THE MODIFIED MERCALLI EARTHQUAKE INTENSITY SCALE – REVISIONS ARISING FROM RECENT STUDIES OF NEW ZEALAND EARTHQUAKES

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SUMMARY

The 1992 New Zealand version of the Modified Mercalli (MM) intensity scale, was the result of a major multi-disciplinary review, and comments were invited. This paper results from considerable use of the 1992 scale in recent studies of twenty two New Zealand earthquakes including two of magnitude $M_s7.8$, and insights into the scale gained from studies of the well-documented $M_w6.6$ 1987 Edgecumbe earthquake. Improvements to the 1992 New Zealand MM intensity scale are offered, including criteria for chimney damage at MM6 to MM8, and also criteria for MM10 to MM12 based on a simple matrix procedure of logical extrapolation from lower intensities, and the use of new construction categories. Discussions of the influence of ground conditions at high intensities, and on definitions of the key terms "partial collapse", "collapse" and "destroyed", are included.

INTRODUCTION

In view of the continuing need in New Zealand for a good felt intensity scale for earthquakes, a Study Group of seismologists, geologists, and engineers of the New Zealand National Society for Earthquake Engineering produced the 1992 proposed revision of the New Zealand version of the Modified Mercalli scale [1]. The Study Group's brief was to review the definitions of the scale in the light of current knowledge and allow for improvements in earthquake resistant construction, such that the scale would be modernised while remaining consistent with the 1931 and 1966 versions where they were valid. The 1992 proposed revision was intended as a working document, with an invitation for critical comments from users on the appropriateness of its wording. (Note that the two previous versions of the New Zealand intensity scale, published in 1966 [2] and 1992 [1], are often also referred to as the 1965 and 1991 versions respectively. I denote them by their publication dates throughout).

Since the availability of the 1992 scale, the present author has been studying damage and intensities in a number of important earthquakes, particularly the $M_s7.8$ earthquakes of Murchison (or Buller) 1929 [3] and Hawke's Bay 1931 [4,5]. Such studies, together with others of the 1987 $M_W6.6$ Edgecumbe earthquakes [6-8] and some reflections on the relevance to New Zealand of damage in Kobe in 1995 [9], have suggested some improvements that should be made to the 1992 proposed scale, mainly at higher intensities. This task may have been eased by my involvement in the Study Group for the 1992 revision, and hence seeing more readily instances of where our modernisation with respect to buildings was too simplistic. In addition it has become evident that the wording of the scale at moderate intensities in relation to chimney damage needed both clarification and justification.

The Modified Mercalli scale has always been thin in its discriminants for the strongest levels of shaking, ie MM10-MM12, and part of the motivation for writing this paper was to redress this situation. In addition the European intensity scale (MKS or EMS), see Appendix A, has recently (1993) been substantially revised [10] and at the time of writing this paper it was still undergoing a three year trial period, so it was timely to review the New Zealand MM intensity scale with a view to attaining appropraite consistency with the European intensity criteria.

While the main thrust of this paper relates to structures, some elaboration of the wording relating to environmental effects has also been deemed to be appropriate.

PERFORMANCE OF CONSTRUCTION AT HIGHER INTENSITIES

Earlier editions of the MM intensity scale used in New Zealand, i.e. 1931 [11] and the New Zealand 1966 version [2], were largely deficient in criteria based on construction performance at MM10 or greater, presumably due to the paucity of MM10+ experience. In addition earlier editions have naturally become out of date with respect to subsequent construction types and design standards. The 1992 New Zealand scale [1], amongst other things, addressed the question of modern construction, but ventured no higher than MM10. In the present paper improvements are suggested for the MM10 construction criteria, and MM11 and MM12 criteria are also proposed.

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In the 1992 scale, four Construction Categories were used. As discussed in my paper on the 1929 Murchison earthquakes [3], compressing the previous (1966) Masonry B and C categories into only one new category was a mistake, so that five categories should then have been used. Although to date most modern earthquake resistant structures have been designed mainly to save lives (by minimising collapses), a new class of minimal damage structures, eg emergency facilities, is now emerging. A new category is introduced here for such structures. The definitions of the six construction categories are given in the Appendix to the scale.

In order to develop logical and internally consistent criteria for construction performance in the intensity scale, a performance matrix of intensity versus construction category was developed, as shown in Table 1. The performance descriptions stay constant (almost) along the rising diagonals of the matrix, as increasing construction quality counteracts increasing intensity. The bottom left hand corner of the matrix (MM7 - MM9) and (Categories I - IV i.e. masonry D - A) are essentially the same as those in the 1966 MM scale [2].

The original MM scales were overly pessimistic about better types of masonry structures at MM10 (saying "most destroyed"). As seen in Table 1, this criterion was not consistent with the underlying intensity increments, MM7-MM9, nor with observation, eg of the 1931 Hawke's Bay earthquake [5]. Allowing for the expanded Construction Categories, the MM10 criteria in Table 1 are consistent with those of the 1992 scale [1].

Extrapolating the rising diagonals in Table 1 gives us, for the first time, a range of construction performance criteria for intensities MM11 and MM12. Excepting the possibility of

Table 1: Intensity versus construction category performance

Intensity	Construction Category					
	Pre-code			Post-code "Brittle" Era	Capacity Design Era	Special Low Damage
	I(1) D(2)	II C	III B	IV A	V	VI
MM12			*Most destroyed*	*Many* Destroyed	Heavily damaged, some with partial collapse	Moderately damaged
MM11		*Most destroyed*	*Many* destroyed	Heavily damaged, some collapsing	Damaged, some with partial collapse	Minor(5) damage, a few moderate damages
MM10	*Most destroyed*	*Many* destroyed	Heavily damaged, some collapse	Damaged, some with partial collapse	Moderately damaged, a few partial collapses(4)	A few instances of damage
MM9	*Many* destroyed	Heavily damaged, some collapse	Damaged, some with partial collapse	Damaged in some cases, some flexible frames seriously	Damaged in some cases, some flexible frames moderately	
MM8	Heavily damaged, some collapse	Damaged, some with partial collapse	Damaged in some cases	A few instances of damage		
MM7	Cracked, some minor masonry falls	A few damaged				
MM6	slight damage may occur					

Notes: (1) Construction categories defined in the Appendix.
(2) Masonry A, B, C, D as defined in the 1966 MM intensity scale [2].
(3) Original MM intensity scale in area bounded by broken line.
(4) Allows for structures of this era not having capacity design or being "below average".
(5) This is speculative, on the optimistic side.
(6) The words in italics were derived by analogy with the EMS [10].

excessive non-linearity in the extrapolation, these criteria are logically based. Non-linearity of material behaviour of course increases with intensity, particularly from MM9 upwards. This means that the relative performance of different construction categories at MM10 to MM12 may not be quite as predicted by linear extrapolation from intensities MM7-MM9, where the relativities are known to be quite good from past earthquake evidence. Non-linearities may arise from material behaviour of the ground or of the construction.

While the MM scale is arbitrary, it needs to be useful and workable, as it has proven to be up to MM9, albeit with some fine-tuning still being made. The proposed new criteria for MM10 - MM12, while apparently logical, remain speculative. They will prove to be useful if they are seen to be internally consistent and fit reasonably smooth attenuation patterns in future large earthquakes. In the medium term, the prospects of direct application and validating of the internal consistency of the MM11 and MM12 criteria in New Zealand are (fortunately for potential victims) small, because of the low probability of MM11 and MM12 strengths of shaking occurring in a New Zealand urban area. However, the MM11 criteria may be of earlier help when MM10 next occurs in deciding that MM10 has *not* been exceeded.

The descriptors of very heavy damage used in Table 1 from MM8 upwards, namely *partial collapse, collapse, destroyed*, have not been defined in earlier versions of the scale, and thus have been open to different interpretations. They are surprisingly difficult to define clearly, simply and uncontroversially. The need here is to define them to be internally consistent within the scale, as well as defining the appropriate absolute level of damage at the highest intensities including consistency with overseas scales. The following definitions are proposed:

Partial collapse: means that part of the building collapses, and a substantial remnant still stands. The volume of the collapsed part is likely to be less than about 30% of the total volume. At minimal partial collapse, virtually no volume (internal void) loss may be involved, i.e. walls may fall but not floors or roof (Figure 1a). A wall falling may be initiated by a parapet or gable falling, which peels off the wall below. Partially collapsed structures may or may not be repairable, depending on which portion has collapsed and on the integrity of the surviving portion. A non-repairable partially collapsed building (e.g. a ground floor soft storey collapse, Figure 1(b)) is better described as "destroyed" (see below).

Collapse: "Collapse" is worse than "partial collapse", implying that the building is not repairable. The loss of internal void volume is likely to be greater than 50%, such as illustrated in Figure 2(a). (The term "complete collapse" is also sometimes used by engineers, though not in the MM scale; this implies a 90% or more loss of internal volume (Figures 2(b)), but such a severe definition for "collapse" is unnecessarily restrictive.)

Destroyed: means "beyond repair". This includes not only collapsed buildings, but also others so heavily weakened or deformed, that it would probably be better/cheaper to rebuild than to repair them (Figures 3(a) and 3(b)). (Collapses are easy to judge, but "beyond repair" often needs time to elapse for true assessment to occur. For example many buildings in Napier in 1931 were initially assessed as beyond repair, but *were* repaired later (Figure 3(c)); and vice versa (Figures 4(a) and 4(b)).

INFLUENCE OF GROUND CONDITIONS ON CONSTRUCTION PERFORMANCE

Ground conditions influence surface shaking at all levels of strength of bedrock shaking. In low strength shaking softer/weaker soils tend to amplify shaking across the full period range, albeit with greater such effect on longer or resonant periods. Thus at lower intensities across-the-board enhancement of intensity is seen on softer/weaker soil, and thus needs no special consideration in the wording of the intensity scale. Extreme cases of soil resonance may also occur (such as affect Mexico City Lake Bed soils), giving MM10 for resonant high-rise construction and no damage for low-rise unreinforced masonry buildings. These situations are perhaps best dealt with on a case-by-case basis as they arise, rather than having special mention in the intensity scale, at least given the present state of knowledge.

Soils effects which seem to warrant addressing within the scale now are the effects of ground conditions at high strength of bedrock shaking, in particular the inability of softer (i.e. weaker) soils to transmit the full amplitudes of short period vibrations. This effect has been demonstrated, for example, by single storey houses (i.e. short period structures) in Napier in 1931, where the damage was 40% more on the stronger/stiffer beach deposits than on the (shallow) harbour reclamation [4]. This observation will be important for assessing very high near-source intensities (MM10+) through what may be conflicting evidence of different heights of building on different ground conditions. Internal consistency within the MM10 to MM12 criteria is only achievable by taking account of different ground conditions, to explain paradoxes of the Napier housing type or the near source equivalent of Mexico City. Hence an extended note relating to the influence of ground conditions at MM10 and greater intensities has been included in the Appendix to the scale.

CHIMNEY RESPONSE VERSUS INTENSITY

The response of unreinforced masonry or concrete domestic chimneys has been and remains a key factor in assigning moderate intensities in New Zealand, particularly in rural areas and small towns. This is because there are few sources of definitive criteria for moderate intensity in such localities, a situation which has been clearly recognised by Dengler and McPherson [12] who recently proposed special MM intensity criteria for sparsely populated areas based on USA experience. The detailed suggestions of their paper deserve to be considered for adoption in New Zealand in due course. Also of interest are the findings of Brazee [13] for chimney damage as experienced in the USA. In a study correlating a very large number of individual intensity elements collected during the period 1928-74, he notes that the fall of chimneys is critical to the assignment of intensity. His criteria for chimneys are consistent with those given here, but he does not give any results specifically regarding the incidence of chimneys falling at MM6 or MM7.

This prompted the present author to examine chimney responses as observed at intensities MM6 to MM8 in a set of New Zealand earthquakes for which data were readily at hand. The observations of chimney damage used in this study were restricted to those where the intensity could be determined by other criteria without reference to chimneys. The chimney responses observed at those localities were then assembled and evaluated for each of the intensities MM6, MM7 and MM8. My

FIGURE 1(A) Examples of Partial Collapse: Taradale Hotel in the 1931 Hawke's Bay earthquake, arguably small volume loss despite collapse of external brick walls, deemed not repairable. (Reproduced by courtesy of the Alexander Turnbull Library, Wellington).

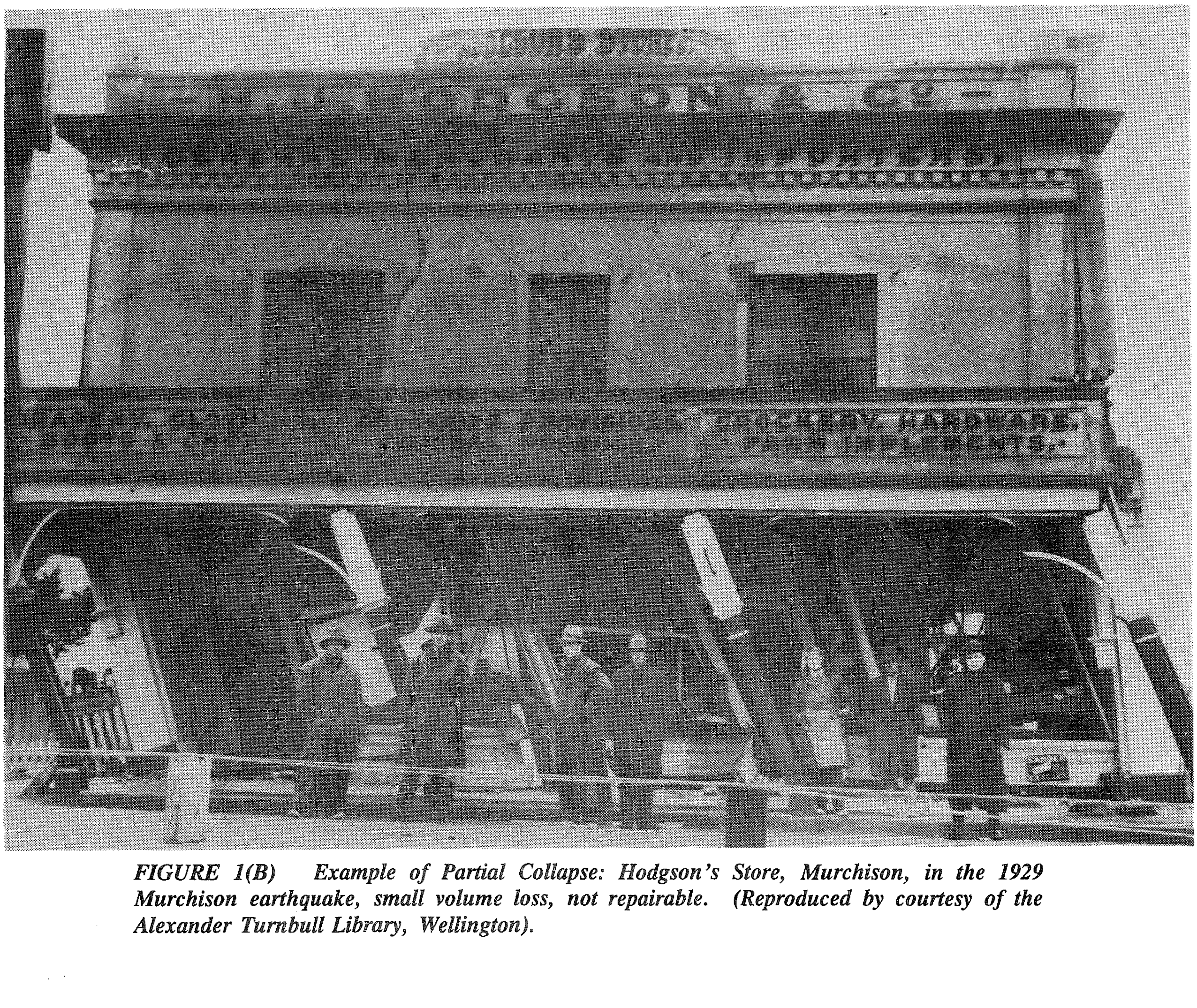

FIGURE 1(B) Example of Partial Collapse: Hodgson's Store, Murchison, in the 1929 Murchison earthquake, small volume loss, not repairable. (Reproduced by courtesy of the Alexander Turnbull Library, Wellington).

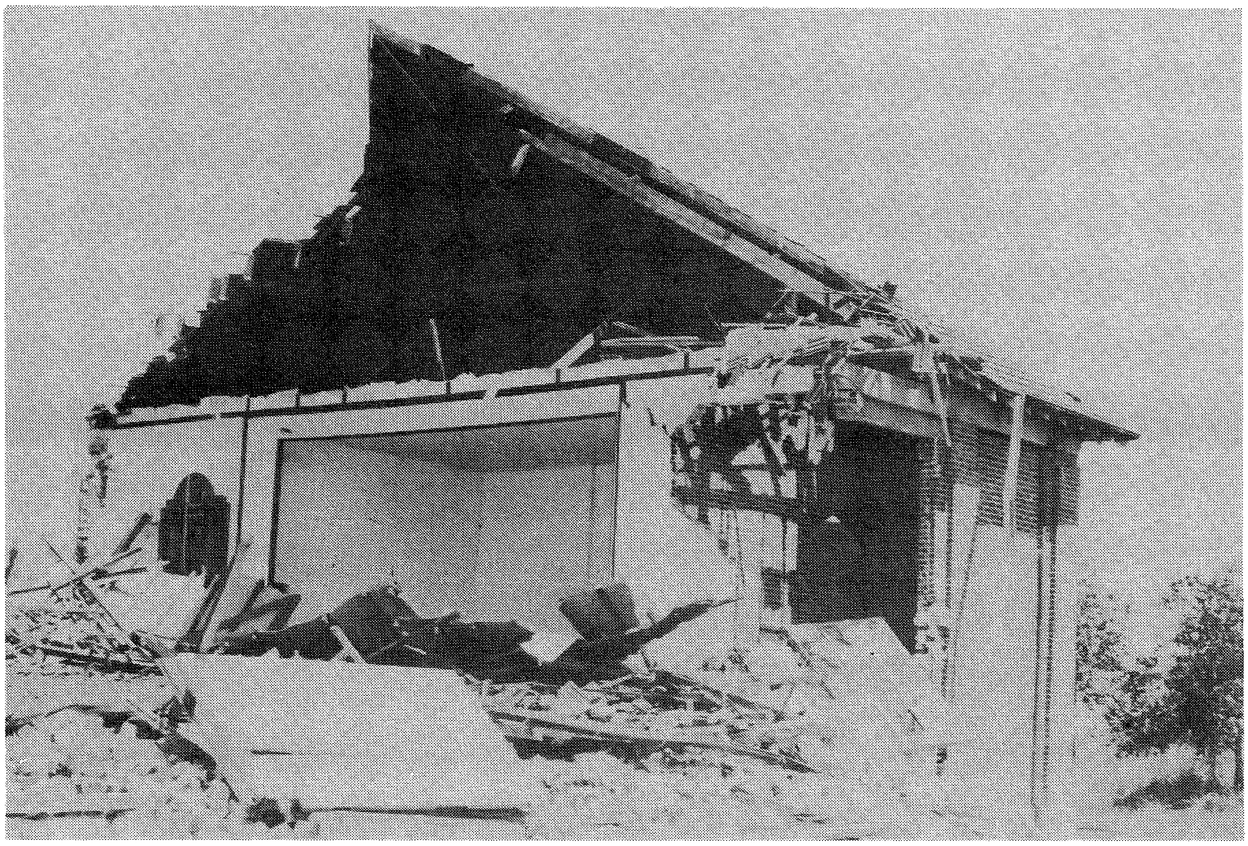

FIGURE 2(A) Example of Collapsed building: Napier Boys High School Assembly Hall in the 1931 Hawke's Bay earthquake, more than 50% volume loss. (Reproduced by courtesy of the Auckland University Architecture Library).

FIGURE 2 (B) Example of Collapsed building: Nurse's Home, Napier Hospital, in the 1931 Hawke's Bay earthquake, 100% volume loss. (Reproduced by courtesy of the Auckland University Architecture Library).

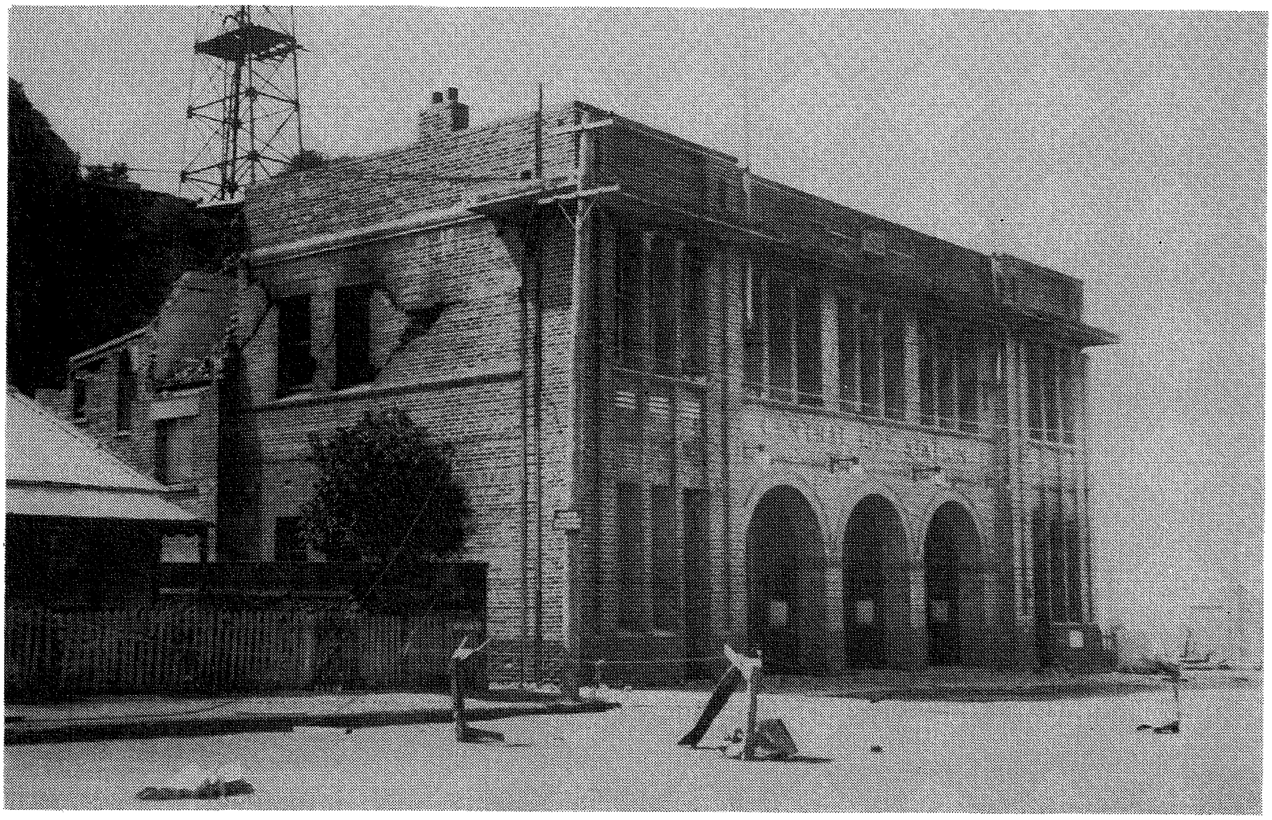

FIGURE 3(A) Example of Destroyed building: Napier Central Fire Station in the 1931 Hakwe's Bay earthquake, no volume loss, but cracked beyond repair. (Reproduced by courtesy of the Alexander Turnbull Library, Wellington).

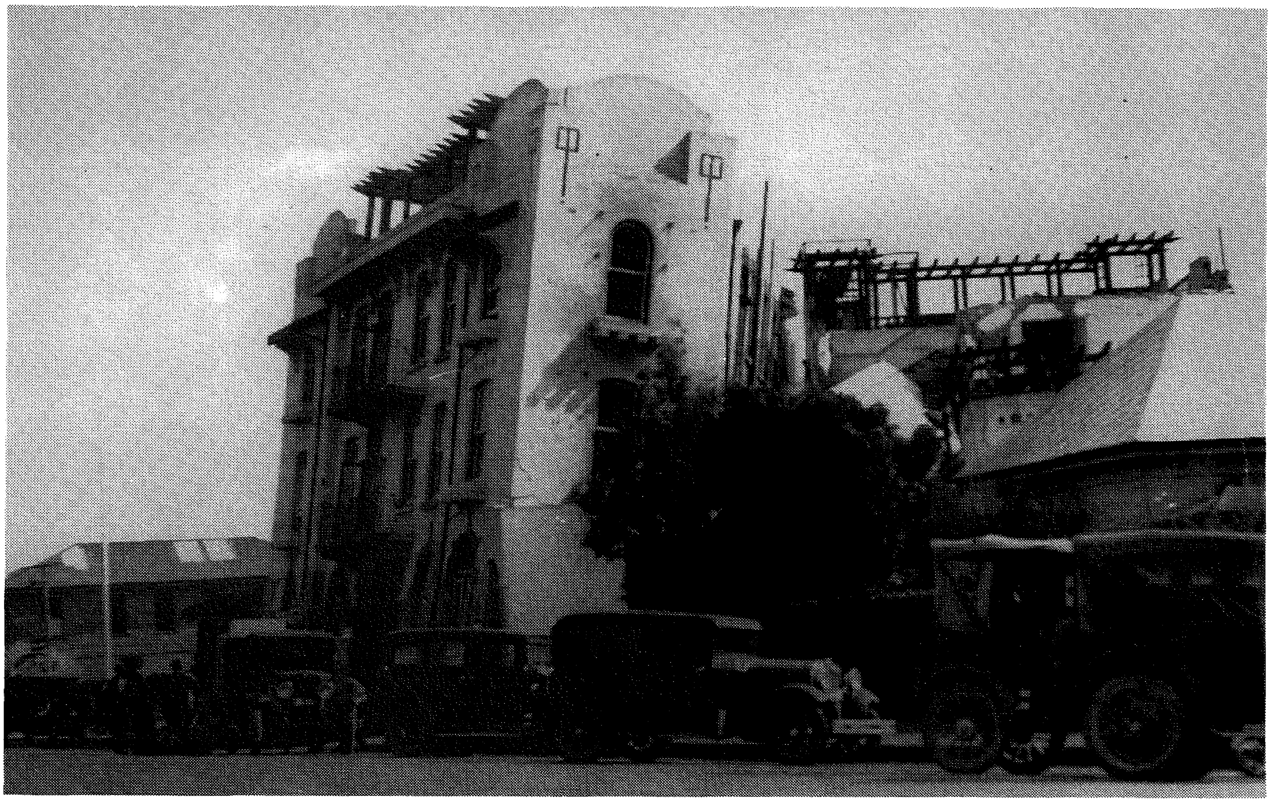

FIGURE 3(B) Example of Destroyed building: Dr Moore's Hospital, Napier, in the 1931 Hawke's Bay earthquake, no volume loss, but tilted beyond repair. (Reproduced by courtesy of the Alexander Turnbull Library, Wellington).

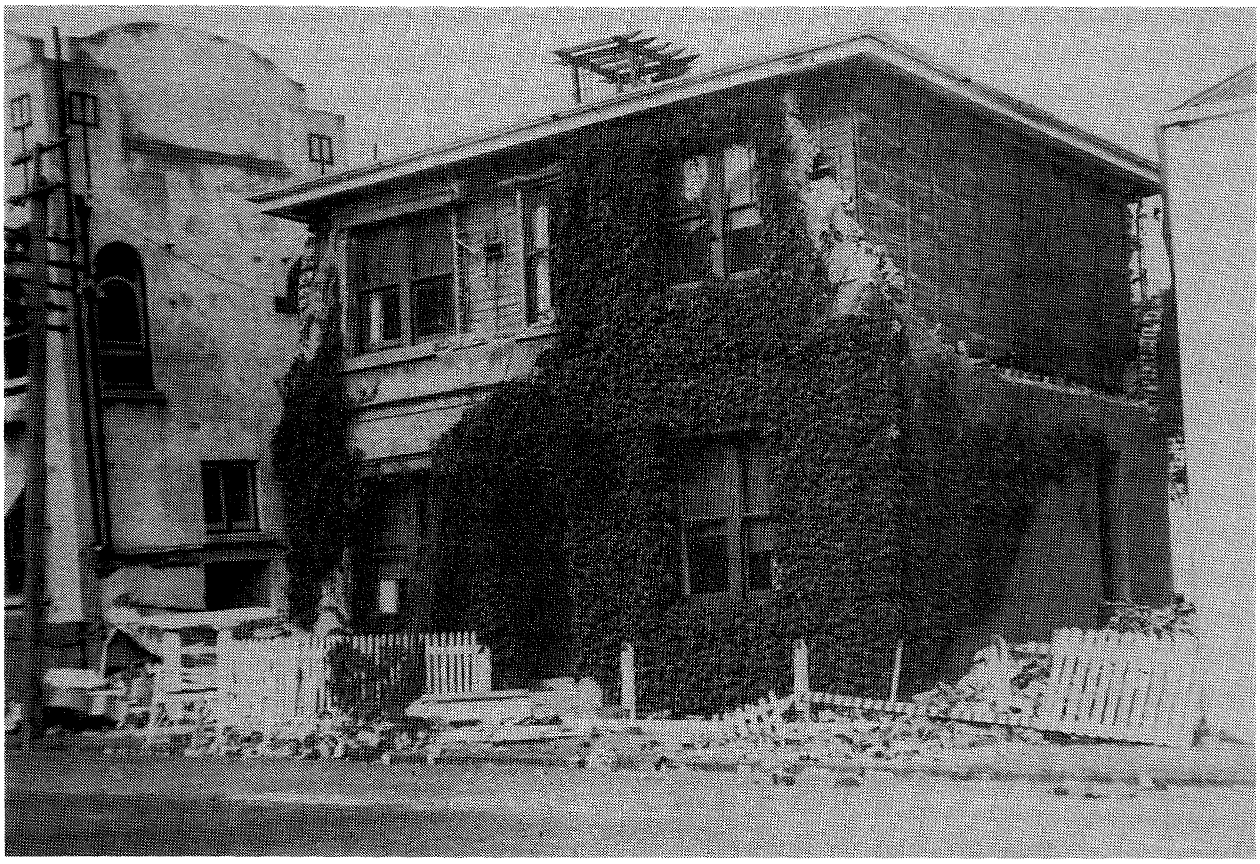

FIGURE 3(C) Example of supposedly Destroyed building: Hawke's Bay Club caretaker's residence, Napier, in the 1931 Hawke's Bay earthquake, stated to be beyond repair (through cracking), but strengthened and still in use in 1996. (Reproduced by courtesy of the Alexander Turnbull Library, Wellington).

data were drawn from ten earthquakes with magnitudes ranging from M_s5.0 to 7.8, dating from the period 1901 to 1942.

In selecting the localities experiencing MM6-8 used in the above analysis it was appropriate to find localities that were relatively unequivocal in intensity terms, i.e. towns located on essentially or predominantly one ground class, i.e. ground having no marked microzones. Thus it was necessary to exclude the large data base of chimney damage data from Wellington as given by Luke [14] resulting from a study of the 1942 Wairarapa earthquakes. Different microzone areas in Wellington experienced MM6, MM7 and MM8 in those earthquakes, with percentages of chimneys damaged varying from 0% to 84% in different suburbs [15]. The data of [14] and [15] do not separate out the chimneys that fell from those that had other damage, and the damage from the two events is compounded, so that the data do not exactly suit the purposes of the current study. However, it seems that the data support the wording proposed here for chimney damage at MM6 to MM8.

My findings are summarised in Table 2 and discussed as follows. For MM6 my data set comprised 30 cases, the numbers of chimneys in the 30 respective localities ranging from 50 to 30,000. The estimated percentage of chimneys which fell ranged from 0 to 3% with an average of 0.5%. This finding leads to the more explicit damage description proposed for MM6 in this paper. It implies slightly more damage than those proposed earlier [1, 2, 11-13].

For MM7 my data set comprises 11 cases, the numbers of chimneys in each locality ranging from 600 to 6500. The estimated percentage of chimneys which fell ranged from 2 to 20% with an average of 8%. This finding leads to the more explicit damage description proposed for MM7 in this paper. It is consistent with that of Dengler and McPherson [12], and elaborates on the meaning of the word "broken" used by others [1, 2, 11, 13].

For MM8 my data set comprises 15 cases, the numbers of chimneys in each locality ranging from 50 to 6600. The estimated percentage of chimneys which fell ranged from 12 to 100% with an average of 55%. This finding leads to more detailed wording than given by Eiby [2], Brazee [13] or the 1931 scale [11] which all simply state that "chimneys fall". It is less severe than Dengler and McPherson [12] who state that "most unreinforced chimneys fall". (Mistakenly, no reference was made to chimneys at intensity MM8 in the 1992 New Zealand scale).

FIGURE 4(A) Examples of Partial Collapse: Seminary at Greenmeadows in the 1931 Hawke's Bay earthquake, small volume loss, stated to be beyond repair, though means of repair were examined. (Reproduced by courtesy of the Alexander Turnbull Library, Wellington).

FIGURE 4(B) Example of Partial Collapse: Empire Hotel, Napier, in the 1931 Hawke's Bay earthquake, about 25% volume loss, stated to be beyond repair, but collapsed portion rebuilt. (Reproduced by courtesy of the Alexander Turnbull Library, Wellington).

Table 2: Incidence of fall* of unreinforced domestic masonry chimneys

Intensity	Number of Intensity Cases	Total number of chimneys per case		Percentage of chimneys which fell		
		min.	max.	min.	mean	max.
MM6	30	50	30,000	0	0.5	3
MM7	11	600	6,500	2	8	20
MM8	15	50	6,600	12	55	100

Note: * "Fall" means that at least the portion of the chimney above the roof-line falls (ie breaks off completely).

RESPONSES OF THE ENVIRONMENT

The wording of the criteria relating to responses of the environment at intensities MM7-MM9 in the 1992 New Zealand scale were seen to need some clarification and expansion. In addition the 1992 scale omitted any reference to the environment at MM10, pending further field data being available. With assistance from my engineering geologist colleagues G T Hancox and N D Perrin, some revisions and additions have been made, including re-introducing environment criteria for MM10, though we have not attempted to suggest environment criteria for MM11 and MM12 at this time.

At a later date it would be helpful if environment responses could be defined in relation to different classes of ground, similar in principle to the classification scheme already used for structures. Such an approach has been suggested for landslides in a study of intensities in the 1929 Murchison earthquake [3], with the landslide vulnerability of the terrain being related to factors such as slope, rock type, stratigraphy and ground water conditions. This issue is currently being addressed by the Institute of Geological and Nuclear Sciences, Lower Hutt, in a study of intensity versus landslides in past New Zealand earthquakes.

Ensuring internal consistency between earthquake effects on buildings and on the environment requires field observations and correlations within given intensity zones. This is often not possible because clearly defined environmental effects do not necessarily occur where there are buildings, such as the absence of buildings in the heavy landslide zone (probably MM10) at the centre of the M_s7.8 Murchison earthquake [3]. In Napier in the 1931 Hawke's Bay earthquake there was significant ground damage (settlement, ground cracking, and water and soil ejections) in parts of the harbour reclamation area, which was largely residential. It has been shown quantitatively [4] that the damage to houses was worse on sites subject to this ground damage than was the damage to houses on other types of ground in the rest of Napier. It is unfortunate from the present point of view that the descriptions still available of the ground damage from this 1931 earthquake are probably not detailed enough for verifying the MM10 liquefaction criteria suggested in this paper.

DISCUSSION OF PROPOSED AMENDMENTS

The proposed amendments and the reasons for them are noted below in ascending order of intensity. (For ease of comparison the text of the 1992 NZ Scale for MM6 - MM10 is included in Appendix B of this paper.)

MM5

Delete: *Direction of motion can be estimated.*
Reason: In hundreds of felt reports, observers have offered an estimated (predominant) direction of motion for intensities as low as MM2. In any case, assigning the direction of motion appears to be largely a matter of fancy.

MM6

Replace: *Unstable furniture overturned.* by: *Very unstable furniture overturned.*
Reason: Only occasional free-standing items with high aspect ratio (e.g. some wardrobes) fall at MM6.

Delete: Suspended ceilings damaged.
Reason: This appears to start at MM7 [16]. (This item was introduced only in 1992.)

Replace: *A few cases of chimney damage.* by: *Damage to a few unreinforced domestic chimneys, some may fall.*
Reason: Refer to text above.

MM7

Add: *Suspended ceilings damaged.*
Reason: Moved from MM6, see above.

Add: *Substantial damage to fragile contents of buildings.*
Reason: This is a logical extrapolation from MM6 reference to contents, and has recently been demonstrated for MM7 in a study of the Edgecumbe earthquake [8].

Replace: *Buildings Type I cracked and damaged.* by: *Buildings Type I cracked, some with masonry falls.*
Reason: Clarification of meaning of word "damaged", because "cracked" is also damaged.

After: Many unreinforced domestic chimneys add: *damaged, often falling from roof line.*
Reason: Refer to text above.

Replace: *Unbraced parapets and architectural ornaments fall.* by: *Unbraced parapets, unbraced brick gables, and architectural ornaments fall.*
Reason: Some gables have fallen at MM7 in past New Zealand and Australian earthquakes [16].

Replace: *Instances of differential settlement on poor or wet or unconsolidated ground.*
by: *Instances of settlement of unconsolidated, or wet, or weak soils.*

Reason: Eliminate redundant unnecessary word "differential", and clarify ground conditions.

After: *Small slides such as falls of sand and gravel banks.* add: *and small rock falls from steep slopes and cuttings.*
Reason: Addition of useful criterion.

After: *A few instances of liquefaction* add: *(ie small water and sand ejections.)*
Reason: Clarification.

MM8
Add: *Buildings Type I heavily damaged, some collapse.*
Reason: This useful criterion has always been missing from the scale, but is obviously implied by interpolation between the relevant criteria from MM7 and MM9, (see Table 1).

Replace: *Buildings Type II damaged, some seriously.* by: *Buildings Type II damaged, some with partial collapse.*
Reason: Revert to 1966 wording, in line with revised definition of Buildings Type II.

Add: *A few instances of damage to Structures Type IV.*
Reason: Revert to 1966 wording, in line with revised Construction Categories.

Replace: *Monuments and elevated tanks twisted or brought down.* by: *Monuments and pre-1976 elevated tanks and factory stacks twisted and brought down.*
Reason: Revert to 1966 scale wording, but with date limits added.

Add: *Most unreinforced domestic chimneys damaged, some below roof-line, many brought down.*
Reason: Refer to text above.

Before: *Slides in roadside cuttings ...* insert: *Small to moderate*
Reason: Clarification

Replace: *Small earthquake fountains and other manifestations of liquefaction.* by: *small water and sand ejections and localised spreading adjacent to streams canals, lakes, etc.*
Reason: Clarification.

MM9
Replace: *Very poor quality unreinforced masonry destroyed.* by: *Many buildings Type I destroyed.*
Reason: Revert (almost) to 1966 wording in line with Construction Categories, for consistency with the EMS [10].

Add: *Structures Type IV damaged in some cases, some with flexible frames seriously damaged.*
Reason: This useful criterion was in the 1931 scale but not in the 1966 scale. It is obviously implied by interpolation between the criteria of MM8 and MM10. This clearly happens in MM9 intensity zones, e.g. as documented for Edgecumbe earthquake [7].

Replace: *Buildings Type III damaged, some seriously.* by: *Buildings Type III damaged, some with partial collapse.*
Reason: For internal consistency (see Table 1).

Replace: *Buildings and bridges Type IV.* by: *Structures Type V.*
Reason: Simply re-labelling due to introducing another Construction Category.

Replace: *with large earthquake fountains and sand craters.* by: *and more widespread, with large water and sand ejections, lateral spreading and flow sliding adjacent to streams, canals, lakes, etc.*
Reason: *Clarification.*

MM10
The 1992 criteria for MM10 have been completely rewritten, partly to incorporate the revised construction criteria. In addition enviornment criteria have been again incorporated, having been omitted from the 1992 New Zealand scale. These new environment criteria are extrapolated from those for MM7-MM9.

MM11 and MM12
No criteria for these intensities were given in the 1992 New Zealand scale.

THE EUROPEAN MACROSEISMIC SCALE

In 1992 European countries published [10] a revision of their intensity scale, previously known as the MSK scale, naming it the European Macroseismic Scale (EMS). Differences in the wording of the New Zealand and European intensity scales are necessary because of the considerable differences in construction types and earthquake design requirements. However, despite such differences in detail, the two scales have traditionally been broadly similar and have been closely equivalent level-for-level. Hence, as EMS-92 includes definitions of Intensities X, XI and XII it is of interest here to compare their higher intensity definitions (Annexe A) with the new MM intensities as defined in this paper.

Converting the EMS building classes and damage grades into the nearest equivalent New Zealand MM intensity scale terminology as used in this paper, the following comparisons arise:

EMS X represents a close match of MM10.

EMS XI represents a close match of MM11 for all criteria except Buildings Type V (EMS Class F) for which the EMS scale expects less damage than does the MMI scale.

EMS XII closely follows the traditional definition of virtually total destruction. This involves a slightly greater increment in damage level than between the immediately lower intensity levels. It nevertheless represents a close match to MM12, indicating slightly greater damage.

It is noted that the present definitions of MM10-MM12 were developed by the author, using Table 1, without prior reference to the EMS, except that the words in italics in Table 1 were added after examining the EMS, in order to achieve greater consistency between the two scales.

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MODIFIED MERCALLI INTENSITY SCALE - NZ 1996

Items marked * in the scale are defined in the note following.

MM1 *People*

Not felt except by a very few people under exceptionally favourable circumstances.

MM2 *People*

Felt by persons at rest, on upper floors or favourably placed.

MM3 *People*

Felt indoors; hanging objects may swing, vibration similar to passing of light trucks, duration may be estimated, may not be recognised as an earthquake.

MM4 *People*

Generally noticed indoors but not outside. Light sleepers may be awakened. Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building.

Fittings

Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock.

Structures

Walls and frame of buildings, and partitions and suspended ceilings in commercial buildings, may be heard to creak.

MM5 *People*

Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people alarmed.

Fittings

Small unstable objects are displaced or upset. Some glassware and crockery may be broken.
Hanging pictures knock against the wall.
Open doors may swing.
Cupboard doors secured by magnetic catches may open.
Pendulum clocks stop, start, or change rate (H*).

Structures
Some windows Type I* cracked.
A few earthenware toilet fixtures cracked (H).

MM6 *People*
Felt by all.
People and animals alarmed.
Many run outside.*
Difficult experienced in walking steadily.

Fittings
Objects fall from shelves.
Pictures fall from walls (H*).
Some furniture moved on smooth floors, some unsecured free-standing fireplaces moved.
Glassware and crockery broken.
Very unstable furniture overturned.
Small church and school bells ring (H).
Appliances move on bench or table tops.
Filing cabinets or "easy glide" drawers may open (or shut).

Structures
Slight damage to Buildings Type I*.
Some stucco or cement plaster falls.
Windows Type I* broken.
Damage to a few weak domestic chimneys, some may fall.

Environment
Trees and bushes shake, or are heard to rustle.
Loose material may be dislodged from sloping ground, e.g. existing slides, talus slopes, shingle slides.

MM7 *People*
General alarm.
Difficulty experienced in standing.
Noticed by motorcar drivers who may stop.

Fittings
Large bells ring.
Furniture moves on smooth floors, may move on carpeted floors.
Substantial damage to fragile* contents of buildings.

Structures
Unreinforced stone and brick walls cracked.
Buildings Type I cracked some with minor masonry falls.
A few instances of damage to Buildings Type II.
Unbraced parapets, unbraced brick gables, and architectural ornaments fall.
Roofing tiles, especially ridge tiles may be dislodged.
Many unreinforced domestic chimneys damaged, often falling from roof-line.
Water tanks Type I* burst.
A few instances of damage to brick veneers and plaster or cement-based linings. Unrestrained water cylinders (Water Tanks Type II*) may move and leak.
Some windows Type II* cracked. Suspended ceilings damaged.

Environment
Water made turbid by stirred up mud.
Small slides such as falls of sand and gravel banks, and small rock-falls from steep slopes and cuttings.
Instances of settlement of unconsolidated or wet, or weak soils.
Some fine cracks appear in sloping ground. A few instances of liquefaction (ie small water and sand ejections).

MM8 *People*
Alarm may approach panic.
Steering of motorcars greatly affected.

Structures
Building Type I, heavily damaged, some collapse*.
Buildings Type II damaged, some with partial collapse*.

Buildings Type III damaged in some cases.
A few instances of damage to Structures Type IV.
Monuments and pre-1976 elevated tanks and factory stacks twisted or brought down.
Some pre-1965 infill masonry panels damaged.
A few post-1980 brick veneers damaged.
Decayed timber piles of houses damaged.
Houses not secured to foundations may move.
Most unreinforced domestic chimneys damaged, some below roof-line, many brought down.

Environment
Cracks appear on steep slopes and in wet ground.
Small to moderate slides in roadside cuttings and unsupported excavations.
Small water and sand ejections and localised lateral spreading adjacent to streams, canals, lakes, etc.

MM9 *Structures*
Many Buildings Type I destroyed*.
Buildings Type II heavily damaged, some collapse*.
Buildings Type III damaged, some with partial collapse*.
Structures Type IV damaged in some cases, some with flexible frames seriously damaged.
Damage or permanent distortion to some Structures Type V.
Houses not secured to foundations shifted off.
Brick veneers fall and expose frames.

Environment
Cracking of ground conspicuous.
Landsliding general on steep slopes.
Liquefaction effects intensified and more widespread, with large lateral spreading and flow sliding adjacent to streams, canals, lakes, etc.

MM10 *Structures*
Most Buildings Type I destroyed*.
Many Buildings Type II destroyed*.
Buildings Type III▽ heavily damaged, some collapse*.
Structures Type IV▽ damaged, some with partial collapse*.
Structures Type V▽ moderately damaged, but few partial collapses.
A few instances of damage to Structures Type VI.
Some well-built* timber buildings moderately damaged (excluding damage from falling chimneys).

Environment
Landsliding very widespread in susceptible terrain, with very large rock masses displaced on steep slopes. Landslide dams may be formed.
Liquefaction effects widespread and severe.

MM11 *Structures*
Most Buildings Type II▿ destroyed*.
Many Buildings Type III▿ destroyed*.
Structures Type IV▿ heavily damaged, some collapse*.
Structures Type V▿ damaged, some with partial collapse.
Structures Type VI suffer minor damage, a few moderately damaged.

MM12 *Structures*
Most Buildings Type III▿ destroyed.
Many Structures Type IV▿ destroyed.
Structures Type V heavily damaged, some with partial collapse.
Structures Type VI moderately damaged.

NOTE TO 1996 NZ MM SCALE

Items marked * in the scale are defined below.

Construction Types:

Buildings Type I (Masonry D in the NZ 1965 MM scale)

Buildings with low standard of workmanship, poor mortar, or constructed of weak materials like mud brick or rammed earth. Soft storey structures (e.g. shops) made of masonry, weak reinforced concrete, or composite materials (e.g. some walls timber, some brick) not well tied together. Masonry buildings otherwise conforming to Buildings Types I - III, but also having heavy unreinforced masonry towers. (Buildings constructed entirely of timber must be of extremely low quality to be Type I).

Buildings Type II (Masonry C in the NZ 1966 MM scale)

Buildings of ordinary workmanship, with mortar of average quality. No extreme weakness, such as inadequate bonding of the corners, but neither designed nor reinforced to resist lateral forces. Such buildings not having heavy unreinforced masonry towers.

Buildings Type III (Masonry B in the NZ 1966 MM scale)

Reinforced masonry or concrete buildings of good workmanship and with sound mortar, but not formally designed to resist earthquake forces.

Structures Type IV (Masonry A in the NZ 1966 MM scale)

Buildings and bridges designed and built to resist earthquakes to normal use standards, i.e. no special collapse or damage limiting measures taken (mid-1930's to c. 1970 for concrete and to c. 1980 for other materials).

Structures Type V

Buildings and bridges, designed and built to normal use standards, i.e. no special damage limiting measures taken, other than code requirements, dating from since c. 1970 for concrete and c. 1980 for other materials.

Structures Type VI

Structures, dating from c. 1980, with well-defined foundation behaviour, which have been specially designed for minimal damage, e.g. seismically isolated emergency facilities, some structures with dangerous or high contents, or new generation low damage structures.

Windows

Type I - Large display windows, especially shop windows.
Type II - Ordinary sash or casement windows.

Water Tanks

Type I - External, stand mounted, corrugated iron water tanks.
Type II - Domestic hot-water cylinders unrestrained except by supply and delivery pipes.

H - (Historical) More likely to be used for historical events.

Other Comments

"Some" or "a few" indicates that the threshold of a particular effect has just been reached at that intensity.
"Many run outside" (MM6) variable depending on mass behaviour, or conditioning by occurrence or absence of previous quakes, i.e. may occur at MM5 or not till MM7.
"Fragile Contents of Buildings". Fragile contents include weak, brittle, unstable, unrestrained objects in any kind of building.
"Well-built timber buildings" have: wall openings not too large; robust piles or reinforced concrete strip foundations; superstructure tied to foundations.
▿ Buildings Type III - V at MM10 and greater intensities are more likely to exhibit the damage levels indicated for low-rise buildings on firm or stiff ground and for high-rise buildings on soft ground. By inference lesser damage to low-rise buildings on soft ground and high-rise buildings on firm or stiff ground may indicate the same intensity. These effects are due to attenuation of short period vibrations and amplification of longer period vibrations in soft soils.

APPENDIX A: Extract from the European Macroseismic Scale - 1992 [10]

EMS X Many buildings of vulnerability class C suffer damage of grade 4. Many buildings of class B and a few of class C suffer damage of grade 5, as do most buildings of class A. Many buildings of class D suffer damage of grade 3; a few suffer grade 4. Many buildings of class E suffer damage of grade 2; a few suffer grade 3. A few buildings of class F suffer damage of grade 2.

EMS XI Most buildings of vulnerability class C suffer damage of grade 4. Most buildings of class B and many of class C suffer damage of grade 5. Many buildings of class D suffer damage of grade 4; a few suffer grade 5. Many buildings of class E suffer damage of grade 3; a few suffer grade 4. Many buildings of class F suffer damage of grade 2, a few suffer grade 3.

EMS XII Practically all structures above and below ground are destroyed.

Note that the correlations between EMS building Classes and MM building/structure Types are approximately A:I, B:II, C:III, D and E:IV, F:V, no EMS equivalent to MM Type VI.

The damage levels in the two scales are harder to compare, but EMS grade 5 ≈ destroyed, 4 ≈ heavily damaged, 2 - 3 ≈ moderate to light damage.

APPENDIX B: Extract from the 1992 New Zealand Intensity Scale [1] included here for comparison purposes

MM6 (1992)

People
Felt by all.
People and animals alarmed.
Many run outside.
Difficulty experienced in walking steadily.

Fittings
Objects fall from shelves.
Pictures fall from walls (H*).
Some furniture moved on smooth floors.
Some unsecured free-standing fireplaces moved.
Glassware and crockery broken.
Unstable furniture overturned.
Small church and school bells ring (H).
Appliances move on bench or table tops.
Filing cabinets or "easy glide" drawers may open (or shut).

Structures
Slight damage to Buildings Type I*.
Some stucco or cement plaster falls.
Suspended ceilings damaged.
Windows Type I* broken.
A few cases of chimney damage.

Environment
Trees and bushes shake, or are heard to rustle.
Loose material may be dislodged from sloping ground, e.g. existing slides,
talus slopes, shingle slides.

MM7 (1992)

People
General alarm.
Difficulty experienced in standing.
Noticed by motorcar drivers who may stop.

Fittings
Large bells ring.
Furniture moved on smooth floors, may move on carpeted floors.

Structures
Unreinforced stone and brick walls cracked.
Buildings Type 1 cracked and damaged.
A few instances of damage to Buildings Type II.
Unbraced parapets and architectural ornaments fall.
Roofing tiles, especially ridge tiles may be dislodged.
Many unreinforced domestic chimneys broken.
Water tanks Type I* burst.
A few instances of damage to brick veneers and plaster or cement-based linings.
Unrestrained water cylinders (Water Tanks Type II*) may move and leak.
Some Windows Type II* cracked.

Environment
Water made turbid by stirred up mud.
Small slides such as falls of sand and gravel banks.
Instances of differential settlement on poor or wet or unconsolidated ground.
Some fine cracks appear in sloping ground.
A few instances of liquefaction.

MM8 (1992)

People
Alarm may approach panic.
Steering of motorcars greatly affected.

Structures
Buildings Type II damaged, some seriously.
Buildings Type III damaged in some cases.
Monuments and elevated tanks twisted or brought down.
Some pre-1965 infill masonry panels damaged.
A few post-1980 brick veneers damaged.
Weak piles damaged.
Houses not secured to foundations may move.

Environment
Cracks appear on steep slopes and in wet ground.
Slides in roadside cuttings and unsupported excavations.
Small earthquake fountains and other manifestations of liquefaction.

MM9 (1992)

Structures
Very poor quality unreinforced masonry destroyed.
Buildings Type II heavily damaged, some collapsing.
Buildings Type III damaged, some seriously.
Damage or permanent distortion to some Buildings and Bridges Type IV.
Houses not secured to foundations shifted off.
Brick veneers fall and expose frames.

Environment
Cracking of ground conspicuous.
Landsliding general on steep slopes.
Liquefaction effects intensified, with large earthquake fountains and sand craters.

MM10 (1992)

Structures
Most unreinforced masonry structures destroyed.
Many Buildings Type II destroyed.
Many Buildings Type III (and bridges of equivalent design) seriously damaged.
Many Buildings and Bridges Type IV have moderate damage or permanent
distortion.

Categories of Construction - 1992 NZ Scale

Buildings - Type I
Weak materials such as mud brick and rammed earth; poor mortar; low standards of workmanship (Masonry D in other MM scales).

Buildings - Type II
Average to good workmanship and materials, some including reinforcement, but not designed to resist earthquakes (Masonry B and C in other MM scales).

Buildings - Type III
Buildings designed and built to resist earthquakes to normal use standards, i.e. no special damage limiting measures taken (mid-1930's to c. 1970 for concrete and to c.1980 for other materials.

Buildings and Bridges - Type IV
Since c. 1970 for concrete and c. 1980 for other materials, the loadings and materials codes have combined to ensure fewer collapses and less damage than in earlier structures. This arises from features such as: (i) "capacity design" procedure, (ii) use of elements (such as improved bracing or structural walls) which reduce racking (i.e. drift), (iii) high ductility, (iv) higher strength.