

## DEVELOPING AND IMPLEMENTING AN INTERNATIONAL MACROSEISMIC SCALE (IMS) FOR EARTHQUAKE ENGINEERING, EARTHQUAKE SCIENCE, AND RAPID DAMAGE ASSESSMENT

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**Abstract:** *Macroseismology plays a crucial role in earthquake hazard and risk analyses, tying earthquake occurrences and impacts from the past with those of the present and future. Nonetheless, even with best practices, there are key limitations to many modern macroseismic data collection approaches. For example, the United States and New Zealand still employ variations of the Modified Mercalli Intensity (MMI) scale, which is consistent with—but inferior to—the more recently developed 1998 European Macroseismic Scale (EMS-98). Practitioners in many other countries outside of Europe deploy EMS-98 informally, and often, so do researchers working there. We report on the efforts to finally develop an International Macroseismic Scale (IMS), building on the impressive EMS-98 framework. We motivate the IMS, noting its seismological and earthquake engineering benefits and summarize the historical efforts leading to this global scale. We then describe key features of the IMS, its consistency, and differences with respect to the EMS-98 framework, including additional structures in an expanded building vulnerability table. Moreover, the IMS will allow for national annexes that document crucial structural characteristics, code era, compliance considerations, and other potential vulnerability modifiers endemic to buildings in that specific region that will help narrow vulnerability class assignments. Lastly, a sizeable ongoing effort entails developing and promoting more uniform, pre-earthquake exposure and vulnerability class data collection and post-earthquake building damage characterization consistent with the requirements of the IMS (i.e., building classes, damage grades, and damage percentages). We will facilitate uniform damage data collection by employing relatable building taxonomies and enhancements to existing inspection and reconnaissance protocols; these conventions, too, will be described in each nation's building annex. Consistent, concerted damage data collection efforts will allow for immediate IMS assignments and contribute directly to better earthquake engineering damage and geotechnical forensics, vulnerability model development, and a host of other earthquake hazard, loss, and risk analyses.*

## 1. Introduction

Macroseismic scales evolve as building practices progress, technologies advance, and lessons learned from experience guide new considerations. Given the continued importance of macroseismic data in a wide range of seismological and earthquake engineering research and practices, it is imperative to reflect on such changes and modify the scales as warranted. Here, we reflect on the potential benefits of a revised International Macroseismic Scale (IMS) and describe the modifications and strategies necessary to implement a scale that could serve worldwide.

Developing the IMS requires: (i) introducing additional building types not fully described in the EMS-98 taxonomy, including modern types of widely used wood frame, reinforced concrete, earthen construction, and steel structures; (ii) collecting and generating additional damage sketches and photos, particularly for structures common outside of Europe, and (iii) making minor revisions to the original EMS-98 guidelines based on lessons learned since 1998. We will release the actual IMS Guidelines at this 18WCEE meeting as a standalone electronic and printed pamphlet, much like EMS-98.

This paper also presents goals for the IMS that are above and beyond the requisite guidelines to apply or implement the IMS in a new area. In particular, the very nature of this new generation of macroseismic scale is very much geared to the earthquake engineering community, in addition to the more typical uses in seismology. As such, we are making a concerted effort to coordinate post-earthquake data collection worldwide that would facilitate IMS assignments. Whereas such a goal is aspirational, it is attainable if sufficient numbers and ranges of building damage collection protocols recognize and reflect the needs and benefits of an IMS. Improved post-earthquake building damage collection will require modifications to protocols used by inspection, reconnaissance, and survey teams. Nevertheless, improved uniformity of building damage data will greatly facilitate the quality and range of applications and studies that use post-earthquake data.

We report on the results of meetings held in 2022 and 2023 to address the above issues and to work towards the International Macroseismic Scale (IMS). We also synopsise several of the related efforts published and presented at this 18WCEE meeting to consolidate the various contributions in the context of the evolving IMS and our strategy for improving post-earthquake damage data collection efforts globally.

## 2. Lead Up to the International Macroseismic Scale (IMS)

Overviews of existing macroseismic intensity scales provided by Musson et al. (2010) remind us that the assignment of intensities varies depending on the scale used, that scales are not all compatible, and that the quality of the assignments depend on the scale employed. Musson et al. (2010) also provide approximate conversions from several standard scales (e.g., MMI, MCS, MSK, and JMA-96) to EMS-98, with the implicit assumption that EMS-98 is the most modern and comprehensive scale yet developed. The wide variety of scales used worldwide and the inconsistency among protocols for assigning them could be improved upon.

In 1998, European nations developed and adopted the European Macroseismic Scale (EMS-98; Grünthal et al., 1998). EMS-98 established a common basis for assigning intensities to European seismic events, overcoming differences among existing intensity scales and producing more consistent and valuable assessments of earthquake shaking and damage. Though developed to be extensible and applicable outside of Europe, nations elsewhere have achieved varying levels of success in such implementations, and it is now considered the most widely used scale worldwide.

A key, implicit evolution from earlier scales to EMS-98 was the general transformation from scales primarily built by and for seismologists to one much more integral to the needs and contributions of earthquake engineers with the behavior of structures more systematically addressed. With IMS, we eliminate the remaining barriers to implementing a global scale that benefits both of these communities, combining seismologists' scientific macroseismic needs with earthquake engineers' desire for more comprehensive and routinely collected building damage data. We note that the IMS should also allow for innovations in citizen-science contributions, remote-sensing technologies, and related artificial intelligence algorithms that can facilitate new strategies for building damage data.

*Table 1. Draft Extended IMS Vulnerability Table. From Schwarz et al. (2024; this meeting)*

Type of structure		Abbr.	Vulnerability class					
			A	B	C	D	E	F
MASONRY	rubble stone, fieldstone	M1	○	—				
	adobe (earth brick)	M2	○	—				
	simple stone	M3		○				
	massive stone	M4			○	—		
	unreinforced, with manufactured stone units	M5		○	—			
	unreinforced, with RC floors	M6			○	—		
	reinforced or confined, with RC floors	M7				○	—	
RC (Cast-in-situ)	frame without ERD	RC1-L		○	—			
	frame with moderate level of ERD	RC1-M			○	—		
	frame with high level of ERD	RC1-H				○	—	
	walls without ERD	RC2-L			○	—		
	walls with moderate level of ERD	RC2-M				○	—	
	walls with high level of ERD	RC2-H					○	
	dual system without ERD	RC3-L			○	—		
	dual system with moderate level of ERD	RC3-M				○	—	
dual system with high level of ERD	RC3-H					○		
RC (Precast)	frame without ERD	RC4-L		○	—			
	frame with moderate level of ERD	RC4-M			○	—		
	walls or dual systems without ERD	RC5-L			○	—		
	walls or dual systems with moderate level of ERD	RC5-M				○	—	
STEEL	frame without ERD	S-L				○	—	
	frame with moderate or high level of ERD	S-M/H					○	
WOOD	frame or walls without ERD	W-L			○	—		
	frame or walls with moderate or high level of ERD	W-M/H				○	—	

○ Most likely vulnerability class; — probable range; ..... less probable, exceptional cases.

Grünthal et al. (1998) provided a brief synopsis of the motivation and contributions to the development of EMS-98, and Wald et al. (2023a) provided additional details. In short, EMS-98 evolved from EMS-92, a derivative of the Medvedev-Sponheur-Karnik (MSK) scale. Earlier efforts at an IMS included a 2014 working group that recognized the need for an expanded vulnerability table aimed at structures worldwide that were not well characterized in EMS-98's limited vulnerability table. Our current effort, fortunately, benefits greatly from past efforts, and several of the luminaries behind the development of EMS-98 had already begun devising strategies to move toward an IMS (e.g., Spence and Foulser-Piggott, 2014, 2015; Schwarz et al., 2015; Abrahamczyk et al., 2017, 2021).

Original members of the EMS-98 Working Group convened an IMS Working Group in 2013 as a joint effort in line with the Mini-Symposium *Conclusions from 15 years of international experience with the EMS-98* at the Vienna Congress on Recent Advances in Earthquake Engineering and Structural Dynamics 2013, organized by J. Schwarz, G. Grünthal, R. Musson, R. Spence and M. Stucchi. Notably, Spence and Foulser-Piggott (2014) drafted proposed modifications to the existing EMS-98 vulnerability table including expanded types of timber and steel buildings. In addition, the IMS Working Group (in its 1<sup>st</sup> phase) made essential recommendations concerning the addition of descriptive diagrams, covering more structural types, damage grades, damage quantities, and regions such as presented in Spence and Foulser-Piggott (2014). Another productive effort toward an IMS occurred prior to and at the 16<sup>th</sup> World Conference on Earthquake Engineering (16WCEE) in Santiago, Chile, in 2017.

An updated review of EMS application and critical reviews were provided by the contributions to Special Session 96 at the 16WCEE entitled "*Evolution of EMS-98: Building Types, Vulnerability Classes and Damage Grade Description toward an International Macroseismic Scale*," organized by Jochen Schwarz, Thomas Wenk, and Gottfried Grünthal. Thereafter, however, progress towards delivering the IMS stalled.

These earlier efforts to envision an IMS, including the 2014 working group contributions and the 16WCEE contributions, did not result in its implementation; nonetheless, their work greatly facilitated our efforts here. The proposed IMS table (shown here in Table 1) builds on Spence and Foulser-Piggott (2015) and is described

more fully in Schwarz *et al.* (2024). An expanded version of the earlier EMS-98 Guidelines was prepared in draft 2015 by Roger Musson.

In 2022, the lead author obtained USGS funding for a pair of IMS-related international workshops at the USGS Powell Center for Analysis and Synthesis in Fort Collins, Colorado. We report on these two workshops and a third meeting in Potsdam, Germany, in July 2023, partly supported by the Global Earthquake Model (GEM). In addition, the USGS supported a parallel research effort by the Applied Technology Council and GNS Science New Zealand to implement the IMS in the United States and New Zealand, respectively. These will be published at this conference (Hortacsu *et al.*, 2024; Charleson *et al.*, 2024) and later formally adopted as an Applied Technology Council Report (ATC-158; ATC, 2023).

### **2.1. First Powell Center Workshop – October 2022, Fort Collins, Colorado**

Wald *et al.* (2023a) comprehensively summarize the First Powell Center IMS Workshop. There were two primary goals.

First, harmonize the MMI Scale with EMS–98 for the United States and New Zealand—which share several similar building types—by considering those structures and associated damage grades not well represented in the current EMS–98 building vulnerability class table. We focused on masonry, reinforced concrete, and light timber frame buildings.

Second, restart interest in the wider IMS by augmenting EMS–98 with new regional building classes and work toward developing a scale that could be used globally. Such an effort requires reviewing and expanding the original EMS–98 explanatory documents and considering any required revisions. The workshop allowed attendees to discuss and refine priorities, define action items, and ultimately begin to implement and build a consensus around the IMS (Wald *et al.*, 2023a,b).

### **2.2. IMS-24 Working Group Meeting – July 2023, Potsdam, Germany**

Following up on the First Powell Center IMS Workshop, Wald organized a meeting of principal EMS-98 and IMS-14 contributors: R. Spence, R. Musson, J. Schwarz, T. Wenk, and G. Grünthal at Helmholtz Centre (GFZ) Potsdam. The other EMS-98 co-editor, Massimiliano "Max" Stucchi, was invited but chose not to participate. Our meeting focused on implementing IMS. The group made fundamental progress and commitments towards the IMS.

The working group identified and distributed several tasks necessary to further the development of the IMS: (1) expand the EMS-98 vulnerability table (Schwarz, Wenk), (2) create additional drawings for structures added to the vulnerability table (Wenk, Spence), and (3) clarify the structure and rewrite portions of the EMS-98 guidelines documentation to accommodate these additions as well as lessons learned since EMS-98 was first introduced (R. Musson). Further, we decided to allow National Annexes to help guide IMS practitioners in each country concerning regional nuances in structural-specific and vulnerability class modifiers related to building codes, local building practices, and other particularities. Rather than continuously updating the IMS to accommodate new national contributions as they are introduced, we considered providing some guidance for National Annexes, allowing for any nations to develop and publish their own Annex and guidelines documents separately. The contributions from the U.S. and New Zealand (ATC, 2023) are planned to be part of the National Annexes.

We deemed it feasible to finish, publish, and roll out the IMS at the July 2024 18WCEE meeting in Milan (this meeting). The publication route would be the same as for EMS-92 and EMS-98 (and later language versions), via the Centre Européen de Géodynamique et de Séismologie in Luxembourg.

### **2.3. Second Powell Center Workshop – October 2023, Fort Collins, Colorado**

The main goals of the second Powell Center Workshop were twofold. First, make further progress on the IMS development, using the United States and New Zealand contributions (Annexes) as the basis for the expanded vulnerability tables and damage grade graphics and continue discussions related to the structure of national Annexes.

The second major goal was to further coordinate reconnaissance and response groups that collect post-earthquake damage data. The Second Workshop leveraged the expertise of participants involved with numerous prior earthquake engineering or macroseismic field reconnaissance experiences around the world. Contributions came from reconnaissance team members from EERI's Learning From Earthquakes (LFE) team,

the Structural Extreme Events Reconnaissance (StEER) team, and the Earthquake Engineering Field Investigation Team (EEFIT). In addition, colleagues at FEMA and the California Office of Emergency Services were in attendance to provide perspectives from multitudes of post-earthquake Preliminary Damage Assessments (PDAs) for loss disbursement. We aim to leverage the efforts of experts already in the field after damaging earthquakes to routinely contribute to IMS intensity assignments and damage data sharing more generally by discussing and implementing modifications to their damage data collection protocols to accommodate the main IMS requirements: assignments of vulnerability class, damage grades, and suitable representation (damage appropriate building damage sampling statistics).

Additional considerations for the second Powell Center Workshop included improving and incorporating internet intensities into IMS for lower (<VII) intensities (e.g., Sbarra *et al.*, 2024) and reaching out to additional nations to begin formally adopting the IMS in their countries.

Unfortunately, the threat of a United States government shutdown in early October 2023 necessitated cancellation of the in-person workshop and only the first goal above was addressed during a two-day virtual meeting. Subsequently, we planned to reconvene the second portion of the meeting in February 2024, in San Francisco.

#### **2.4. 18th World Conference on Earthquake Engineering (18WCEE) Milan**

At the Potsdam workshop in July 2023, we determined that an achievable goal was to complete, publish, and deliver the IMS at the 18WCEE. Subsequently, we planned these efforts with the 18WCEE organizing committee.

### **3. Key Features of the IMS**

Well, first, what is in a name? Despite its name, EMS-98 has already been used widely outside Europe. Though seemingly cosmetic, changing from EMS-98 to IMS acknowledges that a truly international scale would benefit from a fitting description in its very name, consistent with its expansive potential for a globally consistent application. Nothing about IMS is fundamentally different than EMS-98; IMS builds on the success of EMS-98, further expanding its utility and application worldwide.

#### *Consistency with EMS-98*

A foundational goal of IMS is to strive for consistency with earlier assignments and practices described in EMS-98. Backward compatibility of the IMS with EMS-98 is ideal, yet it may be challenging in practice. Additional vulnerability table building types have yet to be thoroughly tested or calibrated. Given the contributions of vulnerability modifiers for various country annexes, they may require refinements to their default and vulnerability class ranges (e.g., Charleson *et al.*, 2024).

Similarly, it is always difficult to assess the uncertainty of historical intensity assignments given limited archival observations, reconciling conversions from other macroseismic scales or via ground motion to intensity conversion equations, or based on modern observations that are less than systematic (say, from media reports). Based on earlier discussions in our workshops, further analyses are required to comprehensively assign uncertainties for macroseismic datasets estimated with the varied approaches and raw data described above (Quitoriano and Wald, 2022).

#### **3.1. Updates to EMS-98**

##### *Vulnerability table expansion*

The IMS extends EMS-98 to be more applicable to building varieties expected to behave differently for a given shaking level. The current consensus vulnerability table by Schwarz *et al.* (2024) (Table 1) build on the outcome of IMS Working Group 2014/2015, the Decisions of IMS WG Meeting Potsdam 22nd and 23rd January 2015 (compiled by Thomas Wenk and agreed by the other WG members Grünthal, Musson, Spence, Schwarz and Foulser-Piggott). Additional structure designations include further distinctions among masonry types and separating steel and timber (wood) buildings to distinguish between those with and without Earthquake Resistant Design (ERD). IMS-24 significantly expands the discussion of ERD and its role in vulnerability class and intensity assignments (Haweyou *et al.*, 2024).

The distinction made with the separation of ERD and lack of ERD for steel expands the possible vulnerability class range to B (non-ERD). Similarly, the non-ERD and ERD distinction for timber now allows for ERD timber

to potentially reach the least vulnerably class (F). This accommodates recent analyses in New Zealand and the United States of light and heavy timber frame structures that are uncommon in European countries (Charleson et al., 2024; Hortacsu et al., 2024). For the U.S and New Zealand, light and heavy timber, and large residential and commercial wood frame structures are accommodated within the ERD and non-ERD categories and more subtle structural differences and damage grades will be further classified and described in both nation’s national Annexes.

*Tying IMS building vulnerability classes to existing building taxonomies*

As discussed below, a key consideration for directly relating post-earthquake building damage data collection efforts to IMS will be providing mapping schemes to and from the expanded IMS vulnerability table with existing taxonomies used by earthquake engineers, building inspectors, and reconnaissance teams. This is facilitated within the notes section of each building vulnerability class and damage grade example (e.g., Figure 1) provided in the IMS building guide. Several possible building taxonomies could be used including EMS-98, ATC-13, ATC-20, GEM, FEMA, PAGER-STR, WHE, and others (e.g., Abrahamczyk et al, 2017, 2021, Brzev et al., 2013; Jaiswal and Wald, 2008; Nicodemo et al., 2020; Porter, 2023; Schwarz et al., 2021; 202). Country-specific building taxonomies could be described building types in their national annex to the IMS.


<b>1986 Carpathia Earthquake, Leovo, Moldava</b>											
Vulnerability Class						Type of Structure	Grade of Damage				
A	B	C	D	E	F	<b>Adobe Masonry</b>	1	2	3	4	5
○	●									●	
											
<p>Comments:</p> <p><b>VC B:</b>                      Adobe masonry building. Adobe stones visible behind fallen plaster. One-story building with rectangular compact layout in plan, relatively long wall piers next to windows, and considerable wall thickness allows, remaining in the probable range, to assume one VC higher than the most likely VC A, i.e. VC B.  <i>For the final classification, it should be verified if a ring beam is present along the top of the walls.</i></p> <p><b>DG 4:</b>                      The loss of connection between external walls and the partial failure at the bottom of the left corner suggests damage of grade 4 (serious failure of walls). The right part of the building seems to be without serious damage and is obviously of a better stage of repair.  <i>The final classification should consider the reasons for this difference.</i></p> <p><small>Photo authors: E.T. Kenjebaev, A.S. Taubaev, Almaty</small></p>											

Figure 1. Example illustrating the classification of damage to building types for IMS (Wenk and Schwarz, 2024 referring to Figure 5-2 in EM S-98). Note that the vulnerability class is now tabulated for each

*example building damage grade image or drawing within the applicable range of the type. Comments now describe the choice of the vulnerability class and the damage grade. Text in Italics give guidance for the interpretation of observation.*

#### *Consideration of non-structural elements*

The expansion of EMS-98's vulnerability table (Table 1) acknowledges the prevalence of low vulnerability (Class E and F) structures in some regions, particularly in wood frame homes in California and New Zealand. Moreover, though the five damage grades form an essential part of EMS-98, an important step towards an IMS is to update descriptions of IMS damage grades for all building types and damage in non-structural elements (Wenk and Schwarz, 2024). These authors review updated quantitative damage grade descriptions, such as crack width, that will be systematically introduced as far as possible (Wenk and Schwarz, 2024).

#### *Explanatory damage drawing and image collection Improvements*

EMS-98 feedback and 25 years of experience recommend the addition of damage grade descriptions for most building types, particularly for timber and steel buildings, while maintaining the five standard EMS-98 damage grades. Illustrations of damage grades will be updated and extended to timber (e.g., Figure 1), steel, and adobe buildings (Wenk and Schwarz, 2024). The 2023 M6.8 Morocco earthquake also shows the need for expanded depictions of damage to the wide range of adobe structures worldwide.

#### *Seismogeological effects*

The IMS guidelines further demote the role of seismogeological effects, such as landslide, liquefaction, lateral spread, ground cracking, and fault rupture, for assigning intensities. Because these geotechnical observations are complicated by unknown and widely varying geotechnical susceptibilities and triggering mechanisms, the new IMS guidelines further explain that these effects are unreliable indicators of shaking intensity.

#### *Highest intensity assignments*

Many traditional macroseismic scales have included intensity levels XI and XII. A guiding principle of IMS is that each degree is recognizably different from adjacent levels. In our modern context, there is inadequate justification for intensity XI and XII; they were sometimes poorly defined or based on extrapolation, or have little observational basis, and thus, they are nearly impossible to assign. The USGS has already eliminated XI and XII from consideration with their application of MMI (Dewey *et al.*, 1995). More critically, those who have assigned these highest intensities in past earthquakes often did so based on inadequate or inappropriate criteria such as ground failure features (mentioned above) or from building damage observations known to saturate above intensity IX. Ten intensity levels are sufficient to describe the corresponding range of ground motions recorded as illustrated on the standardized USGS ShakeMap intensity legend (Worden *et al.*, 2020). Whether inspecting peak ground acceleration (PGA) or velocity (PGV), the 10-level scale corresponds to shaking levels ranging from not-perceptible (0.02 cm/s or 0.1%g) to over 200 cm/s (>100%g), the strongest shaking levels recorded. The IMS now states that intensity XII represent a hypothetical maximum of earthquake effects and due to saturation of observations, both of building damage and ground motions, and that it is recommended not to use intensities XI or XII.

#### *National and regional annexes*

Even with expanded classes of structures in an extended vulnerability table (Table 1; Schwarz *et al.*, 2024) and new considerations of non-structural elements in assigning intensities, IMS needs to guide the evaluation of local and regional structural building types and to give accessible instructions for proper vulnerability class assignments in support of the field work and the interpretation of observed shaking effects. The basis remains as in EMS-98: lessons from earthquakes and the comparison of damage to the predominant building types. Regionally-specific variations of structures should consider the existence of—or temporal variations to—national or local building codes, adherence to such codes, and local systematic structural modifications. The following section delves into where IMS is already effectively in place and details initial considerations for other regions considering developing national annexes.

## **4. IMS National Annexes**

The proposed annex concept is one in which local experts prepare a National Annex that can be read alongside while not being part of IMS-24. Such National Annexes will indicate the typical local buildings and features affecting their seismic performance, and the collection of such Annexes will grow over time. The notion of

National Annexes is analogous to Structural Eurocodes' requirements for the design of buildings and civil engineering works. Eurocodes have core codes complemented by National Annexes related to regulatory safety matters allowing for national choices to be made for construction in a country, and to be published by the relevant national standardization body (Eurocode, 2023).

National Annex guidance should include regionally specific IMS vulnerability class assignments or employ a suitable taxonomy that could easily be converted to IMS classes on the back end. Likewise, it is vital to ensure the use of damage grades consistent with—or convertible to—IMS damage grades. Lastly, IMS and each Annex must strongly emphasize the need for statistical sampling of building damage over as wide a range of damage grades as possible rather than just those buildings most highly impacted.

Countries whose experts can characterize regionally specific building attributes should carefully document such considerations, aided by drawings and images, as needed, to be part of a National Annex. Additional documentation could include guidance for how post-event inspection and reconnaissance teams could move towards damage data collection suitable for both IMS and more general consistency with other collection efforts around the globe.

National annexes would not be included within the IMS-24; intellectual property rights (IPR) remain with the National Annex authors and are distinct from the IPR of scale. The United States (ATC, 2023) and New Zealand (Charleston *et al.*, 2024) intend to develop national Annexes separately, as both nations are in the process of moving from MMI to IMS.

#### **4.1. Cataloging national macroseismic and building-damage data-collection protocols worldwide**

Most countries in Europe have adopted EMS-98. Outside of Europe, many countries have also adopted EMS-98. In fact, worldwide, EMS-98 is clearly the dominant modern scale, and thirty authorized translations are available. Hence, EMS-98 is effectively an international scale. However, whereas some countries have adopted EMS-98 directly, with proper adaptations, in many cases, it has been adapted or implemented inconsistently. Other countries, the United States included, continue to use more limited scales, such as the Modified Mercalli Intensity (MMI) scale. A full accounting is beyond the scope of this paper, but it is a work in progress to do so (Wald *et al.*, 2024), and this process began informally at the first and second Powell Center IMS Workshop.

To further realize a true IMS, with the ultimate objective of a more uniform collection of building damage and macroseismic intensity data after earthquakes worldwide, it is necessary first to create an inventory of protocols used by regional and national authorities worldwide. Such practices vary greatly. Many nations have formally or implicitly adopted the EMS-98 scale. However, even among those who have achieved such uniformity in using that specific (modern) scale, how the data are collected vary considerably. Wald *et al.* (2024) make a first attempt to broadly categorize the range of scales and protocols used worldwide to encourage and facilitate more uniform practices. Their effort to characterize current macroseismic practices will include the findings of a national macroseismic data and practices questionnaire—along with a survey of post-earthquake investigation and inspection protocols—for countries around the globe. The 18WCEE and other international meetings will serve as platforms to solicit contributions to this survey tool.

#### **4.2. New Zealand and United States national annexes**

Initial efforts to develop national annexes occurred in New Zealand and the United States because these countries were key early targets for expanding the IMS vulnerability table for wood frame and other common structures in these regions. The United States and New Zealand share several predominant building types and vulnerabilities (e.g., Jaiswal and Wald, 2008) made similar by climate, socioeconomics, construction practices, and building codes, and can thus be considered together. These shared structures require expansion of the EMS-98 vulnerability table consideration beyond the 15 separate structural types (of which seven are masonry and six reinforced concrete types, with only one each for steel and timber).

Since both countries still employ variants of the MMI scale, both will benefit from a concerted effort to characterize better the unique structural characteristics in each country introduced by robust building codes. Both nations also have well-developed post-earthquake response and inspection protocols that could serve as models for modifications that will allow for IMS assignments and more consistent building damage data collection—one of the main goals tackled at the second Powell Center Workshop.

Charleston *et al.* (2023, 2024) and ATC (2023) provide documentation of the efforts taken towards a New Zealand annex to IMS. The vulnerability modifiers proposed by Spence and Foulser-Piggott (2014, 2015) have been expanded and modified for New Zealand building conditions. Charleston *et al.* (2023, 2024) also elaborate on the EMS-98 damage grade descriptions for unreinforced masonry, reinforced concrete masonry, and for both light and heavy timber frame structures from New Zealand, and provides examples of damaged buildings and their damage grade assignments.

Porter (2023) and ATC (2023) provide documentation of the efforts taken towards a U.S. national annex to IMS. Specific considerations include the suitability of using ATC-20 tagging placards for assigning intensities and vulnerability class assignments for common variants of U.S. buildings, including vulnerability class modifiers due to building irregularities. Porter (2023) describes systematics and modifiers for U.S. building types defined using FEMA P-154, the standard of the U.S. Federal Emergency Management Agency (FEMA; Applied Technology Council, 2005). Included structure types are light-timber framing (FEMA W1 or W1A) and wood frame commercial and industrial buildings over 5,000 square feet (FEMA W2), tilt-up precast concrete (FEMA PC1), reinforced masonry shear wall with flexible diaphragms (RM1), and unreinforced masonry bearing walls (URM). Porter (2023) also includes detailed photos and diagrams of buildings with regular and irregular plans.

### **4.3. Developing additional national annexes**

Following the formal release of the IMS Guidelines, we anticipate a more concerted effort will follow to facilitate the development of national annexes, aiming for key countries where further standardization would be beneficial. Efforts to do so will include collaboration with the USGS, the GEM Foundation, and other international collaboratives with support from international aid and capacity-building agencies. Those interested in developing national annexes should get in contact with the authors.

## **5. Improving post-earthquake building damage data collection and facilitating IMS**

The EMS-98 and IMS assign higher intensities primarily through detailed building damage assessments. Therefore, buildings in the affected region must be characterized by their vulnerability class and associated damage classified (or graded). In addition, damage surveys must be conducted and adjusted according to vulnerability modifiers, with a statistically representative approach. Therefore, obtaining quality EMS-98 intensity assignments demands quality building damage surveys, raising the bar for assessors to evaluate structural characteristics and damage grades through sampling that gathers a representative distribution of both.

In addition to macroseismic intensity assignments, building damage information is needed for multiple response and recovery decisions, including situational awareness, reoccupation decisions, and recovery funding (Loos *et al.*, 2022). Before EMS-98, macroseismic intensity data was primarily in the hands of professional seismologists, and other building damage data was in the hands of professional engineers, architects, or government officials. The emphasis in EMS-98 on assigning intensities through identifying critical aspects of structural vulnerability and quantifiable damage grades (and their statistics) pushes macroseismic assignments further toward the purview of engineers rather than seismologists. This shift towards an engineering-based scale provides an opportunity for engineers, building inspectors, and reconnaissance teams to further coordinate and plan the collection of building damage data after future earthquakes, which benefits intensity assignments and the broader engineering, seismological, and practitioner communities.

### **5.1. Gaps in Traditional Macroseismic Surveys**

Limitations exist to modern macroseismic data collection approaches. Crowdsourced internet intensity reports (such as the USGS' "Did You Feel It?"; Quitoriano and Wald, 2020) are rapidly available and abundant after an earthquake occurs, but they are insufficient for describing higher, damaging intensity levels because assignments require expert knowledge of buildings' structural systems and damage characteristics (Wald *et al.*, 2023a). Field approaches that leverage building damage data to assign macroseismic intensities are, therefore, still required to assign higher intensities and fill gaps in internet reporting despite being costly in terms of time and finances.

Traditional macroseismic field surveys are challenging to carry out mainly due to issues with current post-earthquake damage data collection practices and a lack of dedicated resources. The USGS no longer has dedicated personnel responsible for post-earthquake macroseismic field assignments in the United States.

Similarly, Goded et al. (2024) and ATC (2023) both document the difficulty of systematically assigning intensities with recent efforts to deploy the IMS using building damage data from New Zealand and the United States, respectively. Despite a relatively limited extent of damage, competing collection strategies and goals, combined with regulatory limitations, reduced the quality and availability of data that could be used for macroseismic assignments. For more significant catastrophic disasters—like the 2023 Kahramanmaras, Turkiye sequence—the lack of preplanned strategies for standardized damage data collection and the inconceivable challenges put onto national and local agencies often result in haphazard damage datasets collected between multiple assessors. For example, So et al. (2024) describe some of the many challenges they encountered designing and conducting surveys to systematically collect qualitative data in the affected regions of the 2023 Turkiye earthquake sequence to assign macroseismic intensities, understand causes and types of injuries, and facilitate early recovery.

## 5.2. Updates to Post-Earthquake Damage Survey Collection and Sharing

After impactful earthquakes, building and infrastructure damage data are collected by a variety of official response groups including governmental officials and humanitarian response groups (in the case of international events) to aid decisions on reoccupation, demolition, or repair (e.g., So et al., 2024). At the same time, multiple reconnaissance teams from research and professional organizations, e.g., EERI, StEER, EEFIT and others are deployed to assess the causes behind building and infrastructure damage, geotechnical failures, and ground failure occurrences. An opportunity exists to assign higher macroseismic intensities without substantially more effort by the broader response community by coordinating with field assessors who already collect damage data and extending their surveys to fulfill the data collection goals of both the engineering and seismological communities, with the added benefit of supporting early response and recovery decisions. Some macroseismic intensity surveys were conducted on the ground after the 2023 Kahramanmaras, Turkiye sequence by reconnaissance teams from Japan, but the challenge is how to achieve this at scale. So et al. (2024) trialed an online survey sent to their local network in the affected area to capture information on the respondents' locale, building type and damage at the time of the event, as well as casualty information.

During the Second Powell Center Workshop, we gained a better understand of the range of building inspection and damage collection protocols used worldwide and further developed sampling strategies. Characterizing the range of strategies will allow consideration of the potential for more standardized approaches that could ultimately lead to more uniformity, openness, and consistency with the needs of macroseismic assignments in mind, possibly by morphing existing inspection protocols (such as ATC-20 used in the U.S.; ATC, 2005) to the modern needs of damage data collection. Not only will macroseismic assignments become uniform and ubiquitous, but such damage data could also greatly facilitate the development of improved fragility curves, understanding the causal pathways to casualties, and providing more consistent economic loss data necessary for financial and risk decision-making.

The database on the performance of structures near strong-motion recordings during the 1994 Northridge earthquake (ATC-38 project, ATC, 2000) serves as an example that comes close to the IMS damage data collection requirements. The ATC-38 survey was designed to describe the performance of buildings within 300 meters (or 1000 feet) of nearby strong motion stations that recorded the 1994 Northridge earthquake. Capturing the damage grade for all structures in a selected area is fundamental to IMS. However, it is only sometimes done in practice; undamaged structures are rarely cataloged, so damage statistics suffer from extreme sampling biases. Above and beyond such sampling, IMS requires each building to be assigned an appropriate vulnerability class, adjusted by vulnerability modifiers, and damage grade.

One future direction of note is that the continuing improvement of global and national vulnerability databases (e.g., Yepes-Estrada et al., 2023), could in some cases be preassigned IMS vulnerability classes such that field workers would have a prebuilt, digital inventory from which to work. Such a digital building inventory with vulnerability classes could streamline IMS assignments.

In addition to developing improved and coordinated protocols for data collection, a long-term goal of IMS is to improve the sharing of post-earthquake damage data. Because of the challenge of coordinating data collection

between response teams, it is unusual for these efforts to deploy consistent strategies that result in comprehensive, consistent, and shareable datasets. The lack of complete, open datasets is a barrier for macroseismic intensity assignments and for engineering researchers to characterize causes behind failures and responders to make decisions effectively. Ironically, a fundamental aspect of macroseismic assignments is that damage data are aggregated to anonymize the data so no individual building or reporter can be identified. This aggregation allows these data to be open and shareable, unlike damage reported on specific buildings. The goal is to design a method to aggregate and share building damage data so that they are still usable by the engineering, response, and risk modeling communities to respond to the current earthquake and as well as to help mitigate future losses.

Lastly, we will consider how to coordinate best the several technological tools that have been used for post-earthquake building damage data collection, which now often includes the use of standardized digital forms, geocoded photographs, and smartphone and tablet apps. While the range of these tools is impressive, they also need to be more cohesive. Those most routinely used tools could be modified to facilitate the automatic assignment of IMS intensities while collecting the damage data needed for the users' specific needs. Two strategies we are exploring are (1) modifying questionnaires in current apps to be directly applicable to IMS and (2) converting the results of existing questionnaires in current apps by using schemes that map common building taxonomies (from, say, ATC-20, Hazus, GEM, or FEMA-P154) and damage states to IMS vulnerability classes and damage grades on the backend. In either case, the statistical application of the resulting building damage inventories can be easily mapped to IMS intensities using geospatial analyses.

## 6. Conclusions

We have presented two ambitious efforts to (1) develop, publish, and implement the International Macroseismic Scale (IMS), and (2) fundamentally change the protocols for post-earthquake building damage data collection. These goals are not mutually exclusive. Better, more comprehensive—and open—damage data will not support more rigorous and quantitative earthquake engineering and loss modeling analyses; they will directly and automatically (and, thus, potentially more rapidly) contribute to systematic IMS assignments. These are long-term endeavors, both initiated as part of the two USGS Powell Center Workshops described herein.

An additional requisite goal of IMS is to be backward compatible with EMS-98; efforts are intense. Nevertheless, modernization presents challenges and opportunities to move beyond earlier limitations. The switch from MMI and the full adoption of the IMS in the United States and New Zealand will require comprehensive documentation and professional and public relations for community acceptance. Further, standardizing the assignment of higher intensities by leveraging engineering damage surveys will require modification of existing damage survey protocols. None of these efforts are trivial endeavors.

For wider international adoption of the IMS, it may be particularly challenging to revisit scales in use in countries with less compatibility with EMS-98 than the MMI scale. Of particular concern are scales in use where instrumental intensities are the norm, for example. Such efforts are beyond the scope of this current effort, but we are offering a direction forward for a more significant portion of the globe. In some nations, IMS would be a potential supplementary approach to existing national macroseismic approaches and scales.

Further efforts are required to efficiently and automatically integrate assignment of lower, non-building damage intensities contributed by the public via internet-based questionnaires. A full reckoning of how lower intensity assignments made by the public and higher intensities made by professionals will be transitioned for use in ShakeMap and official macroseismic maps remains a topic of discussion. Fully utilizing the next generation of macroseismic datasets will require a fuller treatment of the uncertainty of internet intensities, modern professionally assigned values, and a revisitation of the uncertainty levels that should be assigned to the wide variety of types and vintages of historical assignments, mainly when used quantitatively.

As of this writing, we intend to roll out the IMS at this meeting. If you are reading this text, presumably, the IMS has already been finalized and delivered at the 18WCEE!

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