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IMPROVEMENTS IN POSTEARTHQUAKE BUILDING SAFETY EVALUATIONS: LESSONS LEARNED FROM RECENT EARTHQUAKES

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Abstract

The ATC-20 report, *Procedures for Postearthquake Safety Evaluation of Buildings,* was published by the Applied Technology Council in 1989 specifically for use by qualified professionals who would be required to make on-the-spot evaluations and decisions regarding continued use and occupancy of damaged buildings. Since 1989, the ATC-20 methodology has been used worldwide in response to earthquakes of varying magnitudes, and a family of ATC-20 documents has been developed, including a second edition of a field manual (ATC-20-1) in 2005.

This paper will reflect on lessons learned during recent development exercises, such as the development of an adaptation of the ATC-20-1 methodology for Bhutan which considered the country's vernacular buildings, made adjustments for its cultural and governmental context, and provided an extensive set of images of varying degrees and types of building damage with the recommended posting category. The paper will also summarize and synthesize lessons learned from postearthquake safety evaluations conducted after recent damaging earthquakes, such as 2010 in Chile, 2011 in New Zealand, 2014 in Napa, California, and 2015 in Nepal. The original ATC-20 methodology has been adapted to other structural and governmental contexts, including documents funded by the local governments of New Zealand and Nepal. Each of these adaptations offered enhancements to the existing methodology and utilized different methods of communication. This paper will present a best practices overview from observed modifications.

For example, following the magnitude-6.2 22 February 2011 Christchurch, New Zealand earthquake, local officials, despite being initially caught off guard and unprepared for the scope and severity of the damage, made over 72,000 building inspections in 10 days. Many useful practices were instituted, including an emphasis on shelter-in-place, the addition of usability categories to placards, use of indicator buildings to help determine if reinspections after major aftershocks were warranted, and the forming of specialized teams to deal with specific concerns (such as buildings in danger of collapse). The approach taken by the New Zealand government in assessing buildings in Christchurch and subsequent modifications they made to their approach presents a major opportunity to learn from the experience, and this paper will present how this information can be used to update and improve the ATC-20 procedures.

In Nepal, a variety of postearthquake evaluation practices were observed, with extensive volunteer efforts both by engineers from Nepal and from many other countries. Nepal's guidelines include photographs of damaged buildings consistent with Nepal's building stock with the damage clearly linked to the recommended placarding categories of INSPECTED, RESTRICTED USE, and UNSAFE.

Keywords: postearthquake safety evaluation, inspection, tagging, placards

1. Background of Postearthquake Safety Evaluation Methodology

The Applied Technology Council first published the ATC-20 report [1], *Procedures for Postearthquake Safety Evaluation of Buildings*, in 1989 to document procedures and guidelines for the safety evaluation of damaged buildings. Two weeks after the completion of the ATC-20 report, the methodology was used in the magnitude-6.9 Loma Prieta earthquake that struck the San Francisco Bay Area in California and caused casualties and significant damage to buildings and infrastructure.

The ATC-20 documents are written specifically for use by qualified professionals who would be required to make on-the-spot evaluations and decisions regarding continued use and occupancy of damaged buildings. The current methodology provides procedures for rapid and detailed evaluations that result in posting them as INSPECTED (green placard), RESTRICTED USE (yellow placard) or UNSAFE (red placard). Also included are special procedures for evaluation of essential buildings (e.g., hospitals), evaluation procedures for nonstructural elements and geotechnical hazards, and limited guidance on human behavior following earthquakes. Rapid evaluations typically take 10-30 minutes per building and provide an initial general assessment of damage and safety, typically from the exterior of the building; the suggested personnel include building inspectors, civil and structural engineers, architects, and disaster workers. Detailed evaluations take one to four hours per building; they are a more thorough visual examination of the building and its structural system; they often occur after an initial Rapid Evaluation; and structural engineers are the recommended personnel [2]. A third level of evaluation, termed an Engineering Evaluation, is defined but not discussed in detail. It is conducted by structural engineering consultants hired by the owner.

The ATC-20 methodology is unique in its ability to provide a rapid assessment of the extent and significance of reductions in lateral capacity. Other building evaluation methods exist, but they are generally more costly, more time-consuming, can require more experience, and in some cases are focused on specific structural systems. Table 1 below is from [3]. It provides a simplified comparison of currently available prominent seismic evaluation methods used in the United States, both for undamaged buildings and for earthquake-damaged buildings with respect to the time required to perform the evaluation, the relative cost, and the qualifications needed to perform the evaluation.

Table 1 - Comparison of Prominent Seismic Evaluation Methods in the United States (from [3])

Undamaged Buildings	FEMA P-154 [3]	ASCE/SEI 41 Tier 1 [4]	ASCE/SEI 41 Tier 2 [4]	ASCE/SEI 41 Tier 3 [4] FEMA P-807 [5] FEMA P-58 [6] HAZUS [7]
Earthquake-Damaged Buildings	ATC-20 Rapid [2]	ATC-20 Detailed [2]	FEMA 352 [8] ATC-52-4 [9]	FEMA 306 [10] ATC-52-4 [9]
Time Required	Minutes	Hours	Days	Weeks
Relative Cost	$	$$	$$$	$$$$
Qualifications	Properly trained building professionals	Structural engineers experienced in seismic evaluation and design		

Since the original publication of ATC-20 in 1989, additional documents have been developed, including:

- ATC-20-1 *Field Manual*, published as first and second editions in 1989 and 2005 [2], respectively, summarizes the postearthquake safety evaluation procedures in a brief, concise format designed for ease of use in the field.

- ATC-20-2 report, *Addendum to the ATC-20 Postearthquake Building Safety Evaluation Procedures* [11], provides updated assessment forms, placards, and procedures that are based on a review and evaluation of the application of the procedures following five earthquakes occurring after the initial release of the ATC-20 report in 1989. One of the principal recommendations is the replacement of the yellow LIMITED ENTRY posting placard with a revised yellow placard entitled RESTRICTED USE.

- ATC-20-1 *Bhutan Field Manual* [12], published in 2014, was developed as an adaptation of ATC-20-1 *Field Manual* to account for Bhutan's vernacular buildings, as well as Bhutan's cultural and governmental context. During the development, a number of improvements were made to the presentation of material in the ATC-20-1 *Field Manual*, including a graphical format with numerous images to help engineers evaluate damaged buildings more accurately. Also, the procedures incorporate recent lessons learned during postearthquake safety evaluations following the Chile (2010) and New Zealand (2010-2011) earthquakes.

- A training slide set [13], a technical brief concerning earthquake aftershocks and building safety evaluation [14], and a set of case studies [15] are also available as part of the series of ATC-20 documents.

2. Recent Use of the Guidelines

The following is a brief summary of the implementation of the ATC-20 methodology in recent damaging earthquakes.

2.1 New Zealand (2010 and 2011)

Earthquake Event: A series of earthquakes occurred in and around Christchurch, New Zealand between September 2010 and June 2012. The first of these, the M_w 7.1 Darfield Earthquake, occurred on September 4, 2010 and caused significant structural and geotechnical damage, but no fatalities. Chartered engineers volunteered for postearthquake evaluation efforts, and nearly 8,000 buildings received rapid (Level 1) evaluations [16]. Selected buildings were later assessed with detailed (Level 2) evaluations. The most devastating earthquake of the sequence occurred on February 22, 2011 with a magnitude of $M_w = 6.2$, causing major structural and geotechnical damage and 182 deaths. A total of over 72,000 buildings were evaluated in the first 10 days and over 130,000 in the first 21 days [17]. Both Level 1 and Level 2 evaluations were conducted, with local and international volunteer and contract engineers as a resource.

Evaluation Methodology: The ATC-20 methodology was initially adopted for use in New Zealand in 1998 and then revised in 2004 and 2009 [18]. An unpublished 2010 draft [19] was in existence at the time of the Christchurch earthquakes, but it was generally not used [17]. The official document [18] utilized in the Christchurch earthquakes has a three-placard system similar to ATC-20 with two levels of evaluation, Level 1 and Level 2, equivalent to the ATC-20 Rapid and Detailed Evaluations, respectively. In addition, this methodology includes the assessment of usability categories during a Level 2 evaluation to provide more details on the structure condition and continued use of the building. Based on the experience from Christchurch, New Zealand later updated its procedures in 2014. These are in [20].

2.2 Chile (2010)

Earthquake Event: The February 27, 2010 M_w 8.8 Chile Earthquake caused major damage from both ground shaking and the subsequent tsunami over a widespread area of Chile, resulting in over 500 deaths, over 81,000 dwelling units destroyed and another 109,000 units with major damage, and between 50 to 100 multistory reinforced concrete building with severe damage [21]. There was extensive damage to adobe and unreinforced brick masonry bearing wall construction.

Evaluation Methodology: Postearthquake safety evaluation of buildings was carried out by a variety of groups, with inconsistent signage providing directions to potential occupants, highlighting the need for developing a standardized methodology and process for postearthquake safety evaluation, with clear responsibilities and public communications.

2.3 Napa, California (2014)

The following summary is taken from the discussion in [22].

Earthquake Event: The magnitude-6 South Napa earthquake occurred on August 24, 2014 and caused some structural damage and one fatality. Safety evaluations were typically conducted by local building department staff along with volunteers, mutual aid, and state personnel provided through Office of Emergency Services for the State of California (Cal OES). Hospitals were evaluated by structural engineers from the Office of Statewide Health Planning and Development (OSHPD), and local schools in Napa were evaluated by engineers and architects hired by the school district. Cal OES coordinates the process of providing safety assessment program evaluators trained in postearthquake safety evaluations and maintains a database of approximately 6,000 Safety Assessment Program (SAP) evaluators who have completed a training program based on ATC-20-1 and have registered as Disaster Service Worker.

Evaluation Methodology: Although all of the jurisdictions followed the general procedures of ATC-20-1, there were some differences among jurisdictions, and there were issues in how the safety placard system was used. Some buildings had multiple conflicting placards. Others buildings were posted with UNSAFE (red) or with RESTRICTED USE (yellow) placards that allowed access inconsistent the ATC-20-1 criteria and recommendations. Some cities posted internet advisories to the public on the meaning of the different placards that were also inconsistent with the ATC-20-1 definitions and intent.

2.4 Nepal (2015)

Earthquake Event: The M_w 7.8 Gorkha earthquake of April 25, 2015 and its aftershocks destroyed over half a million homes, killed over 8,700, and injured over 22,000 [23]. Per [24], nearly 60,000 postearthquake evaluations were conducted within six weeks of the earthquake by government agencies and volunteer organizations including the Nepal Engineers' Association and other NGOs. The placarding was done formally for government buildings with posted placards. For non-government buildings, a placard was typically not posted, but the evaluators discussed their findings and recommendations with the owner and tenants following the visit. In some communities, the results of the evaluation were communicated by colored dots spray-painted on the building façade.

Evaluation Methodology: Per [24], the Nepal had developed guidelines [25] prior to the earthquake that were adapted from [1], [2], and [10] with information specific to Nepal. The rapid evaluation methodology resulted in three colored placards, differing from the U.S. version only in the meaning of the yellow placard (entry is only by the owner, only for emergency purposes). The detailed evaluation methodology is substantially different from the ATC-20-1 detailed evaluation, and results in five "Damage Grades" and retrofit recommendations. The resulting document contains illustrative photographs of different damage grades.

3. Common Themes

3.1 Availability of Guidance Specific to the Local Context

Although some countries have developed their own postearthquake evaluation methodologies (e.g., New Zealand and Nepal), local guidelines are not available in every country with seismic hazard. Although a simple translation of the existing methodology developed for the U.S. context may seem efficient, in order to ensure successful implementation of a published methodology, it is important that guidance is developed with consideration of the local context. This can include both cultural and legislative context, as well as technical context that refers to the local building stock.

During the development of the *Bhutan Field Manual*, specific considerations were given to the usability of the document. The size of the *Bhutan Field Manual* was increased to contain more information and as allowed by the size of the pockets in the local clothing. The photos and illustrations in the document were carefully developed to allow reproduction in black and white, as necessary, without losing meaning. Based on cultural and legislative considerations, the guidance in the document was adjusted to be consistent with observed local risk tolerance, and the placards were not developed as mandatory for single-family residences due to input from the Bhutan Department of Engineering Services. A major component of adapting the ATC-20 methodology originally developed in the U.S. was understanding the differences in the building stock and developing new chapters that address building types that were not previously available. For example, ATC-20-1 contains a single chapter on unreinforced masonry, with a focus on brick bearing wall buildings. The *Bhutan Field Manual*, on the other hand, contains separate chapters on rammed earth, stone masonry, adobe, brick and concrete block masonry, and reinforced concrete frame buildings with masonry infill, as well as chapters on timber, bamboo, and plaster buildings. Development of these chapters involved collaboration with local engineers and field data collection. An example of key inspection points for rammed earth building in Bhutan is shown in Fig. 1.

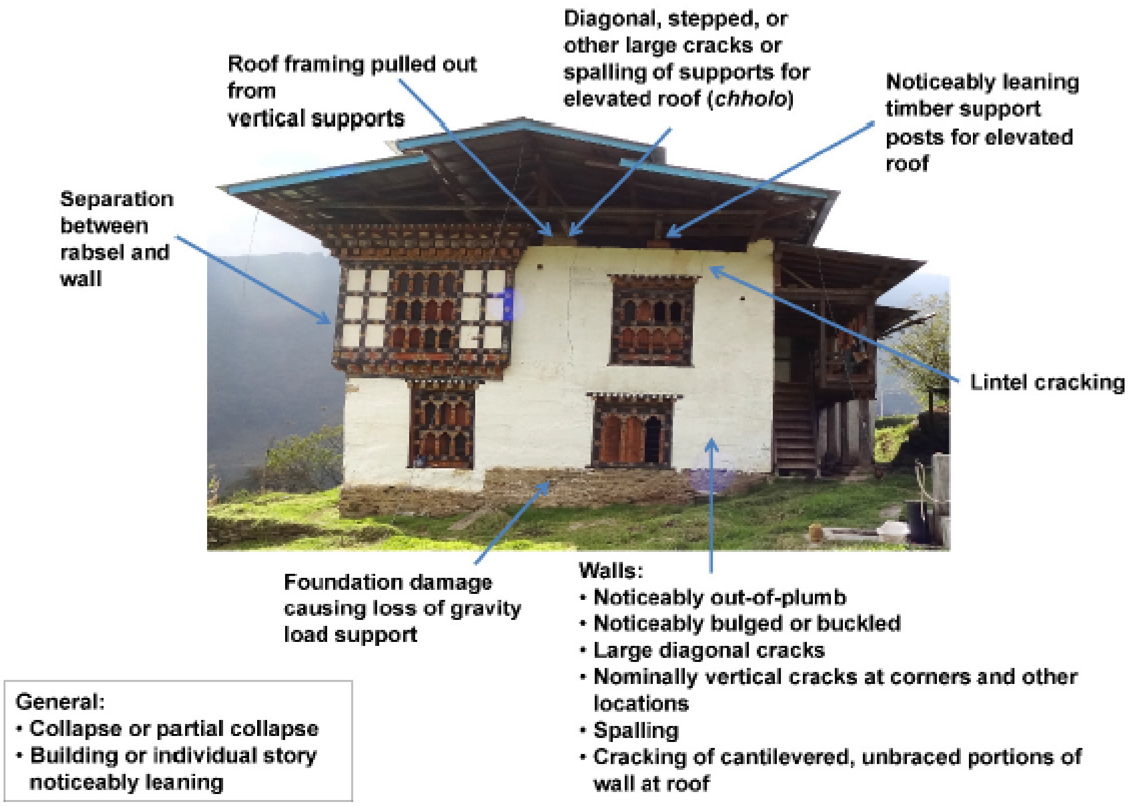

Figure 5-3 Photo showing a rammed earth building in undamaged state. Highlighted points indicate potential areas and types of damage that should be inspected during the evaluation. Interior conditions are not shown, such as floor framing pulled out from vertical supports, timber column (*kaw*) noticeably out-of-plumb, buckled, or failed, and failure or incipient failure of significant vertical-load-carrying element.

Fig. 1 – Overview of inspection points and principal safety concerns in Bhutan rammed earth [12]

3.2 Target Audiences and Format of Guidance

Postearthquake safety evaluation guideline documents have several potential target audiences. The primary audience is the evaluators who will follow the document in making evaluations. However, guideline documents will also be helpful to building officials, inspectors, and other government officials with jurisdiction over the building stock who will review safety evaluations and plans for repair and retrofit. These officials are typically responsible for managing and administering an evaluation program. It is also possible that there are owners and occupants who may have detailed interest in understanding the criteria and process used in evaluations. It is important that the guideline documents have appropriate information for all of these potential audiences and uses.

It is envisioned that evaluators receive postearthquake safety evaluation training that includes presentation of case studies with adequate visual guides. As a complement, the second edition of ATC-20-1 *Field Manual* was developed to contain only limited illustrations and photographs. However, it is observed that in order to ensure consistent and high quality evaluations, more visual guidance should be presented to the users of the

ATC-20-1 *Field Manual*. The *Bhutan Field Manual* was developed with this in mind, and example photographs with call-outs when necessary were provided for nearly all possible damage types. It is also important to note that not all damage cases on the field will be the worst case. Accordingly, the *Bhutan Field Manual* included illustrations of lower levels of damage and the resulting recommended posting category. A similar approach should be implemented for other updated guidelines.

3.3 Content of Guidance

3.3.1 Usability Categories and Shelter-in-Place Guidelines

The New Zealand guidelines [19 and 20] include "usability" categories to provide additional information beyond the basic posting category that is useful for both the building occupants and policy makers dealing with assessment and recovery. This information can be entered into a database for tracking, as well as to provide estimates of damage necessary for allocating resources for early recovery and reconstruction. These were added to the *Bhutan Field Manual* and are similar to [19]. They include the distinction made between stable and unstable red-tagged structures in [2]. Table 1 shows the categories used in [12].

Table 1 – Usability Category Definitions in the ATC-20-1 *Bhutan Field Manual* [12]

Damage Intensity	**Posting**	**Usability Category**
Light damage	INSPECTED (Green)	G1: Occupiable, no immediate further investigation required. G2: Occupiable, repairs may be necessary.
Moderate damage	RESTRICTED USE (Yellow)	Y1: Short-term entry. Y2: Repairs required for safe entry to damaged parts.
Heavy damage	UNSAFE (Red)	R1: Unsafe but stable. Repairs may be possible. R2: Unsafe and unstable. May not be repairable. R3: At risk from adjacent premises or ground failure.

As noted in [17], more formal guidelines need to be developed to allow shelter-in-place for those homes and residences safe to do so. This involves not only building structural and nonstructural safety, but includes concerns about public health, sanitary issues, and fire protection concerns. Can a toilet be used, or must portable toilets be brought in? Are the electrical and gas services safe to use? If shelter-in-place can be used, the number of public shelters needed can be lessened, perhaps substantially. An important distinction is the difference between structural safety and habitability. ATC-20 focuses on damage to the structure and life safety risks. Whether power, water, sewer, and communication services remain operational is not explicitly addressed, nor is whether the building can still be locked or otherwise secured against intruders. For residential placards, New Zealand's Earthquake Commission adopted a "3S" approach, meaning if a building was "Safe" per the structural evaluation, sanitary, and secure (lockable), then the residence was considered usable for shelter-in-place. Check boxes were added to the inspection forms to identify the sanitary and secure categories.

3.3.2 Guidance for Assessing Damage and Threats from Liquefaction, Landslides, and Rockfalls

Evaluation procedures and criteria for geotechnical hazards such as liquefaction, subsidence, landslides and rockfalls are limited in existing evaluation methodologies such as ATC-20-1. Liquefaction was severe and extensive in the Christchurch earthquakes and caused significant damage to buildings and infrastructure. [17] notes guidance is needed to address:

> *(1) when a building should be demolished because it cannot be economically repaired or strengthened; (2) when an area is unfit for future or rebuilt underground utilities; (3) how and when to re-level a house; and*

(4) recommended soil mitigation techniques to prevent or minimize differential settlements in the future (to avoid recurrence of liquefaction-induced damage).

Landslides and rockfalls occurred in the Port Hills area following the Christchurch earthquakes. Due to the steep terrain in Nepal, landslides and rockfalls are common occurrences even without earthquake shaking. The 2015 earthquakes only exacerbated the problem with significant pipeline damage, building damage, and loss of life. In one district alone, 32 villages had to be relocated. More detailed guidance is needed to determine safe distances from landslide and rockfall threats.

3.3.3 Guidance for Cordoning, Barricading, Shoring, and Emergency Stabilization

Additional guidelines should be developed on cordoning, barricading, shoring, and emergency building stabilization. ATC-20-1 has some guidelines on barricading, but only briefly mentions cordoning areas. Similarly, the whole topic of emergency building stabilization and shoring needs to be addressed in a document that can be used after an earthquake to draw on previous experience and successful practices. Because of the potentially severe impact of cordons on individuals and businesses, particularly prolonged closures, advice on this topic needs to be carefully developed [17].

3.3.4 Risk Tolerance, Conservatism, and the Economic Impact of Placarding

Postearthquake evaluation criteria are almost exclusively based on engineering judgment. The basic question is typically whether the building is at a significantly increased risk of damage in a similar sized aftershock. Since different engineers could reach different conclusions in looking at the same level and type of damage, a goal of postearthquake guidelines is to provide some consistency and clarity to the spectrum of risk. Observations of the approach taken in different earthquakes and different countries show that the level of acceptable risk can differ as well as the resulting evaluation conclusion. In the development of the *Bhutan Field Manual*, one of the concerns was not to create overly conservative criteria given that the primary building stock includes various forms of unreinforced masonry buildings that will usually have cracks and settlement before an earthquake occurs. In developed countries with greater resources for repair and reconstruction, there may be a tendency to place a more conservative rating on a damaged building than there would be in a developing country with less resources to house those displaced. It is important for guideline writers to acknowledge that judgment is involved and seek to find consensus among a large spectrum of knowledgeable stakeholders.

3.3.5 Aftershock Risk

Christchurch and Nepal suffered greatly from aftershocks, and there are lessons to be learned by the experience there. Relatively large aftershocks occurred that produced new significant damage and required re-inspections. ATC-20-1 provides guidance with “wait periods” before entry and “time limits” on the length of entry. These are from [14] and are based on aftershock research by the U.S. Geological Survey, primarily for California earthquakes. The guidance given should be updated for new information and research broadened for applications beyond California. Discussion of “foreshocks” should be included [17].

3.3.6 Residential vs. Non-Residential Evaluations

In Christchurch, different procedures evolved for residential buildings. The “yellow and green tags were replaced by a white leaflet informing owners to hire a structural engineer to do a more detailed inspection. The red tag was still utilized for structures deemed unsafe [16].” New Zealand’s updated guidelines [20] have separate inspection forms for residential and commercial construction. In the development of the *Bhutan Field Manual*, the Bhutan government decided to retain the typical approach of placards carrying mandatory status, except for single family residences where they were kept voluntary and special placards were created with different wording. Updates to future postearthquake safety guidelines will need to weigh the added complexity of multiple forms against the benefits of more directly addressing residential construction and associated political concerns.

3.3.7 Need for More Engineering Evaluation Methodologies

Engineering evaluation methodologies beyond the ATC-20 detailed level are needed. The U.S. has procedures for selected building types such as steel moment frame buildings or concrete buildings. Following the 2010-2011 earthquakes, New Zealand has developed more comprehensive procedures covering many building types [26].

3.3.8 Additional Structural Topics in Need of Clarification

With each earthquake and application of postearthquake methodologies, new items are found where additional advice and guidance is needed. In the 2010-2011 Christchurch earthquakes, horizontal cracks were observed in concrete shear wall buildings, and fractured vertical rebar was found. A better understanding of the cause and how to investigate and assess the damage are needed. Cavity wall construction was present in many unreinforced masonry buildings in Christchurch increasing the risk of wall damage. There were also significant failures of stairs and precast floor damage. Advice on how to assess cavity wall construction, stair-to-primary structure damage, and precast floor-to-concrete frame damage would be beneficial.

With the prevalence of reinforced concrete frame buildings infilled with masonry throughout the world, more detailed guidance would be valuable on assessing the various types of damage to the frame and infill would be beneficial. The *Bhutan Field Manual* included more detail than in ATC-20-1, but more examples and detail could be provided.

3.3.9 Advice on Use and Misuse of Forms

While postearthquake safety evaluation guidelines typically provide instruction on how to use evaluation forms and placards, they typically do not provide advice and warning regarding common mistakes or inappropriate practices. These usually occur with the RESTRICTED USE placard. Guideline updates should consider showing examples of inappropriate practices and/or provide warnings. Examples could include items such as (1) do not leave previous placards after a new one is posted, (2) do not post different placard categories at different building entrances, (3) do not use ink that cannot survive sunlight or rain, (4) do not change the wording on the recommended forms, and (5) do not forget to check the required boxes on the RESTRICTED USE placard.

3.4 Evaluator Qualifications and Training

Although it would be preferred to utilize experienced structural engineers for postearthquake safety evaluations, it has long been recognized that following a large event, there are simply not enough engineers available to meet the need. It is also thought that for many buildings undergoing rapid evaluations, a structural engineer is not necessarily required. What is critical is that the evaluator has an understanding of local building construction techniques and has been sufficiently trained in the evaluating earthquake damage. Proper training helps to establish context and clarity on the rationale and criteria underpinning the methodologies.

There was limited training of evaluators in Christchurch and Nepal. In the United States, a large number of volunteers are trained in the <u>rapid</u> evaluation methodology of ATC-20 in four- to six-hour long courses. They are not all structural engineers, but include other disciplines such as civil engineers, architects, building inspectors, and contractors. Following training they receive a card confirming their status and are entered into a database of available trained evaluators.

However, there is currently no training offered on conducting <u>detailed</u> evaluations. Detailed evaluations are more challenging and involve developing a deeper understanding of the structural system, critical elements in the load path, the behavior that occurred in the earthquake, and the level of severity of the damage that occurred. It is preferred that detailed evaluations be performed by structural engineers. Development of a consistent training course for detailed evaluations would provide a better-trained evaluator pool to handle the detailed evaluations that are needed. A similar program for geotechnical and specialists in liquefaction, subsidence, and landslide/slope stability issues is also desirable [17].

3.5 Communication of Evaluation Results

The red/yellow/green placarding systems is now the de-facto international standard in postearthquake safety evaluations. However, experience in recent earthquakes suggests that the public interprets the message of a green placard as "safe" rather than "inspected," thus setting up inappropriate expectations for the building's remaining seismic resistance capacity. The INSPECTED placard merely means the building is as viable and as safe as it was before the event, with no guarantee of future performance. Under any of the postearthquake safety methodologies being used, including ATC-20-1, as noted in [17]:

> *A building that is undamaged and posted INSPECTED after a small earthquake may suffered significant damage or even collapse in a subsequent event that subjects the building to additional and/or stronger ground motions....For instance, the Pyne Gould and CTV buildings had been posted as INSPECTED following the [distant September 2010] event, but both collapsed [following the much strong shaking of the February 2011 event], killing many occupants.*

Partly in response to this experience, the latest New Zealand guidelines [20] have changed the colors and titles on the placards (see Table 1). The remaining wording on the placard was also changed to provide more warnings and disclaimers.

Table 1 – Placard Changes in New Zealand

Placard Color/Title/Subtitle Used During 2010-11 Christchurch Earthquakes [17]	**2014 Placard Color/Title/Subtitle in [20]**
Green: INSPECTED: No restriction on use or occupancy	White: CAN BE USED: No restrictions on access
Yellow: RESTRICTED USE: No entry exceed on essential business	Yellow: RESTRICTED ACCESS: - To parts of the building or for - Short term entry only
Red: UNSAFE: Do not enter or occupy (This is not a demolition order)	Red: ENTRY PROHIBITED (This is not a demolition order)

While many are concerned with these changes, the changes underscore the importance and difficulty of communicating postearthquake safety issues to the public. After the 2014 Napa Earthquake, cities provided advisories to try to help clarify the meaning of the placards, but they were not consistent with the intent of the ATC-20-1 methodology. And as noted above, a leaflet was used to help inform homeowners regarding building evaluations in Christchurch. Improved language and guidance on communicating with the public are needed.

3.6 Postearthquake Safety Evaluation Program Management Issues

3.6.1 Guidelines for Management of Postearthquake Safety Evaluations

Once rapid ATC-20-1 focuses on the technical details of individual building evaluation. One of the consistent lessons in major earthquakes is the critical importance of implementing and managing an effective evaluation program for the affected area. Guidelines or resource documents are needed to summarize the advice, lessons, and different approaches that have been successful and those where issues arose. ATC-109 [17] provides a list of details and issues to consider primarily from U.S. experience and identifies the many successful practices in the 2010-2011 Christchurch earthquakes. Some general issues and recommendations are provided below.

3.6.2 Prioritization of Detailed Evaluations

Once rapid evaluations are complete, the program can and often does continue to undertake detailed evaluations for selected buildings. Currently, no guidance is provided in ATC-20 regarding the prioritization of detailed evaluations. After the 2011 New Zealand earthquake, the priorities were established for selecting buildings for detailed evaluations [16]. Low priority was given to building with Level 1 UNSAFE placards. Medium priority was assigned to buildings with Level 1 RESTRICTED USE placards. High priority was given to buildings where with a Level 1 INSPECTED placard that identified the need for a Level 2 inspection. The highest priority was assigned to buildings most likely to be used in recovery or that could result in reducing the extent of the cordoned area.

3.6.2 Quality Assurance Techniques

The third edition of FEMA P-154 [3], which focuses on evaluating buildings for seismic potential hazards before an earthquake, introduced the concept of a Supervising Engineer who should be a local practicing structural engineer with a background in seismic evaluation and risk assessments. The Supervising Engineer is available for screeners to consult with during field screening, reviews completed forms, and assists in interpreting the results of the program. A similar approach can be applied to safety evaluations after an earthquake to provide higher quality assurance and ensure more consistent evaluation results. The Supervising Engineer(s) can perform review of received evaluation forms and compare them with the placard status and photos of damage. They can periodically reinspect selected buildings. They can look for trends in the results coming from different evaluators and whether there are special issues that are common and need general guidance for all evaluators.

3.6.3: Private Engineer Posting and Building Occupancy Resumption Programs

One of the major challenges in conducting postearthquake safety evaluations is the availability of trained engineers. When the local cadre of volunteer engineers is not sufficient, it is typical to reach beyond local and national borders. In addition to engineers who are able to volunteer their services, there is also the capacity of private engineers who can provide evaluation services under contract to building owners. The utilization of this capacity was limited in response to the Christchurch earthquake, because private engineers did not have the authority to post the official placards, causing multiple postings on buildings. The City of San Francisco has a form of private engineer posting, developed as part of its Building Occupancy Resumption Program. Under this program, a pre-event inspection plan is developed for a building and approved by the City, and engineers to make the inspections are pre-qualified. At least one other California city has adopted this program.

3.6.4 Targeted Safety and Evaluation Teams

One of the most effective innovations in the 2010-2011 Christchurch earthquake response was the establishment of targeted safety and evaluation teams for specific sections of the city or issues in the community. The teams targeted shopping malls, suburbs, critical buildings, cordoning and access, and demolition. ATC-20 recommends conducting safety evaluations first for hospitals, police and fire stations, and emergency operations headquarters. Officials in Christchurch added grocery stores, hardware stores, and pharmacies to the list of high priority inspections. By initially focusing selected resources to pursue evaluations of targeted community elements, officials were able to move more rapidly to open up, or deem unsafe, entire segments of the community. This approach can have advantages over the block-by-block method used in other places [17].

3.6.5 Indicator Buildings

Significant aftershocks were a major issue in Christchurch and Nepal. As summarized in [12], one approach to help determine whether an aftershock has caused damage that warrants reinspections is through the use of indicator buildings. First implemented during the 2010-2011 series of earthquakes in Christchurch, the concept is to select a set of representative buildings in the affected area, such as a city. The local authority monitors these buildings and reinspects them following an aftershock. If the indicator buildings experience new damage in the aftershock, it is recommended that other similar buildings in the affected area be reinspected. If the indicator buildings do not experience new damage, the local authority would not reinspect similar buildings. This approach can help prevent unnecessary reinspections. Where resources are available, strong motion instruments can be deployed in the indicator buildings for comparison with response recorded in other areas.

3.6.6 Other Administrative Considerations

A number of other administrative suggestions can help improve the effectiveness of a postearthquake evaluation program. These include keeping digital records, periodically posting evaluation statistics and status and cordoning restrictions to the public, organizing supplies into backpack size units before the earthquake [16], having inspectors check in with program administrators periodically [16], and having search and rescues personnel serve as safety escorts in buildings with more severe damage [17]. [16] notes the value in having structural drawings where available, and [26] envisions a database of information from pre-earthquake evaluations to help with postearthquake evaluations. Obviously, some approaches will be more viable in certain events and in countries with more resources.

3.6.7 Legal and Policy Issues

Depending on the legal and social context of the country, it can be valuable to implement legislation or policies prior to earthquakes to make the postearthquake safety evaluation process more effective. For example, California has "Good Samaritan" laws to protect evaluators from liability. It may be necessary to have local ordinances or national laws formally authorizing the evaluation and placarding process and how it expires. This has not been a significant issue in the U.S., but it was in Christchurch.

4. Closure

Recent experiences with postearthquake safety evaluations in major earthquakes have shown that current evaluation methodologies can be effective tools in helping to understand the relative safety of damaged buildings, to prioritize recovery actions, and to improve community resilience. However, as the above discussion shows, there are many opportunities for improvement in developing updated guidance.

5. References

[1] Applied Technology Council (1989): *Procedures for Postearthquake Safety Evaluation of Buildings*. ATC-20 report. Redwood City, California.

[2] Applied Technology Council (2005): *Field Manual: Procedures for Postearthquake Safety Evaluation of Buildings, Second Edition*. ATC-20-1 report. Redwood City, California.

[3] Federal Emergency Management Agency (2015): *Rapid Visual Screening of Buildings for Potential Seismic Hazards, Third Edition.* FEMA P-154 report. Prepared by the Applied Technology Council for the Federal Emergency Management Agency (FEMA), Washington, D.C.

[4] American Society of Civil Engineers (2014): *Seismic Evaluation and Retrofit of Existing Buildings*. ASCE/SEI 41-13 report. Reston, Virginia.

[5] Federal Emergency Management Agency (2012): *Seismic Evaluation and Retrofit of Multi-Unit Wood-Frame Buildings with Weak First Stories.* FEMA P-807 report. Prepared by the Applied Technology Council for the Federal Emergency Management Agency (FEMA), Washington, D.C.

[6] Federal Emergency Management Agency (2012): *Seismic Performance Assessment of Buildings, Volume 1 – The Methodology.* FEMA P-58 report. Prepared by the Applied Technology Council for the Federal Emergency Management Agency (FEMA), Washington, D.C.

[7] Federal Emergency Management Agency (2009): *Multi-Hazard Loss Estimation Methodology, Earthquake Model, HAZUS-MH MR4 Technical Manual.* Washington, D.C.

[8] Federal Emergency Management Agency (2000): *Recommended Postearthquake Evaluation and Repair Criteria for Welded Steel Moment-Frame Buildings.* FEMA 352 report. Prepared by the Structural Engineers Association of California, the Applied Technology Council, and the Consortium for Research in Earthquake Engineering for the Federal Emergency Management Agency (FEMA), Washington, D.C., USA.

[9] Applied Technology Council (2010): *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Post-Earthquake Repair and Retrofit Requirements*. ATC-52-4 report. Redwood City, California.

[10] Federal Emergency Management Agency (1998): *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings*. FEMA 306 report. Prepared by the Applied Technology Council for the Federal Emergency Management Agency (FEMA), Washington, D.C.

[11] Applied Technology Council (1995): *Addendum to the ATC-20 Postearthquake Safety Evaluation of Buildings*. ATC-20-2 report. Redwood City, California.

[12] Applied Technology Council, (2014): *ATC-20-1 Bhutan, Field Manual: Postearthquake Safety Evaluation of Buildings*. Prepared for Royal Government of Bhutan by the Applied Technology Council in a partnership with Geohazards International, and the Bhutan Department of Engineering Services and Department of Disaster Management of Redwood City, California.

[13] Applied Technology Council (2002): *Postearthquake Safety Evaluation of Buildings Training CD*. ATC-20-T. Training presentation of 230 slides. Redwood City, California.

[14] Applied Technology Council (1999): *Earthquake Aftershocks—Entering Damaged Buildings*. ATC Techbrief 2 report. Redwood City, California.

[15] Applied Technology Council (1996): *Case Studies in Rapid Postearthquake Safety Evaluation of Buildings*. ATC-20-3 report. Redwood City, California.

[16] Marshall JD, Jaiswal K, Gould N, Turner F, Lizundia B, Barnes JC, (2013): Post-Earthquake Building Safety Inspection: Lessons from the Canterbury, New Zealand, Earthquakes. *Earthquake Spectra*, Volume 29, No. 3, 1091-1107, August.

[17] Applied Technology Council (2014): *Building Safety Evaluation after the February 22, 2011 Christchurch, New Zealand Earthquake: Observations by the ATC Reconnaissance Team*. ATC-109 report. Redwood City, California.

[18] New Zealand Society for Earthquake Engineering, (2009): *Building Safety Evaluation During a State of Emergency*, Wellington, New Zealand.

[19] New Zealand Society for Earthquake Engineering, (2010): *Building Safety Evaluation During a State of Emergency*, Guidelines for Territorial Authorities. Draft updated version as of 14 July 2010, Wellington, New Zealand.

[20] Ministry of Business, Innovation and Employment (MBIE) (2014): *Field Guide: Rapid Post Disaster Building Usability Assessment – Earthquakes*, Wellington, New Zealand, May.

[21] Moehle JP, Frost JD (2012): Preface to 2010 Maule, Chile Earthquake Special Issues. *Earthquake Spectra*, Volume 28, No. S1, vii-viii, June.

[22] Federal Emergency Management Agency (2015): *Performance Assessment of Buildings and Nonstructural Components in the 2014 South Napa Earthquake.* FEMA P-1024 report. Prepared by the Applied Technology Council for the Federal Emergency Management Agency (FEMA), Washington, D.C.

[23] National Planning Commission (2015): *Nepal Earthquake 2015: Post Disaster Needs Assessment, Executive Summary*. Government of Nepal, Kathmandu, Nepal, available at http://www.npc.gov.np/en/download/major_reports (revision July 30, 2015).

[24] Lizundia, et al. (2016): *EERI Earthquake Reconnaissance Team Report: M7.8 Gorhka, Nepal Earthquake on April 25, 2015 and its Aftershocks*, May, Earthquake Engineering Research Institute: Oakland, California, available at: https://www.eeri.org.

[25] National Society for Earthquake Technology (NSET) and Department of Urban Development and Building Construction (DUDBC) (2009): *Seismic Vulnerability Evaluation Guideline for Private and Public Buildings, Part II: Post Disaster Damage Assessment*, Kathmandu, Nepal.

[26] Galloway B, Hare J, Brunsdon D, Wood P, Lizundia B, Stannard M (2014): Lessons from the Post-Earthquake Evaluation of Damaged Buildings in Christchurch. *Earthquake Spectra*, Volume 30, No. 1, 451-474, February.