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Keeping Earthquake Engineering Objectives in Perspective: A 2020 View

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ABSTRACT: The overall objectives of earthquake engineering can be summarised as being to *gather, shape and apply knowledge to reduce the impact of earthquakes on our communities*. These objectives have been re-affirmed by recent major earthquakes, and supported by the 2015-2030 framework ratified at the third UN World Conference on Disaster Risk Reduction at Sendai, Japan in March.

This paper takes a ‘2020’ view in two different ways. Firstly, a look back on the key strategic lessons for the earthquake engineering profession to have come from the Canterbury Earthquake Sequence and subsequent recovery activities, and other events around the Pacific. We can now more clearly understand the different dimensions of *pre-event mitigation and preparedness* and *post-event response and recovery*, and the need to more systematically evaluate the financial trade-offs and consequences at a community level between pre- and post-event actions. Secondly, consideration is given to areas of adjustment in earthquake engineering focus as we progress toward 2020. One key issue is the need for a greater awareness of uncertainty in both our analysis and presentation, particularly in the face of pressure from building owners and the community for scientists and engineers to provide greater ‘accuracy’ of outputs and outcomes.

1 INTRODUCTION

As five years has now passed following the September 2010 Darfield earthquake, and the recovery process advances, some of the broader strategic lessons are coming into clearer focus. A number of other developments have occurred in New Zealand, including the continued progression of the Building Act (Earthquake Prone Buildings) Amendment Bill into its final stages.

The past five years have also seen other significant earthquake and other natural hazard events across the Pacific that range in scale and impact. While each have their own lessons, there are some common threads.

From a global perspective, the Sendai Framework for Disaster Risk Reduction 2015-2030 (UN, 2015) adopted in March of this year provides a renewed focus on preventing new risk, reducing existing risk and strengthening resilience. This framework also articulates the need for improved understanding of disaster risk in all its dimensions of exposure, vulnerability and hazard characteristics, and the strengthening of disaster risk governance.

A recent two-day forum held in Wellington to mark five years since the beginning of the Canterbury Earthquake Sequence has helped put some of the local and global lessons into a better perspective. This significant forum enabled many of the key players and organisations involved in the recovery ‘journey’ to pause and reflect on the lessons for the built environment in the wider context of the natural, social and economic environments.

This paper provides high-level commentary on these developments and lessons and the current context of earthquake engineering. As part of considering what are the ‘macro’ lessons, observations are made about keeping ‘accuracy’ in perspective, and the need to be more aware of the impact of the uncertainties inherent in our work.

2 STRATEGIC POINTERS FROM RECENT PACIFIC NATURAL HAZARD EVENTS

The previous five years have seen a number of significant hazard events around the Pacific. The events listed below feature magnitude and impacts that range from extreme in terms of loss of life and economic effects through to smaller events with nevertheless surprising economic loss characteristics.

- Christchurch (Lyttelton) earthquake (2011)
- Tohoku earthquake and tsunami (2011)
- Brisbane floods (2011)
- Cook Strait, New Zealand earthquakes (2013)
- South Napa, California earthquake (2014)

It is instructive to consider some of the more strategic hazard risk management learnings from these events, and reflect on some commonalities.

(1) Understanding the Financial Trade-offs Associated with Disaster Risk Management

These and other global events such as Hurricane Sandy in the United States have highlighted that a better understanding of the economic impact of the different components of disaster risk is required, along with the financial trade-offs and consequences at community level. This would assist in making progress towards a more appropriate balance between *pre-event* mitigation and *post-event* response to impacts, involving more deliberate consideration of which components of risk should be ***avoided***, ***controlled***, ***transferred*** or ***accepted*** across the event scales.

While much of the work of earthquake engineering professionals typically focuses on aspects within risk *control* and *transfer*, there is clearly a need to have a greater focus on risk *avoidance* (eg avoiding exposure of new developments to significant natural hazards through more effective land-use planning).

Understanding and communicating seismic risk is a common element that sits across all four of these risk components, and is the key to achieving appropriate risk *acceptance* – that is, accepting some repair for foreseeable damage from regular events, and some losses for extreme events.

(2) What is 'Too Big to Fail', and how consequence should be better reflected in the design of certain critical facilities

The Fukushima Daiichi nuclear power plant located on the east coast of Japan was designed for severe ground shaking and tsunami impact, essentially in line with established practice for facilities of this nature. But the size of the impacting waves resulting from the M9.0 Tohoku earthquake significantly exceeded this design provision. As well as the direct damage caused to the plant from the overtopping, the emergency generators located in the lower levels of the plant quickly became submerged. The inability to provide auxiliary power for cooling of the reactor cores led directly to catastrophic failure of the plant, with resulting release of radioactive material which continued for a considerable period of time.

These direct impacts had national and international consequences, with the shutdown of all of Japan's nuclear plant prompting a global revisitation of nuclear plant vulnerability concerns and energy strategies, leading to the mothballing of nuclear plants in Japan and across the world.

The general view is that if the emergency generators had been located on the upper levels of the plant and had continued to function, the overheating of the reactor cores may well have been prevented. Positioning the emergency generators with appropriate regard to the occurrence of events greater than the assumed design level would have been a very low-cost resilience investment. Applying a 'Too Big to Fail' philosophy to critical infrastructure elements (O'Rourke, 2015) and looking beyond return periods for design would ensure that appropriate resilience provisions are made.

The risks (and indeed the illogicality) of placing key electrical equipment in the basements of buildings in a Central Business District has also been clearly illustrated in both the Queensland floods (January 2011) and the Christchurch earthquake (February 2011). This is a prime illustration of a risk avoidance measure.

(3) Cascade failures of infrastructure sectors and the potential for significant indirect losses

Identifying specific cascade failure scenarios for community infrastructure is complex, and continues to be the subject of considerable effort by researchers internationally. Recent events and other studies have however re-iterated the critical importance of power supply on the continued operation and immediate restoration of other utility services.

Following the February 2011 Christchurch earthquake, local electricity distribution company Orion managed to restore 90% of their network within ten days (Kestrel Group, 2011). This in turn was a key factor in enabling the telcos (and other lifeline utilities) to maintain their core services. It is understood that Orion came close to losing their network for as long as six months, which would have also impacted severely on telco and other networks – that is, led to a cascade failure. The added impact on the community would in turn have generated significant indirect economic losses.

Similarly, the impairment or loss of access into an affected area has a direct impact on the ability of other utilities to respond, as well as other community support functions. While loss of general access into the earthquake affected area was not a feature of the Christchurch earthquake, Wellington provides a contrasting case. A recent study by the Wellington Lifelines Group indicates that the major disruptions to state highways and major arterial routes into Wellington City following a Wellington Fault earthquake means that it is likely to take up to 80 days before business can resume (Mowll et al, 2012).

(4) The need to consider increased flood risk as a consequence of major earthquake

The Canterbury Earthquake Sequence has highlighted the potential for major earthquakes to add to flood vulnerability of urban areas. Eastern Christchurch has experienced significant problems from increased flood risk due to a combination of global tectonic settlement and local overall ground settlement due to liquefaction. The level of protection provided by stopbanks has reduced with lowering ground levels, and the effectiveness of stormwater networks greatly diminished due to regrading of sections of pipes – all in addition to the direct damage to stormwater networks.

It has been observed that Christchurch has experienced 100 years of sea level rise through the Canterbury Earthquake Sequence (van Ballegooy, 2014).

The potential for exacerbated flood risk should therefore be included in conjunction with earthquake hazard considerations in future land use planning, as well as considering risk reduction in developed urban areas.

(5) The vulnerability of flexible building structures to moderate earthquakes

The high level of non-structural damage experienced by a range of buildings following the Darfield and Cook Strait earthquakes in particular has highlighted two things – firstly, the lack of attention being paid to the seismic design and specification of non-structural items, and secondly the consequences of designing buildings for high ductilities.

The Cook Strait earthquakes also highlighted the vulnerability of inter-storey separations to damage in moderate (or greater) earthquake shaking. As one example, two central city car parking structures took more than eighteen months for structural and other repairs before being brought back into service.

(6) Greater planning effort should be given to the co-ordination and sharing of information

Data management frameworks and their linkages with business as usual systems, particularly in relation to property records, should be mapped out and included in response plans, including required authorisation(s). A key element of this in the New Zealand context is the need for a unique identifier protocol for buildings. Without this, many aspects of a response which depend on mapping (most notably post-earthquake rapid building assessment) are highly inefficient.

These are examples of what can be regarded as 'macro lessons' – strategic pointers that should be influencing and guiding seismic design of buildings and infrastructure more strongly than is arguably the case at present.

3 THE BUILT ENVIRONMENT LEADERS FORUM

There are many lessons to come from the Canterbury earthquakes and the recovery process, in addition to those touched on earlier in this paper. In September 2015, key NZ government and research agencies (the Ministry of Business, Innovation and Employment, EQC and the Building Research Association of New Zealand) hosted the Built Environment Leaders Forum. Timed to mark five years since the 4 September 2010 Darfield earthquake which commenced the Canterbury Earthquake Sequence, the purpose of the forum was to reflect on the lessons from the event and the response and recovery that followed, and to consider how those lessons apply to both major shock events such as earthquakes and to incremental hazards, notably climate change. The forum was attended by almost 200 senior figures from local and central government agencies, research agencies and practitioners across the built environment, along with others with wider responsibilities in disaster risk reduction. The forum featured four international specialists from the fields of seismic hazard risk communication, infrastructure resilience, urban planning and disaster recovery and climate change.

The importance of incentivising private investment in disaster risk reduction and the use of different mechanisms to achieve this for buildings and infrastructure networks was highlighted at the forum. While the commercial property sector advocated for tax rebates offered as an incentive for seismic strengthening (noting that the City of Los Angeles is currently considering a proposition for a 30% tax rebate for this work), the government currently has no intention to provide such incentives. Some New Zealand local authorities offer limited assistance for the strengthening of earthquake-prone heritage buildings – for example, Wellington City Council contributes toward the cost of a heritage conservation plan and a detailed seismic report from an engineer.

A related point is acknowledgement that investment in risk reduction needs to take place progressively over time, particularly for large property portfolios and infrastructure networks.

There is also a much greater awareness of viewing the built environment as a supply chain, and the need to strengthen all of the various components. This requires the active consideration of risk at every stage from considering the suitability of a site through to the review and consenting of a completed design and its construction – with an emphasis on appropriate decision-making at each phase. One of the related concepts presented at the Forum was that of the building and construction system as a system of systems. This can be visually represented as a truss, as shown in Figure 1 (Stannard, 2015). This representation highlights the number of elements involved, and indicates their interaction, to ensure that buildings are built (or not built), appropriate to the risk. Each element is typically a system in their own right, such and the way they inter-relate is in some cases more implicit than explicit. Realistic societal expectations provide an overarching context to the building and construction system - having informed and risk-aware owners as purchasers and maintainers of buildings is key to satisfactory outcomes. A good building code, standards and guidance are central components of the system, which is supported by education and training. Designers who know what they are doing, along with proper design review processes are also key elements, along with competent builders and suppliers and appropriate construction monitoring and inspection.

If all the truss elements (sub-systems) are in place with good connections between them, a strong overall system exists. Importantly, building failures typically occur when several parts of the system fail or are weak, rather than just one element – hence the need for appropriate governance and oversight of the overall system.

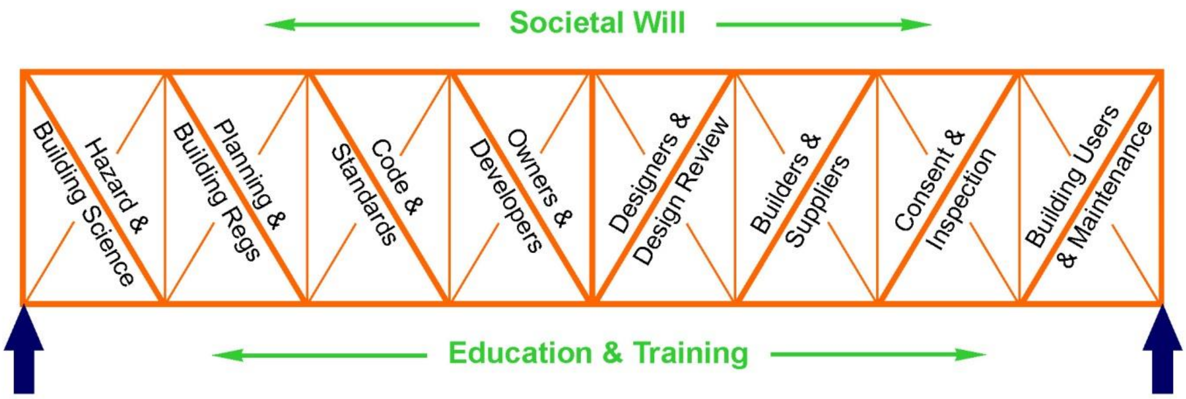

Figure 1: A representation of the building and construction system (Stannard, 2015)

There is greater awareness that building design codes principally address life safety, and do not fully provide for property protection. While major modern structures in the Christchurch CBD met engineering expectations in providing for life safety, many were demolished because the building structure was damaged beyond repair. As part of reducing the wider economic impact of major natural hazard events, greater consideration is now being given to repairability in design, and the extent to which this should be provided for more explicitly in design codes.

A summary of key lessons considered at the Forum is provided in Table 1.

Table 1: Summary of Key Lessons Considered at the September 2015 Built Environment Leaders Forum (MBIE, 2015)

Strategic Issues	• Public understanding of the risks posed by natural hazards needs to improve to support more consistent avoidance of risks in vulnerable areas • Key institutions need better scientific and engineering capability to manage disaster risk • Review legislation and controls to manage natural hazards to avoid under-concern on risks before events and over-concern afterwards
Economics of Resilience	• Financial risk transfer remains a key strategy for New Zealand's approach to disaster risk management as we are a small economy with very high hazard exposures • A 'systems approach' that addresses all factors that influence vulnerability is required for more effective management of hazard risk • Effective hazard risk management requires co-ordination and alignment across all levels of government
Land Use Planning	• Land use planning legislation needs to better recognise natural hazards • Greater understanding of the potential for exacerbated flood risk following major earthquakes is required • A national data hub for natural hazard information should be established
Building Performance	• Establish how well current structural design standards deliver building performance in line with community expectations • Better understand community's appreciation of seismic risk • Improving the review and consenting processes associated with the design of buildings is urgent
Infrastructure	• Resilient infrastructure is a worthwhile investment • Major vulnerabilities in national infrastructure systems should be identified and tackled • A longer term view to managing infrastructure assets and natural hazard risks is needed

4 AWARENESS OF THE NEED FOR INSTITUTIONAL TECHNICAL CAPABILITY

The Canterbury earthquakes have led to a realisation that having appropriately positioned technical capability and leadership in key local and central government agencies, integrated with policy development and implementation processes, is an important element in raising the effectiveness of resilience planning and delivery.

As well as enhancing the management of disaster risk (prior to and in response to disaster events), stronger technical capability in key organisations will enable appropriate and more timely scientific and engineering input into policy development. For agencies with responsibility for large property portfolios, having such a capability provides a better linkage with asset management strategies and processes. In turn, this helps put seismic risk in a more realistic perspective, avoiding the pendulum swing of under-concern to over-concern.

Similar observations have been recently made in other countries; as *Engineers Australia* Chief Executive Stephen Durkin urged the Australian Federal Government to re-think its technical capability in March of this year, he noted (Civil Engineers Australia, 2015):

> *'Without engineers and other technical staff in-house, the government limits its ability to deliver and manage programs'*

Key government agencies in New Zealand have recently enhanced their engineering capabilities in different forms and/ or increased their capacity. Immediately following the Darfield Earthquake in 2010, the Department of Building and Housing created the Engineering Advisory Group (EAG) to provide it and other government agencies with direct access to engineering capability and capacity to develop technical guidance and related inputs to assist the recovery (Brunsdon et al, 2013a). Subsequently, MBIE have taken on additional engineering capability directly, with the EAG now an external group providing advice across the range of work programmes of the Building System Performance branch.

In 2012, the Ministry of Education has established a panel of experienced structural and geotechnical engineers (the 'Engineering Strategy Group') to prepare specific guidance for assessing existing and the design of new school buildings. In addition to the five structural and geotechnical engineers that comprise the ESG, a critical linkage into the Ministry's Education Infrastructure Service is provided through the recently created position of *Senior Policy Manager, Engineering and Design*.

The initial work of the ESG focused on obtaining a better understanding of the seismic capacity of existing school buildings, the majority of which are of older timber-framed construction. Many of these are of standard layouts and forms of construction. Through the initiation of a destructive testing programme, it was demonstrated that single storey timber framed structures with light roofs on flat ground present a low seismic risk (Brunsdon et al, 2014). A key guiding principle has been to align the approach to risk with the Ministry's core asset management processes and philosophies. Significant savings have resulted through the direction of more efficient seismic assessment programmes, and the avoidance of unnecessary strengthening. This work has more recently extended to the production of a suite of design guidance standards for new school buildings covering both structural and architectural aspects.

Territorial authorities in New Zealand have limited engineering capacity and capability, and this has generally been the case for some time. Most usually engage engineering consultancies to assist with their technical functions in relation to Building Control (local regulator) and asset manager (owner). Recent events, including isolated building failures, have highlighted the importance of effective design review in maintaining the quality of building stock, and the importance of compliance reviews to an effective building system as noted in the previous section.

5 GREATER EMPHASIS ON UNDERSTANDING AND CONVEYING UNCERTAINTY

The volume of scientific and technical data created by and available to the earthquake engineering profession has grown exponentially in recent years. The rapid increase in data capacity which, along with increasing instrumentation deployed, has enabled programmes such as GeoNet to gather and make available a vast volume of data. Similarly, there has been an unprecedented volume of geotechnical data during the Canterbury recovery, and this led the creation of the Canterbury Geotechnical Database to systematically capture and make available this data. Following the success of the Canterbury Geotechnical Database, it is being broadened to become a national geotechnical database.

However, notwithstanding this explosion of base data, many downstream engineering design and assessment processes still rely on the application of engineering judgement. Most notably this judgement relates to the modelling of a structure, its foundations and the ground, whether for the design of a new building or the assessment of an existing structure. The outputs from the modelling are always sensitive to input assumptions, and in the vast majority of cases the benefit of any increase in ‘accuracy’ of the input data is not able to be reflected in refinement of the overall design or assessment.

As part of appropriately recognising this sensitivity, there are two important considerations. Firstly, is the application of increasingly precise numerical key parameters via code and guideline processes in balance or consistent with the various modelling and other assumptions inherent in the overall process? Further reflection may be warranted on the impact of increasingly precise parameters - individually and/ or cumulatively.

The second consideration is that one of the key roles of earthquake engineering professionals is to appropriately convey uncertainty as part of effective risk communication. This is a particular responsibility, noting that the community doesn’t have a clear or consistent understanding and perception of seismic risk. Scientific and engineering reports – whether they be reports on regional hazard assessments, Design Features Reports for new designs, or reports on seismic assessments – must acknowledge the uncertainty associated with both the input parameters and the analysis methods used.

These considerations are very much ‘in play’ in New Zealand, following on from a period of variability in seismic assessments following the Canterbury earthquakes. This has resulted from a combination of additional factors, including the limitations of the current assessment methods in dealing with low and medium-rise buildings (particularly those of low mass) and engineers with a range of experience in seismic assessments undertaking this work. Liability perceptions in the aftermath of the Canterbury Earthquakes Royal Commission of Inquiry have also played a part (Brunsdon et al, 2013a).

For new buildings, an area needing attention from a process (or system) perspective is that of Low Damage Design. In the rush to bring some technical solutions to market, there has been a lack of attention to how they will be applied across the range of building situations, and by engineers across the range of technical capabilities. As well as better guidance for designers, there is a clear need for fully independent peer reviews of designs using new technology (especially noting the limited technical capability of many Building Control Authorities as noted above) and closer monitoring until their use becomes established and familiar.

For existing buildings, in New Zealand the implementation of the Earthquake-prone Buildings Building Act Amendment) Bill will be a challenging exercise as noted above, and for some, a consuming one. The full revision of the NZSEE guidelines for the assessment of existing buildings is a major project with the underlying imperative of increasing the consistency of assessments. The revised guidelines place considerable emphasis on evaluating both the overall strength and the deformation capacity of a building, rather than just rating the building on the strength of the limiting member(s). It is hoped that this will enable practitioners to more clearly distinguish between buildings that represent a *significant* seismic risk (ie. heavier and more brittle buildings) from those that represent a *possible* seismic risk (ie. lighter buildings of low nominal strength but with considerable deformation capacity). This will create communication challenges for the profession, as some buildings that have previously been identified as being earthquake-prone are likely to be found to not be so with appropriate application of technical guidance.

This will also require a better alignment of the perception of risk within and across the profession, as a pre-requisite to conveying seismic risk more effectively to the wider sets of stakeholders. This also provides an opportunity for engineers to convey uncertainty more effectively, and to work more collaboratively with other engineers to resolve areas of difference that arise on specific assessments.

6 CONCLUDING OBSERVATIONS

The past five years have seen a number of significant hazard events around the Pacific, most notably the 2010/11 Canterbury Earthquake Sequence and the 2011 Tohoku, Japan earthquake and tsunami.

In New Zealand, the focus has been on the recovery from the Canterbury earthquakes, and identifying and communicating the lessons nationally and internationally. There is a better understanding of the different dimensions of *pre-event mitigation and preparedness* and *post-event response and recovery*, and the need to more systematically evaluate the financial trade-offs and consequences at a community level between pre- and post-event actions.

This paper has highlighted some of the strategic pointers that need to be taken from the local and global events during this period. These provide a signal as to the key issues that the earthquake engineering profession needs to be conscious of and plan for in the journey toward 2020, with the key points summarised below:

1. Earthquake engineering professionals should support the push for stronger Disaster Risk governance in line with one of the priorities of the Sendai 2015-2030 Framework – locally, nationally and globally. A key element of this is promoting the need to have technical *capacity*, *capability* and *leadership* in the right places, particularly in key local and central government agencies.
2. In advocating seismic risk reduction, we must always be conscious of economic reality – ie. the economic constraints and drivers. It is important to distinguish between situations where seismic risk needs to be addressed with a degree of priority and those where it should be addressed as part of asset management processes (ie. redevelopment, renewals and upgrades).
3. With respect to infrastructure resilience, there is a need to re-iterate that mitigation is a long game – progressive and persistent investment via a planned programme is required. Within this concept, there can be different risk reduction investment profiles at the macro (network) and micro (facility) scales.
4. In pursuing the objective of more resilient communities, greater emphasis should be placed on *risk avoidance* (eg. avoiding exposure of new developments to significant natural hazards through more effective land-use planning). For existing low-lying and coastal urban centres and critical facilities, a more conscious multi-hazard approach needs to be taken to appreciate the exacerbated flood risk generated by significant earthquakes. This involves understanding the likely nature of post-earthquake ground level changes, and the associated potential adverse impact on flood resistance and drainage systems.
5. The process of developing, designing, constructing and maintaining a building needs to be viewed more as a system – or as a system of systems, to be more correct. Building failures typically involve a combination of factors and considerations. Better treatment of the seismic restraint of non-structural elements and building contents and services during both design and construction phases is a prime illustration of this. Greater commitment to improved implementation is emerging from the various sectors, noting that this is not just an issue for designers to resolve.
6. The earthquake engineering profession needs to consider the elements of uncertainty more consciously, particularly in hazard and building assessments. This is highlighted by the increasing precision that is emerging for some technical parameters used in assessment and design of buildings and networks. For the design and assessment of buildings, this ‘refinement’

is happening in the main on the *loading* (or demand) side of the equation, and is not always being matched by a corresponding increase in 'accuracy' on the *capacity* side, due to the many modelling assumptions involved. A related aspect of this is balancing the increasing detail and prescription in codes with guidance on exercising judgement.

7. While data proliferates along with the capacity of databases and data storage systems, we have lost the ability to organise and share technical (ie non-commercially sensitive) information, including in the critical response and recovery phases of major events. A related point is the continued lack of unique identifier protocol for buildings in New Zealand. Progress towards resolving these issues is now a pre-requisite for enhanced *pre-event mitigation and preparedness* and *post-event response and recovery*.

Some of the 'macro lessons' outlined in this paper also reinforce the perennial 'don't forget the small stuff' message – including the likes of putting generators and sub-stations in locations within buildings that won't flood; providing seismic restraint for key items of plant; and maintaining close relationships with the people you may be working alongside in the response to major events.

The principal message to come from the events of the past five years and the above points is that attention needs be given to some of the 'bigger picture' strategic considerations. This comes at a time when the contrasting tendency is to place effort on refining key technical parameters and analytical models to achieve greater 'accuracy'. Placing greater emphasis on understanding and conveying uncertainty is therefore a key step in the more effective communication of seismic risk to the community.

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