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A Revision of the Modified Mercalli Seismic Intensity Scale

Report of a Study Group of the New Zealand National Society for Earthquake Engineering

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Introduction

The Modified Mercalli Intensity Scale has been used to categorise non-instrumental observations of earthquakes in New Zealand since the mid-1940s when it replaced the Rossi-Forel Scale then in use. A version modified to improve its usefulness for New Zealand conditions was published by Eiby in 1966. Its principal strengths have been its proven utility and its universality. Its main weakness is the great difference between the current stock of structures in New Zealand and that for which the scale was originally constructed, a difference made greater by the steady improvement in the earthquake performance of both commercial and domestic buildings since the 1930s.

This weakness, and other concerns about internal consistency of some of the effects, led to the NZ National Society for Earthquake Engineering commissioning a Study Group in 1990 to revise the scale so that:

(i) it is internally consistent

(ii) it is still consistent with overseas practice

(iii) it represents the smallest possible departure from the existing (1965) and the original 1931 scales.

It is not proposed to explain herein at any length the rationale of a descriptive intensity scale. It suffices to say that the purpose of the scale is to quantify specific manifestations of earthquake shaking so that, typically, the greatest strength of shaking in a particular event and the way in which the shaking diminishes with distance ("attenuates") can be quantified. This information is essential in turn for quantifying the hazard posed by earthquakes and assessing their likely impact on structures. In an ideal (better instrumented!) world, this information would be derived from ground motion recorders - accelerometers and seismometers - but the volume of such data in New Zealand is not yet adequate for improving our models and the great majority of our most important, damaging earthquakes occurred before the availability of adequate - or indeed any - instrumental information. Thus, an accurate appraisal of our large historical earthquakes depends critically on a sound and consistent appraisal of their effects on people, structures and the landscape.

Now it is not a concern that any great errors have been made in appraising these important historical events. The skill and experience of researchers such as Hayes, Eiby and others in

consistently assigning intensities is not in doubt. However, the current generation of seismologists and engineers have had few local examples of really strong shaking to appraise, and assessment of the likely impact of, say, a future 1931 Hawkes Bay-sized event on a modern city requires that maximum use is made of these recent experiences.

Accordingly, we have set out to try to incorporate modern experience into the scale. Effects have been added where there was confidence that these effects did indeed occur at the same intensity as the ones already listed, and effects were deleted where they were found to be inconsistent.

The range of effects at any intensity in an Intensity Scale enables the user to judge that the correct general level of intensity has been ascribed. There are numerous examples in numerous earthquakes of inconsistencies between specific effects. A recent moderate earthquake under the central North Island (2 September 1991) awoke "most" people in Wellington (MM 5), but all other effects were consistent with MM 4. Therefore care has to be exercised to examine all effects to ensure that an incorrect intensity is not being assigned because of an anomalous effect.

The report lists the proposed revision of the scale, describes the process of its construction and gives the reasons for particular departures from the old one. The Group invites debate and comment on the proposal.

Layout of the Report

The new scale is laid out alongside the 1965 version (Eiby, 1966) for comparison. Comments relating to specific deletions or new inclusions are included under the entries for each intensity. The items in the new scale are grouped into four headings: "people", "fittings" (short for "furniture, fittings and non-structural components"), "structures" and "environment" - this is done to make explicit the trend through increasing intensities for effect on structures to become more important, so that at MM 9 and above almost all the data comes from effects on "structures".

In the Appendix to the scale, the definitions of various terms have also been revised. Most important, the "Masonry" categories have been abandoned and replaced with four "Building types" which are more relevant to current New Zealand conditions. Other changes have been made to the definitions of "Windows" and "Water tanks". Some items have been designated "Historical" where these may be important in assessing historical earthquake reports but are unlikely to have modern application. The previous definition of "weak chimneys" has been made redundant by the explicit inclusion of "unreinforced" in MM 7.

Effect on Structures

The Study Group debated the inclusion of effects on a number of sub-categories of structure. It was agreed that, for example, buildings of irregular shape for which there had been no compensation in the design would be more likely to suffer damage than more regular structures, and that houses with tile roofs were more likely to suffer damage, because of the weight of the tiles, than similarly sized and clad houses with iron roofs. However, it was agreed to be essential that the scale itself be kept simple; and that the tasks of distinguishing a significant degree of complexity of shape, or significantly greater tendency to damage, were difficult and complex ones. Therefore, such information should not be included in the scale but should remain as cautionary notes to users of the scale when confronted with damage to irregular structures, etc.

Effect on the Environment

One of the expectations of the study was that greater use could be made of descriptions of effects on the environment - liquefaction, landslides, ground damage, etc. In fact, the historical data were disappointingly few and there was concern about the variability of some of these effects with geological conditions.

It is very likely that liquefaction begins to become general under favourable conditions at MM 8, but there is some evidence of its onset (because of local amplification ?) at MM 7, where there are some half a dozen reports in the historical record (Fairless, 1984; Fairless & Berrill, 1984). Overseas data support general liquefaction at MM 8 (Seed and Idriss, 1982).

The fall of loose material, rock falls and landslides also depends on variable factors of slope, material strength and ground water conditions. Some overseas events suggest landslides commonly occur at MM 7 or even 6, but this is not in accord with New Zealand data, where minor slips may occur at such low intensities, but major slides probably initiate at about MM 8 and are only general at MM 9.

The Study Group has tended to omit references to waves and splashed water. While it is clear that the severity of such waves must increase with intensity, the accurate appraisal of the effect, especially post-hoc, is very doubtful, and we see little point in retaining these items.

MM 11 and 12

There is unresolved debate as to whether there actually have occurred intensities sufficiently greater than MM 10 to justify a further step or steps on the scale. The individual diagnostics of MM 11 and MM 12 in the old scale are mostly misplaced or ambiguous. Great damage to railway

lines and underground pipes occurred at Edgecumbe in an environment of shaking intensity of MM 9 or at most MM 10. The general destruction of wooden frame structures has not been observed in New Zealand.

Consequently, we prefer to omit any diagnostics from MM 11 and 12 and leave the question of shaking of this intensity to further investigations and future observations.

Instrumental Data and Associations

It would be useful and valuable to have an association between Felt Intensities and instrumentally measured quantities, especially peak ground acceleration. The Study Group considered including such information in an Appendix to the Report. However, it was decided in the end that the New Zealand data for this were of themselves inadequate at the higher intensities. At both MM 5 and 6, the least and greatest of peak ground acceleration recorded in New Zealand differ by a factor of more than 10. An association therefore remains in the category of a research project. A consistent Intensity Scale is the first step in such a project.

Membership of the Study Group

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MODIFIED MERCALLI INTENSITY SCALE - NZ 1991

	NZ 1965	NZ 1991 Proposed
MM 1	Not felt by humans, except in especially favourable circumstances, but birds and animals may be disturbed. Reported mainly from the upper floors of buildings more than 10 storeys high. dizziness or nausea may be experienced. Branches of trees, chandeliers, doors, and other suspended systems of long natural period may be seen to move slowly. Water in ponds, lakes, reservoirs, etc., may be set into seiche oscillation.	MM 1 *People* Not felt except by a very few people under exceptionally favourable circumstances.
MM 2	Felt by a few persons at rest indoors, especially by those on upper floors or otherwise favourably placed. The long-period effects listed under MM1 may be more noticeable.	MM 2 *People* Felt by persons at rest, on upper floors or favourably placed.

MM1. Comment

(1) "Reported mainly from ..." defines one favourable circumstance.

(2) "Birds and animals disturbed" and "systems of long natural period may ... move slowly". This is a statement that these phenomena may be observed at <u>any</u> intensity and are thus not definitive of any particular intensity.

MM2. Comment

The reference to an increase in long-period effects is tautological: it will be true of <u>all</u> intensities.

NZ 1965	NZ 1991 Proposed
MM 3 Felt indoors, but not identified as an earthquake by everyone. Vibration may be likened to the passing of light traffic. It may be possible to estimate the duration, but not the direction. Hanging objects may swing slightly. Standing motorcars may rock slightly.	MM 3 *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.
MM 4 Generally noticed indoors, but not outside. Very light sleepers may be wakened. Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building. Walls and frame of buildings are heard to creak. Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock, and the shock can be felt by their occupants.	MM 4 *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 rattles. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock. *Structures* Walls and frame of buildings may be heard to creak.

MM3. Comment

(1) The use of "trucks" rather than "traffic" is considered clearer.

(2) The NZ 1965 qualification "but not direction" is redundant - see MM 5.

(3) The reference to motorcars rocking slightly, but with the suggestion that their occupants could be unaware of the motion is considered doubtful (cf MM 4).

MM4. Comment

(1) "Very" qualification for light sleepers superfluous.

(2) If standing motorcars rock, their occupants are likely to feel the movement.

(3) Creaking of walls is not general at this level.

	NZ 1965	NZ 1991 Proposed
MM5	Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people frightened. Direction of motion can be estimated. Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Some windows cracked. A few earthenware toilet fixtures cracked. Hanging pictures move. Doors and shutters may swing. Pendulum clocks stop, start, or change rate.	*People* Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people alarmed. Direction of motion can be estimated. *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 P* cracked. A few earthenware toilet fixtures cracked (H).

MM5. Comments

(1) "Alarmed" for "frightened". This is consistent with higher intensities, but there is some feeling that "fright" rather than "alarm" may generally be better.

(2) Pictures "knock" rather than swing at this intensity.

(3) Inclusion of "shutters" with doors is doubtful; few New Zealand houses have them, and most are secured.

* See Appendix.

NZ 1965	NZ 1991 Proposed
MM6 Felt by all. People and animals alarmed. Many run outside. difficulty experienced in walking steadily. Slight damage to Masonry D. Some plaster cracks or falls. Isolated cases of chimney damage. Windows, glassware, and crockery broken. Objects fall from shelves, and pictures from walls. Heavy furniture moved. Unstable furniture overturned. Small church and school bells ring. Trees and bushes shake, or are heard to rustle. Loose material may be dislodged from existing slips, talus slopes, or shingle slides.	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. 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 P*, glassware and crockery 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.

MM6. Comment

(1) Pictures secured with modern pinned picture hooks unlikely to fall at this intensity.

(2) "Some" (rather than "Heavy") furniture moved <u>on smooth floors</u>. Furniture on carpet unlikely to move at this intensity.

(3) "Plaster" falls - ambiguous. "Stucco" rather than interior plaster is intended.

(4) Cracking to weak chimneys is common.

* See Appendix

	NZ 1965	NZ 1991 Proposed
MM7	General alarm. Difficulty experienced in standing. Noticed by drivers of motorcars. Trees and bushes strongly shaken. Large bells ring. Masonry D cracked and damaged. A few instances of damage to Masonry C. Loose brickwork and tiles dislodged. Unbraced parapets and architectural ornaments may fall. Stone walls cracked. Weak chimneys broken, usually at the roof-line. Domestic water tanks burst. Concrete irrigation ditches damaged. Waves seen on ponds and lakes. Water made turbid by stirred-up mud. Small slips, and caving-in of sand and gravel banks.	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. *Structures* Unreinforced stone and brick walls cracked. Buildings Type I 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 P* burst. A few instances of damage to brick veneers and Gibraltar board linings. Unrestrained water cylinders may move and leak. Some windows Q* 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.

MM7. Comment

(1) "Noticed by motorcar drivers who may stop." Modern cars transmit the shaking to the occupants more effectively than old ones. This effect may commerce at a lower intensity.

(2) "Trees and bushes strongly shaken" is too subjective to be of much use.

(3) Buildings types replace Masonry types.

(4) "Concrete irrigation ditches" doubtfully damaged at this intensity.

(5) Commencement of damage in a number of areas at this intensity in brick veneers, wall linings, ordinary windows, perhaps liquefaction under most favourable conditions.

(6) "Waves seen" not useful and omitted.

(7) "Slides" rather than "slips" is consistent with international use.

(8) Care must be taken to ensure that ground cracking was due to shaking and not shrinkage, etc.

	NZ 1965	NZ 1991 Proposed
MM 8	Alarm may approach panic. Steering of motorcars affected. Masonry C damaged, with partial collapse. Masonry B damaged in some cases. Masonry A undamaged. Chimneys, factory stacks, monuments, towers, and elevated tanks twisted or brought down. Panel walls thrown out of frame structures. Some brick veneers damaged. Decayed wooden piles broken. Frame houses not secured to the foundation may move. Cracks appear on steep slopes and in wet ground. Landslips in roadside cuttings and unsupported excavations. Some tree branches may be broken off. Changes in the flow or temperature of springs and wells may occur. Small earthquake fountains.	MM 8 *People* Alarm may approach panic. Steering of motorcars greatly affected. *Structures* Unreinforced Buildings Type II damaged with partial collapse. Reinforced Buildings Type II 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.

MM8. Comment

(1) Steering of motorcars is likely to be so affected that drivers will have to stop.

(2) Changes to building damage consistent with changes to Building types.

(3) "Weak Piles" covers a wider range than "Decayed wooden piles".

(4) "Tree branches broken off" is too likely to depend on the state (i.e. rottenness) of the branch.

(5) "Manifestations of liquefaction" - these are likely to be general at this intensity in susceptible ground.

(7) "Changes in the flow or temperature of springs and wells may occur" - no New Zealand data to support inclusion at this intensity. Springs and wells are affected by stress changes before and after a shock.

	NZ 1965	NZ 1991 Proposed
MM 9	General panic. Masonry D destroyed. Masonry C heavily damaged, sometimes collapsing completely. Masonry B seriously damaged. Frame structures racked and distorted. Damage to foundations general. Frame houses not secured to the foundations shifted off. Brick veneers fall and expose frames. Cracking of the ground conspicuous. Minor damage to paths and roadways. Sand and mud ejected in alluviated areas, with the formation of earthquake fountains and sand craters. Underground pipes broken. Serious damage to reservoirs.	MM 9 *Structures* Reinforced Buildings Type II seriously damaged. Damage or permanent distortion to some post-1980 buildings. 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.

MM9. Comment

(1) "Sand and mud ejected" - an intensification of MM8 effects.

(2) "Serious damage to reservoirs" - not at this intensity without qualification about the construction of the reservoir.

(3) "Minor damage to paths" and "underground pipes broken" - very doubtfully by shaking at this intensity.

(4) "Landsliding general" - the area of widespread landslides has approximately corresponded to the MM 9 isoseismal in several historical events.

	NZ 1965	NZ 1991 Proposed
MM 10	Most masonry structures destroyed, together with their foundations. Some well built wooden buildings and bridges seriously damaged. Dams, dykes, and embankments seriously damaged. Railway lines slightly bent. Cement and asphalt roads and pavements badly cracked or thrown into waves. Large landslides on river banks and steep coasts. Sand and mud on beaches and flat land moved horizontally. Large and spectacular sand and mud fountains. Water from rivers, lakes and canals thrown up on the banks.	MM 10 *Structures* Many Buildings Type III (and bridges of equivalent design) seriously damaged. Many post-1980 buildings and bridges have moderate damage or permanent distortion.

MM10. Comment

(1) Very few clear examples of MM 10 in the recent past.

(2) Damage that could arise from static compression or dilatations of the ground ("bent railway lines", "cracked pavements") is omitted.

(3) "Large landslides" occur at lower intensities under favourable (i.e. saturated) conditions.

(4) Liquefaction effects here represent a subjective intensification.

(5) "Water thrown up on banks" may occur at lower intensities.

NZ 1965	NZ 1991 Proposed
MM 11 Wooden frame structures destroyed. Great damage to railway lines and underground pipes.	
MM 12 Damage virtually total. Practically all works of construction destroyed or greatly damaged. Large rock masses displaced. Lines of sight and level distorted. Visible wave-motion of the ground surface reported. Objects thrown upwards into the air.	

MM11. Comment

Great damage to underground pipes and railway lines not unambiguously caused by shaking - observed at MM 9 at Edgecumbe.

"Wooden frame structures destroyed" did not appear in pre-1965 versions of the scale.

MM12. Comment

"Large rock masses" have undoubtedly been displaced at lower intensities (e.g. 1929).

"Lines of sight and level distorted" and "visible wave motion reported" undoubtedly occur at lower intensities.

"Objects thrown upwards", when general, indicates a vertical acceleration of more than 1.0 g. Where this has been reported it has been in an area of generally lower intensity.

Appendix

NZ 1965

Categories of non-Wooden Construction

Masonry A Structure designed to resist lateral forces of about 0.1 g, such as those satisfying the New Zealand Model Building Bylaw, 1955. Typical buildings of this kind are well reinforced by means of steel or ferro-concrete bands, or are wholly of ferro-concrete construction. All mortar is of good quality and the design and workmanship is good. Few buildings erected prior to 1935 can be regarded as in category A.

Masonry B Reinforced buildings of good workmanship and with sound mortar, but not designed in detail to resist lateral forces.

Masonry C 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.

Masonry D Buildings with low standard of workmanship, poor mortar, or constructed of weak materials like mud brick and rammed earth. Weak horizontally.

Windows

Window breakage depends greatly upon the nature of the frame and its orientation with respect to the earthquake source. Windows cracked at MM5 are usually either large display windows, or windows tightly fitted to metal frames.

NZ 1991 Proposed

Categories of Construction

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

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

Buildings Type III: Buildings designed and built (from c.1936 - c.1980) to resist earthquakes to normal use standards, i.e. no special damage limiting measures taken.

Post-1980 Buildings and bridges: Since about 1980 the loadings and materials codes have combined to ensure less 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.

Windows

P - large display windows, especially shop windows.

Q - ordinary sash or casement windows.

NZ 1965

Categories of non-Wooden Construction

Water Tanks

The "domestic water tanks" listed under MM7 are of the cylindrical corrugated-iron type common in New Zealand rural areas. If these are only partly full, movement of the water may burst soldered and riveted seams.

Hot-water cylinders constrained only by supply and delivery pipes may move sufficiently to break the pipes at about the same intensity.

NZ 1991 Proposed

Categories of Construction

Water Tanks

P - External, stand mounted, corrugated iron water tanks.

Q - Unrestrained domestic hot-water cylinders.

H - (Historical). Item probably has little modern application but important for historical events.

General Comment

"Some" or "a few" indicates that the threshold of a particular effect has just been reached at that intensity.