THE MODIFIED MERCALLI INTENSITY SCALE – REVISIONS ARISING FROM NEW ZEALAND EXPERIENCE

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ABSTRACT

Recent studies of the effects and Modified Mercalli (MM) intensities of New Zealand earthquakes have established criteria that will improve the reliability of intensities assigned using a number of effects, particularly the incidence of chimney damage and a wide range of environmental phenomena. The proportions of brittle chimneys which were damaged at intensities MM5 –MM10 have been counted from the very detailed database of the 1968 M_w 7.2 Inangahua earthquake, and are shown to relate well to the proportions of chimneys which fell in 10 other earthquakes. Criteria based on environmental effects at intensities MM5-MM10 have been extended based on detailed studies of 22 earthquakes. These criteria have been adopted in an international intensity scale for environmental effects.

It was also found that the stopping of clocks should be a criterion for MM3, not MM5, and similarly the disturbance of liquids should be used at the threshold intensity of MM3 rather than MM4, as in the present MM intensity scale.

With the probable saturation of intensity at MM10, the criteria for MM12 have been omitted.

INTRODUCTION

Since publishing a revision to the New Zealand version of the Modified Mercalli (MM) scale (Dowrick, 1996), the first author of this paper has reviewed the data for assigning c. 5,500 local intensities in over 120 New Zealand earthquakes, covering the period 1876-2003. In addition, he has studied the damage to houses in the 1968 M_w 7.2 Inangahua earthquake as a function of MM intensity (Dowrick *et al*., 2001). In the course of that research, some improvements to the criteria for assigning intensities have become apparent. These relate to damage to brittle domestic chimneys, stopping of clocks, disturbance of liquids and damage to sanitary fittings.

Additional environmental criteria relating to independently determined MM intensities were derived as a result of examination and quantification of the full range of ground damage effects observed in an engineering geology study of 22 New Zealand earthquakes by Hancox *et al*. (1997; 2002).

The above matters are discussed below.

DAMAGE TO BRITTLE DOMESTIC CHIMNEYS

Until recent times, the incidence of damage to brittle (mainly unreinforced masonry) domestic chimneys has been crucial to the assignment of intensities MM6-MM8 in earthquakes in the USA (Brazee, 1980), and in many other countries including New Zealand. The MM intensity scale and the European Macroseismic Scale have chimney damage criteria for MM6-MM8, as given here in Appendix 1. Dowrick (1996) quantified the incidence of fallen chimneys in 10 New Zealand earthquakes for intensities MM6-MM8, as presented again here in Table 1. The "fall" of chimneys was defined as "at least the portion of the chimney above the roof-line falls (i.e. breaks off completely)".

Table 1: Incidence of fall* of unreinforced masonry domestic chimneys (from Dowrick, 1996)

Intensity	Number of Intensity Cases	Total number of chimneys per case		Proportion of chimneys which fell		
		Min.	Max.	Min.	Mean	Max.
MM8	15	50	6,600	0.12	0.55	1.0
MM7	11	600	6,500	0.02	0.08	0.20
MM6	30	50	30,000	0	0.005	0.030

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

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As the nature of the damage to chimneys is often reported simply as “damaged”, the number of chimneys which actually fell at a given location is often unclear. Hence it has become apparent that statistics on the incidence of “damaged” chimneys would provide more reliable and usable criteria for assigning intensity. The large and very detailed database from the earthquake insurance claims on the Earthquake and War Damage Commission from the 1968 M_w 7.2 Inangahua earthquake, provide an ideal opportunity to assemble such statistics, albeit from only one earthquake. The data are strong in both quantity (see Table 1) and quality. The statistics are truly representative because not only were there data on nearly all insured houses, but also information on chimney status existed for nearly all these houses.

The database used was assembled during the study by Dowrick *et al*. (2001) of damage ratios for domestic property in that earthquake. Damage data was assembled over a wide range of intensities, i.e. MM5-MM10. The data was organized into sets according to intensity zones, where each zone incorporated all the houses between adjacent isoseismals. Thus, for example, the MM6 zone is the area between the MM6 and MM7 isoseismals. For each intensity zone a count was made of the total number of insured houses, the number of houses damaged, and the number of houses with damaged chimneys. In 1968, at the time of the earthquake, nearly all chimneys were brittle (the remainder were made of galvanized iron). The statistics extracted from the database are presented in Table 2.

In the intensity scale the threshold of chimney damage is MM6, and we see from column (8) of Table 2 that at MM6 c. 5 percent of houses (with brittle chimneys) had chimney damage in the Inangahua earthquake. It is also seen that there was a very small incidence of chimney damage in the MM5 zone, i.e. 15 per 10,000 houses with brittle chimneys. If the occupant of one of these houses sent in a “felt report” on the earthquake, the local intensity would have been assigned as MM6. It would have been one of the MM6s in the MM5 zone. In fact there are eight MM6s in the MM5 zone on the (revised) isoseismal map (Figure 1) contributing to the natural variability of the spatial distribution of intensity.

It is noted that the author has recently reviewed the intensities for the Inangahua earthquake, and resulting revisions have necessitated revisions to the locations of the southern parts of the MM8 and MM9 isoseismals. These changes in turn have resulted in revisions to the database for the MM7-MM9 zones used by Dowrick *et al*. (2001.)

At the time of the earthquake, most houses had at least one brittle chimney, but it was not feasible to establish the actual percentage of houses with such chimneys. Hence for the purposes of this study it was assumed that 90 percent of houses had brittle chimneys, so that the numbers of houses in column (1) are 90 percent of the actual numbers of houses in the database.

The data for incidence of chimneys which fell (from Table 1), and those for incidence of chimneys which were damaged (column 8 of Table 2), are plotted on Figure 2. As expected, it is seen that the proportion of damaged chimney that fell increases with increasing intensity. Dividing the mean proportion that fell by the proportion damaged, we obtain the ratios 0.09, 0.13, and 0.60 for MM6, MM7 and MM9 respectively. These figures are consistent with the criteria of the MM intensity scale (Appendix 1). At intensity MM10, it is known from the Inangahua earthquake and the much larger sample from Napier in 1931 (Dowrick, unpublished data) that very close to all brittle chimneys fall. We can thus interpolate between that and 0.6 at MM8 to infer that on average about 85 percent of damaged brittle chimneys fall at MM9 (Figure 2).

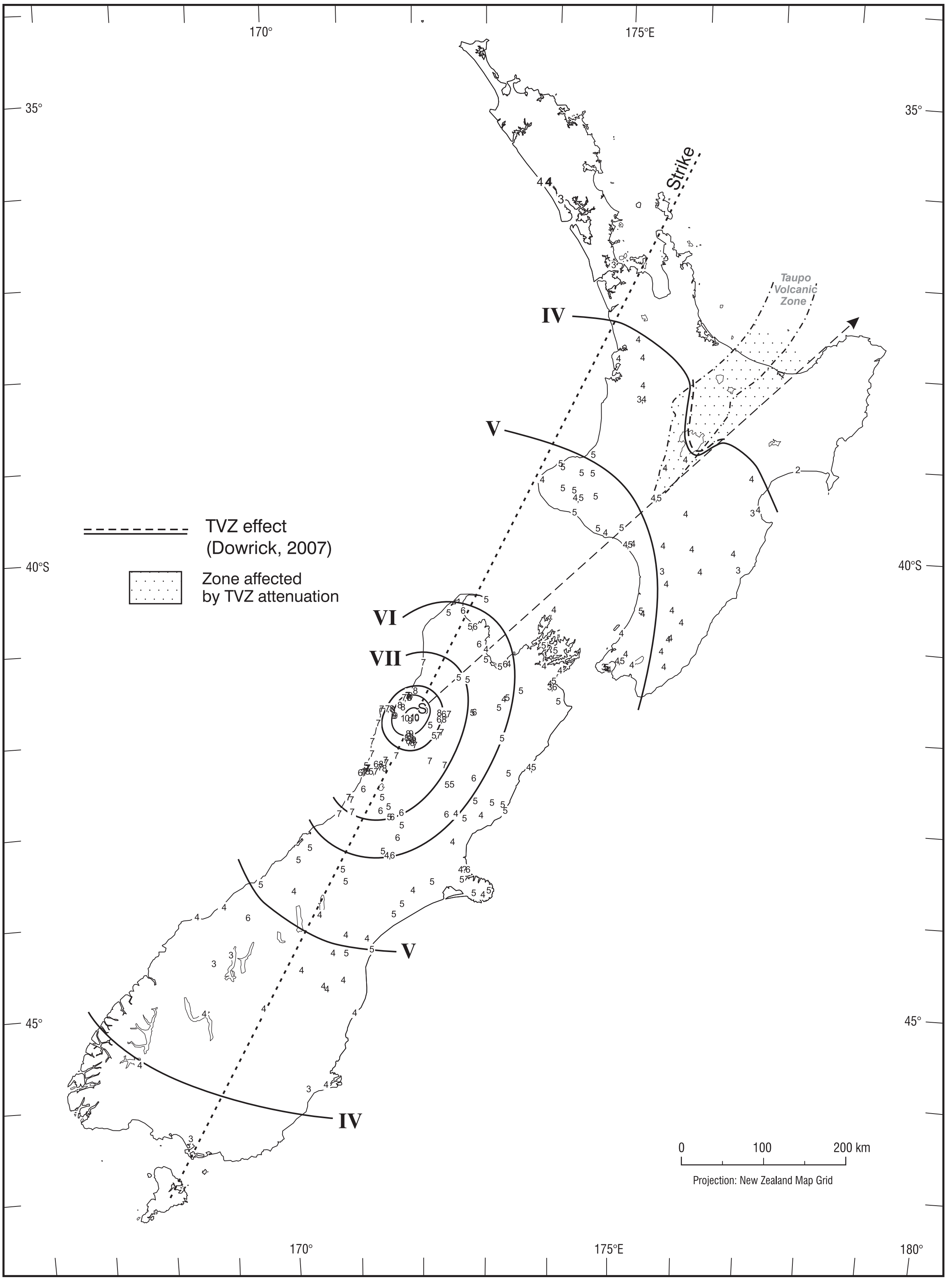

Figure 1. ***Revised isoseismal map of the 1968 M_w 7.2 Inangahua earthquake.***

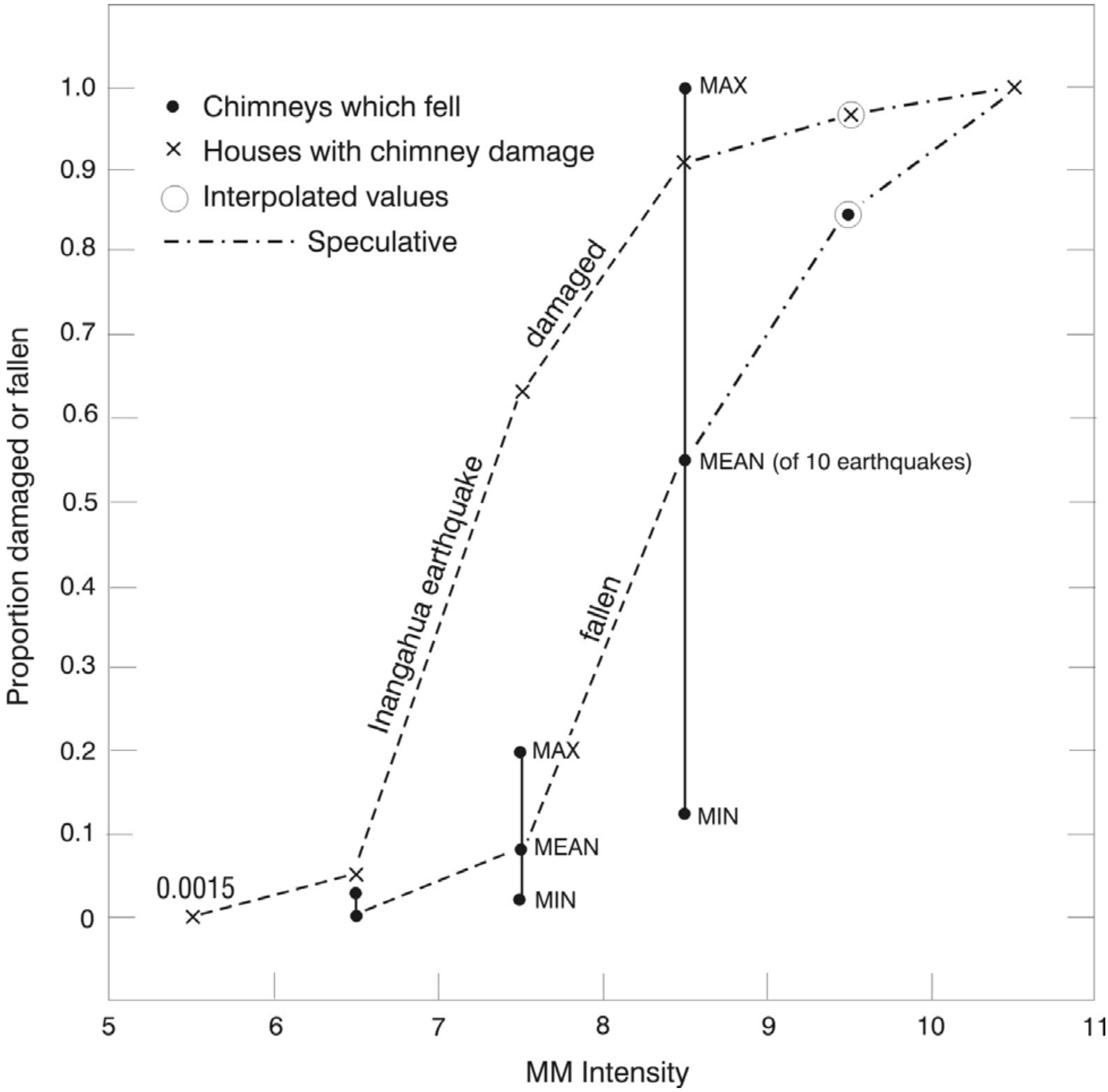

Figure 2. Proportions of brittle chimneys (1) damaged, and (2) fallen, as functions of Modified Mercalli intensity, in New Zealand earthquakes.

ENVIRONMENTAL EFFECTS

Hancox et al. (1997; 2002) studied the environmental effects of 22 New Zealand earthquakes that occurred in the period 1855 – 1995, with magnitudes in the range M_w 5.1-8.2 (Table 3). These earthquakes affected a wide range of terrains and ground conditions with intensities ranging up to MM10 in the four largest events. The wide range of events studied enabled a comprehensive range of types of ground damage to be assessed and quantified, at all relevant intensities, including landslides, incipient landsliding, ie. cracks and rents in slopes and ridges, lateral spreading of natural and made-ground, subsidence of fill and embankments, and various liquefaction effects.

The above phenomena were related through degrees of severity to the MM intensities determined from non-environmental criteria in the earthquakes concerned. This procedure resulted in a set of environmental criteria for intensity which is more comprehensive than that the 1996 MM intensity scale. The threshold adopted in the MM scale for environmental effects has been reduced from MM6 to MM5, as occasionally loose boulders on very steep slopes have been dislodged in the MM5 zones of New Zealand earthquakes.

Rainfall before an earthquake can substantially increase the number and size of landslides caused by the earthquake (Hancox *et al*., 2004; Dellow & Hancox, 2006). This increases the scatter in the relationship between intensity and landslides which creates a source of variability in intensities assigned from landslides only, a variability that is seldom present in intensity criteria based on damage to the built environment. Buildings can of course suffer enhanced earthquake damage from environmental effects such as landslides and liquefaction.

The area affected by landsliding during the 2004 Rotoehu earthquake fits well against the area/magnitude mean regression line for worldwide earthquake data, but is slightly

Table 3. Historical earthquakes causing substantial landsliding in New Zealand

NAME	DATE (UT)	MAGNITUDE (1)	DEPTH km(2)	EFFECTS	KEY REFERENCES
Marlborough	15 Oct 1848	M_w 7.5	10	MM9 in Wairau and Awatere valleys; surface faulting in Awatere valley. Many slides in epicentral area.	[21], GNS Files (3)
Wairarapa	23 Jan 1855	M_w 8.2	19	MM9 in Wellington; widespread landsliding in Wellington region.	[16], [20]
Nth Canterbury	31 Aug 1888	M_w 7.1	8	Surface faulting at Glynn Wye.	[4]
Cheviot	15 Nov 1901	M_w 6.8	10	Landslides at MM8-9; roads blocked.	
Cape Turnagain	8 Aug 1904	M_w 7-7.2	16-40	Widespread damage and landslides in Nth Wairarapa.	[6]
East Cape	7 Oct 1914, 28 Oct 1914	M_w 6.6 M_w 6.4	20 35	Significant landsliding; 1 death due to landsliding.	[6], [30]
Arthur's Pass	9 Mar 1929	M_w 7.0	11	Widespread landslides in mountainous country.	[38]
Buller (Murchison)	16 Jun 1929	M_w 7.7	9	Widespread catastrophic landslides; extensive damage; surface faulting; 17 deaths, 14 from landslides.	[8], [27], [33]
Hawke's Bay	2 Feb 1931	M_w 7.8	15	Widespread damage, surface faulting, landslides; 261 deaths (none from landslides).	[2], GNS Files
Wairoa	16 Sep 1932	M_w 6.8	8	Damage in Gisborne and Wairoa; significant landsliding.	[31]
Waione (formerly Pahiatua)	5 Mar 1934	M_w 7.4	12	Much landslide damage in S Hawke's Bay and N Wairarapa.	[6], [16]
Wairarapa	24 Jun 1942 1 Aug 1942	M_w 7.1 M_w 7.0	12 40	Much damage in Wairarapa and Wellington; many landslides.	[6]
Lake Coleridge	26 Jun 1946	M_w 6.5	9	Some minor landsliding.	[6], [18]
Peria	22 Dec 1963	M_w 4.9	6	Minor landsliding.	[14]
Inangahua	23 May 1968	M_w 7.2	10	Much damage; extensive and very large landslides in Buller area; 1 death, from landsliding.	[1]
Waiotapu	14 Dec 1983	M_w 5.1	3	Minor landslide effects.	[6]
Edgecumbe	2 Mar 1987	M_w 6.5	6	Much damage, surface faulting; many landslides and extensive liquefaction.	[6], [19], [29]
Weber I	13 May 1990	M_w.6.4	11	Widespread minor landsliding in weak Tertiary rocks; minor damage to roads.	[6], [35]
Ormond	10 Aug 1993	M_w 6.2	39	Widespread minor landsliding in weak Tertiary rocks; minor damage to roads.	[36], [37]
Secretary Island	10 Aug 1993	M_w 6.8	22	Sparsely distributed landsliding over a wide area; generally small slides.	[39]
Arthur's Pass	18 Jun 1994	M_w 6.7	6	Widespread landsliding in the Southern Alps epicentral area.	[32], GNS Files
Arthur's Pass	29 May 1995	M_L 5.5	4	Landslides affected road cuts and fills.	[33]

NOTES:Most of the magnitudes are given by Dowrick & Rhoades (1998)

(1) Centroid (centre of fault rupture surface) depths (km) mostly from Dowrick & Rhoades (1998).
(2) Files and other seismological and landslide data held by the Institute of Geological & Nuclear Sciences Limited (GNS).
(3) The approximate size of landslides referred to in this table are:
(4) Very small (10^3 m^3); Small (10^3-10^4 m^3); Moderate (10^4-10^5 m^3);
(5) Large (10^5-10^6 m^3); Very large (1-50 x 10^6 m^3); Extremely large (> 50 x 10^6 m^3).

above that for historical earthquakes in New Zealand. This is probably because slopes in the area were saturated when the 2004 earthquakes occurred, as the same slopes did not fail when shaken at least as strongly during the 1987 Edgecumbe earthquake (Hancox *et al*., 1997). That earthquake occurred in summer when the slopes would have been drier and less susceptible to failure. Based on the type, size and number of landslides, and the minor soil liquefaction effects that occurred, the maximum Modified Mercalli felt intensity in the epicentral area during the two largest (M_L 5.4 and M_L 5.0) earthquakes of the swarm is estimated to have been about MM7. This is generally consistent with the many felt intensity reports of MM7 and few of MM8 in the Lake Rotoehu and Lake Rotoma area.

The above work by Hancox et al. (1997; 2002) has been accepted internationally, being incorporated into intensity scales based solely on environmental effects (INQUA, 2003; Guerrieri & Vittori, 2007). These scales have adopted their various landslide types and ground damage and liquefaction effects at the various intensity levels, and also the terms used to describe landslide size.

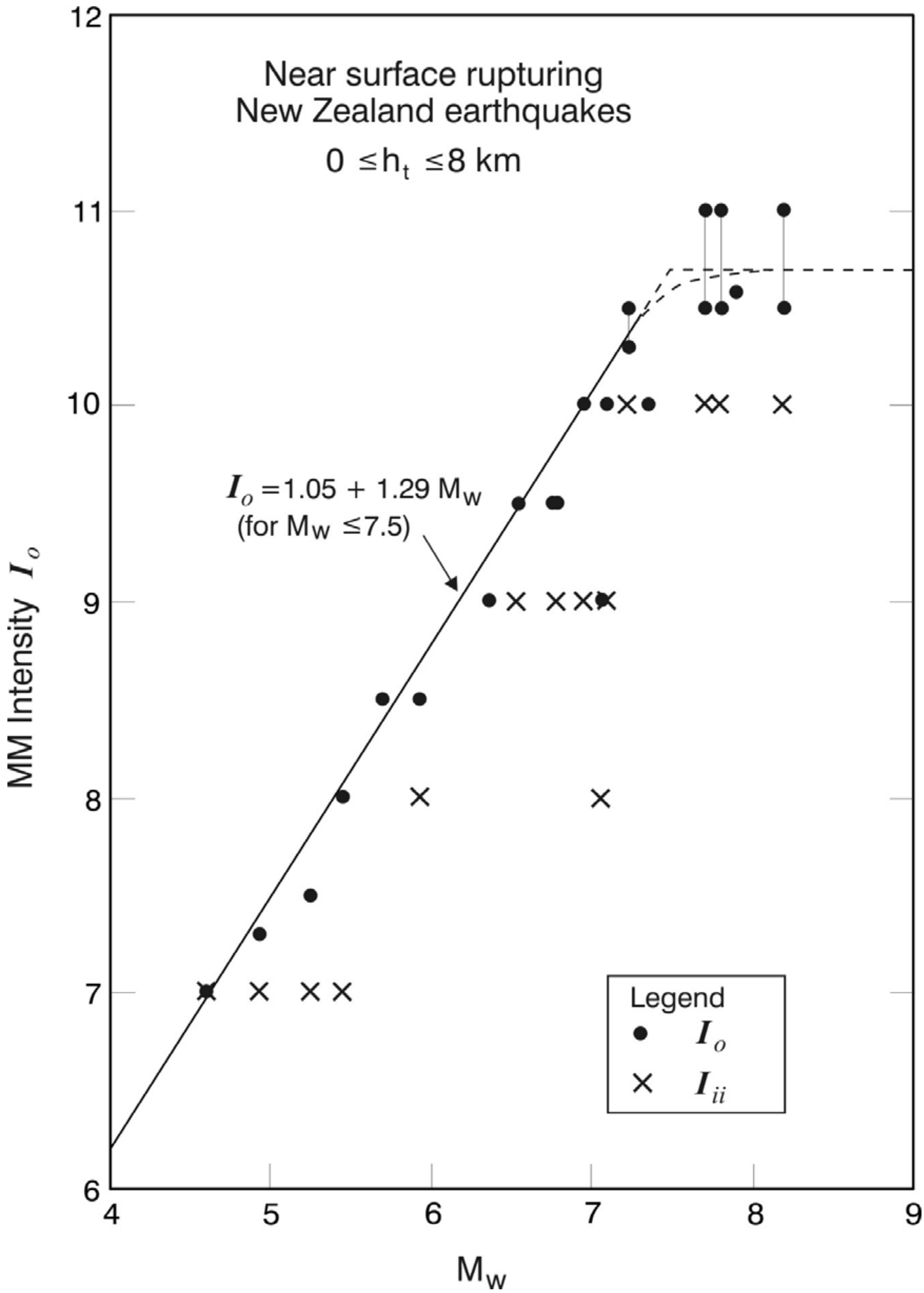

Figure 3. Plot of data for intensity at centre (I_o) and innermost isoseismal (I_{ii}) for near surface rupturing earthquakes, with upper bound line for I_o versus magnitude (from Dowrick and Rhoades, 2005).

STOPPING OF CLOCKS

One of the criteria for MM5 in the MM scale (Wood & Neumann, 1933; Dowrick, 1996) says: "Pendulum clocks stop, start, or change rate." In reading reports of the effects of many past earthquakes in New Zealand, the first author has frequently come across cases of clocks stopping in shaking which is clearly less strong than MM5. For example, in Morrinsville a clock in one particular house stopped in both the 1931 M_w 7.8 Hawke's Bay earthquake and in the subsequent 1931 M_w 6.9 Wairoa earthquake, where the intensity was MM3 in both events. In the 1962 M_w 5.0 Aria earthquake, pendulum clocks stopped at two locations, one where the intensity was MM4, and the other, Te Aroha, where the intensity was MM3.

It is therefore proposed that the criterion of the stopping of clocks should be transferred to intensity MM3.

DISTURBANCE OF LIQUIDS

The original MM intensity scale of Wood & Neumann (1933) gave criteria with increasing disturbance of liquids in open containers, from MM4 to MM6. In the current New Zealand version of the scale the response of liquids is (correctly) no longer mentioned at MM5 and MM6, while at MM4 the criterion is: "Liquids in open vessels may be slightly disturbed."

It is of interest to note that quite large responses of liquid also occur at low intensities in long duration shaking, i.e. in large magnitude events, no doubt because of the very low damping of low viscosity liquids such as water. This is illustrated by the half metre high waves observed in the public baths in Hamilton in the 1931 M_w 7.8 Hawke's Bay earthquake. The most extreme example of the sensitivity of water to lengthy low amplitude shaking occurred in the 1929 M_w 7.7 Buller earthquake. In Dargaville, 640 km from the source, the town gas tank was observed to be rocking in the water in which it was floating.

SATURATION OF INTENSITY

While the original MM scale of Wood and Neumann (1933) went to MM12, Eiby (1966) did not extend the scale beyond MM10, and the European Macroseismic Scale (which is equivalent to the MM scale) also stops at intensity X. The possibility of stronger shaking than MM10 was allowed for by Dowrick (1996) by reintroducing MM11 and MM12.

The maximum intensity observed in New Zealand earthquakes is MM10 (in four events). The possibility that MM intensity does not exceed a certain value, ie. it saturates (as does peak ground acceleration), was explored by Dowrick and Rhoades (2005). They plotted the maximum intensities observed in the 18 shallowest events in their database (for which the top of the fault rupture was ≤ 8 km) as a function of magnitude. As seen in Figure 3, saturation of intensity becomes noticeable at a magnitude of about M_w 7.5, and at an intensity of nearly MM11. As a consequence, we have decided to omit intensity MM12 from this upgrade of the scale, leaving the criteria for MM11 for ease of assessing whether that intensity is reached in some future powerful earthquake, rather than just MM10.

CONCLUSIONS

1. Statistics have been assembled on the percentages of brittle chimneys that are damaged in earthquakes, at intensities ranging from MM5 to MM10. These will help in assigning more reliable earthquake intensities.
2. The criteria for environmental effects have been substantially expanded throughout the range of intensities MM6 - MM10, and loose boulders have been observed to be dislodged occasionally at MM5.
3. The criterion of the stopping of clocks should be moved from intensity MM5 to MM3.
4. The threshold for the disturbance of liquids is currently given at MM4 in the New Zealand MM intensity scale, but quite substantial waves have been observed in liquid containers at MM3 in long duration shaking. A new criterion has been introduced at MM3 for the latter effect, and the MM4 criterion has been restricted to earthquakes of small to medium size.
5. The full text of the revised version of the scale is given here in Appendix 2.
6. The criteria for intensity MM12 have been omitted because of the likelihood that intensity saturates at nearly MM11.

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APPENDIX 1

Extracts from the New Zealand version of the Modified Mercalli scale relating to chimney damage (Dowrick, 1996; and this paper)

MM6 Damage to a few weak chimneys, some may fall.

MM7 Many unreinforced domestic chimneys damaged, often falling from the roof-line.

MM8 Most unreinforced domestic chimneys damaged, some below roof-line, many brought down.

APPENDIX 2

MODIFIED MERCALLI INTENSITY SCALE - NZ 2007

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

Revisions in this version of the scale are shown in italics.

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.

Fittings

Liquids in large open containers may be disturbed (sometimes considerably) in large magnitude (long duration) earthquakes. Pendulum clocks may stop, start, or change rate (H).*

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 *in small to medium-sized earthquakes*. Standing motorcars may rock.

Structures

Walls and frames 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.

Structures

Some windows Type I* cracked. A few earthenware toilet fixtures cracked, *in timber buildings with inadequately braced piles.*

Environment

Loose boulders may occasionally be dislodged from steep slopes.

MM6 *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.

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 *and scree* slopes.

A few very small (≤10^3 m^3) soil and regolith slides and rock falls from steep banks and cuts.

A few minor cases of liquefaction (sand boil) in highly susceptible alluvial and estuarine deposits.

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 common.

Instances of settlement of unconsolidated, or wet, or weak soils.

A few instances of liquefaction (ie. small water and sand ejections).

Very small (≤10^3 m^3) disrupted soil slides and falls of sand and gravel banks, and small rock falls from steep slopes and cuttings are common.

Fine cracking on some slopes and ridge crests.

A few small to moderate landslides (10^3 –10^5 m^3), mainly rock falls on steeper slopes (>30˚) such as gorges, coastal cliffs, road cuts and excavations.

Small discontinuous areas of minor shallow sliding and mobilisation of scree slopes in places.

Minor to widespread small failures in road cuts in more susceptible materials.

A few instances of non-damaging liquefaction (small water and sand ejections) in alluvium.

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, *and damage to earthenware sanitary fittings may occur*.

Most unreinforced domestic chimneys damaged, some below roof-line, many brought down.

Environment

Cracks appear on steep slopes and in wet ground.

Significant landsliding likely in susceptible areas.

Small to moderate (10^3-10^5 m^3) slides widespread; many rock and disrupted soil falls on steeper slopes (steep banks, terrace edges, gorges, cliffs, cuts etc).

Significant areas of shallow regolith landsliding, and some reactivation of scree slopes.

A few large (10^5-10^6 m^3) landslides from coastal cliffs, and possibly large to very large ($\geq 10^6$ m^3) rock slides and avalanches from steep mountain slopes.

Larger landslides in narrow valleys may form small temporary landslide-dammed lakes.

Roads damaged and blocked by small to moderate failures of cuts and slumping of road-edge fills.

Evidence of soil liquefaction common, with small sand boils and water ejections in alluvium, and localised lateral spreading (fissuring, sand and water ejections) and settlements along banks of rivers, lakes, and canals etc.

Increased instances of settlement of unconsolidated, or wet, or weak soils.

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 widespread and damaging in susceptible terrain, particularly on slopes steeper than 20˚.

Extensive areas of shallow regolith failures and many rock falls and disrupted rock and soil slides on moderate and steep slopes (20˚-35˚ or greater), cliffs, escarpments, gorges, and man-made cuts.

Many small to large (10^3-10^6 m^3) failures of regolith and bedrock, and some very large landslides (10^6 m^3 or greater) on steep susceptible slopes.

Very large failures on coastal cliffs and low-angle bedding planes in Tertiary rocks. Large rock/debris avalanches on steep mountain slopes in well-jointed greywacke and granitic rocks. Landslide-dammed lakes formed by large landslides in narrow valleys. Damage to road and rail infrastructure widespread with moderate to large failures of road cuts and slumping of road-edge fills. Small to large cut slope failures and rock falls in open mines and quarries.

Liquefaction effects widespread with numerous sand boils and water ejections on alluvial plains, and extensive, potentially damaging lateral spreading (fissuring and sand ejections) along banks of rivers, lakes, canals etc). Spreading and settlements of river stop-banks likely.

MM10 *Structures*

Virtually all Buildings Type I destroyed*.

Most Buildings Type II destroyed*.

Buildings Type III $^{\nabla}$ heavily damaged, some collapse*.

Structures Type IV $^{\nabla}$ damaged, some with partial collapse*.

Structures Type V $^{\nabla}$ 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.

Similar effects to MM9, but more intensive and severe, with very large rock masses displaced on steep mountain slopes and coastal cliffs. Landslide-dammed lakes formed. Many moderate to large failures of road and rail cuts and slumping of road-edge fills and embankments may cause great damage and closure of roads and railway lines.

Liquefaction effects (as for MM9) widespread and severe. Lateral spreading and slumping may cause rents over large areas, causing extensive damage, particularly along river banks, and affecting bridges, wharfs, port facilities, and road and rail embankments on swampy, alluvial or estuarine areas.

MM11 Structures

All Buildings Type II $^{\triangledown}$ destroyed *.

Many Buildings Type III $^{\triangledown}$ destroyed *.

Structures Type IV $^{\triangledown}$ heavily damaged, some collapse*.

Structures Type V $^{\triangledown}$ damaged, some with partial collapse.

Structures Type VI suffer minor damage, a few moderately damaged.

Environment

Environmental response criteria have not been suggested for MM11 as that level of shaking has not been reported in New Zealand or (definitively) elsewhere. As discussed in the text, it is likely that the MM scale in fact saturates between MM10 and MM11.

NOTES TO 2007 NZ MM SCALE

Items marked * in the scale are defined below.

CONSTRUCTION TYPES:

Buildings Type I (Masonry D in the NZ 1966 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, critical facilities which must remain operational after earthquakes, 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 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 foundation

$^{\nabla}$ 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 of 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.