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POSTEARTHQUAKE SAFETY EVALUATION PROCEDURES FOR BHUTAN BUILDINGS

J. E. Rodgers[1], B. J. Lizundia [2], S. Yangdhen [3], Y. Lotay [4], A. Hortaçsu [5] and K. D. Tshering[6]

ABSTRACT

Bhutan, a small Himalayan nation, suffered two moderate earthquakes, in 2009 and 2011, and in the aftermath local engineers had no standard by which to judge the safety of damaged buildings. GeoHazards International and the Applied Technology Council formed a unique partnership with the Royal Government of Bhutan's Department of Engineering Services and Department of Disaster Management to provide Bhutan-specific postearthquake evaluation guidance and meet this need. The project team adapted the guidance in the ATC-20 family of documents, primarily the most recently revised document, ATC-20-1 Field Manual: *Postearthquake Safety Evaluation of Buildings*, Second Edition. Adaptations account for Bhutan's vernacular buildings–including types not covered in the US version of ATC-20 such as rammed earth and bamboo–as well as Bhutan's cultural and governmental context. The Bhutan field manual describing these procedures utilizes a new, graphical format with numerous images to help engineers evaluate damaged buildings more accurately. The procedures incorporate recent lessons from Chile and New Zealand, as well as advances since the ATC-20-1 Second Edition was published. In addition to providing Bhutan's engineers with consistent guidance for safety evaluations, when complete the procedures will provide a vehicle for collecting damage data necessary for reconstruction planning and serve as a model for adapting ATC-20 elsewhere.

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Background

Bhutan is a small Himalayan nation exposed to significant earthquake hazard due to its location in the tectonic collision zone between the Indian and Eurasian plates, as Figure 1 shows. In 2009, Bhutan experienced its first damaging earthquake in a number of years–ending a period of relative seismic quiescence–when a M6.1 event struck Mongar district in eastern Bhutan. This moderately sized local earthquake caused what appear to have been moderate levels of shaking,

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though there are no strong motion records to determine actual shaking in the most heavily affected areas. Both vernacular and public stone masonry buildings in several districts suffered heavy damage, and a number of buildings, including school buildings and a health clinic (called a Basic Health Unit; Bhutan also has smaller Out-Reach Clinics) collapsed [1]. At the time of the earthquake, Bhutan's engineers had no damage or safety assessment procedures, and conducted initial damage assessments using the European Macroseismic Scale damage grade definitions [2]. The inspections carried out by government engineers for most buildings did not include a determination of the safety of the building, though the School Planning and Building Division (SPBD) did assign a "risk factor" of low, medium or high to damaged school buildings based primarily on observed earthquake damage (personal communication, Karma Sonam, 2012).

In 2011, western Bhutan was shaken by the M6.9 Sikkim-Nepal border earthquake, centered approximately 100 kilometers from Bhutan's western border. In the western districts, rammed earth buildings are the most common type of vernacular construction. These buildings experienced unexpectedly severe damage, including several dramatic collapses [3,4] despite shaking that appears to have been generally light. Following the earthquake, engineers still had no guidance on safety of damaged buildings, though damage assessment procedures had been improved. Engineers relied on individual judgment to give occupants advice on whether buildings were "not fit to live" in, with mixed results. At one damaged building several of the authors visited, the inspector had classified major, stability-threatening damage as moderate. Fortunately, the occupants had the good sense to move out after feeling the building sway back and forth as they moved about the top story.

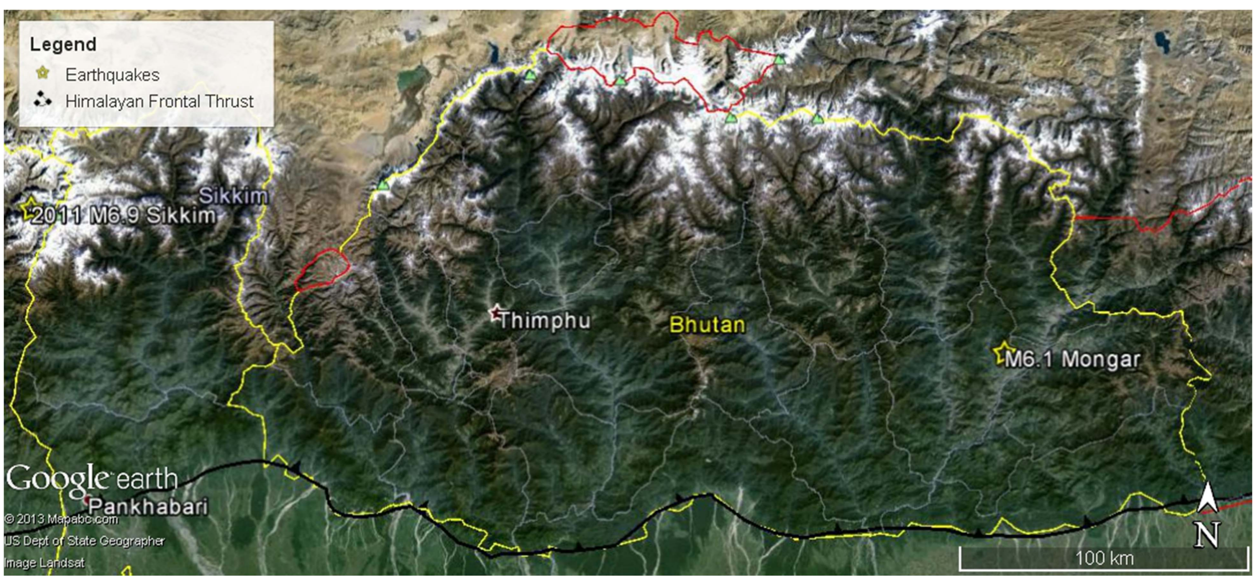

Figure 1. Bhutan's geographic location and the location of the 2009 and 2011 earthquakes

The damage resulting from the 2009 earthquake caused great concern within the government and the engineering community, causing Bhutan to begin focused efforts to improve earthquake safety on a number of fronts, including devoting more human resources toward earth science and earthquake engineering, including hazard and vulnerability assessment, awareness-raising, design improvements and increased readiness for the next earthquake, including development of postearthquake damage assessment procedures. The 2011 earthquake reinforced government concerns about the vulnerability of the building stock in future earthquakes, and spurred action by international donors to reduce the risk and improve readiness. As part of this larger effort, GeoHazards International (GHI) began supporting the Department of Disaster Management (DDM) and Department of Engineering Services (DES) through a series of activities designed to provide technical resources and capacity building for pre-earthquake building vulnerability assessment and post-earthquake damage and safety assessment, as well seismic hazard assessment. After it became clear that post-earthquake safety evaluation procedures were a significant need, GHI initiated a partnership with the Applied Technology Council (ATC), the creators of *ATC-20: Postearthquake Safety Evaluation of Buildings* [5], to develop procedures appropriate to Bhutan's specific needs and context.

Bhutan Building Types

Bhutan's vernacular architecture is considered a national cultural treasure. Vernacular building types include rammed earth, rubble and semi-dressed stone masonry, ekra (also known as ikra or Assam-type, a lightweight timber frame construction with plastered woven bamboo and reed wall panels), timber and bamboo. Though beautiful, many building types have seismic vulnerabilities caused by tall walls, elevated roofs and large windows. Other key deficiencies in vernacular buildings include a lack of positive diaphragm-to-wall ties and inadequate wall continuity at corners. Rammed earth, adobe and vernacular stone masonry walls (the latter often built with mud mortar) are generally unreinforced and have low shear strength. Based on damage observed following the 2009 and 2011 earthquakes, significant damage is expected in strong shaking, especially in rammed earth and rubble stone buildings. Figure 2 shows damaged vernacular buildings.

Figure 2. Vernacular stone masonry (left) and rammed earth (right) buildings showing types of damage many such buildings suffered in the 2009 and 2011 earthquakes, respectively. (Photo credits Department of Disaster Management, GeoHazards International)

Bhutan's cities are also expected to experience significant damage in a major earthquake. The capital Thimphu in particular has large numbers of recently built reinforced concrete buildings with unreinforced masonry infill walls and unreinforced, unanchored brick façade elements used in the upper stories to mimic traditional architectural elements. While most concrete buildings are constructed to India's seismic design codes (which Bhutan's building code incorporates by reference), damage to columns is expected in open ground stories and other locations where stairs or infill walls adversely affect their response. Brick infill walls and façade elements are likely to cause significant falling hazards during and after a strong earthquake. Larger cities such as Thimphu and Phuentsholing, the main border city with India, have a number of older reinforced concrete buildings constructed before Bhutan adopted earthquake-resistant design codes in 1997. While some of these buildings may have been built to Indian seismic design standards, those constructed prior to 1993, when India introduced special seismic detailing requirements for reinforced concrete frames, are expected to experience earthquake damage similar to that observed in non-ductile concrete frame buildings elsewhere. Figure 3 shows examples of both older and newer concrete buildings.

Figure 3. Older reinforced concrete buildings in Phuentsholing (top); new reinforced concrete frame buildings in Thimphu (bottom); (Photo credits Janise Rodgers, GeoHazards International).

Approach to Developing Bhutan-specific Safety Evaluation Procedures

At the beginning of the document development process, GHI, ATC, DES and DDM determined that it would be better to adapt the existing ATC-20 procedures to Bhutan conditions rather than to start completely afresh. While Bhutan has several unique building types and a specific governmental and cultural context, the underlying technical basis for evaluating the safety of damaged buildings remains the same, and many postearthquake safety evaluation issues and needs are common across geographic and cultural contexts. These include government and professional responsibility for public safety, the need for consistent evaluations and clear communication with building owners, the need for trained evaluators to provide the necessary consistency, a limited number of available evaluators in affected jurisdictions, and the need to protect evaluators from liability claims and keep them safe in the field.

GHI, ATC and DES formed a project engineering panel of Bhutanese and US engineers to guide the adaptation of ATC-20 procedures. Bhutanese panel members represent the numerous government agencies responsible for most post-earthquake evaluations and assessments, including DDM, which leads post-earthquake response and coordinates assessments; DES, the main government engineering agency; municipalities and district administrations; and government agencies responsible for specific types of buildings, such as the Department of Culture (heritage buildings), Health Infrastructure Development Division (hospitals and clinics) and School Planning and Building Division (schools). Bhutan’s government is democratic but much more centralized than in India or the United States. Bhutan has a limited number of private consulting engineers, who are not organized in professional associations, so the pool of potential assessors is smaller than in many other places.

The panel met electronically via videoconference and Skype® video, as well as in person. The Bhutan members and the US members also met separately in person to work out specific technical and policy-related issues in advance of meetings of the full panel. Bhutan project engineering panel members have experience in damage assessment after the recent earthquakes, Bhutan’s disaster management systems, design and construction practices for vernacular and engineered buildings, and regional variations in buildings. The US panel members are experienced engineers who have all spent significant time in the field in Bhutan, and are familiar with the building stock. This on-ground experience is critical for a technically sound and locally credible adaptation. US panel members also have both US and international experience in postearthquake safety assessment, and are able to share lessons learned elsewhere. US panel members visited numerous buildings in western Bhutan damaged by the 2011 earthquake; most of the 2009 damage had been repaired by the time the project started.

A small writing team from ATC and GHI was responsible for synthesizing all the technical and policy input from the project engineering panel and producing a draft document for the panel’s review. The writing team had access to numerous local sources of information, including many photographs of damaged buildings, damage assessment reports, and papers on typical construction and earthquake vulnerabilities. The writing team also spent significant time in the field viewing earthquake-damaged buildings and typical construction, with members visiting eastern, western, central, and southwestern Bhutan.

Key Adaptations and Changes to the US Version of ATC-20

To aid safety evaluators in the field, the team decided to prepare a field manual, using the most recent document in the US ATC-20 family of documents, ATC-20-1: *Field manual: postearthquake safety evaluation of buildings*, Second Edition [6], as a starting point. The team is also preparing a short accompanying document that describes the adaptation process and the rationale for important technical and policy decisions. Key adaptations included substantial changes to the building types covered; a new more graphical format for detailed evaluations that directly relates damage images to specific safety concerns and provides quantitative criteria; additional descriptions of crack types and damage mechanisms; expanded examples; revised forms and placards; and revised introductory material appropriate to the Bhutan context. The project engineering panel retained many core ATC-20 concepts, including Safe, Restricted Use and Inspected as the three posting categories; the red-yellow-green placarding scheme; placards that only indicate a change in the building's ability to resist an aftershock producing site shaking as strong as the main shock rather than ability to resist future larger events; rapid and detailed evaluations; and allowing only qualified and trained building professionals to evaluate buildings.

Each vernacular building type required development of a new chapter in the document. For example, the US version of ATC-20 has a single chapter for all masonry buildings. Bhutan has a great variety of earthen and masonry buildings, including rammed earth, adobe, and several types of stone masonry, which represent the majority of the building stock. Bhutan also has several vernacular timber-based systems that merit their own chapters. The project engineering panel also decided to omit a number of building types in the US version of ATC-20 that are not present in Bhutan, including steel, precast / prestressed concrete, tilt-ups and mobile homes. In Bhutan, steel is only used for large industrial facilities that are outside the scope of the document.

The new more graphical format of presenting damage information in the detailed evaluation chapters is intended to help engineers provide more accurate and consistent evaluations. Table 1 shows an excerpt of the new format, for selected damage to walls in rammed earth buildings. Each chapter contains an extensive table that presents damage information for the overall building, roof and floor framing, columns, walls, diaphragms, foundations and other hazards. In addition to images of most unsafe conditions, the new format also provides images showing damage that would result in an Inspected posting, to help prevent overly conservative postings. The table provides images demonstrating use of the Restricted Use posting for portions of the building where falling hazards create safety concerns. Rammed earth buildings in particular can suffer impressive looking cracks that do not create the safety risks that would trigger an Unsafe posting.

The table and added text in each chapter provide evaluators with guidance on interpreting the safety implications of different types of damage, particularly crack types and sizes in masonry buildings. The table includes quantitative criteria for certain types of damage to help evaluators determine the appropriate posting.

Table 1. Excerpt of part of wall damage section of rammed earth condition table showing new, more graphical format for detailed evaluations

Condition and Posting	**Illustration**
Rammed Earth Walls	
Nominally Vertical Cracks at Corners Post UNSAFE when cracks go through the wall.	 Photo credit: Melvyn Green, MGA
Vertical Cracks in Other Locations Post UNSAFE when there are a several cracks along the wall line and there is significant spalling associated with the crack.	
Post RESTRICTED USE when cracks go through the spandrel, but the pier or wall remains largely intact.	
Post INSPECTED if cracks do not go completely through a wall and do not have out-of-plane offsets along the crack.	

To help engineers apply the evaluation procedures, the document authors expanded the examples to cover more scenarios that evaluators are likely to encounter in the field. The team also rewrote and revised a great deal of text in field manual to account for Bhutan's customs and conditions.

Conclusions

With the newly developed postearthquake evaluation procedures, Bhutanese engineers will be much better equipped to consistently determine building safety after an earthquake, and to communicate that information to building owners and occupants. The process of adapting postearthquake safety assessment guidance to a different geographic, governmental and cultural context serves as a model for similar efforts in countries that would like to build on existing resources to develop their own postearthquake safety evaluation guidance. The pairing of local engineers knowledgeable about local buildings and local earthquake damage with engineers experienced in postearthquake safety evaluation and guidance document development was essential to developing a robust guidance document. The project team anticipates that the field manual, though specific to Bhutan, will provide an excellent starting point for developing guidance in areas with similar building types, and portions may be directly applicable in other areas with the same building types.

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