International alignment and update of the New Zealand earthquake intensity scale

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ABSTRACT

The New Zealand Modified Mercalli intensity (MMI) scale was last revised in 2008. Even so, the scale's lack of specificity on New Zealand's structures for MMI>8 intensity levels has made it difficult to assign values for recent large earthquakes such as in Christchurch and Kaikōura. This paper outlines the progress of New Zealand engineers and seismologists towards developing an intensity scale to be aligned with an International Macroseismic Scale, also under development.

The current update of the New Zealand scale is based upon the widely-used European Macroseismic Scale 1998 (EMS-98). EMS-98 represents a significant improvement upon the current New Zealand scale due to its more quantitative and engineering-based intensity definitions; however, some of the building types whose damage is used to assign intensities greater than MMI 7 are not representative of the New Zealand building stock.

The paper begins by explaining the importance and relevance of an intensity scale to engineers, and then outlines EMS-98, followed by the draft International Macroseismic Scale 2015 (IMS-2015) and the current New Zealand intensity scale. After reporting on the past and future process of the update for New Zealand, the paper includes descriptions of proposed New Zealand-appropriate changes to IMS-2015. The final section describes how intensity assignments based upon the

proposed scale are currently being reviewed and calibrated using building damage datasets from several recent New Zealand earthquakes.

1 INTRODUCTION

The most common information available immediately after a damaging earthquake is its magnitude and epicentre. However, the extent of the affected area and the geographical distribution of the shaking are essential information needed as quickly as possible by emergency responders, engineers, councils, and the public. These are obtained with the use of macroseismic intensity, a parameter to estimate the degree of ground shaking using different measures, including the extent of the building damage.

Macroseismic (earthquake shaking) intensities are assigned using macroseismic scales. These describe observations at different intensity levels (usually I to XII), based on the effects on people, objects, buildings and the environment. New Zealand's current intensity scale was last modified in 2008 (Dowrick et al. 2008). For earthquakes with intensities up to VII, reported effects on people and objects are enough to assign an intensity level. However, from intensities VII-VIII and above, buildings can suffer considerable damage and the assignment of intensity values involves an engineering study of buildings' damage levels and building types prior to the assignment of an intensity level (e.g., Coppola et al. 2010).

This paper summarises efforts to update the EMS-98 (Grünthal 1998) and IMS-2015 (Spence and Foulser-Piggott 2015) scales to include New Zealand-specific building types and their likely damage, with the aim of using that scale in the future, and also contributing to the on-going development of an International Macroseismic Scale (IMS). The benefits of an IMS include more internationally consistent and accessible post-event loss datasets and more accurate ShakeMaps (Wald et al. 1999a, 2021, Horspool et al. 2015). These in turn lead to better structural engineering and geotechnical post-event studies, seismic loss and risk estimates, and better correlations between macroseismic intensity and ground motion parameters.

1.1 Macroseismic intensities and earthquake engineering

Engineers both contribute to the determination of macroseismic intensities and are among the beneficiaries of the information. While seismologists can assign intensities at low levels of shaking from public response through internet-based questionnaires, engineering knowledge of building and damage types is required to assign more severe intensity values as described above. At present this requires engineers and seismologists to specifically observe damaged buildings and degrees of damage. However, initiatives are underway, in conjunction with the work described in this paper, to capture this information during post-earthquake rapid building assessments.

Engineers benefit from macroseismic intensity values in many ways. First, the geographical distribution of shaking as expressed by reported intensities is crucial for engineers contributing to earthquake response. Consulting engineers use intensities, especially in the absence of local ground motion records, at building sites of interest for structural analyses and to communicate with clients. The use of intensities can be direct, or by converting intensities to common earthquake engineering ground motion parameters (e.g., peak ground or spectral acceleration) derived using well-established relationships as is done in ShakeMap. Engineers active in research can thus use intensities to model landslides, liquefaction, and casualties.

For those associated with the insurance or re-insurance industries, intensities are fundamental for hazard and risk modelling to estimate the impact of damage and loss on portfolios. While seismologists are the primary instigators and beneficiaries of macroseismic scales, social scientists are also reliant upon them for studies of human behaviour and public education during and prior to earthquakes.

1.2 European Macroseismic Scale 1998 (EMS-98)

EMS-98 has replaced the outmoded Modified Mercalli Intensity (MMI) scale, developed in 1931 (e.g., Wald et al. 2022). EMS-98 accounts for building vulnerability classes and ratios of given structure classes at specific degrees of damage, thereby enabling more rigorous intensity assignments compared to those using MMI, particularly for high intensities, above VII.

EMS-98 is at present the most comprehensive scale worldwide. It consists primarily of a detailed classification of Vulnerability Classes and Damage Grade descriptors (Figure 1) and accompanying guidelines and commentary. The process of assigning an intensity level based upon building damage is essentially a three-step process. First, a group of similar buildings in the same area, suburb or town that have been damaged are allocated a Vulnerability Class based upon the Vulnerability Table. Then, after deciding upon a Damage Grade for every building, including undamaged buildings, from on-site observations and with help from both drawings and photographs of damage included in EMS-98, an intensity is assigned to a geographical area in accordance with EMS-98's definition of intensity degrees. For example, the definition of intensity VIII includes effects on people and building contents and 'Many buildings of vulnerability class A suffer damage of grade 4; a few of grade 5. Many buildings of vulnerability class B suffer damage of grade 3; a few of grade 4. Many buildings of vulnerability class C suffer damage of grade 2; a few of grade 3. A few buildings of Vulnerability Class D sustain damage of grade 2.' EMS-98 also provides definitions of 'few', 'many' and 'most'.

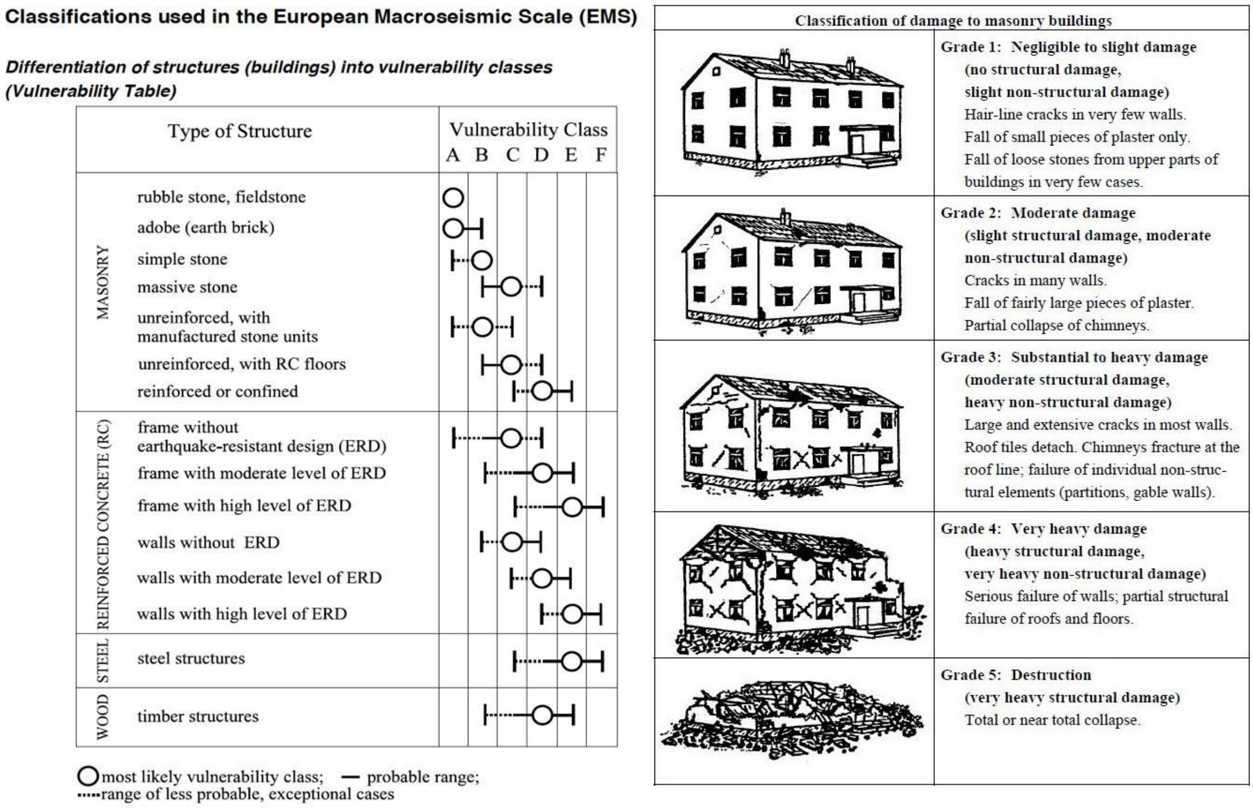

Figure 1: EMS-98 Vulnerability Classes for different building types and Damage Grade descriptors for masonry buildings (from Grünthal, 1998).

1.3 Description of the draft International Macroseismic Scale (IMS-2015)

For the purposes of this project, IMS-2015 is taken as the revised draft prepared for the IMS Working Group in 2015 (Spence and Foulser-Piggott 2015). Currently, IMS-2015 only contains information on building typology, vulnerability and damage, so before it becomes a complete and stand-alone macroseismic scale several key sections from EMS-98 need to be inserted within it. It is relevant to briefly describe IMS-2015 since the proposed New Zealand Macroseismic Scale (NZMS) is based very closely upon IMS-2015.

A key principle of IMS-2015 is that intensity assignments made using that scale are consistent with those made using EMS-98. It is therefore no surprise that the two documents have strong similarities. IMS-2015 is based upon EMS-98, albeit with enhancements due to both the need for internationalisation, and to update a document over 20 years old.

Not only does IMS-2015 have a truly international scope of building materials and types, it elaborates on and enhances how Vulnerability Classes and Damage Grades are assigned. This leads to more robust intensity assignments. For example, IMS-2015 introduces Vulnerability Modifiers. They enable intensity assessors to refine the final choice of Vulnerability Class in a manner that is more explicit than the guidance provided in EMS-98. For reinforced concrete buildings the Vulnerability Modifiers are: the level of earthquake-resistant design (missing in EMS-98), quality and workmanship, state of preservation, structural regularity, position (relative to other buildings), and strengthening. Also, IMS-2015 introduces damage diagnostics for steel and timber buildings and elaborates upon the damage definitions for masonry and reinforced concrete buildings in order to improve the accuracy of Damage Grade choices.

1.4 Description of the current New Zealand MMI scale

The New Zealand MMI scale (NZMMI-2008) was updated most recently in 2008 (Dowrick et al. 2008). NZMMI-2008 generally takes a less detailed approach than EMS-98. For example, there is far less emphasis on structural types and structural materials, although four different grades of brick masonry are acknowledged. Vulnerability is mainly linked to building age in recognition of significant seismic performance-affecting code changes; for example, before the mid-1930s, and mid-1930's to c.1970 for concrete and c.1980 for other materials.

NZMMI-2008 also takes a less detailed approach to damage states compared to the five well-defined Damage Grades of EMS-98 that are further elaborated on by IMS-2015. As an example of the lack of damage detail, consider the rather vague and sparse descriptions of damage to Type V or post-1970's buildings for different intensities:

MM8 – no damage is mentioned for Type V buildings.

MM9 – damage or permanent distortion

MM10 – moderately damaged but few partial collapses

MM11 – damaged, with some partial collapse.

Unfortunately, this lack of damage detail caused great difficulty in assigning high intensity levels for damaging earthquakes such as the 2010-2011 Canterbury earthquake sequence (Goded et al. 2019) and the Mw 7.8 14/11/2016 Kaikōura earthquake (Goded et al. 2017).

However, the greatest difference between NZMMI-2008 and EMS-98 (and IMS-2015) is the extent to which NZMI-2008 includes environment damage, such as landslides and liquefaction, but which is discounted in EMS-98.

1.5 Process of moving to a revised New Zealand Macroseismic Scale (NZMS)

Several issues and initiatives have led to this current project of updating NZMMI-2008. These include difficulties in assigning high intensity levels, the development of IMS-2015, and the interest within both New Zealand and the U.S.A. in aligning with an International Macroseismic Scale while having their similar and predominant building types explicitly included within it.

In mid-July 2022, funding was provided through a new ATC-158 project – 'Development and implementation of damage matrices for US buildings in accordance with EMS-98'. The project is funded by the U.S. Geological Survey (USGS), and this was supplemented by GNS Science partially funding two staff members. Then, from 10-14 October 2022 twenty-three participants gathered in person or virtually at a U.S. Geological Survey funded Workshop at the John Wesley Powell Center for Analysis and Synthesis, Fort Collins, Colorado (Wald et al. 2023). The participants included the authors of this paper.

Since that Workshop the lead author of this paper has modified IMS-2015 for New Zealand conditions and three other New Zealand co-authors have reviewed revised draft sections on masonry, reinforced concrete and timber buildings. Comments have also been received from the primary author of IMS-2015. GNS Science staff are about to begin using damaged and undamaged building data from the 2010-2011 Canterbury earthquake sequence to assign Vulnerability Classes, Damage Grades and intensities as part of reviewing and calibrating the proposed NZMS.

Several more steps need to be taken to produce the final NZMS. First, images illustrating Damage Grades of the different structural materials and diagrams, like those of Figure 1, are to be sourced and completed. Then, in order that the NZMS is a stand-alone document yet compatible with EMS-98, three sections from EMS-98 need to be edited in some cases and then inserted into the current draft document. These sections are the Definition of Quantity (i.e., 'few', 'many' and 'most'), the Definitions of Intensity Degrees and finally, the Guidelines and Background material. Once all this material has been added it is proposed that that updated version of NZMS be subject to review by a New Zealand Society for Earthquake Engineering working group, and after revision and approval, published. It is envisaged that the working group will invite comment from interested parties before completing the NZMS.

The authors acknowledge that NZMS will require regular updates in the future to reflect on-going changes in design and construction practice, such as may occur as a result of the recent update of the National Seismic Hazard Model (GNS Science 2022).

2 UPDATING THE DRAFT INTERNATIONAL MACROSEISMIC SCALE (IMS-2015) FOR NEW ZEALAND CONDITIONS

This section describes the changes made to IMS-2015 in order to create the current draft of NZMS. As already mentioned, IMS-2015 is intended for use in seismically-active countries worldwide. Therefore, throughout the document reference to countries other than New Zealand are removed and New Zealand-specific information added. The most significant changes made to IMS-2015 are to the Vulnerability Table and to the sections describing each major structural material; masonry, reinforced concrete, steel and timber. Changes to the Vulnerability Classes, structural materials, Vulnerability Modifiers and Damage Grades are also outlined. Diagrams and photographs illustrating the Damage Grades, similar to those provided in EMS-98 are yet to be provided. The Vulnerability Table from IMS-2015 is shown in Figure 2 together with the proposed Vulnerability Table for NZMS. The differences between these two tables are explained in the remainder of this section of the paper. The similarities of both these Vulnerability Tables to the EMS-98 Vulnerability Table, shown in Figure 1, can be seen.

In the following sub-sections, only the most significant changes necessary to align IMS-2015 to New Zealand conditions for each structural material are outlined.

2.1 Masonry

The masonry section of the IMS-2015 Vulnerability Table is amended as follows. The materials 'Massive stone' and 'Confined masonry' are removed as they are not found in New Zealand, and 'Cut stone masonry' is also referred to as ‘ashlar’. The Vulnerability Classes for the remaining masonry materials remain the same as IMS-2015 (and EMS-98).

The descriptions of the masonry materials are edited to reflect New Zealand conditions.

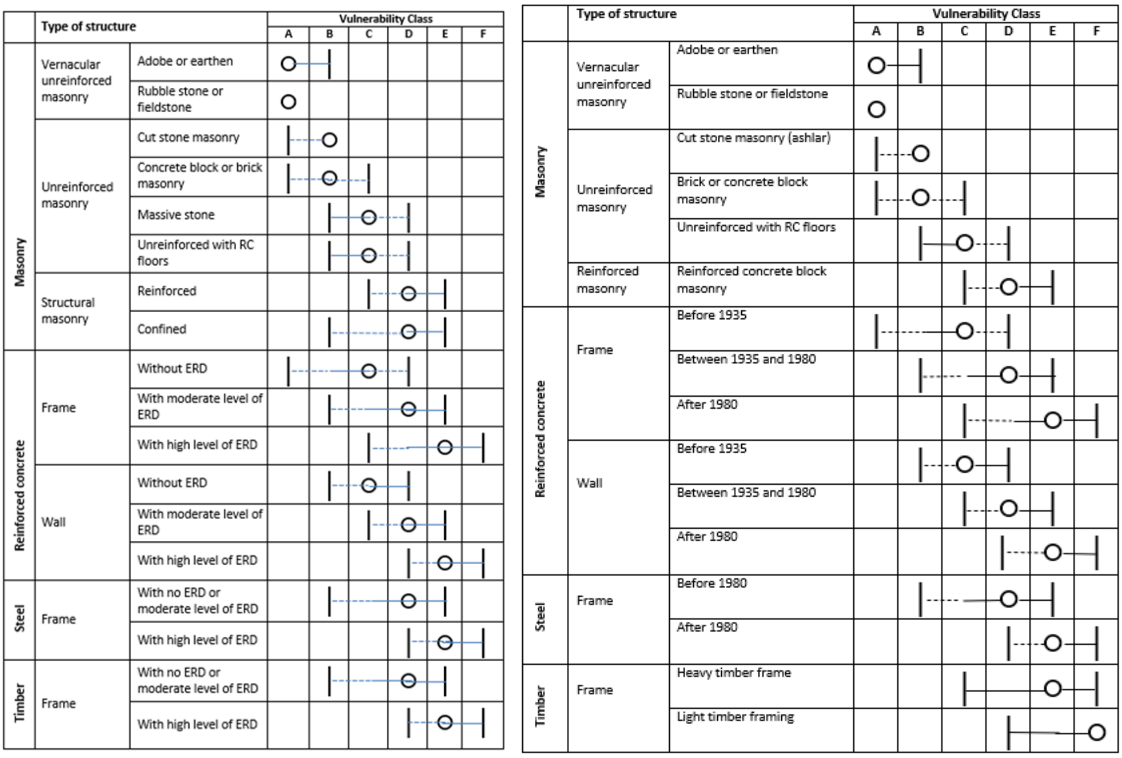

Figure 2: IMS-2015 Vulnerability Table (from Spence and Foulser-Piggott 2015) (left) and the proposed Vulnerability Table for NZMS (right).

Regarding the Quality and Workmanship Vulnerability Modifier, it is noted that poor quality masonry does not bond bricks together, and that this can be observed in partially collapsed buildings where the rubble consists of individual bricks rather than larger blocks of masonry. For the Floor and Roof modifier, IMS-2015 allows increasing or decreasing vulnerability up to one Vulnerability Class, but now only a decrease in one Vulnerability Class is allowed. In other words, NZMS assumes poor connections between walls and floors and roof based on the 2011 Christchurch earthquake damage (Dizhur et al. 2011), so no further increase in vulnerability is warranted. The allowable State of Preservation modifier has been changed to allow for an ‘increase in vulnerability’, rather than a ‘minor increase in vulnerability’. This change reflects how an increase in vulnerability due to a previous damaging earthquake could be more than minor. The Regularity modifier has also been changed to allow a decrease in vulnerability by less than one Class for masonry buildings with internal structural or non-structural walls, that reduce the likelihood of roof collapse. The beneficial presence of such interior light-timber framed walls was widely observed after the 2010-2011 Canterbury earthquake sequence. The only change to the Strengthening modifier is to substitute the strengthening techniques in IMS-2015 with those typically used in New Zealand (MBIE 2017a).

Various changes are also made to the Damage Grade (DG) diagnostics. To IMS-2015’s DG3 ‘Out-of-plane failure of gable walls’ is added ‘and walls supporting light roofs’, once again reflecting damage observed in Christchurch. And for the same reason, URM damage at DG4, is elaborated upon by adding ‘Large diagonal cracks in wall piers and spandrels due to in-plane forces’. Also, the word ‘Extensive’ is added to ‘out-of-plane failure of load-bearing walls in order to differentiate this damage from DG3.

Figure 3 shows the proposed Damage Grade table for NZMS.

Grade	Definition (EMS-98)	Description (EMS-98)	Further details for URM and RCM (unreinforced and reinforced concrete masonry
1	Negligible to slight damage (no structural damage, slight non-structural damage	Hairline cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.	
2	Moderate damage (slight structural damage, moderate non-structural damage	Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of URM chimneys.	URM: Cracks around door and window openings in walls with large proportion of openings; movements of lintels; cracks at the base of parapets. RCM: minor separation of walls from the floor and roof diaphragms.
3	Substantial to heavy damage (moderate structural damage, heavy non-structural damage)	Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roofline; failure of individual non-structural masonry elements (partitions, gable walls).	All: Diagonal and X-shaped cracks near or between openings; vertical corner cracks; horizontal upper wall cracks, sliding cracks. URM: Masonry walls may have visible separation from diaphragms. Out-of-plane failure of large pieces of the external wythes of masonry walls. Out-of-plane failure of gable walls and walls supporting light roofs, especially two storey and higher masonry buildings. RCM: Some walls may have visibly pulled away from the roof.
4	Very heavy damage (heavy structural damage, very heavy non-structural damage)	Serious failure of walls; partial structural failure of roofs and floors.	URM: Extensive out-of-plane failure of load-bearing walls; wedge-shaped separation of walls at the corner(s). Large diagonal cracks in wall piers and spandrels due to in-plane forces. Beams or trusses may have moved relative to their supports. RCM: Large, through-the-wall diagonal cracks and visibly buckled wall reinforcement. • *Wooden diaphragms* may exhibit cracking and separation along plywood joints. • *RC diaphragms* may exhibit cracking. Partial collapse of the roof may result from failure of the wall-to-diaphragm anchorages or the connections of beams to walls.
5	Destruction (very heavy structural damage)	Total or near total collapse.	Collapse of roof and or floors due to in-plane or out-of-plane failure of the walls. 15% or above of the total plan area of URM buildings and 5 – 15% of high-rise, mid-rise and low-rise RCM buildings respectively expected to be collapsed.

Figure 3: Masonry Damage Grade table for NZMS

2.2 Reinforced concrete

The only changes made to the Vulnerability Table of IMS-2015 (Figure 2) are to replace the term ERD (Earthquake Resistant Design) with dates corresponding to step-changes in the seismic design and detailing of reinforced concrete structures. These dates are well known and recognized by New Zealand engineers. Hence the three categories of increasing earthquake resistance are; 'Before 1935', 'Between 1935 and 1980' and 'After 1980'. The first requirement for earthquake resistant design was introduced in the 1935 by-law NZSS 95:1935. 1980 is an approximate date reflecting when both ductile design and reinforced concrete ductile detailing converged:

> "However, it was not until the revamp of the New Zealand loading code NZS 4203 in 1976, the update of the ACI-318 code in 1977 and the various drafts of the 1982 edition of the NZS 3101 concrete design standard (NZS 3101:1982) that modern seismic design for RC buildings was fully codified in New Zealand" (MBIE 2017b).

No changes are made to the Vulnerability Classes.

As for the IMS-2015 reinforced concrete Vulnerability Modifiers, a new modifier, 'Design Strength' is introduced to account for the variation of seismic design strengths by up to a factor of 4.5 due to seismicity variation within New Zealand (Standards NZ 2004). A minor increase in vulnerability is warranted for buildings located where seismicity is low, and a decrease applies in areas of highest seismicity. The greater strength of important buildings, like hospitals, also is to be taken into account. Other changes to the Vulnerability Modifiers include that to the Quality and Workmanship modifier. An increase in vulnerability is considered appropriate where precast flooring systems are present, based on observations from the 2010-2011 Canterbury earthquake sequence (Weng et al. 2011) and the Kaikōura earthquake (Henry et al. 2017).

Minor changes only are made to the reinforced concrete Damage Grades in order to reflect likely damage specific to precast floor systems.

2.3 Steel

As for reinforced concrete structures, the two categories of steel frames in the IMS-2015 Vulnerability Table are identified by dates – 'Before 1980' and 'After 1980'. The date 1980 is chosen to both acknowledge the introduction of NZS 4203:1976 and NZS 3404:1977, the standard enabling steel structures to meet the ductility and capacity design requirements of NZS 4203 (Beattie et al. 2008). No changes are made to the Vulnerability Classes.

The Vulnerability Modifiers of IMS-2015 are unchanged apart from several minor additions that note the importance of welding quality control and the possibility of corrosion increasing structural vulnerability.

The damage grade diagnostics for steel buildings remain unchanged except that the non-structural damage for reinforced concrete structures is included in the Damage Grades.

2.4 Timber

The Vulnerability Table in EMS-98 has just one category for timber structures while IMS-2015 includes two categories: 'With no ERD or moderate level of ERD' and 'With high level of ERD'. These two categories of timber structures are modified in NZMS to 'Heavy timber frame' and 'Light timber framing'.

Heavy timber frame construction, albeit relatively uncommon, refers to structures whose timber members resist lateral loads by bending and or tension and compression, and whose cross-sections are far larger than that of light timber framing. Timber moment frames and braced frames, including those of pole houses, are the typical structural systems observed in heavy timber frame construction. It is designed and constructed according to the appropriate New Zealand Standards. The NZMS Vulnerability Class range is the same as that in IMS-2015 for 'With high level of ERD' except that the highest Vulnerability Class is moved from D to C. This is due to the likelihood of increased damage for non-ductile designs prior to NZS 4203:1976 as well as possible deterioration of the timber as discussed in the Vulnerability Modifiers.

Light timber framing refers to timber stud-wall construction that comprises the vast majority of house construction in New Zealand. The vulnerability range is identical to that in IMS-2015 for 'With high level of ERD', spanning over three classes, except that the most probable Vulnerability Class is reduced to the minimum possible, Class F. This decrease of vulnerability is made on the basis of generally excellent seismic performance during New Zealand earthquakes from Napier 1931 to the present day (e.g., Cooney 1979 and Buchanan 2011). Severe structural damage has been very rare in well-built houses, but minor damage to wall linings prevalent. The extent of the three Vulnerability Class range acknowledges how heavy veneers and roofs increase vulnerability. Unlike reinforced concrete and steel construction where vulnerability is linked to age of construction, post-1980 houses, at least during the 2010-2011 Canterbury earthquakes, did not perform better than older houses which also performed very well: "There is an insignificant reduction in damage as a consequence of the introduction of NZS 3604 [in 1978], although the effect of more rigorous requirements may be offset by a design trend to more irregularly shaped dwellings with more and larger windows" (Thomas 2017). Newer houses also have more open room layouts (Khajehzadeh and Vale 2017).

The timber descriptive section of IMS-2015 is rewritten to acknowledge the specifics of New Zealand's light timber framed construction.

The 'Design Strength' Vulnerability Modifier is included for the same reasons as given for reinforced concrete buildings, except that a minor increase in vulnerability is warranted for construction prior to c. 1980 and the design of ductile structures. This modifier is applicable to heavy timber construction only. Regarding the 'Quality of Construction and Workmanship', the maximum increase or decrease of one or more Vulnerability Classes is reduced to just one Vulnerability Class only. This is due to the reasonably uniform standard of New Zealand house construction compared to variations internationally. In an additional change to the 'Quality of Construction and Workmanship' Vulnerability Modifier, an increase in vulnerability is suggested for buildings prior to 1980. They can lack sub-floor bracing and where there are heavy roofs may have insufficient bracing walls (Cooney 1979). In IMS-2015, application of the 'Regularity' Vulnerability Modifier is allowed to result in a 'minor increase in vulnerability'. But due to increased damage from asymmetric walls and large windows that facilitate views (Buchanan 2011), NZMS allows an increase of up to one Vulnerability Class. There are no significant changes to the Vulnerability Modifiers 'State of Preservation' and 'Strengthening'.

A new Vulnerability Modifier, 'Cladding and Roof Materials' is introduced in NZMS to allow for the effects of heavy wall and roof claddings. An increase of up to two Vulnerability Classes is permissible. Although design requirements since 1980 allow for increased earthquake forces from these heavy components, brick or block veneers and concrete or clay tile roofing are likely to increase damage. Therefore pre-1980 buildings with veneers have their vulnerability class increased by one class, and newer buildings by the equivalent of half a class. An exception is made for post-1996 buildings with screw-fixed veneers. These performed well in the 2010-2011 Canterbury earthquake sequence (Dizhur et al. 2013), yet possibly less so in the Kaikōura earthquake (Dizhur et al. 2017). A similar principle applies for heavy roofs. Pre-1980 buildings with heavy roofs warrant a vulnerability increase by one class as no design allowance was made for their additional mass. However, in post-1980 buildings the additional roof weight was accounted for in design and construction. Therefore, post-1980 to 1996 light timber frame buildings with both heavy veneers and roofs have their Vulnerability Class increased by one half. For similar pre-1980 buildings, the vulnerability increase will be two classes and for post-1996 buildings, no increase.

The main change to NZMS Damage Grades for timber structures (Figure 4) is the addition of a new column 'Additional diagnostics for heavy timber frames'; non-structural damage included in the Damage Grades for reinforced concrete structures is included. Otherwise, the Damage Grades of IMS-2015 are slightly elaborated upon, drawing on New Zealand research and earthquake damage observations (Thomas and Shelton 2012 and Buchanan 2011).

3 CALIBRATION OF THE PROPOSED NEW ZEALAND MACROSEISMIC SCALE USING 2010/2011 CANTERBURY EARTHQUAKE SEQUENCE BUILDING DAMAGE DATA

The calibration work will be carried out using observed data from recent New Zealand damaging earthquakes (e.g., Darfield 2010 and Christchurch 2011). It is envisioned that observed building damage information in each event, from available databases (e.g., CEBA (Lin et al. 2016), URM (Moon et al. 2014 and Ingham and Griffith 2011a and b) and BRANZ (Beattie et al. 2015)) will be reviewed to assess intensity degrees according to the proposed NZMS method (Section 2). The estimated NZMS intensities will then be compared with past MMI assignments for those earthquakes using different methods, such as traditional MMI assignments, DYFI data

(Wald et al. 1999b), or community intensities (Goded et al. 2018, 2019), and reasons considered for discrepancies.

Grade	*EMS-98 Definition*	*Elaboration for light timber framing structures*	*Additional diagnostics for heavy timber frames*
1	Negligible to slight damage (no structural damage, slight non-structural damage	No damage to structural framing. Few hairline cracks in internal walls or masonry veneer or unreinforced masonry chimneys.	Few cracks at intersections of partition walls, exterior claddings and ceiling; a few ceiling tiles have moved; untied HVAC equipment moves.
2	Moderate damage (slight structural damage, moderate non-structural damage	Little or no damage to structural framing. Small damage to stopping plaster over connectors or cracks at gypsum plasterboard sheet edges at corners of wall openings, cracking at room corners and in ceilings; cracks in masonry veneers; cracks in masonry chimneys and small pieces of plaster fall.	Some movement at connections between structural members. More extensive cracking of partitions; loss of ceiling tiles and damage to supporting rails; some light fittings damaged; a few connections of pipework leak.
3	Substantial to heavy damage (moderate structural damage, heavy non-structural damage	Some frame distortion visible. Some windows cracked. Veneers fail and expose frame. Large cracks in plaster or plasterboard sheet edges at corners of wall openings, corners and ceilings. Roof tiles detach. Unreinforced masonry chimneys fracture at roof line. Some shifting off unsecured foundations, subfloor bracing damaged.	Cracks or wood splitting and damage of connections between structural members. Most partitions severely cracked; some glazed claddings cracked; partial collapse of ceiling and falling of light fittings at some locations; leaks develop in pipework at many locations.
4	Very heavy damage (heavy structural damage, very heavy non-structural damage)	Serious frame distortion. Detachment of plasterboard wall and ceiling linings. Windows cracked and glass fallen. Extensive failure of masonry veneers. Toppling of most masonry chimneys. Houses not secured to foundations, shifted off. Failure of subfloor bracing.	Failure of structural connections between heavy timber frame members. Slack or broken braces in cross-braced timber frames, large splits in timber members. Complete failure of partitions; claddings damaged and fallen glazing; ceilings and suspended light fittings partially collapsed; some exterior wall panels severely damaged and a few fallen; pipes and ducts broken with extensive leaking.
5	Destruction (very heavy structural damage)	Total or near total collapse of entire structure.	Structure may have large permanent lateral displacement, may collapse or be in imminent danger of collapse; structure may slip and fall off foundations.

Figure 4: Damage grade descriptions for timber frame structures from NZMS

4 SUMMARY

This paper outlines the development of an updated New Zealand Macroseismic Scale (NZMS) intended to align with a new International Macroseismic Scale, also a work in progress. Both of these scales are based upon EMS-98 and are intended to be as consistent as possible with it. The next step towards a final version of NZMS is to use building damage datasets from several recent New Zealand earthquakes in order to assign intensities. This process is part of the review and calibration of the proposed NZMS.

5 ACKNOWLEDGEMENTS

This work was supported by the ATC-158 project grant and the John Wesley Powell Center for Analysis and Synthesis, in Fort Collins, Colorado, funded by the U.S. Geological Survey. S. Lin and T. Goded were partially supported by New Zealand Ministry of Business, Innovation and Employment (MBIE) through the Hazard and Risk Management programme: *P1.6 Built Environment & Performance Project*. Strategic Science Investment Fund, contract: C05X1702.

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