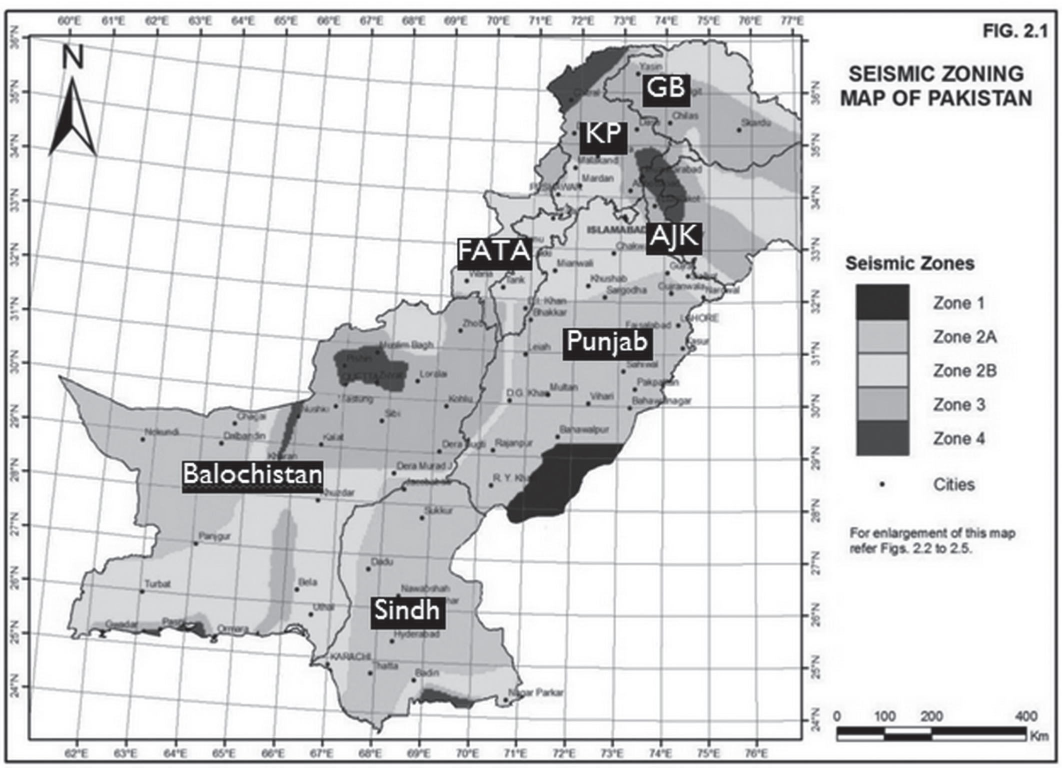
Seismic Vulnerability Assessment of Pakistan Unreinforced Masonry Buildings at a National Scale

Hamid Mahmood and Jason M. Ingham
University of Auckland, New Zealand

Online material: Seven tables showing a comparison of unreinforced masonry (URM) buildings in Pakistan and New Zealand; and results of seismic vulnerability assessment of Pakistan's URM buildings using three assessment methods.

INTRODUCTION

Seismic activity in Pakistan has generally been concentrated in the northern part of the country, the northern and southwestern parts of Balochistan Province, and the coastal areas of Sindh Province, as reflected in the Pakistan seismic zoning map (Figure 1). In the last one hundred years alone, the country has experienced the M 7.5 1935 Quetta earthquake (30,000 fatalities), M 8.0 1945 Makran Coast earthquake (4,000 fatalities), M 6.2 1974 northern Pakistan earthquake (5,300 fatalities), and M 7.6 2005 Pakistan earthquake (86,000 fatalities) (U.S. Geological Survey historic worldwide earthquakes, http://earthquake.usgs.gov/regional/world/historical_country.php#pakistan). Pakistan unreinforced masonry (URM) buildings suffered extensive damage in the 2005 Pakistan earthquake (Rossetto and Peiris 2009) and other historical earthquakes; however, URM construction continues to be prevalent in Pakistan primarily due to the availability of raw materials and the continued use of traditional construction practices. Pakistan has experienced high human and economic losses in previous earthquakes, and similar or even worse statistics can be



▲ **Figure 1.** Seismic zoning map of Pakistan (reproduced from MHW 2007; however, province names were added). KP = Khyber Pakhtunkhwa; FATA = Federally Administered Tribal Areas; AJK = State of Azad Jammu and Kashmir; GB = Gilgit-Baltistan.

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expected in future earthquakes, in part due to the existence of a potentially vulnerable URM building stock, the seismic vulnerability of which must be assessed to minimize future losses.

Seismic vulnerability assessment of existing buildings can be performed by identifying at-risk buildings in a locality by using rapid screening methods and then by conducting detailed seismic investigations of the identified buildings. However, this procedure can be cumbersome and time consuming when considering a large number of buildings. As a total of 19.2 million housing units (PCO 1998b) existed in Pakistan in 1998, the use of an efficient method to estimate the number of seismically at-risk buildings within the country is needed. Representative building typologies facilitate an understanding of seismic vulnerability at a national scale; therefore properties and representative building typologies of Pakistan URM buildings are presented here. Rapid seismic evaluation methods are applied on the presented typologies to identify at-risk buildings. Typologies have been used elsewhere in world for conducting seismic vulnerability assessment of buildings (Binda and Saisi 2005; Korkmaz *et al.* 2010; Lutman 2010; Nollet *et al.* 2005), but previous Pakistan URM building characterization studies (Ahmad *et al.* 2010; Ali 2006; Ali and Muhammad 2007; Mumtaz *et al.* 2008) have focused only on certain parts of the Khyber Pakhtunkhwa (KP) and the state of Azad Jammu and Kashmir (AJK).

Little work to assess the seismic vulnerability of Pakistan buildings has been reported. Ali and Naeem (2007) conducted a dynamic field test on a single-story single-room URM structure to understand the seismic vulnerability of URM buildings in Peshawar (KP). Ahmad *et al.* (2010) adopted a nonlinear displacement-based approach to conduct earthquake loss esti-mation of URM buildings in Mansehra (KP) and predicted significant economic losses (collapse of 12–33% of houses) and human losses (injuries and deaths of 7–17% of the population). Maqsood and Schwarz (2008a) presented typical Pakistan buildings and assigned each type a vulnerability class. For each administrative unit of Pakistan, they reported a mean vul-nerability index (MVI), which was calculated by assigning a number (1– 6) to a building type. They extended their work (Maqsood and Schwarz 2008b) to report vulnerability classes for additional building types and modified vulnerability classes for the building types that were included in their earlier work. The results, presented in the form of mean damage grades for Muzaffarabad (AJK), did not compare well with the observed damage. Results of macro level vulnerability assessment of the region affected by the 2005 Pakistan earthquake region were reported (Maqsood and Schwarz 2010b) by considering two scenarios: 1) just before the 2005 earthquake; and 2) at the time of the publication of their paper, including buildings that were reconstructed after the earthquake.

Most of the existing Pakistan research is limited in scope and focused on specific regions. Also, the previously conducted assessments were not comprehensive, as no or very few struc-tural forms were considered and only one assessment method was employed in each work. More work involving a compre-hensive set of building typologies and different assessment techniques for comparison is thus required.

TYPOLOGIES OF PAKISTAN UNREINFORCED MASONRY BUILDINGS

A general description of Pakistan URM buildings and their typologies is presented here. As of 1998, 58.5% (46% rural, 85.8% urban) of Pakistan housing units had either fired-clay brick masonry, concrete block masonry, or stone masonry outer walls, and 34.5% (44.7% rural, 12.2% urban) had either unbaked (sun-dried) brick masonry or earth bound outer walls (PCO 1998c). In the absence of detailed data for the 34.5% earth-bound buildings, it is not possible to accurately determine the proportion of adobe (URM) buildings and rammed earth (non-URM) buildings, and hence the mid-point value is adopted, resulting in the estimate that approximately 75% of all Pakistan buildings are constructed of URM. This figure does not include commercial and mixed use buildings, which are estimated to be 5% of the number of housing units. With these assumptions and an assumed increase in the number of housing units proportional to the increase in population since 1998 (the estimated current population of Pakistan is 177 million [PCO 2011], which is approximately 35% higher than the 1998 population of 132 million [PCO 1998a]), the total number of URM buildings is conservatively estimated to be 19 million. One to two story high URM buildings with 230-mm-thick fired-clay solid brick walls are usually employed in urban parts of Pakistan except Karachi (Ali 2006), where concrete block buildings are prevalent. Concrete blocks are available in a range of sizes and may be either solid or hollow, and are popular due to the convenient availability of raw materials and low wall footprint to floor area ratio in parts of Pakistan where clay bricks are not locally manufactured. Adobe buildings are common in rural areas of Pakistan, especially in Balochistan Province and in the Federally Administered Tribal Areas (FATA) (Maqsood and Schwarz 2008a, 2010a). In mountainous regions of Pakistan, stone has always been the dominant masonry unit due to its ready availability. Stones may be undressed, semi-dressed, or dressed to achieve a smooth surface, and often only facing stones on exterior walls are dressed. Stone walls often consist of a number of wythes and are thicker than walls in modern urban buildings; a wall thickness of 300–450 mm has been reported in the literature (Ali and Muhammad 2007).

Mortar can be either a cement, sand, or local admixture mix, or composed of mud, clay, or lime. Most modern buildings employ cement-based mortar, which consists primarily of one part cement and four to eight parts sand (Ali and Naeem 2007; Maqsood and Schwarz 2008a) and may contain locally available materials for improvement of mortar properties and reduction of cost. Mud or cement mortar is generally used to bond stones (Ali and Muhammad 2007), and in some cases no mortar is used at all, and wall cavities are filled with rubble to achieve an approximately level surface.

Approximately 45% of urban buildings have concrete roofs and floors (PCO 1998c). Many new buildings have reinforced concrete (RC) roofs and floors, and a common variation of RC is the so-called reinforced brick concrete (RBC) construction, where a large chunk of concrete within a grid of steel

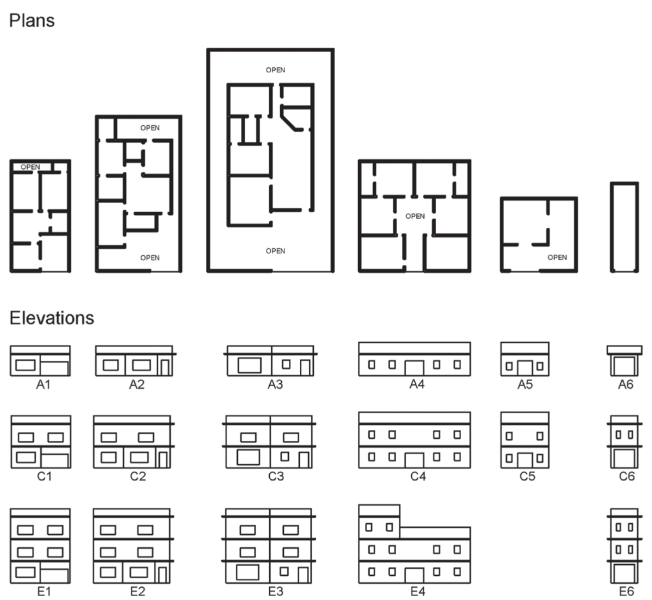
TABLE 1 Typologies and variations of Pakistan URM buildings.			
Typologies			
Typology	**Description**		
A	Single-story isolated building		
B	Single-story row building		
C	Two-story isolated building		
D	Two-story row building		
E	Three-story or higher isolated building		
F	Three-story or higher row building		
G	Any building not falling in the above categories		
Variations of each typology			
Variation Number	**Title of variation**	**Area (m^2)**	**Description**
1	A1, B1, C1, D1, E1, F1	<150	Small residential building
2	A2, B2, C2, D2, E2, F2	150–300	Medium residential building
3	A3, B3, C3, D3, E3, F3	>300	Large residential building
4	A4, B4, C4, D4, E4, F4	–	Village or small town residential building
5	A5, B5, C5, D5	–	Village residential building (no such typology E & F buildings)
6	A6, B6, C6, D6, E6, F6	–	Commercial or commercial-residential buildings

reinforcing bars is replaced with cheaper fired-clay bricks. In smaller towns, steel girder floors are common, where bricks are placed over inverted-T beams, which, in turn, rest on steel girders. Steel girders are replaced with wood beams where wood is easily available; this is especially the case in hilly areas, where wood/steel trusses are also used in roofs, and thin corrugated galvanized iron (CGI) or "cement sheets" are employed as a roof covering (Javed *et al.* 2006). Cement sheets were intro-duced in Pakistan in the early 1950s and are manufactured by a mechanical process involving asbestos fiber and cement slurry (Jehan 2004).

Adequate stiffness and integrity of roofs and floors is essential for a uniform distribution of inertia on walls (IAEE:NICEE 2005). RC and RBC roofs and floors, which are usually cast in situ over the walls, typically have a sound floor-wall connection. Sufficient bond quality can also be achieved with cement sheets if strong mortar is used at the floor-wall interface. Unfortunately, the floor-wall connection is frequently compromised in Pakistan URM buildings due to inadequate construction supervision and the use of poor construction materials. Steel and wood girder floors and trusses are seated directly on their support walls without the provision of any special seismic connection. Walls with a weak floor-wall connection could easily lose lateral support if the lateral seismic force exceeds the frictional force between the roof or floor and the wall.

Pakistan URM buildings are characterized here into seven general typologies (Table 1) for their seismic assessment at a national scale. The typologies closely imitate New Zealand typologies (Russell and Ingham 2010), and distinction has been made on the basis of number of stories and whether a building is isolated or a component of a row of similar buildings. Further distinctions have been made for each typology, except for typology G, on the basis of building area, layout of rooms, and building use. Ground floor plans and front elevations for the typologies and their variations are shown in Figures 2–3. The building dimensions are intentionally not provided to emphasize the variations within each typology; however, a range of building footprint areas is provided in Table 1 and all figures are drawn to scale. Pakistan URM buildings are generally rectangular with a plan aspect ratio of 1:1.5 (length parallel to the road:length perpendicular to the road). Stairwells are mostly present in buildings taller than one story, but are omitted here for simplicity.

Typology A buildings are isolated, one-story structures that are more common in newly developed residential areas, or in hilly areas where uneven terrain makes row construction of buildings difficult. Typology A buildings are subdivided into variations A1–A5 (residential) and A6 (commercial). Variation A1 buildings are small residential buildings. The exterior walls in these buildings serve as boundary and external load bearing walls, and the front walls have openings for doors and windows. A parapet of constant height is usually provided around the perimeter of the covered area. Variation A2 buildings (Figure 4A) are medium-sized residential buildings, with a central covered area enclosed by a continuous load-bearing wall, but only a part of the boundary wall is load-bearing. The central covered area in variation A3 residential buildings is completely separated from the perimeter boundary wall. Variation A4 and A5 buildings are village or small town single-story residential buildings. Parapet heights are generally in excess of one meter to meet the greater privacy requirement in conservative village



▲ **Figure 2.** Representative ground floor plans and front elevations for the variations of typology A, C, and E buildings (non-load-bearing boundary walls, stairs and stairwells not shown for simplicity).

societies. Variation A5 buildings are basic village houses with only a small part of their area used for residential purposes. There is typically only one room in the house. Variation A6 buildings (Figure 4B) have an open front to allow greater access into the building, which is a requirement of the commercial nature of the building. The ratio of side width to front length is generally much greater than 1.0.

Typology B buildings are single-story structures arranged in a row. Each row of buildings can contain two to 15 houses. Two independent (but connected) parallel walls are provided at the junction of two buildings within a row. Typology B structures are primarily residential, but commercial buildings can be found. Each building within a row can be different in layout and building height. Variations B1, B4, and B6 of typology B buildings all have component buildings connected to each other throughout along both sides (see Figure 4C). Variation B2 buildings can be considered row buildings with only two component buildings. The covered area of the component buildings in a variation B3 building is not attached to the other buildings within the row. Group typology B buildings (not shown for brevity) are made up of two parallel typology B buildings with common back walls, and are prevalent in urban parts of Pakistan.

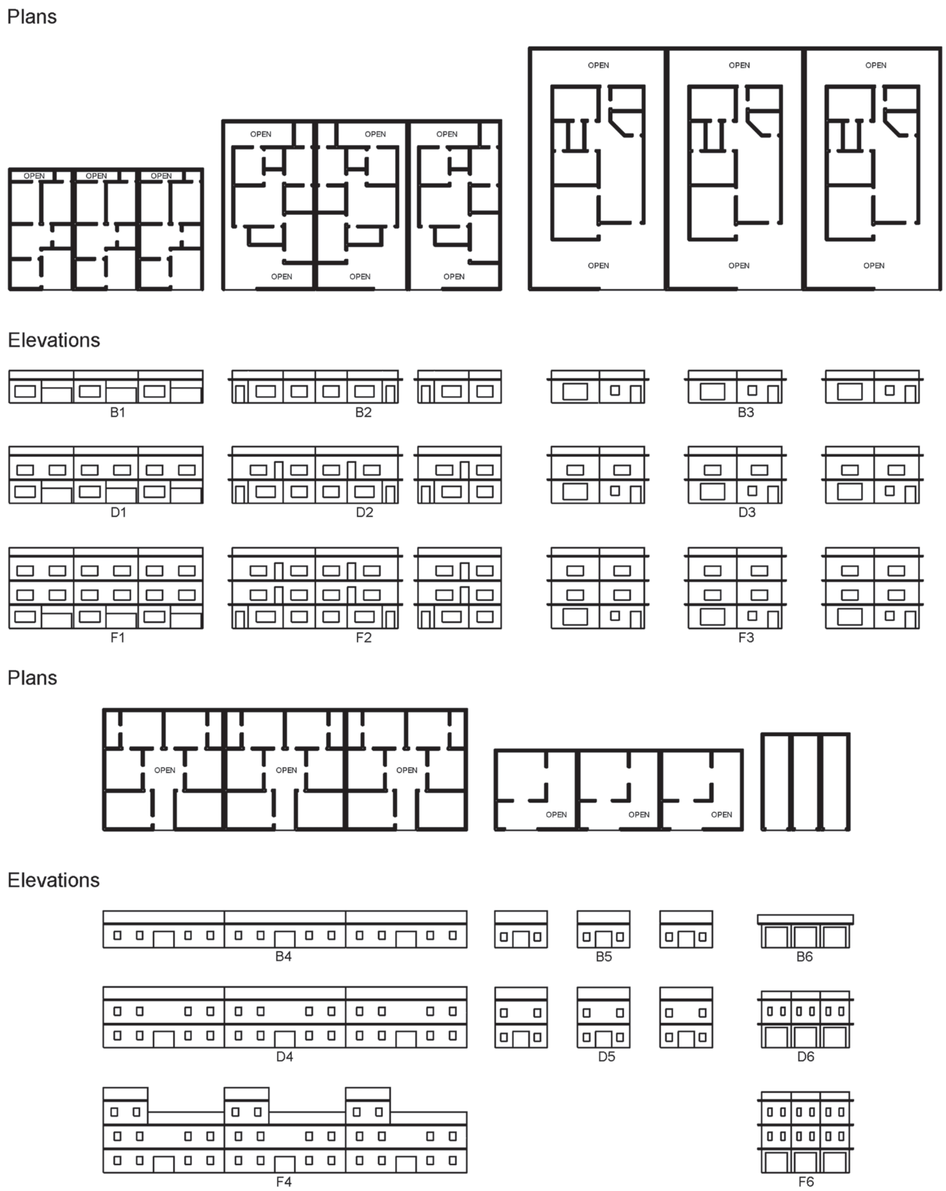
Typology C buildings (Figure 4D) are two-story isolated buildings, and in commercial buildings (variation C6) the upper floor can also be used for residential purposes by the provision of rooms. The wall thickness is generally the same as in typology A buildings. Typology D buildings are essentially a row of typology C two-story buildings and are located uniformly in both large urban centers and small towns (Figures 4E and 4F). As for typology B buildings, variation D3 component buildings can be considered to structurally behave independently. Further variations are possible due to the presence of individual buildings with a different number of stories within a typology D building.

Typology E buildings (Figure 4G) are isolated buildings with three or more stories and are not common in Pakistan. Ultimately many buildings of this typology form a part of a row building (typology F) due to the later construction of adjacent houses. This later addition of adjacent houses may not be possible in hilly areas due to uneven terrain. In some cases, only a part of the top floor is built. Variation 5 for typology E and typology F buildings is not shown as such buildings are rare. Typology F buildings (Figure 4H) are row buildings that are three or more stories high and are more prevalent than typology E buildings, particularly in commercial and historic parts of Pakistan cities. URM buildings that cannot be considered typology A–F buildings are categorized as typology G buildings, and include but are not limited to religious structures (mainly mosques and shrines, but also some churches and temples) and public buildings. Typology B and D buildings are the most prevalent in Pakistan, but frequent intermixing of typologies occurs. It is, however, believed that the presented typologies are sufficiently representative for seismic vulnerability assessment of Pakistan URM buildings.

SEISMIC VULNERABILITY ASSESSMENT AT A NATIONAL SCALE

Seismic vulnerability assessment of Pakistan URM buildings at a national scale is conducted here by making use of the presented typologies and modifying three well-established rapid assessment methods for Pakistan conditions. The scope was limited to (1) fired-clay brick buildings with concrete roofs and floors; (2) fired-clay brick buildings with lintel bands and concrete or timber roofs and floors; (3) concrete block buildings with concrete or timber roofs and floors; and (4) massive stone masonry buildings with concrete or timber roofs and floors. Other building types, such as rubble stone masonry and adobe, were considered to have a significantly higher seismic vulnerability, as determined by the proposed seismic vulnerability classification of Indian buildings (Sinha and Goyal 2004), which can be considered similar to Pakistan buildings. The vulnerability classification by Maqsood and Schwarz (2008b) for Pakistan buildings does not provide separate classes for rubble stone masonry and massive stone masonry, and hence was not considered.

Seismic assessment methods can be subdivided mainly into analytical methods, empirical methods, and the so-called hybrid methods, which are a combination of analytical and empirical methods. More detail is given in Calvi *et al.* (2006); however, analytical methods require large amounts of input data, are computationally intensive, and require high levels of technical skill and time. Empirical methods are most suited to the assessment of a large number of buildings with limited data available, as is the case with Pakistan buildings, and are hence employed here. The three empirical methods used in this research were selected because of their technical superiority



▲ **Figure 3.** Representative ground floor plans and front elevations for the variations of typology B, D, and F buildings (non-load-bearing boundary walls, stairs and stairwells not shown for simplicity).

and higher level of detail (New Zealand method) than other similar methods, wide international adoption (US method), and the similarity between Pakistan buildings and the buildings originally addressed by the method (Indian method). A brief description of each method and its modifications for Pakistan buildings is provided here.

New Zealand Method

The New Zealand method (NZSEE 2006) is a two-stage process that consists of the initial evaluation procedure (IEP), which is intended as a coarse screen, followed by the detailed assessment, which is conducted for structures that are assessed as "typically requiring" detailed evaluation. The IEP is a step-by-step procedure to calculate for a building the percentage of new building standard (%NBS), which is a number expressing the assessed structural performance of the building compared with the requirements for a new building. Buildings with %NBS ≤ 33 are considered earthquake prone (EP) (high risk buildings). More details are available in the original document (*i.e.*, NZSEE 2006).

The IEP was applied to the buildings within the scope of this study with only minor modifications due to various similarities between Pakistan and New Zealand URM construction (see Table S1 in the electronic supplement to this article.). Pakistan URM buildings were considered to correspond to New Zealand buildings constructed before 1935, *i.e.*, before the introduction of a seismic code in New Zealand. This is a reasonable assumption, as most Pakistan URM buildings are non-engineered buildings. Also, by comparing Pakistan URM buildings to at least 75-year-old New Zealand URM buildings,

▲ **Figure 4.** Photographic examples of Pakistan URM buildings (typologies A–F): (A) = Typology A, variation A2; (B) = Typology A, variation A6; (C) = Typology B, variation B6; (D) = Typology C, variation C3; (E) = Typology D, variation D2 (continued on next page).

most cases of age-related structural degradation were addressed. Because of a higher probability of construction defects and the use of relatively inferior materials in Pakistan buildings, a conservative approach was taken by multiplying %NBS with (1) 0.85 for buildings constructed using cement-based mortar and (2) 0.70 for buildings constructed using lime-based mortar, because lime-based mortar was used only in old Pakistan buildings and is expected to have degraded over time. Each typology was considered to be founded on different soils, viz. A/B (strong rock/rock) through E (very soft soil) (Standards New Zealand 2004). A fundamental period, T, of less than 0.4 seconds was assumed in accordance with the NZSEE (2006). Conservatively, the assessment was limited to buildings with a height less than 11 m.

Hazard factors (0.075 to zone 1; 0.15 to zone 2A; 0.20 to zone 2B; 0.30 to zone 3; and 0.40 to zone 4) were assigned to each seismic zone of Pakistan based on the peak ground acceleration (PGA) levels specified in the Building Code of Pakistan (MHW 2007), which is based broadly on the 1997 Uniform Building Code (UBC-97) (ICC 1997). The other factors were

▲ **Figure 4** (continued from previous page). Photographic examples of Pakistan URM buildings (typologies A–F): (F) = Typology D, variation D6; (G) = Typology E, variation E3; (H) = Typology F, variation F6 (reproduced from http://www.flickr.com/photos/thewazir/2250097987/sizes/o/in/set-72157603711278042/).

calculated from NZSEE (2006) and the New Zealand earthquake loading standard (Standards New Zealand 2004). To incorporate the effects of structural deficiencies, a factor B equal to 0.4 was assigned to typologies C6, D6, E6, and F6 due to the potential for soft story formation. The "compensating factor" F was estimated for each building typology on the basis of building height (lower buildings are considered safer and hence have higher compensation factor), presence of adjacent buildings (row buildings have a higher F factor), and roof and floor materials. Buildings with concrete roofs and floors were assigned a higher F value than timber-floored buildings, ranging from 1.6 to 2.4. Buildings with timber roofs and floors were assigned lower F factors, varying from 1.0 to 1.7. The lower score for buildings with timber floors was primarily due to the potential for loss of support to walls in an earthquake due to poor or no connections between walls and floors. See Tables S2 and S3 in the electronic supplement for the results of this assessment for URM building typologies located in different seismic zones and founded on different soils; EP buildings are shown shaded.

U.S. Method

For verification of the assessment results obtained using the New Zealand method, the Federal Emergency Management Authority (FEMA) rapid visual screening method (here called the "U.S. method") (ATC 2002) was selected due to its widespread adoption internationally (in India by Sinha and Goyal 2004; in Turkey by Sucuoglu *et al.* 2007). A building is assigned a basic score, which is then modified for the building height, the presence of any structural weaknesses, the soil type, and whether the building is designed according to a seismic code, to obtain a final score, S. It has been suggested by FEMA (ATC 2002) that buildings with $S < 2.0$ should be evaluated in detail (hence considered EP). The score (S) was lowered for Pakistan buildings due to the reasons already stated for the New Zealand method; the S score was multiplied by (1) 0.85 for buildings constructed using cement-based mortar that have concrete roofs and floors, (2) 0.72 for buildings constructed using cement-based mortar that have timber roofs and floors, (3) 0.70 for buildings constructed using lime-based mortar that have concrete roofs and floors, and (4) 0.60 for buildings

TABLE 2 Equivalent Seismic Hazard Zones and Soil Types		
Seismic Hazard Zones		
Zone	**US Method**	**Indian Method**
1	Low	II
2A	Moderate	III
2B	Moderate	IV
3	High	V
4	High	V
Soil Types		
New Zealand	**US Method**	**Indian Method**
A/B	A/B/C	I
C	D	II
D	E	III
E	–	–

constructed using lime-based mortar that have timber roofs and floors. A comparison of the UBC-97 seismic zone map of the United States and the U.S.A. seismic hazard map provided in ATC (2002) was performed to determine Pakistan seismic hazard zones for use with the U.S. method, which were approximately equivalent to those listed in Table 2. A similar comparison was made for the soil types in ATC (2002) and the New Zealand loading standard (Standards New Zealand 2004) (see Table 2 for results) on the basis of shear wave velocity, soil strength data, or general description. Buildings founded on soil type E were not considered for this analysis, because no ATC soil type could be considered comparable to New Zealand soil type E. See Tables S4 and S5 in the electronic supplement to this article for the results of this assessment for URM building typologies located in different seismic zones and founded on different soils; EP buildings are shown shaded.

Indian Method

The Indian method (Sinha and Goyal 2004) was adopted due to numerous similarities between construction materials and building forms in India and Pakistan and because of the geographical proximity of Pakistan and India as neighboring countries. The Indian method is a modification of the U.S. method and provides additional building types including four different types of URM buildings and modified values of parameters for score S for Indian building stock and construction practices. Buildings with score S < 0.7 are considered EP. The S score was multiplied by 0.85 for Pakistan buildings with timber roofs and floors, because the Indian method does not differentiate between buildings with concrete floors and buildings with timber floors. Equivalent seismic zones and soil types were approximately determined (BSI 2002; Sinha and Goyal 2004) and are shown in Table 2. Sinha and Goyal used the same S values for zone IV and V buildings due to "the influence of a large number of other factors on the building performance when the ground shaking is very intense" (Sinha and Goyal 2004, 4). Buildings founded on soil type E were not included in the assessment. See Tables S6 and S7 in the electronic supplement for the results of this assessment for URM building typologies located in different seismic zones and founded on different soils; EP buildings are shown shaded.

Summary of Results

There was a high level of a consistency between the results obtained from the New Zealand and U.S. methods, as high vulnerability of all buildings in seismic zones 3 and 4 and low vulnerability of most buildings in seismic zone 1 was indicated. Mixed results were obtained for seismic zones 2A and 2B. The Indian method was the least conservative of the three methods, as the method showed that generally all buildings other than two-story and taller variation 6 buildings in most seismic zones can be considered as not requiring detailed seismic evaluation (not EP).

CASE STUDY

We evaluated the relevance of this seismic vulnerability analysis to two major cities of Pakistan, Muzaffarabad and Rawalpindi-Islamabad. Muzaffarabad was severely damaged in the 2005 Pakistan earthquake, and we applied the three assessment methods to the pre-earthquake buildings of the city for verification of the methods. Rawalpindi-Islamabad twin cities consist of Pakistan's capital, Islamabad, and a major city, Rawalpindi. The URM buildings of Rawalpindi-Islamabad suffered no or minor damage (narrow cracks in some URM walls) during the 2005 Pakistan earthquake. We applied the three methods to identify EP buildings in the twin cities. The exact data for the type of soil in each city are not available, so soil types were approximately classified based on the consulting engineering experience in Pakistan of the first author.

Muzaffarabad

Muzaffarabad is located in seismic zone 4 (MHW 2007), and Muzaffarabad's soil type is considered to be type C for this assessment. Unreinforced concrete block masonry buildings with either concrete or timber roofs and floors were a popular form of construction in Muzaffarabad (Rossetto and Peiris 2009) at the time of the 2005 Pakistan earthquake, and hence this evaluation was limited only to unreinforced concrete block masonry. Most Muzaffarabad URM buildings can be considered B1–B2, B4, B6, D1–D2, D4, or D6 buildings, constructed with cement-based mortar. As Tables S2 and S4 in the electronic supplement (New Zealand method and U.S. methods) show, all Muzaffarabad buildings are EP. On the contrary, the Indian method (Table S6) indicates that only variation 6 multistory buildings (D6) are EP. Recognizing that Muzaffarabad unreinforced concrete block masonry suffered extensive damage in the 2005 Pakistan earthquake, the results of the New Zealand and U.S. methods more accurately correlate with observed damage. Maqsood and Schwarz (2008a) assigned Muzaffarabad an MVI of 1.5–2.0 (medium-high vulnerability), which is a lower vulnerability than that obtained using the New Zealand and U.S. methods.

Rawalpindi-Islamabad

Rawalpindi-Islamabad twin cities are located in seismic zone 2B (MHW 2007). In general, URM buildings employ fired-clay bricks, have RC and RBC roofs and floors, and are built using cement-based mortar. Most buildings can be considered typology D1–D4 and D6 buildings. The total number of pacca (built using sound materials, such as RC, fired-clay brick, concrete block, and stone) housing units in Rawalpindi-Islamabad is 580,000 (PCO 1998c). For this assessment, the twin cities soil was considered to be soil type C (shallow soil). All three methods determine that only variation D6 buildings are EP. Maqsood and Schwarz (2008a) assigned Rawalpindi-Islamabad an MVI of 2.0–2.5 (medium vulnerability).

DISCUSSION AND CONCLUSIONS

Simplified building typologies for Pakistan URM buildings were presented as a tool for performing seismic vulnerability exercises at a national scale by identifying the prevalent building typologies in a region. The assessment results generally showed high vulnerability for buildings located in seismic zones 3 and 4 and significantly lower vulnerability for buildings located in seismic zones 1 and 2. The case study of Muzaffarabad showed that the New Zealand and U.S. seismic assessment methods are applicable to Pakistan URM buildings. The New Zealand and U.S. method provide similar results; however, the New Zealand method is recommended over the U.S. method due to its greater technical detail. The Indian method is not conservative and should only be used after making suitable adjustments based on the past observed earthquake behavior of Pakistan URM buildings. The results of the New Zealand and U.S. methods for the case study cities are comparable with the findings of previous work; however, in addition to understanding general vulnerability, vulnerable building typologies can also be identified, thus resulting in a more insightful assessment. Buildings in major cities employ better construction materials, and higher seismic vulnerability is expected for smaller towns and villages where buildings are constructed using low-strength materials and under poor quality control. The seismic vulnerability of large parts of Pakistan requires more attention by the concerned authorities to reduce the risk to the inhabitants of Pakistan and to protect the architectural heritage of the country. An effort ultimately leading to these goals has been made here.

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Department of Civil and Environmental Engineering
University of Auckland
3 Grafton Road
Auckland, New Zealand
hmah012@aucklanduni.ac.nz
(H. M.)
j.ingham@auckland.ac.nz
(J. M. I.)