so that:

- Smith's more weakly attenuated Type B[22] earthquake would apply and hence maximise the area of damaging effects;

- areas as far to the north of Wellington and also as far to the south as possible would be affected (see Figure 1) according to the isoseismal formulae determined by Smith[21]. Thus two earthquakes for each value of MM Intensity in Wellington were chosen, a total of four events.

The values of Richter magnitude for the scenario events were calculated in the same way as explained by Dowrick[8] to obtain most likely values. The frequency distributions are annexed as Appendix II. The values of Richter magnitude occurring most frequently are 7.8 for the MM IX events and 8.4 for the MM X events (8.2 was used because of the uncertainty of the cut-off maximum value.) The average return periods for the events can be computed from Appendix II as

MMX : 1100 years
MMIX: 246 years

The latter value compares well with the value of 220 years calculated by Smith and Berryman[26] using the same seismicity model.

4.3 Distribution of Intensity of Ground Shaking

.1 Isoseismal maps of events

The isoseismal maps of each of the four scenario events studied, based on Dr Smith's work, are as shown in Figure 1.

.2 Microzones

Large variations in the nature and intensity of ground shaking during an earthquake can occur within quite short distances. Corresponding "anomalous" distribution of building damage can therefore result in built-up areas. The sharp variations in shaking and damage can be correlated with the nature of the ground at respective sites. Attempts to delineate these different soil types are known as microzoning.

An attempt to allow for effect of microzoning is included in modern seismic design codes. For example, Milne and Rogers[19] report that the Canadian code recommends a 50% increase in the calculation of loading for structures on soft soils (this corresponds to an increase in modified Mercalli intensity of about three quarters of a step). The New Zealand Loadings Code[12] requires a lesser increase.

Table 3 shows a range of approaches to microzoning compared with the approach used for this study. In each case the figures represent an increase or decrease to "average ground" MM values.

TABLE 3: COMPARISON OF ESTIMATES OF MICROZONE EFFECTS

Ref	Ground Description	Increment
(1)	Igneous rocks	- 1
	Franciscan formation	- 1
	Pre-tertiary marine and non-marine sediments	0
	Tertiary marine sediments	0
	Alluvium	+ 1
(2)	Rock (eg, granite, gneiss, basalt)	- 1
	Firm sediments	0
	Loose sediments (sand, alluvial deposits)	+ 1
	Moistened sediments, artificially filled ground	+ 1½
(16)	Good ground	0
	Identificable bad ground (eg, reclamation)	+ 2
	Recent alluvium or volcanic ash	+ 3
(17)	Basement rock, except for crush zone of (Wellington) fault or within 10 m of surface	0
	Compact sediment	+ 1
	High porosity sediment	+ 2
	Deep alluvium	+ 3
Assessments used for this study		
	Basement rock (with exclusions as ref 17	- 1
	Compact sediment (assumed average ground)	0
	High porosity sediment	+ 1
	Deep alluvium	+ 2

In the present study, microzone considerations have been applied only to buildings in the Wellington metropolitan area. Reference (18) proposes microzones for Wellington City and Berryman's recommendations[17] have been used here with the assumption that "average ground" is the middle of the three subdivisions in reference (18). The study of Smith[20] forms the basis for calculating the spread of earthquake shaking effects from the earthquake source in this study and assumes average ground conditions. Hence, for Wellington City, the "average ground" intensity (MM) values were decreased by one unit for "basement rock" conditions and increased by one unit where "high porosity sediments" underlaid the buildings. All buildings in Lower Hutt were assumed to be founded on soft soil (deep alluvium) and the "average soil" MM value incremented by 2; an increment of 1.5 was applied to buildings in Petone(17), where ground conditions were considered to fall between the last two categories.

This refinement was not considered justified for buildings outside of the Wellington metropolitan area or houses in any area, as the total value of building concentrations experiencing severe shaking would be much less, by comparison.

4.4 Valuation and Classification of Buildings

.1 Indemnity value

Under the 1944 Earthquake and War Damage Act, all property insured against loss or damage by fire becomes automatically insured for earthquake damage, up to the level of the property's indemnity value.(9)

Says Sherburd(9), "Indemnity value is not defined in the Act, nor in insurance policies and many recent Court of Appeal decisions confirm that there is no single simple formula for establishing indemnity value."

Thus, there is difficulty at the outset in determining indemnity value for any property. While the quantity has also been described as "replacement value minus depreciation",(9) neither of these quantities is readily available.

However, we were advised(10) that the Valuation Department's "equalised value", ie, current valuation for the covered property would be a satisfactory approximation to "indemnity value". As discussed subsequently, this information was available. For the purposes of this study, it was therefore decided to use Valuation Department statistics(24) and computerised data "equalised" to March 1983 as the measure of both indemnity value and current market value.

.2 Building classifications used in Californian studies

In principle, the finer the subdivision of building classes, the less the error in estimate of damage for each class. Algermissen et al(1) divided building types in the San Francisco Bay area into five broad classes, and further subdivisions resulted in no fewer than 26 descriptions of building type. From this study, simple linear damage/intensity curves were estimated.

In studies such as the present one where large numbers of buildings are involved, a more crude classification is necessary because of the nature of the basic data. Whitman et al[4], in documenting characteristics and earthquake damage of buildings shaken by the 1971 San Fernando earthquake, found that it was necessary to limit the documentation to:

- date of construction;
- number of storeys;
- valuation or gross area;
- geographic location.

In a questionnaire, respondents were asked to indicate simply whether the building was constructed of steel, concrete or brick masonry. It was felt that it was beyond their ability to differentiate further, eg, to describe their building as a frame or shear wall structure. Thus, a further subdivison into structural material type was possible. However, there were no brick masonry buildings in the region surveyed.

.3 Classification data available

In the course of the present study the Study Group wrote to 89 local bodies in the region affected in the event of the scenario earthquakes. We sought information on the form and availability of their data for buildings other than houses. The text of the letter appears in Appendix I. Most local bodies replied to our letter and the resulting conclusion was that, with the significant exception of Wellington City Council, local body building records were generally incomplete and would have to be searched and transcribed by hand. This was not practicable for the present study, and it was therefore decided to limit classifications to those which could be made from Valuation Department data.

The Valuation Department listings categorise the building structure only in terms of the materials visible to an observer standing outside the building. Clearly there is no possibility of distinguishing, for example, between a frame and shear wall structure and, moreover, the interior structural material may not be that which is visible to the observer. However, all other data required by Whitman et al[4] is available in these listings and the date of construction can be used to a certain degree to correct apparently wrong inferences of the structural material type, eg, a building constructed in the 1940's would not be expected to be of unreinforced brick masonry.

The Wellington City Council had kindly made available to the study group its records for the central business district. Wellington City Council seismic classification values were added to the Valuation Department building descriptions where possible and used to confirm the relevant classifications.

From this data it was possible to group buildings by the following classes:

(a) houses (assumed timber-framed);

(b) unreinforced masonry;

(c) pre-1936 reinforced concrete;

(d) 1936-1977 reinforced concrete;

(e) post-1977 reinforced concrete.

The year 1936 is taken as the final year during which buildings not designed for earthquake resistance were completed. 1977 is the assumed final year for which buildings not designed to the current Loadings Code (NZS 4203:1976)[12] were occupied.

4.5 Relationships Between Intensity and Building Damage

.1 Seismic intensity and damage

In the modified Mercalli scale, levels of seismic intensity are defined by direct reference to effects on buildings. The threshold of building damage in New Zealand conditions occurs at an MM value of VI or VII.[4,11]

Summarising the effects of the San Fernando earthquake of 1971, Whitman[4] notes the following trends among the concrete and steel buildings:

MM VI — Most buildings suffered no damage. Some buildings had partition wall cracks but only to a very limited extent.

MM VII — Significant damage to the pre-1933 (pre-seismic design) buildings, while the performance of the modern buildings, both steel and concrete, was very satisfactory. Repair of cracks and partition walls accounted for most of the damage.

MM VII.5 Only the post-1947 (seismic design) steel buildings did not suffer extensive damage. The post-1947 concrete buildings were damaged considerably.

MM VIII Modern concrete buildings received very extensive structural damage.

.2 Mean damage ratios

The "Mean Damage Ratio" (MDR) expresses the value of damage to a building, resulting from earthquake shaking to a given value of modified Mercalli intensity (MM), as a proportion of the value of the building in its undamaged state. It is assumed that the value represented by the numerator is the cost of repairing the damage.

The relationship between MDR and MM clearly depends on the nature of the building structure. As an example, unreinforced brickwork would be expected to experience far greater damage at a given value of MM than a modern reinforced concrete building.

The limited quantity and reliability of data available to assess mean damage ratios for the various MM intensities and building classification types were a serious difficulty for the study. Dowrick(8) had earlier found that determining damage ratios appropriate to New Zealand was difficult because:

"(a) few data exist on a world scale;

(b) even less data is available for New Zealand;

(c) most existing data is poorly documented and vaguely defined;

(d) there is very wide scatter in the data;

(e) data does not exist for all New Zealand types of construction; and

(f) data is virtually non-existent for very high intensity shaking (because this occurs very rarely, especially in built-up areas)."

Algermissen and Steinbrugge(11) state that:

"The most useful published sources of loss data are found in the studies of the most recent earthquakes, although data extending back to the 1906 San Francisco shock still have substantial value. A review of several publications showed that the damage data in the publications are not usually compatible. Further, a more detailed review of all major sources shows that data are far from complete for all intensities for all building classes."

.3 Selection of MDR's for the study

The mean damage ratios used for this study are summarised in Figure 2. They were derived from a variety of sources as shown in Figures 3-6, with different sources being used for the different building classes referred to in section 4.4.3.

Buildings of class (a), housing, were assumed to be timber framed. MDR/MM data for timber dwellings in the United States[15] was plotted together with a single estimate for New Zealand from Cooney and Fowkes[14]. This correlated well with the US information (Figure 3). Based on the two points at MM IX a constant value of coefficient of variation of 20% was assigned to the MDR/MM curve, which is shown in Figure 2.

For classes (b), (c) and (d) references (1) to (7) were used. Predictably, considerable scatter was evident in the data plotted from these references.

Building class (e) (post-1977) is the modern ductile building designed to deform and crack in a controlled, safe manner rather than fail in a brittle, possibly catastrophic way. We are not aware of any damage cost data for such buildings subjected to strong earthquake shaking.

We deduced the form of MDR/MM relationship primarily by comparison with the curve already obtained for the 1936-1977 reinforced concrete buildings. NZS 1900:1965, chapter 8[15] was also of help, together with the component damage matrices of Whitman, Hong and Reed[6], particularly for assessing how much to decrease the MDR value of 10% for 1936-1977 buildings at MM VIII. We deduced that this figure should drop to about 2.5%. Values at MM IX and X were obtained by roughly maintaining parallelism from the new MM VIII value with the curve for 1936-1977 concrete structures. Based on the range of estimates from members of the Study Group, a constant coefficient of variation of 30% was assigned to this curve, which is included in Figure 2.

A number of other factors which arose in assessing MDR/MM relationships for each building type. These are discussed in the next section.

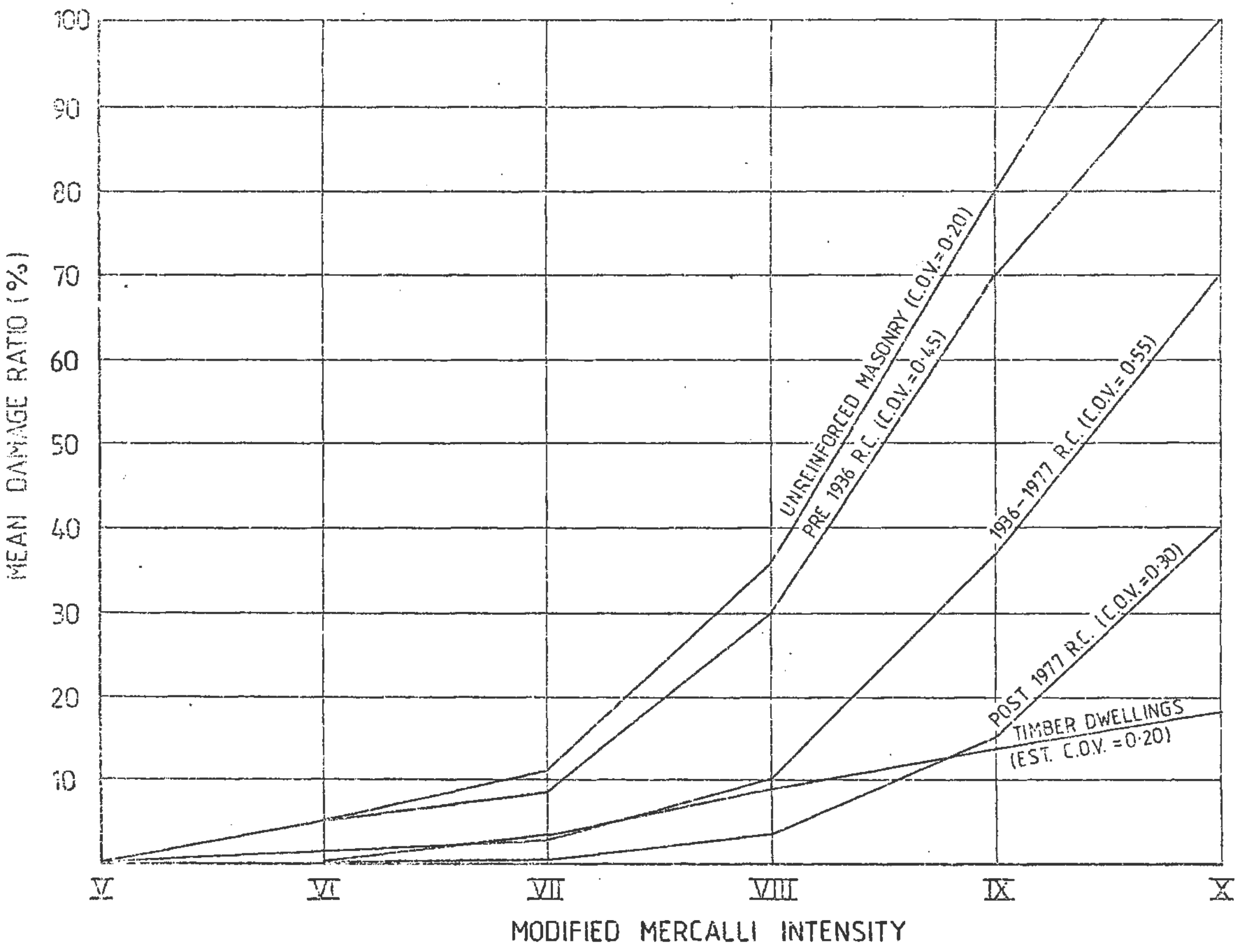

Fig 2   Damage Intensity Relationships Used In This Study

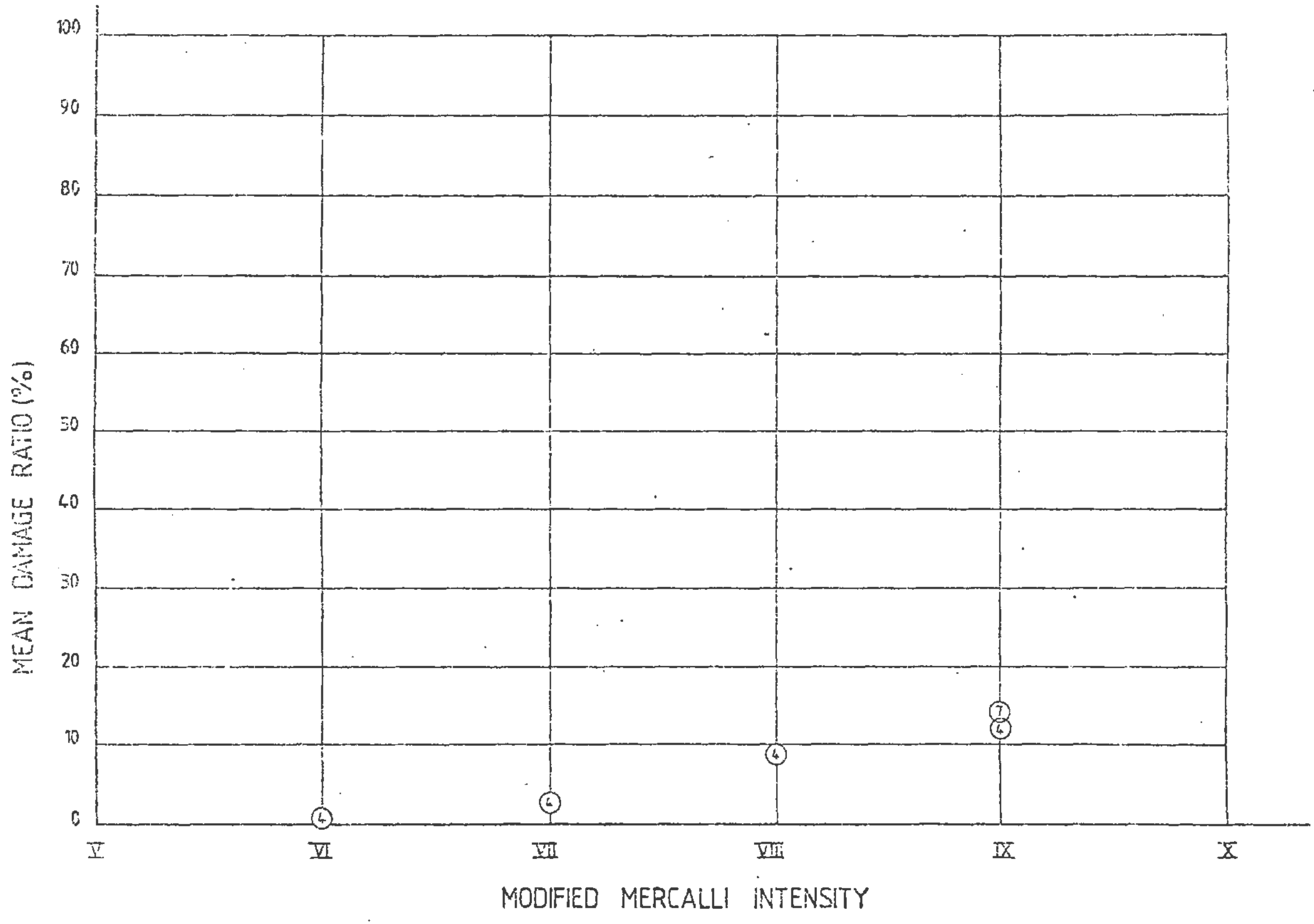

Fig. 3. Damage Intensity Relationship For Timber Dwellings

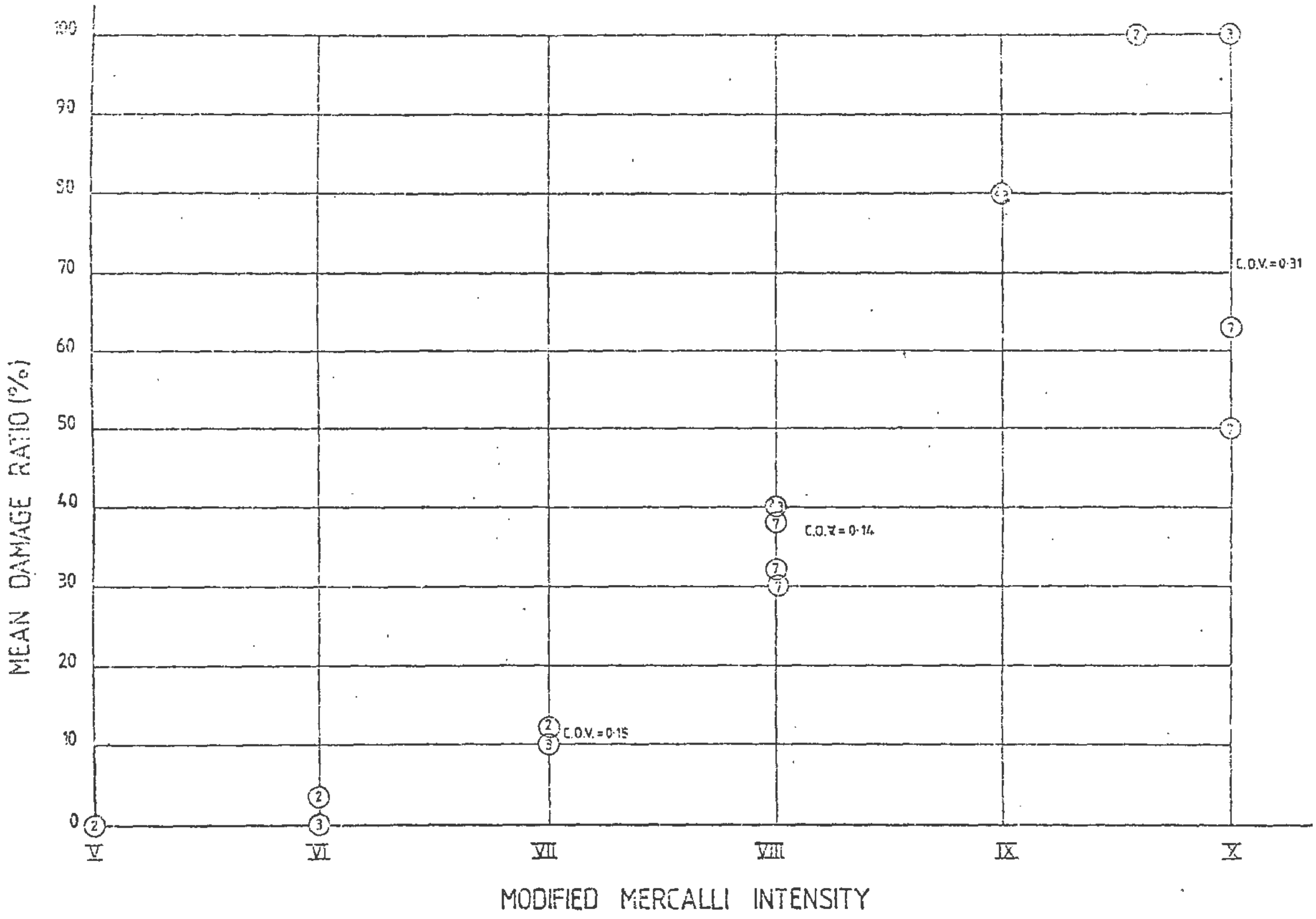

Fig. 4. Damage Intensity Relationship For Unreinforced Masonry

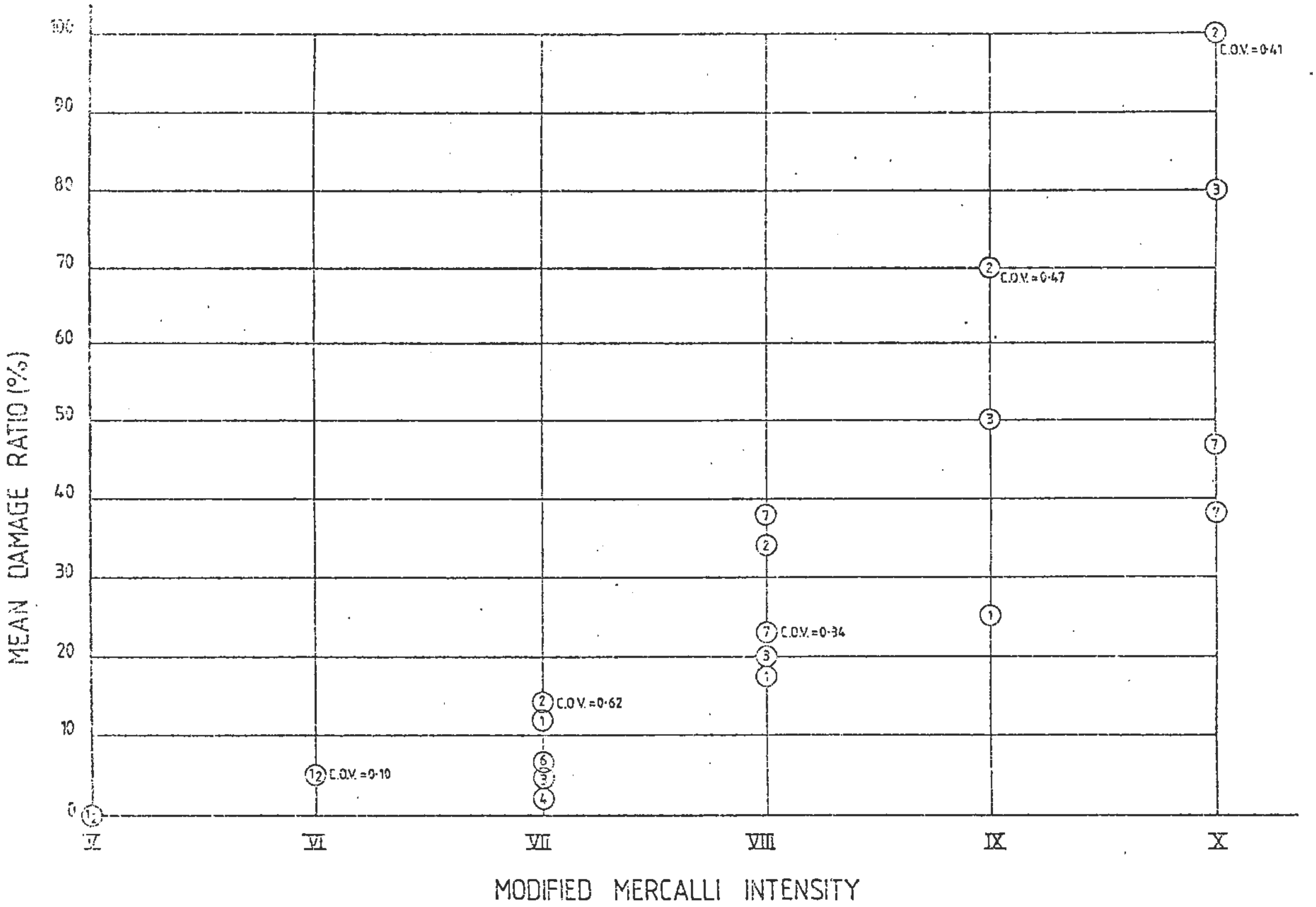

Fig. 5. Damage Intensity Relationship For Pre 1936 Reinforced Concrete

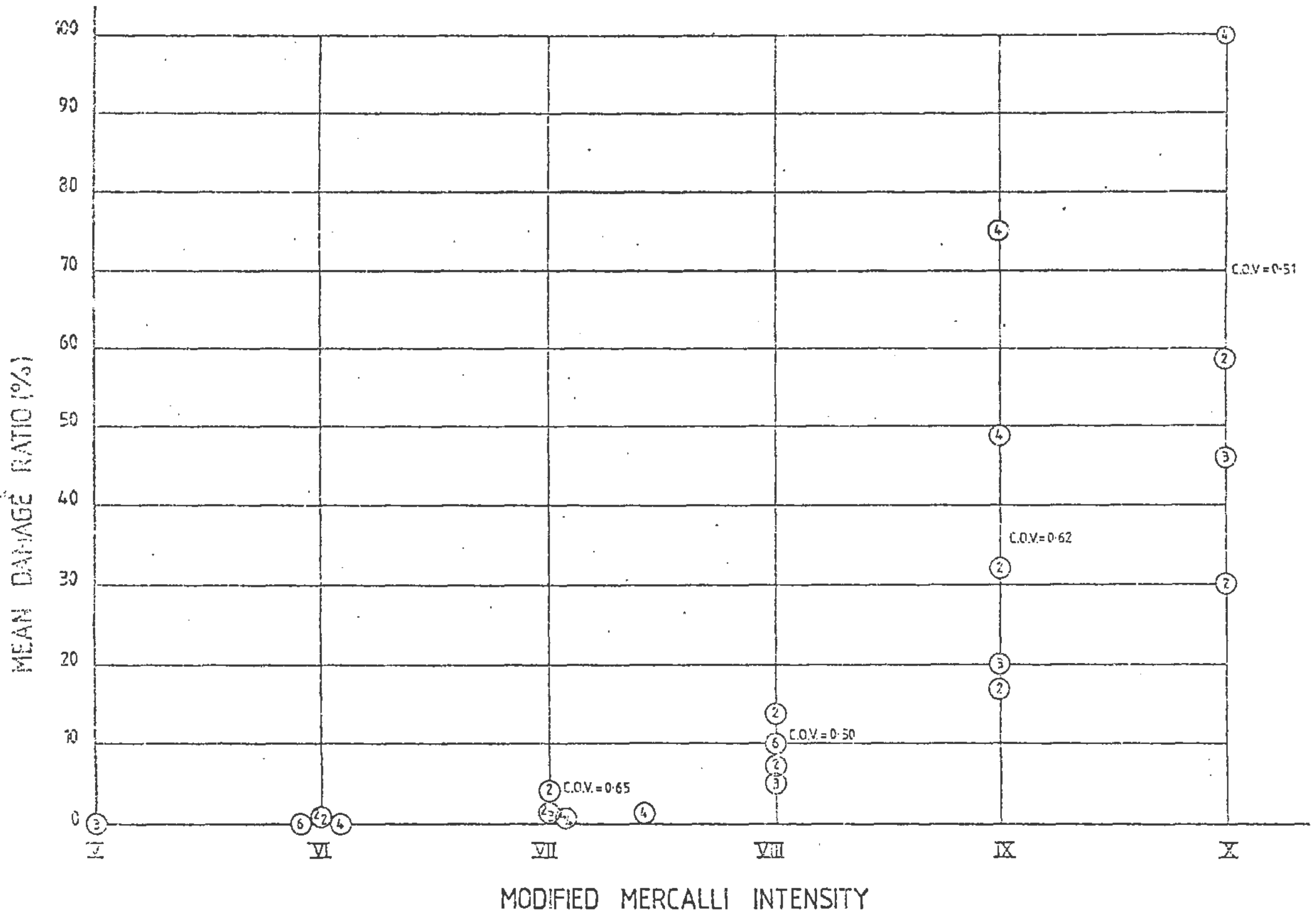

Fig. 6. Damage Intensity Relationship For 1936 - 1977 Reinforced Concrete

.4 Independence, reliability and consistency of data

The bulk of data available was not "raw", but rather best estimates made from uncited source information. Perhaps this is not as disturbing as it may appear because an experienced authority Steinbrugge(13) asserts that "most loss data published in engineering and scientific reports after an earthquake require major interpretative efforts to have any use".

Algermissen and Steinbrugge(11) believe, too, that "MM intensity maps, together with the loss-intensity relationships developed using relevant experienced judgement, are the best bases for this kind of study".

The bulk of information available to us had therefore already been filtered, hopefully on the basis of "experienced judgement", but very likely includes various "interpretations" of the some raw data.

Figures 3 to 6 show the raw data used as a basis for obtaining the final MDR/MM relationships used in this study. The degree of scatter at each value of MM was quantified as the coefficient of variation (COV). This number(23) describes the standard deviation of data from its mean value, expressed as a proportion of the mean. Interestingly, the number was often similar for different MM values within a figure and, in order to ease computation, a constant value of COV has been used in the analysis of each class of structure (see Figure 2).

The bounds represented by $\pm$ one standard deviation have statistical meaning in the case of data following a normal distribution(23) in that there is a 65% chance that the true answer lies within those bounds: for example, when the mean value is two units and the COV 0.5 (standard deviation one unit), there is a 65% (two-thirds) probability that the answer (eg, expected seismic damage cost) lies between one unit and three units!

Such high values of COV reflect the considerable uncertainty involved in a study such as this and this uncertainty must be given due emphasis. In their analysis of seismically designed buildings where MDR exceeded 10%, Whitman, Hong and Reed(6) report values of COV from 40% to 130%.

We discounted some published data on on the basis that it was assessed for a situation where the standard of construction would probably be generally inferior to that applying in New Zealand.

Figure 7 was prepared during smoothing of mean values derived for three building classes (unreinforced masonry, pre-1936 reinforced concrete, 1936-1977 reinforced concrete). The objective was to obtain a credible relationship between respective building classes at a given level of ground shaking (MM), and between different levels of ground shaking for a given building class. It is clear that, in some cases, considerable alteration to the mean values obtained from the available data has been judged necessary.

Average values of coefficient of variation deduced from the raw data were not altered, however, and these together with the adjusted mean values are depicted in the final curves shown in Figure 2. Although continuous curves are drawn, the MM scale is actually discrete.

.5 Basis of comparison of damage

Whitman, Hong and Reed(6) highlight the difference in MDR when it is measured on the basis of market value rather than replacement cost. They make the following observations:

> "The <u>market value</u> by itself is seldom a definite quantity but rather a random variable depending on many factors affecting the building owner and the economical strength of the community. It appears that the best way to obtain a consistent estimate of the market value is to multiply the assessed value, which can be obtained from the County Assessor's Office, by a certain factor."

> "The <u>replacement cost</u> is more-or-less a definite value ... The best way to obtain the replacement cost is to start with the permit values at the time of construction and then to correct this value by multiplying by an inflation index."

The difference between the two values, arising from depreciation, inflation and market conditions, will be great for old buildings and "the assessed market value may be more meaningful for studies conducted by the insurance industry"(6).

For the Los Angeles area, it was found(6) that market value generally exceeded replacement value for buildings less than about five years old but drops to a constant 40% of replacement value for buildings in excess of 20 years old.

If this is true in New Zealand, then it follows that values of MDR based on market value would be more than

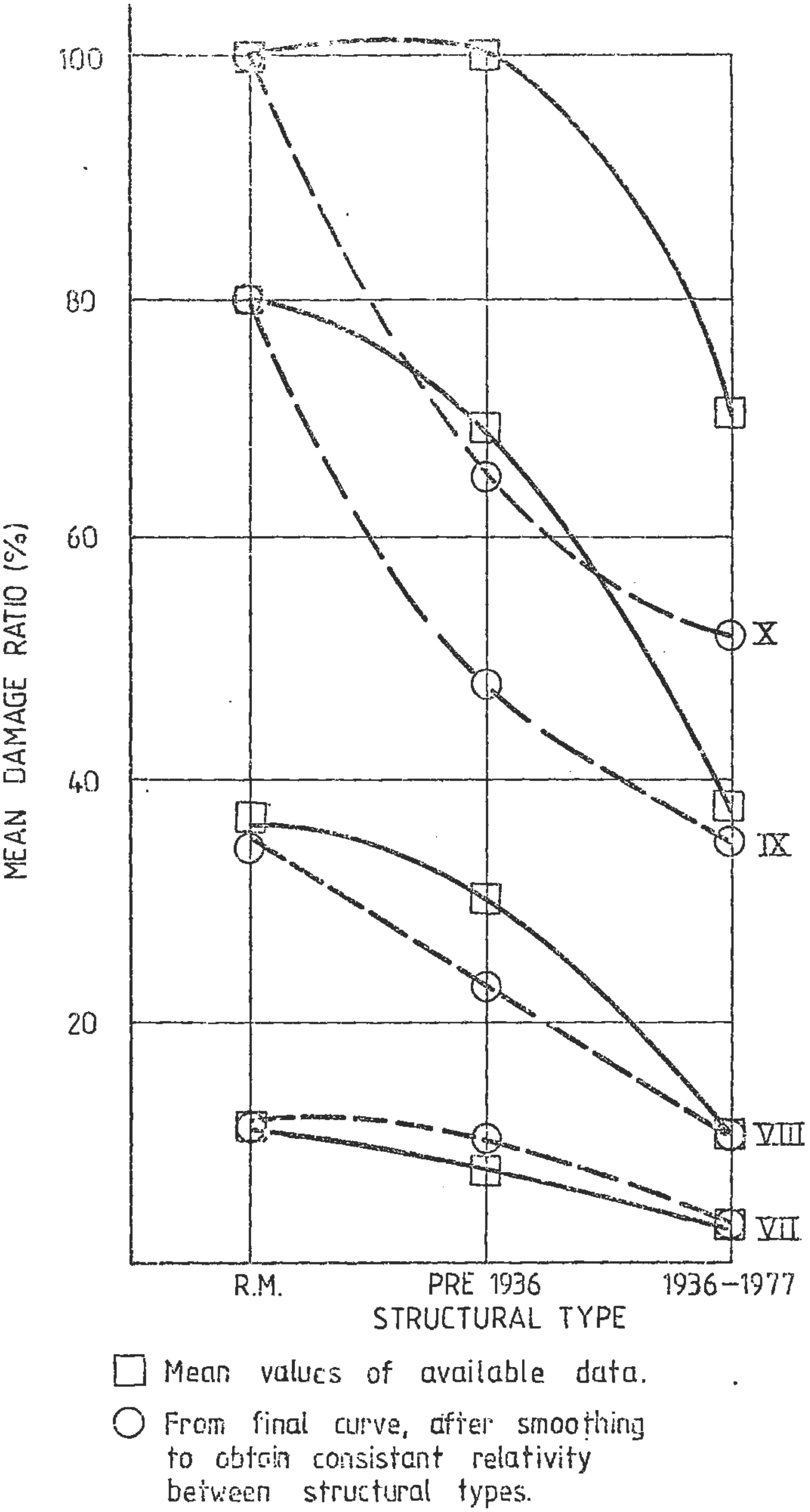

Fig. 7. Smoothing Of Mean Values Of Raw Data To Improve Relativity Between Building Types.

twice that based on replacement value for the majority of buildings being considered.

However, the essential question pertains to the data available: How were these MDR's assessed - as a proportion of market value or replacement value? Unfortunately the answer is not clear from the definitions available, as is evident below:

Munich Re[3] : Loss estimate is given "as a percentage of the total value".

Algermissen et al[1]: "The percent loss is defined here as the average percentage of the total cash value required to fully repair in kind any building of a particular class experiencing ground motion represented by a particular degree on the MM intensity scale."

In this study it was assumed that all estimates of MDR available were calculated on an identical basis. The MDR/MM relationships finally obtained were compared where possible with the two bases for calculating MDR in Whitman et al[6] for MM intensity VII and VIII. Table 4 shows these values together with MDR values from the final curves prepared for this study (Figure 2).

TABLE 4: REINFORCED CONCRETE BUILDINGS MEAN DAMAGE RATIO

ROW		MM VII		MM VIII	
	Row 1 & 2: Row 3:	Pre-1933 Pre-1936	Post-1947 1936-1977	Pre-1933 Pre-1936	Post-1947 1936-1977
1	Market value[6]	0.0604	0.0094	--	0.0963
2	Replacement (6) cost	0.0322	0.005	-	0.05
3	This study	0.08	0.025	0.03	0.10

From Table 4 it is evident that row one correlates better with results from the present study than row two. Therefore, MDR values deduced are assumed to be calculated on a market value basis. This accords with the expectation that damage assessors would naturally tend to think of the value of an undamaged building in terms of today's value on the market.

It must be emphasised that the total repair cost could, especially for old buildings, exceed the product of MDR and market value by several-fold. This is because a moderate to severely damaged older building would probably be demolished and rebuilt to current standards. For these buildings, an MDR of several hundred percent would lead to the true cost of repair, and it is conceivable that the cost of restoring moderately to lightly damaged buildings to their pre-earthquake state without "betterment" [8] could easily exceed the indemnity value of the building.

Nevertheless, calculations in this study have been determined to the level of the liability of the Earthquake and War Damage Commission who will pay on insured buildings up to indemnity value. With MDR effectively determined as a proportion of indemnity value in this study, this means that the maximum applicable value of MDR is 1.00 (or 100%), the limit shown in Figure 2.

4.6 Building Contents

It is appreciated that, especially for an older building, the value of its contents could be of the same order as the market value of the building. It is also recognised that contents can be damaged in an earthquake.

The Study Group was unable to find significant published information on this important problem.

Munich Re[3] asserts that there is a direct relationship between the loss estimate of a building and the loss of building contents, as shown in Table 5.

TABLE 5: MUNICH RE ESTIMATE OF CONTENTS LOSS

MM Intensity	VI	VII	VIII	IX	X	XI	XII
Proportion of Building Loss	1/5	1/4	1/3	1/2	2/3	4/5	9/10

As noted earlier, previous studies have taken a much coarser estimate of contents loss.

In the absence of data from actual earthquakes, the Study Group obtained opinions of expected contents loss from two leading insurance companies and a leading Loss Adjuster. Based on these options, it was decided to use an estimate of contents loss in the case of housing equal to one third of the upper and lower estimates of housing loss. In the case of other buildings, 60% of the upper and lower values of building damage was used. This was based on further consideration[25] of data used in reference (8).

4.7 Computation of Damage Costs

.1 Valuation Department data

The housing and other building data used in this study was obtained from Valuation Department information using two different methods.

For housing, a list of the local authorities within the area affected by earthquake intensity of MM VII and greater was compiled to cover all the four events. For the cities, boroughs and counties the total improved value of all the residential dwellings was obtained using Valuation Department statistics. The latitudes and longitudes of the local authority centres were used to co-ordinate their positions and this information was stored on the computer dataset along with the associated improved values and a factor for updating these values to March 1983. Coordinate sets defining all the elliptical isoseismals for the four events (Figure 1) were compared with locations of housing groups in turn and the housing data records thus sorted into their appropriate MM intensity. The expected housing loss for each seismic event was then calculated using the MDR value for the respective MM intensities.

In the case of buildings other than houses, computer tape listings for the central business districts (CBD) were obtained from the Valuation Department for Christchurch, Nelson, Wellington/Hutt, Wanganui, Palmerston North, Hastings and Napier cities.

The above cities were used as models for other cities within the earthquake affected area for which no computer tape listings were obtained. For example, New Plymouth City was considered to have a similar distribution of building types as Wanganui City and adjustment to building loss was made to take account of the variation in total building value between the two cities. The additional buildings outside the CBD of a city were assumed to have the same average loss per building as those in the CBD. The total building value for each city was obtained from Valuation Department statistics.

The total values of non-housing buildings in towns of borough status was also obtained. The majority of the buildings in these boroughs were assumed to be of older construction than typically occurs in the larger cities where redevelopment of the urban areas has occurred on a more frequent basis. The ratio of:

$$\frac{\text{total building loss}}{\text{total building value}}$$

as determined for Wanganui City was used to represent the proportion of building loss expected in these smaller urban centres for the respective intensity of ground shaking postulated in any of the four scenario events.

ST NO.	STREET	SITE COVER	AREA	CAPITAL VALUE	LAND VALUE	USE	AGE	CONST MATERIAL	MZONE	WCC CLASSN
10	ABEL SMITH ST	32	59	235000	215000	75	2	CC	2	C
12	ABEL SMITH ST	39	39	225000	135000	75	6	CI	2	
24	ABEL SMITH ST	13	13	170000	167000	82	7B	WI	2	
36	ABEL SMITH ST	17	35	71000	43500	80	5	CF	2	C
39	ABEL SMITH ST	71	79	420000	168000	81	7	CI	2	
42	ABEL SMITH ST	59	59	175000	172000	83	X	XI	2	
46	ABEL SMITH ST	23	40	100000	100000	80	P	WI	2	
65	ABEL SMITH ST	122	122	400000	317000	84	4	CX	2	
70	ABEL SMITH ST	10	12	39000	33000	75	X	XX	2	C
71	ABEL SMITH ST	37	74	220000	85000	70	7A	CI	2	C
74	ABEL SMITH ST	78	111	278000	277000	80	X	XX	2	B
75	ABEL SMITH ST	13	21	62500	59000	84	0	WI	2	
77	ABEL SMITH ST	10	19	48500	44000	84	9	WI	2	
79	ABEL SMITH ST	8	15	51500	49000	84	9	WI	2	
80	ABEL SMITH ST	44	162	230000	215000	20	X	BX	2	
81	ABEL SMITH ST	10	26	255000	242000	84	X	XX	2	
88	ABEL SMITH ST	23	33	75000	52500	23	X	XX	2	
89	ABEL SMITH ST	12	23	65000	62000	84	9	WI	2	
90	ABEL SMITH ST	22	49	165000	50000	84	7B	CI	2	C

FIG. 8 SAMPLE COMPUTER LISTING

Figure 8 shows the form of central building data used for the major urban areas. The record for each building contains mainly data obtained from Valuation Department land use data tapes: the street number, street name, site cover, floor area, capital value, land value, use, age and construction material. For the Wellington/Hutt metropolitan area, microzone data and, where known, the Wellington City Council building classification has been added. This information was used to determine the structural material and age of construction for each building.

.2 Computation

The isoseismals for the four scenario events (Figure 1) indicate the various MM intensities affecting any particular urban centre.

The MDR value for the appropriate MM intensity was selected and a computer program was used to sort out building construction, microzone area and age of construction before computing the expected loss for each building. The loss was calculated as the product of MDR and the difference between capital value (CVAL) and land value (LVAL) for each building where the value was adjusted to March 1983. The values were summed to give a total expected building loss for each urban area, and finally for each event.

Government-owned buildings are not a charge on the Earthquake and War Damage Commission and so were separated from the computer listings. These buildings were determined for the Wellington metropolitan area and for the Wanganui CBD. Approximately 5% of the total building value in the former case belongs to the Government and approximately 10% in the case of Wanganui CBD. It was assumed that the distribution of ages and of structural condition of Government owned buildings was the same as that of the other buildings, and that, apart from the Wellington metropolitan area, 10% of buildings were Government owned. On this basis, the buildings assumed to be covered by the Earthquake and War Damage Commission were estimated by subtraction of Government owned buildings.

5.0 RECOMMENDATIONS FOR FURTHER STUDY

5.1 The Earthquake and War Damage Commission would obtain an indication of the expected annual loss if the present study was extended to cover all insured properties in the country and a complete range of seismic events. If such information is considered necessary then it is recommended that a study be commissioned.

5.2 The lack of available data on value of contents adds uncertainty to the results of the present study. A survey of insurance policy data for contents is recommended to refine this aspect.

5.3 A clearer picture of the number and values of uninsured properties would permit refinement of the result of the present study. A survey of policy data and correlation with Valuation Department data is therefore recommended.

5.4 It is recommended that the Earthquake and War Damage Commission set up machinery to enable the rapid commissioning of a detailed survey of damage and its cost when earthquakes of significant effect occur. Such a survey could lead to a large reduction in the uncertainty of damage relationships used in the present study.

6.0 ACKNOWLEDGEMENTS

Grateful acknowledgement is made of the free contribution to the study by the Ministry of Works and Development of staff and computing resources.

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APPENDIX I: LETTER SENT TO LOCAL AUTHORITIES

28/397/11/1

20 July 1983

The Town Clerk

Dear Sir

ESTIMATION OF COST RESULTING FROM A LARGE EARTHQUAKE

The National Society for Earthquake Engineering has been asked by the Earthquake and War Damage Commission to advise on the expected cost to them following a large earthquake centred near Wellington City. Such an earthquake would be felt over much of the country and cause damage over a wide area.

The commission is concerned with the value of losses to buildings and houses, which it would have to recompense, and seeks a clear indication as to the adequacy of its fund to cover such an event.

Several thousand buildings are in the affected zone and collation of this data for the Wellington municipality has been started wth cooperation of Wellington City Council. Buildings will be listed on computer by street address and include description of:

- date of construction (or issue of building permit);
- number of storeys;
- floor area;
- seismic classification (if given).

A description of usage (ie, an indication of contents), structural material (eg, brick masonry, reinforced concrete) and structural form (eg, shear wall, frame) will be included if possible.

The study group carrying out this task seeks the cooperation of your local authority in providing data on buildings in your area. The data will be treated in confidence and will not be used for any purpose other than achieving the objective of this study. It will be stored on the Ministry of Works and Development computer and access restricted by way of a password. The data received from you will be returned immediately it is filed on computer, without photocopying.

Wellington City Council have forwarded all their building data.

The cost of people and computer is not being charged to the Earthquake and War Damage Commission.

For your information, the study group consists of the following personnel:

- D L Hutchison (MWD) Convenor;
- D J Dowrick (Consulting Engineer);
- A K Perry (Consulting Architect);
- D J Darwin (Wellington City Council);
- G R Birss (MWD, Technical Secretary).

The accuracy of the estimate obtained from this study depends, in the first instance, on the completeness of new data. For this reason, your assistance is essential.

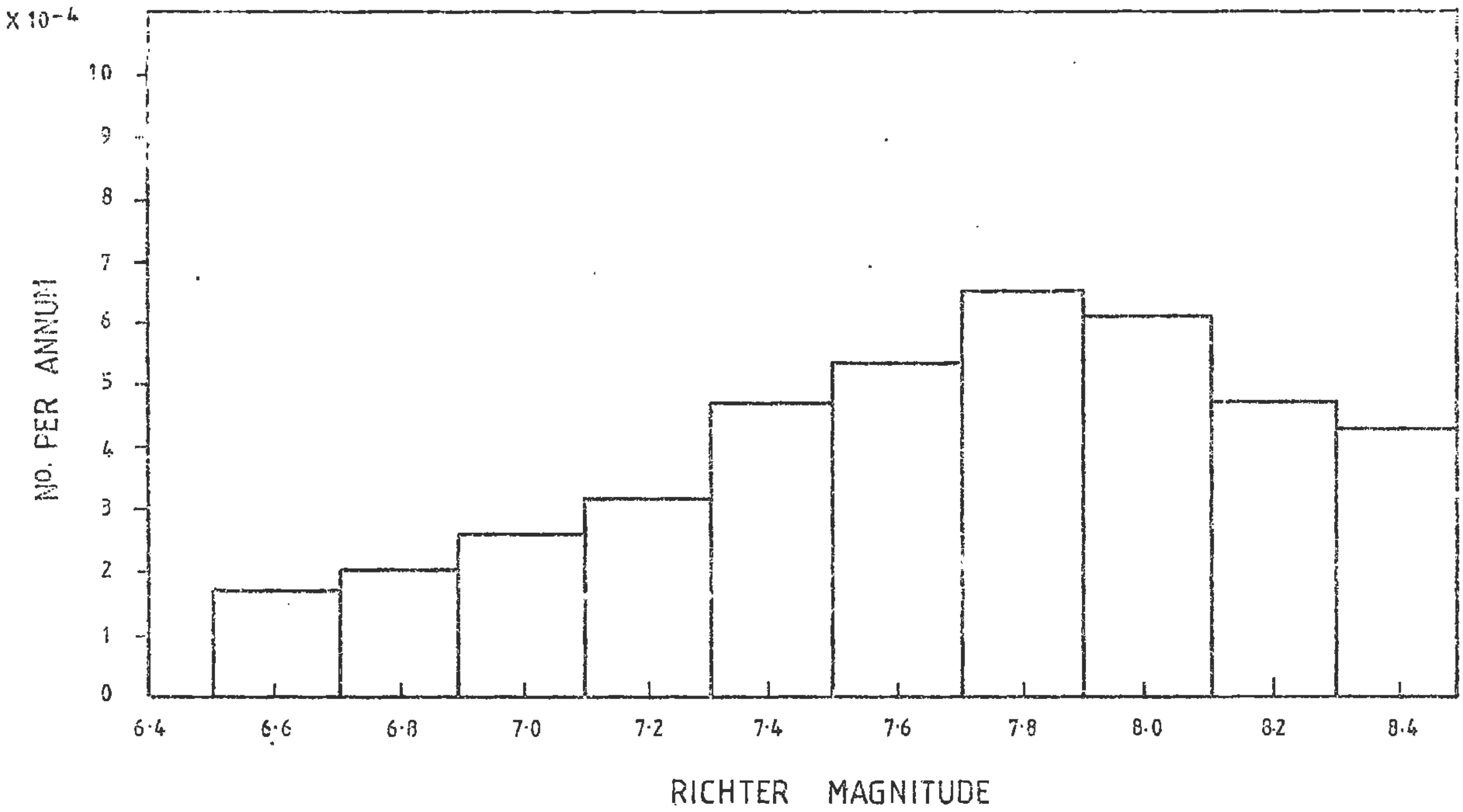
Housing stock will be determined from published Housing Corporation data. However, there may be other information which is most reliably available as local knowledge, eg, information on nature of soil in the built-up areas (soft, hard, fill, steep slopes etc).

Would you kindly advise re:

- the form and availability of your building data;
- the total number of "buildings" (ie, inhabited structures other than housing, but including multi-storey flats);
- the total number of single storey dwellings;
- an officer with whom future contact can be made.

This information would be appreciated before the end of August 1983.

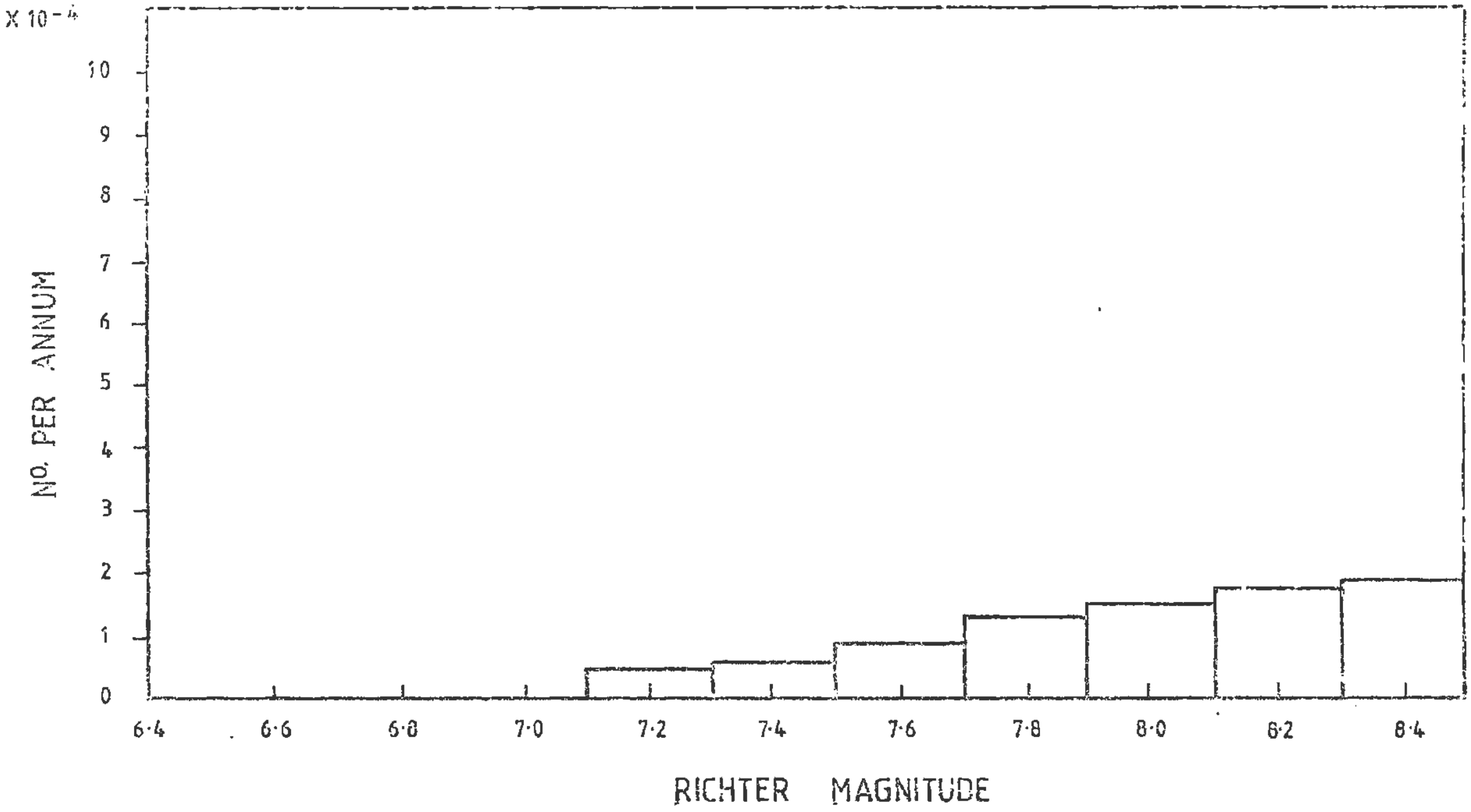
D L Hutchison
Study Group Convenor



Appendix II

Frequency Distribution of Scenario Earthquakes

(a) MMIX Event



Appendix II

Frequency Distribution of Scenario Earthquakes

(b) MMX Event

APPENDIX III: COMPOSITION OF STUDY GROUP

At the time of defining the original objectives of the study, it was proposed that the study group would consist of:

"- an engineer from the MWD (MWD have offered time of a suitable engineer provided Government losses are included in the study);

- an engineer from Wellington City Council structural section (WCC have also expressed interest in the study and have a body of relevant data);

- a structural engineer;

- an engineer or architect with experience of non-structural elements;

- a liaison member from Earthquake and War Damage Commission.

People co-opted for short terms would have expertise probably in:

- seismology;

- microzoning/engineering geology;

- particular areas of potential damage outside the experience of the group."

The Study Group consisted of:

D L Hutchison (Ministry of Works and Development), Convenor
D J Darwin (Wellington City Council)
D J Dowrick (Brickell Moss and Partners)
C W Mouat (Earthquake and War Damage Commission)
A K Perry (KRTA Limited)
G R Birss (Ministry of Works and Development)

Advice on specialised matters was sought from:

G A Eiby
K R Berryman
W D Smith