Analysis of Building Damage during the 8 October 2005 Earthquake in Pakistan

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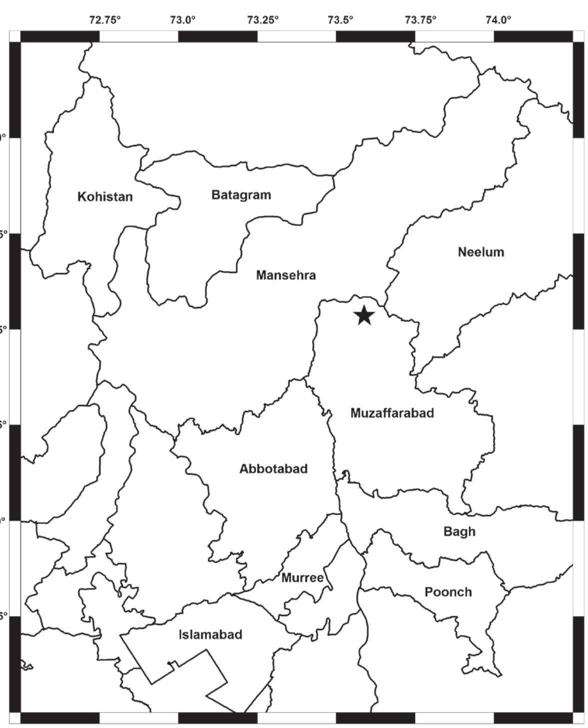
INTRODUCTION

The strongest earthquake in the history of Pakistan jolted the northern region at 08:50 local time (03:50 UTC) 8 October 2005. The epicenter of the earthquake was determined by the U.S. Geological Survey (USGS) to be 34.493°N and 73.629°E. This location is in the northern portion of Muzaffarabad district. It had a magnitude of 7.6 with a depth of 26 km. The earthquake caused extensive damage, destruction, and loss of life over a wide region (almost 30,000-km^2) including Muzaffarabad, Mansehra, Batagram, Bagh, and Poonch (see figure 1). The impact of the main shock was felt as far away as Lahore (350 km from epicenter). About 90,000 people died, 79,000 were injured, and more than 3.5 million were rendered homeless. More than 1,200 aftershocks were recorded through 7 November 2005.

According to government figures, 19,000 children died in the earthquake, most due to the collapse of school buildings. The earthquake affected more than 500,000 families. More than 400,000 buildings were damaged. The destruction of about 7,000 school buildings and several hospitals caused further difficulties in relief operations and social rehabilitation. Adobe, stone masonry, concrete block masonry, brick masonry, and timber structures are the dominant building types in the region. Reinforced concrete frame structures usually are constructed only in urban areas.



▲ **Figure 1.** Epicenter, most affected area and selected seismic recording station.

This article is the outcome of a field visit made just after the event. The field visit was supported by the German Task Force for Earthquakes (GeoForschungsZentrum, Potsdam) and Earthquake Damage Analysis Center (EDAC), Weimar (Maqsood *et al.* 2006).

SEISMOLOGICAL ASPECTS

Regional Seismic History

Figure 2 shows the past seismicity in and around Pakistan. There was no major event recorded in the recent past in the epicentral area before the 8 October 2005 earthquake. But very high seismic activity was seen after the main event, in terms of the 1,209 aftershocks recorded between 7 October 2005 and 7 November 2005. Three hundred seventy-four aftershocks were recorded in the first four days after the main shock. Of the total 1,209 aftershocks, 57 had magnitudes greater than 5.0 (Pakistan Meteorological Department, http://www.pakmet.com.pk). Figure 3 shows the magnitude distribution of the aftershocks during the above-mentioned period. These strong aftershocks resulted in greater damage to already-damaged structures.

Strong-motion Recordings

Several strong-motion networks are operated by different institutes in Pakistan. The locations of the recorders near the affected area are Abbottabad, Murree, and Nilore (see figure 1). These are operated by the Micro Seismic Studies Programme (MSSP), Pakistan Atomic Energy Commission. These recorders are placed in buildings and are not free field recorders.

The Abbottabad instrument is located in a small room constructed on alluvium, almost 35 km from the epicenter of the 8 October 2005 event. The Murree instrument, 80 km from the epicenter, is inside a room on the ground floor of a two-story building on a steep slope. The Nilore instrument, 120 km from the epicenter, is placed in the basement of a single-story building constructed on sandstone (Durani *et al.* 2005). The strong-motion recording of the main shock at the Abbottabad

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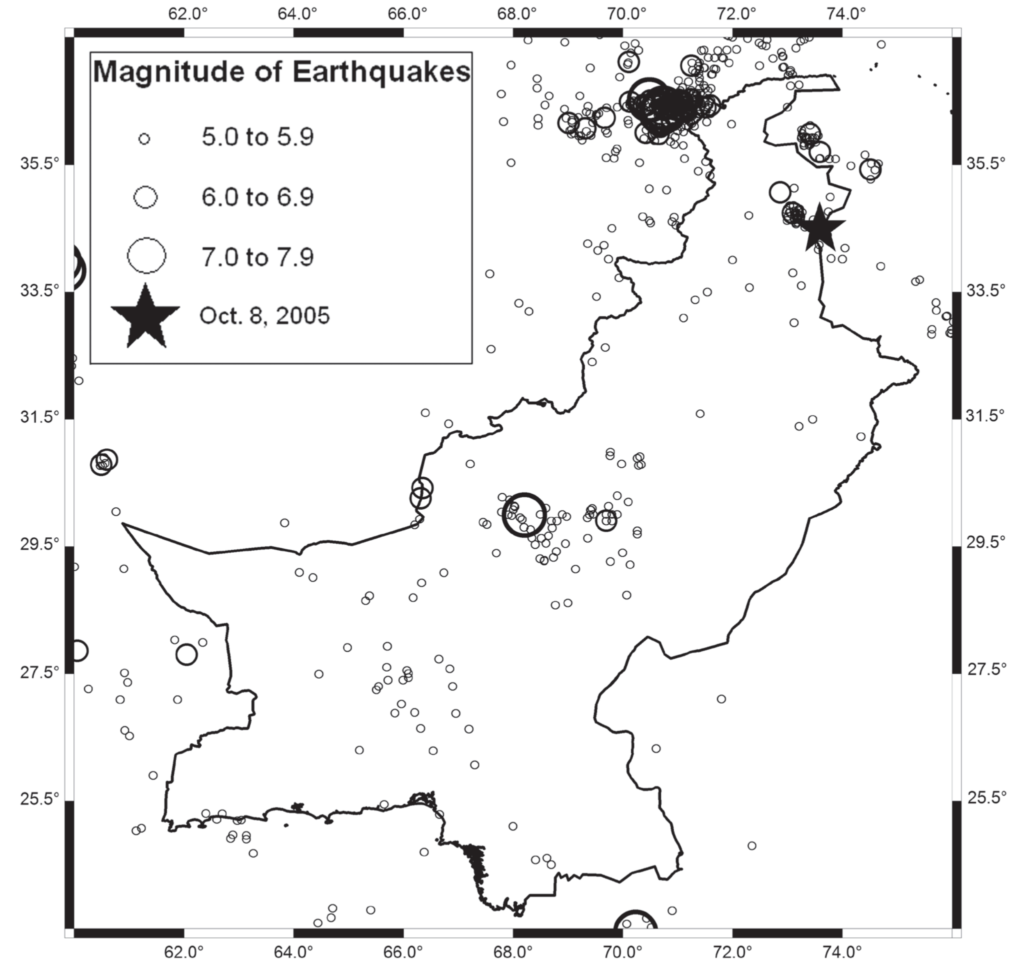
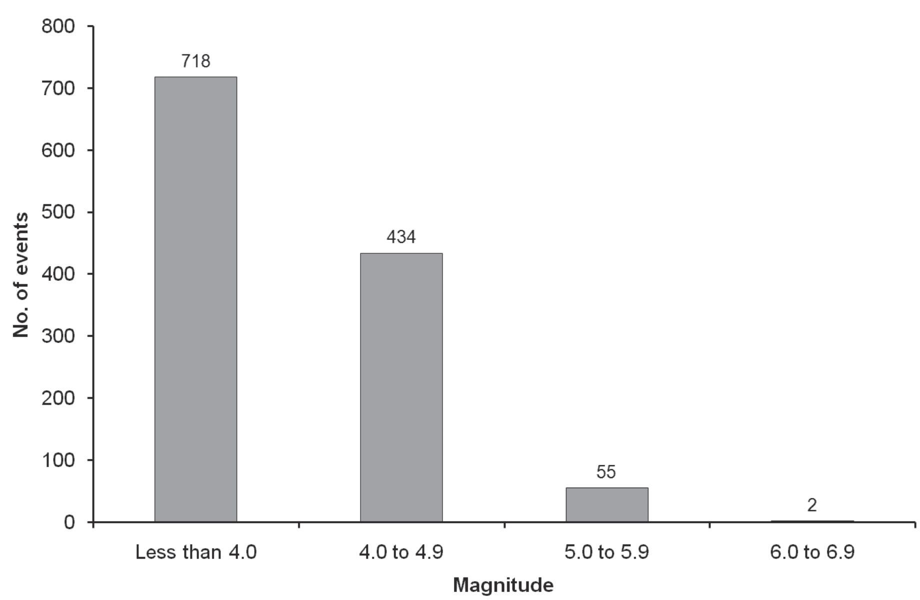
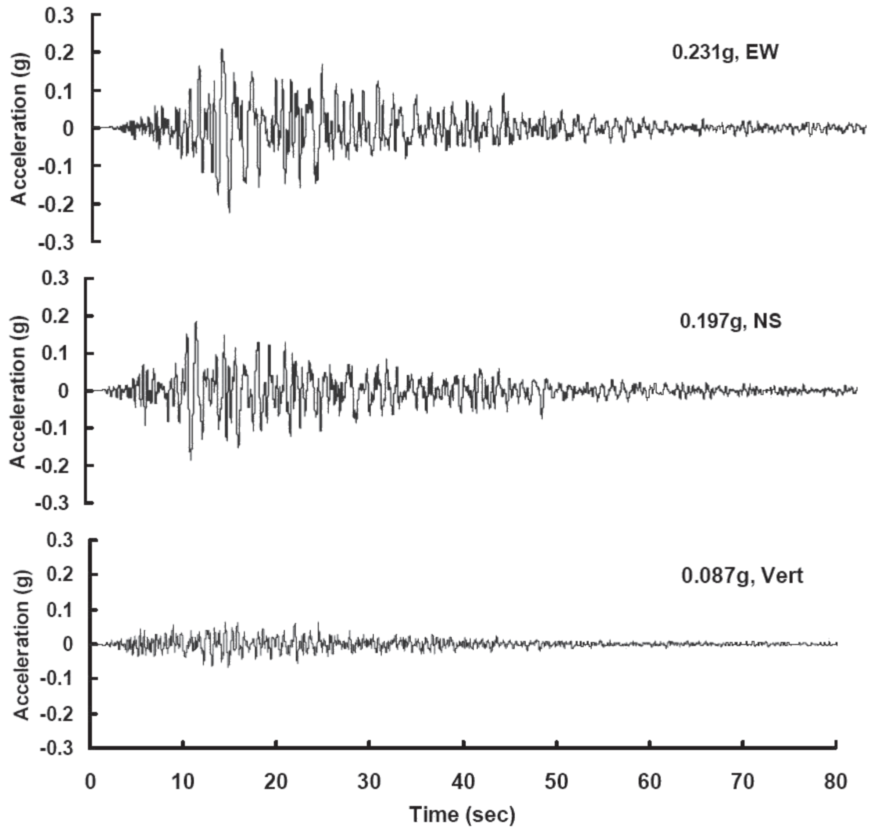


▲ **Figure 2.** Past seismicity of Pakistan (USGS Global Seismographic Network, http://earthquake.usgs.gov/regional/world/historical.php.)



▲ **Figure 3.** Magnitude distribution of aftershocks (Pakistan Meteorological Department, http://www.pakmet.gov.pk).



▲ **Figure 4.** Recording of main shock at Abbottabad recording station, 35 km, see figure 1, taken from Durani *et al.* 2005.

TABLE 1
Strong Motion Recordings (from Durani *et al.* 2005)

Recording Station	Distance from epicenter (km)	Peak Ground Acceleration (g)		
		EW	NS	Vertical
Abbottabad	35	0.231	0.197	0.087
Murree	80	0.075	0.078	0.069
Nilore	120	0.026	0.023	0.030

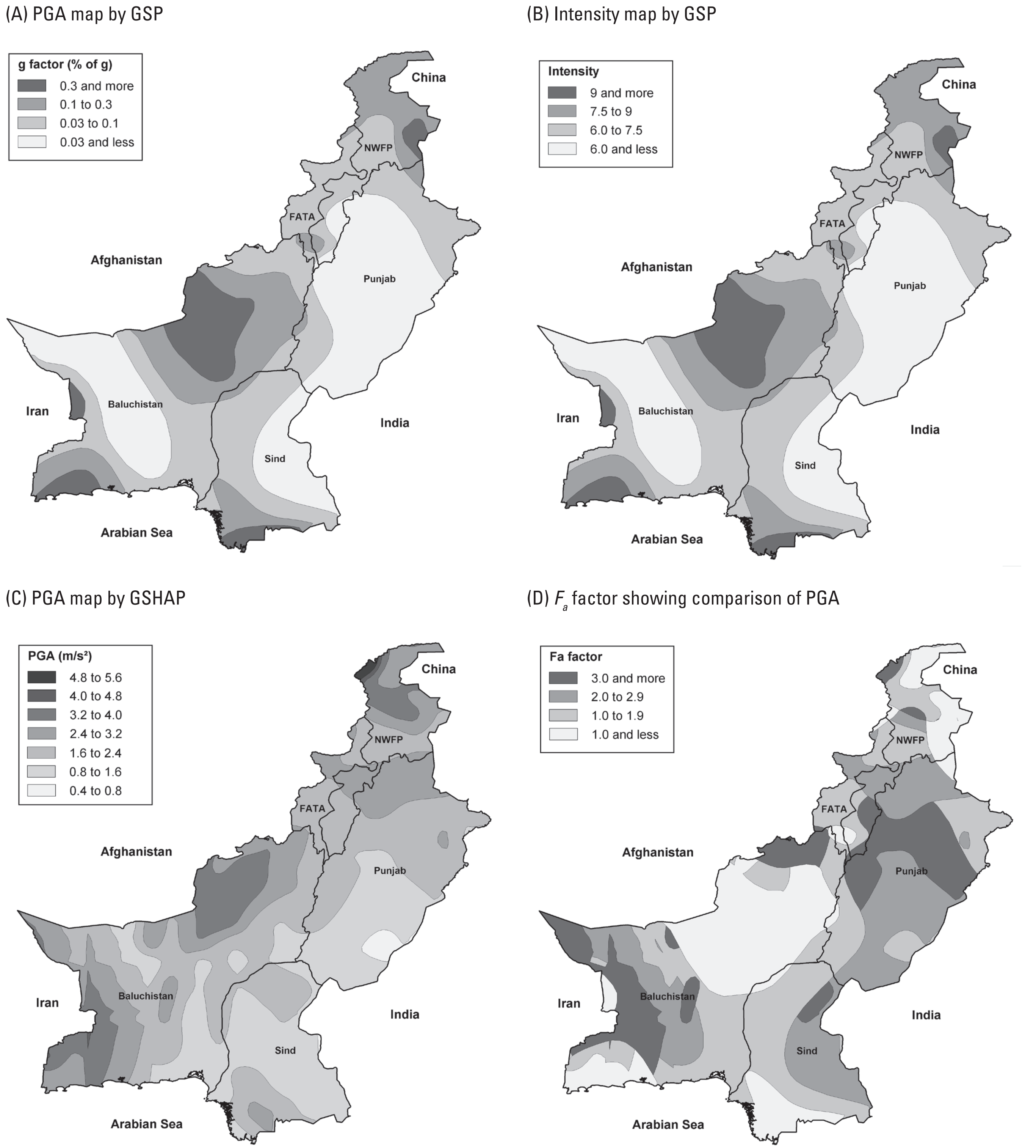
recording station is shown in figure 4. The 5% elastic spectrum shows a relatively broad range of high amplification, from 0.4 to 1.5 seconds for the EW direction of strong-motion recording at the Abbottabad station.

Table 1 shows the PGA values of the main shock at different recording stations. The signal from Abbottabad station is the most usable of the three available records, because it is obtained from an area where significant damage occurred (Durani *et al.* 2005).

Seismic Zoning Maps

A new seismic hazard zoning map was prepared (see figure 5) by the Geological Survey of Pakistan (GSP), http://www.gsp.gov.pk, after the 8 October 2005 event. The country is divided into four zones ranging from "no damage zone" to "major damage zone" according to the "intensity" and the "g factor." According to the Global Seismic Hazard Assessment Program map (GSHAP 1999; see figure 5), the most vulnerable parts of Pakistan are parts of Balochistan province in and around Quetta, stretching to the Afghan border; and western parts of Balochistan, which include the Makran coast to the Iranian border.

Figure 5 presents a comparison of the hazard assessed by the GSP and GSHAP in terms of peak ground acceleration (PGA). The hazard is assessed in terms of PGA (m/sec^2) with 10% probability of exceedance in 50 years. In PGA comparisons, an "F_a factor" is used to identify the areas where the difference is more acute. For intensity comparison, the PGA values can be converted into intensity by several correlations, *e.g.*, Murphy and O'Brien (1977), Wald *et. al* (1999), and, recently, Atkinson and Kaka (2007). The above-mentioned relations are used to prepare intensity maps, but no identical solution is found in the case of GSP, which has identical maps in terms of



▲ **Figure 5.** Comparison of GSP (A and B) and GSHAP hazard assessment (C and D). The F_a factor defines the level of difference between the two hazard assessments. The hazard assessed in the two maps is the same in the regions where the F_a factor is 1.0. The higher the F_a factor, the higher the difference between the GSHAP and GSP hazard assessment. That means that the GSP has underestimated the hazard.

* The hazard is assessed in terms of PGA (m/sec^2) with 10% probability of exceedance in 50 years. $F_a = PGA_{GSHAP} / PGA_{GSP}$

PGA and intensity. However, this aspect needs in-depth study and is subject to further refinement (Maqsood, in progress).

From the comparison, we see that the densely populated area of Punjab and the area near the Indian border are underestimated by the GSP relative to the GSHAP. The same is the case in the region near the Iranian border on the western side.

Intensity Assessment

From the field surveys, the epicentral intensity can be estimated and interpreted to be X. Near the epicenter, the city of Muzaffarabad suffered great damage (IX on European Macroseismic Scale 1998 [EMS-98 scale]), and the city of Balakot was almost totally destroyed (X–XI on EMS-98 scale). The building topology was such that most of the residential buildings were made of stone or concrete block masonry. The primary load-bearing elements were walls with clay or weak cement-sand mortar. Hence the failure of these masonry walls resulted in complete collapse or heavy damage in the epicentral area.

Damage also was seen in more distant locations such as Abbottabad (35 km from epicenter), Islamabad (110 km from epicenter), and Lahore (350 km from epicenter). But damage in these areas could be a result of local site effects or poor construction rather than direct intense shaking from the earthquake.

EXTENT OF DAMAGE

Overview

The earthquake affected North-West Frontier Province (NWFP) and Azad Jammu and Kashmir (AJK) in the northern part of Pakistan (see figure 1). The affected districts in NWFP are Abbottabad, Batagram, Kohistan, Mansehra, and Shangla. Muzaffarabad, Bagh, and Poonch were the districts in AJK that suffered heavy damage due to shaking.

Table 2 indicates that the direct economic loss was more than $5 billion. The estimates were prepared by the Asian Development Bank and World Bank (2005) after surveying the damaged areas.

There were 787,583 housing units in the affected area, of which 203,579 were completely destroyed, while 196,574 were damaged to various degrees (Asian Development Bank and World Bank 2005). A distribution of these units in the various districts of the earthquake-affected areas, broadly categorized as AJK and NWFP, is presented in table 3.

Loss estimates show that 84% of the total housing stock was damaged in the affected districts of AJK, while 36% of the total housing stock was damaged in the five affected districts of NWFP.

Field observations and statistics suggest damage to a broad range of construction including both engineered and non-engineered structures. Schools and medical facilities were among the hardest-hit structures.

TABLE 2
Economic Loss Due to Earthquake
(Asian Development Bank and World Bank 2005)

Category	US $ M	Percentage of total
Relief	1,092	21.0
Death and injury compensation	205	3.9
Early recovery	301	5.8
Restoration of livelihoods	97	1.9
Reconstruction	3,503	66.4
Short-term reconstruction	450	8.7
Long-term reconstruction	3,053	58.7
Total	5,198	100.0

Description and Vulnerability of the Building Stock

The statistical data and survey of structures in the region reveals the following dominant building types: adobe, stone masonry, concrete block masonry, brick masonry, and timber structures. Reinforced concrete (RC) frame structures usually are constructed only in urban areas. The percentage of RC structures is very small compared to the other types; therefore, RC structures are not mentioned separately in the building type distribution but are included in brick masonry structures in figure 6.

Table 4 presents the description of the main load-bearing elements in different building types in Pakistan. Primary elements are the vertical load-bearing members. Secondary elements are the horizontal load-bearing members, while tertiary elements are the floors and roofs.

The majority of the building stock consists of non-engineered structures. The building stock in the region can be classified into five categories depending upon the material used in walls and roofs. The distribution of the various building types in the affected areas is shown in figure 6.

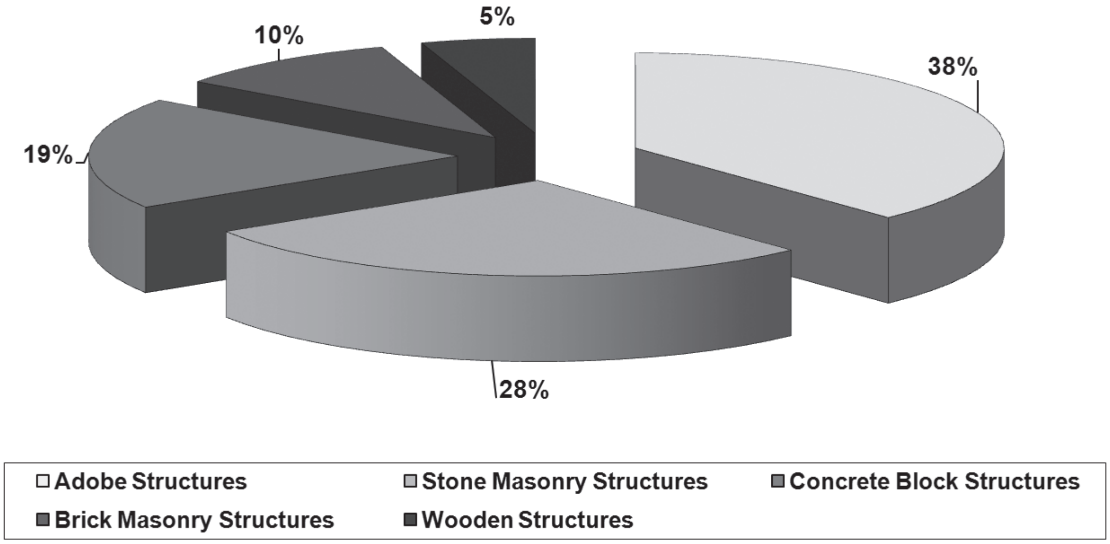
The seismic vulnerability of buildings in Pakistan is generally very high. The range of probable vulnerability class (VC)

TABLE 3
Overview of Damaged Houses
(Asian Development Bank and World Bank 2005)

District	Total Units	Damaged Units	Damaged Units (%)
AJK Affected Districts			
Muzaffarabad	123,769	98,221	79
Bagh	59,623	55,014	92
Poonch	61,678	51,705	84
AJK Total	244,979	204,940	84
NWFP Affected Districts			
Shangla	67,003	26,482	40
Mansehra	203,109	74,605	37
Kohistan	74,087	22,745	31
Abbottabad	153,819	34,012	22
Batagram	44,585	37,369	84
NWFP Total	542,604	195,212	36
AJK+NWFP	787,583	400,153	51

TABLE 4
Description of Building Types in Pakistan

Type	Elements		Description
Adobe Structure	Primary	Adobe walls	Low-strength adobe walls are used, which normally don't have any vertical wooden post.
	Secondary	Adobe walls	No additional system such as crown beam or pilasters is provided to restrain the out-of-plane failure.
	Tertiary	Wooden and mud roof	Wooden logs (beams) with heavy mud roof and straw are used as roof.
Stone Masonry Structure	Primary	Simple or rubble stone masonry walls	Simple or rubble stone masonry walls are normally used in lean cement-sand mortar, often with mud mortar and sometimes even without any mortar.
	Secondary	Simple or rubble stone masonry walls & wooden vertical post, if provided	The walls don't have a proper connection among the stone layers. The walls are normally without any vertical post but occasionally wooden posts are also provided.
	Tertiary	Wooden and mud roof	Wooden logs (beams) with heavy mud roof and straw are used as roof.
Concrete Block Masonry Structure	Primary	Concrete block masonry walls	Low to medium quality concrete blocks with compressive strength of about 5–6 MPa are used. Generally cement-sand mortar of 1:8 ratio is used for this type of building. The dimension of the block is 300 mm x 150 mm x 150 mm.
	Secondary	Simple or rubble stone masonry walls and wooden vertical post, if provided	Concrete block masonry walls resist the lateral loads. Lintel beams are provided over the openings of doors and windows, but generally they do not run continuously throughout the perimeter. Ring or connecting beams between roof and masonry walls are rarely provided. In some constructions, concrete or wooden posts are provided for lateral load resistance.
	Tertiary	Cement or iron sheet roof	The roof slab is made of cement or iron sheets that normally are light-weight. Sometimes a 150-mm thick reinforced concrete slab is also used.
Brick Masonry Structure	Primary	Solid burnt brick walls	Clay brick with compressive strength of about 8 MPa are used in walls. Generally cement-sand mortar of 1:6 ratio is used for this type of building. The dimension of the brick is 230 mm x 115 mm x 75 mm.
	Secondary	Solid burnt brick walls with lintel beams. Ring beams & vertical concrete or wooden post, if provided.	Solid burnt brick walls resist the lateral loads. Lintel beams are provided over the openings of doors and windows, but generally they do not run continuously throughout the perimeter. Ring or connecting beams between roof and masonry walls are rarely provided. In some constructions, concrete or wooden posts are provided for lateral load resistance.
	Tertiary	Reinforced concrete roof slab	The roof slab is made of reinforced concrete having compressive strength of 21 MPa and 150-mm thickness. The mixed ratio of concrete is 1:2:4.
Timber Structure	Primary	Timber frame: wooden columns & beams with infills	Timber frames, placed in longitudinal and transverse directions, are filled with masonry walls. Most of the buildings are rectangular in shape with few openings.
	Secondary	Timber frame: wooden columns & beams with infills	Timber frames, placed in longitudinal and transverse directions, are filled with masonry walls.
	Tertiary	Wooden and mud roof	The floor structure is made of timber planks. The roofing material is usually light when it is made from galvanized iron sheets. Timber planks with heavy mud roof and straw are also used as a roof.



▲ **Figure 6.** Building type distribution in affected areas.

TABLE 5
Vulnerability Class of Building Types.

		Vulnerability Class					
Type of Structure	**Description**	**A**	**B**	**C**	**D**	**E**	**F**
Adobe	EMS-98	○					
	Pakistan *	○					
Stone Masonry	EMS-98	├----	○				
	Pakistan *	○					
Concrete Block Masonry	EMS-98	├----	○	----┤			
	Pakistan *	○					
Brick Masonry	EMS-98		├----	○	----┤		
	Pakistan *			○			
Timber	EMS-98		├-----	——	○	—┤	
	Pakistan *				○		

○ Most likely vulnerability class
— Probable range
-- Range of less probable
* On the basis of field survey, only most likely vulnerability class is assigned to building stock in Pakistan

is more or less an indicator of the level of Earthquake Resistant Design (ERD) provided. To determine the VC involves consideration of the level of the regularity as well as the quality or workmanship of the different building types or structural systems and the implementation of modern design principles in the area.

Table 5 presents the typical VC, its ranges according to EMS-98 (Grünthal *et al.* 1998), and also the existing VC of the structures according to building conditions in Pakistan. The VC assigned to the Pakistani building stock is lower compared to the typical VC according to EMS-98 (Grünthal *et al.* 1998). This is because of poor material, workmanship, and design and construction practices that were seen during the field visit.

DAMAGE TO REINFORCED CONCRETE STRUCTURES

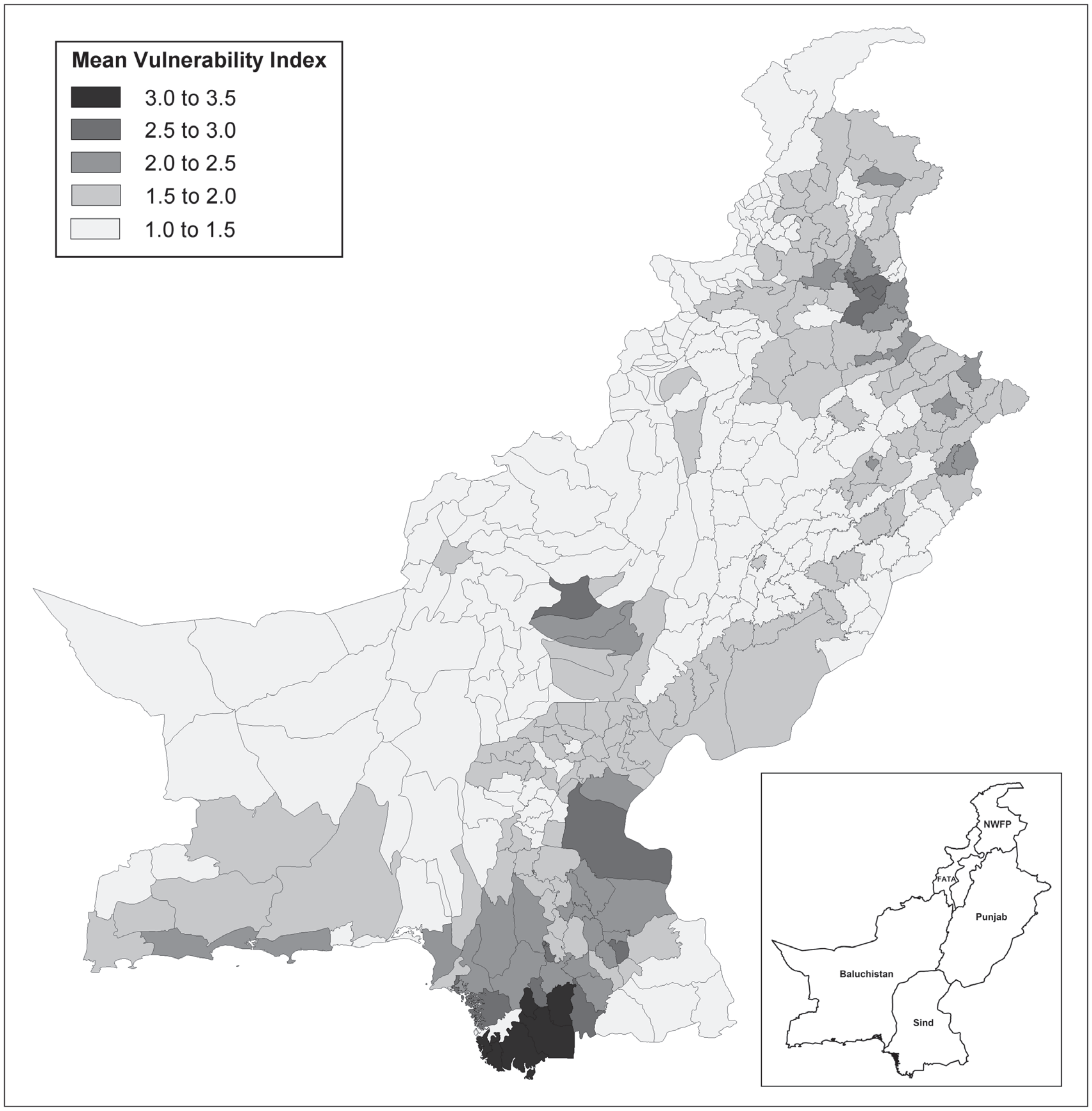
There are many reinforced concrete frame structures with infill walls in Balakot (Blk) and Muzaffarabad (Muz), the cities hardest hit by the earthquake. Almost 5% of the building stock is composed of RC structures, but these buildings are found only in urban areas due to the economic constraints of people living in rural areas. Most of these buildings were not designed by qualified engineers, and those designed by engineers were normally designed for gravity loading only. Serious building-code violations were seen in these semi-engineered or designed structures. A number of these buildings completely collapsed or suffered serious damage, while the other semi-engineered buildings designed for gravity load suffered relatively little damage.

Soft-story effect

Many hotels and an entire string of shopping plazas along the main road of Balakot collapsed or suffered severe damage due to soft-story effect (see figures 8, 9, and 10). It is obvious from the failure mechanisms that these buildings were designed primarily for gravity loads with no consideration for lateral forces. The ground floor was used as shops without infill walls, thus creating a soft-story effect that led to the failure.

Short-column effect

Lack of knowledge of engineering design was seen in the field trip. Figure 11 shows that the short-column effect (*i.e.*, the column fails by shearing) and the lack of seismic consideration resulted in the failure of many columns in cities such as Muzaffarabad and Balakot.



▲ **Figure 7.** Mean vulnerability index (MVI) of building stock in Pakistan.

▲ **Figure 8.** Soft-story effect (Blk).

▲ **Figure 9.** Soft-story effect (Blk).

▲ **Figure 10.** Soft-story effect (Blk).

▲ **Figure 11.** Short-column effect (Blk).

▲ **Figure 12.** Strong beam–weak column (Blk).

▲ **Figure 13.** Anchorage and development length (Blk).

Strong beam–weak column

Many structures suffered severe damage because of the strong beam–weak column phenomenon. These weak columns (see figure 12) were not able to sustain the horizontal earthquake loading and failed, resulting in the collapse of the structure.

Anchorage

Figure 13 shows the failure of a beam column joint due to insufficient development length, which resulted in the collapse of the structure: the length of the embedment of the steel bar should be enough to develop the full tensile strength, controlled either by pullout or splitting.

Concrete confinement

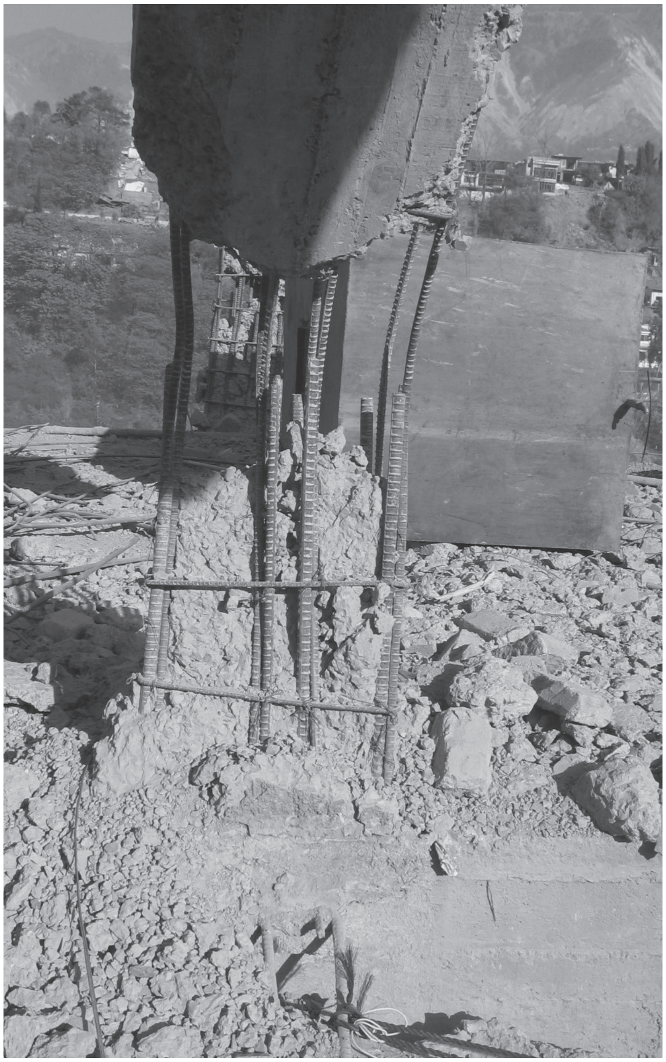
Some of the failures were directly caused by improper lateral confinement provided by insufficient shear reinforcement or ties. The spacing of the ties did not satisfy even the gravity-load requirements. Figure 14 shows the spacing of the lateral ties at the bottom of the column, which were completely absent afterward.

Lap splice length and location

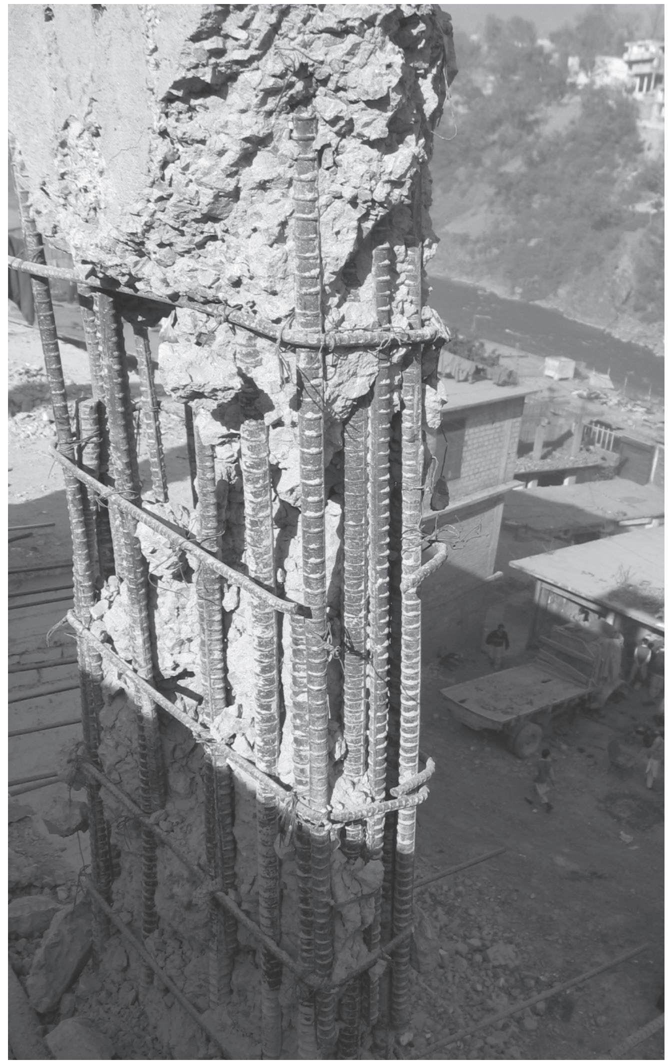
Bar splices have to be provided to join two steel bars. These splices should be provided at a location of low stress. However, as shown in figure 15, the lap splices were provided at the bottom of the column, where there is always a high resistance demand; also the lap splice length was found to be inadequate.

Smooth reinforcing steel bars

The failure of beam column joints also resulted from the bond failure of concrete and the steel reinforcement because of the use of smooth reinforcing bars (figure 16).



▲ **Figure 14.** Lateral confinement of concrete (Blk).



▲ **Figure 15.** Location of lap splice (Blk).

▲ **Figure 16.** Smooth reinforcing steel bars (Blk).

▲ **Figure 17.** Detailing of reinforcement (Blk).

Detailing of reinforcement
Improper and deficient detailing was also a key factor in the collapse of many structures (figure 17). The building also highlights the poor quality control on the part of building officials.

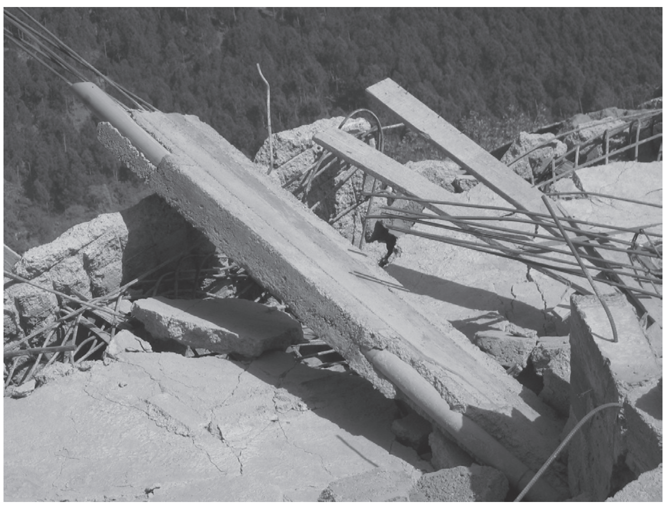
Construction practices
Public awareness of construction practices was found to be poor. The use of large PVC pipe for drainage inside a concrete column reduced its strength to a large extent, which resulted in its failure (figure 18).

Workmanship
Poor workmanship was also a key factor in the damage of many structures. A wooden plank was left inside the concrete beam (figure 19), which made this section weaker; the beam in this section collapsed. There was no inspection carried out during or after the construction, which allowed the builders to use low-quality material.

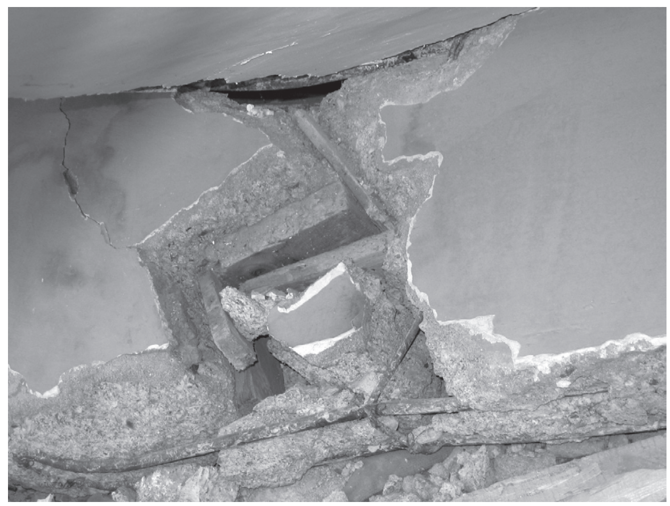
Quality of concrete
The nature of the damage indicates poor-quality construction, as shown in figure 20. Pouring and compaction of the concrete was not done properly, thus leaving honeycombing and voids in the hardened state of a beam.

Water tanks on the roof
Large water tanks on the roof (figure 21) attracted high inertial forces. The water tank was not adequately anchored to the roof, which caused it to fall to the ground.

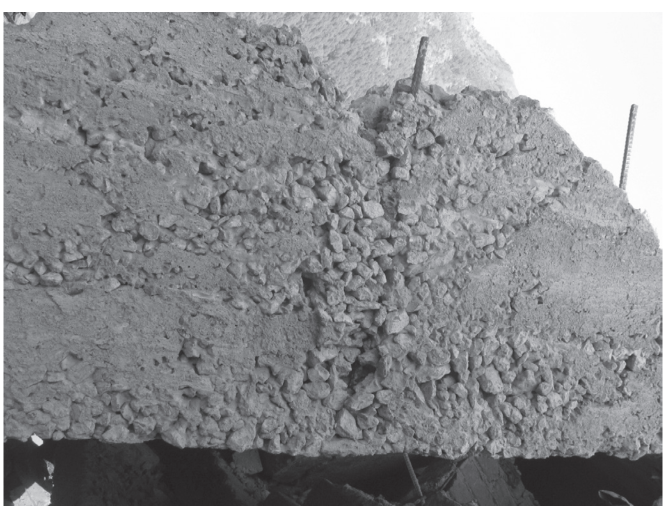
Construction supervision
The examples shown clearly indicate that supervision during construction is either not being carried out or is not up to standards. The structures also show poor public awareness about engineered structures and the building code.



▲ **Figure 18.** Construction practices (Blk).



▲ **Figure 19.** Workmanship (Blk).



▲ **Figure 20.** Quality of concrete (Blk).

▲ **Figure 21.** Large water tanks at roof (Muz).

SPECIAL CASE—MARGALLA TOWERS

In Islamabad (Isb), 100 km away from the epicenter, the only structure that collapsed due to the shaking of the earthquake was a multistory residential apartment building, the Margalla Towers (figure 22).

About 100 people died due to the collapse of three of the building's 10 units. Each unit had 10 stories and a basement that was used as parking area. Each unit had concrete floors, which rested on concrete beams and columns. The infill masonry walls in the remaining standing units had numerous in-plane shear cracks. The maintenance of the buildings was poor. The basements suffered from severe seepage problems as shown in figure 23.

The units that remained standing did not suffer major structural damage, which suggests that either structural detailing was different in the failed units or these units were defective because of low-quality construction. The collapsed units were built in the final phase of construction.

▲ **Figure 22.** Margalla Towers (Isb).

▲ **Figure 23.** Seepage and maintenance problem (Isb).

Damage to Masonry Structures

About 47% of the total building stock in the region consisted of masonry structures, either brick masonry, concrete block masonry, or stone masonry. Out of these masonry buildings, 10% had reinforced concrete slab roofs, 19% had cement or iron sheet roofs, and 28% had wooden roofs.

In urban areas, burnt brick masonry with reinforced concrete slab is becoming more common and is widely prevalent among structures inhabited by the middle-class population in urban areas in the past 30 years. A symmetric building plan is used. Brick masonry walls in cement mortar function as the main load-bearing element. The roof structure is a cast-in-situ reinforced concrete slab. The lateral forces are carried by the walls in the direction of seismic forces. The masonry walls thus act as shear walls. The reinforced concrete roofs are generally flat and are directly supported by the walls and act as a rigid diaphragm. The lateral loads in these structures are distributed to the walls through the reinforced concrete slab. These buildings suffered heavily due to the earthquake shaking; almost half of this type of structure was severely damaged. The unbaked brick buildings (adobe) could not withstand the earthquake shaking, and almost 95% of them suffered heavy damage. The main causes of failure of masonry structures can be summarized as follows:

Weight of the Roof

The main cause of collapse of masonry structures was the heavy weight of the roof, which attracted large inertial forces (figure 24). The slender unreinforced walls, without adequate connectivity to the roof, were not able to withstand these inertial forces.

Slenderness of Walls

The heavy weight of the roof and the high inertial forces resulted in out-of-plane failure of the slender walls (figure 25).

▲ **Figure 24.** Heavy roof (Muz).

Inadequate wall thickness and height resulted in slender walls which were not able to sustain the shaking of the earthquake.

Vertical Posts

There was no vertical element of concrete or wood to resist the horizontal forces, and the cracks ran throughout the wall without any resistance (figure 26).

Ring or Bond Beam

Due to the absence of a ring beam or bond beam, there was no proper connection between the walls and the roof, and hence there was no horizontal element to support the vertical members in resisting the lateral forces.

Openings in the Walls

Relatively big openings in the walls also contributed to the damage (see figures 26 and 27).

Quality of Mortar

The quality and quantity of cement-sand mortar was not up to standards. Hence the bond between the bricks and stones was not found to be perfect. In brick masonry structures, cement-sand mortar was generally used. But in concrete block masonry and stone masonry structures, lean cement-sand mortar was used. In rural areas, we saw masonry without mortar.

Earthquake Reconstruction and Rehabilitation Authority (ERRA)

To reconstruct more than 400,000 structures that collapsed or were severely damaged during the earthquake, the government of Pakistan has established an Earthquake Reconstruction and Rehabilitation Authority (ERRA, http://www.erra.gov.pk). The main functions of ERRA are:

- Surveying to assess damage and needs in the affected areas.
- Formulation of a comprehensive umbrella development program to provide for:
- Planned settlements, housing, government buildings and offices, utilities and services, infrastructure, health and education facilities, and irrigation and agriculture facilities;
- Environmental rebuilding, including cleaning of watersheds, reforestation programs, and other environmental interventions to restore the ecosystems.
- Preparation of a resettlement plan for the affected population.
- Identification, preparation, approval, and execution of projects.
- Developing steps and measures to ensure execution of the approved projects and development programs in accordance with the time schedule.
- Prescribing cost-effective technology, building codes, architectural designs, specifications, and construction materials for housing and other buildings in earthquake-prone areas to safeguard against future seismic activity.
- Review of the building codes of the various urban development authorities; recommendation of appropriate changes

▲ **Figure 25.** Out-of-plane failure (Muz).

▲ **Figure 26.** Shear cracks (Muz).

▲ **Figure 27.** Large openings (Muz).

to ensure quality construction and to maintain building standards in the country.
- Facilitation of reconstruction-related industry in the affected zones.

Recommended Reconstruction Measures

The government has adopted an "owner-driven" strategy for housing reconstruction. Affected households will receive housing grants from the government. The guiding principles for housing reconstruction include:

- Establish building standards and designs that are earthquake-resistant.
- Rebuild in situ. Minimal population relocation should take place.
- Rebuilding will be owner-driven, but assisted and inspected by the government.

RISK ASSESSMENT

Vulnerability of Existing Building Stock

Table 6 shows the distribution of the different building types in different provinces of Pakistan. The statistics reveal that more than half of the total building stock is made up of adobe and stone masonry structures, which are the most vulnerable to damage. Moreover, the building type distribution is not homogeneous in Pakistan; for example, 73% of the buildings in Baluchistan province are adobe while in Punjab the number is 31%.

Figure 7 presents the regionalization factor in terms of mean vulnerability index (MVI), which shows the mean vulnerability class of the building stock in an administrative unit according to EMS-98. For calculating the MVI, a number from 1 to 6 is assigned for each vulnerability class from A to F. Taking the mean over the different percentages of each vulnerability class leads to a prediction of the mean vulnerability index for a certain building stock.

The lower the MVI, the higher the vulnerability of buildings to damage. From figure 7, it is clear that buildings in Pakistan have low resistance for earthquake shaking and are vulnerable to damage during an earthquake.

Earthquake Scenarios

In the first step, for the assessment of potential seismic losses, work with deterministic event scenarios coupling the seismic hazard with the vulnerability of the built environment and the exposed values could be done. Improvement in the assessment of the seismic hazard in Pakistan is being carried out, but needs further revision, as observed in figure 5 in the F_a factor.

An effort is made in terms of derivation of Mean Vulnerability Index (MVI) for Pakistan to define the vulnerability of building stock. The MVI is based on characteristic features of the buildings. However, detailed research is being carried out in this field for more refinement (Maqsood, in progress).

The MVI derived in the present study reveals that the building stock of Pakistan mainly consists of low earthquake resistant structures, especially in the western part of Pakistan, *i.e.*, FATA and Baluchistan Province. Together with high seismic hazard and highly vulnerable building stock in these areas, the corresponding seismic risk requires particular measures including immediate actions in form of guidelines for new construction.

Furthermore, in the next step, behaviour of typical building types under seismic action should be evaluated, so that strengthening and retrofitting measures be carried out. It is important to quantify the risk associated with earthquakes in order to predict the expected seismic losses and to make the authorities sensitive to the existing problem for short and long term actions.

CONCLUSIONS AND SUMMARY

Public awareness of earthquake hazard seems to be poor despite the fact that the region lies in a moderate to high seismic zone according to the seismic zoning map of Pakistan.

The shaking due to the main event of the 8 October 2005 earthquake resulted in severe devastation in northern Pakistan, particularly in the Muzaffarabad, Bagh, and Balakot region. Shocks of the earthquake were felt over a very wide area, as far away as Lahore (350 km).

Damage to reinforced concrete and masonry building structures, as well as to the different types of non-engineered

TABLE 6
Building Type Distribution in Pakistan

Region	Adobe Structures (%)	Stone Masonry Structures (%)	Concrete Block Masonry Structures (%)	Brick Masonry Structures (%)	Wooden Structures (%)
Pakistan (total)	36.0	24.0	13.1	21.4	5.4
Sindh	36.6	1.3	20.9	25.5	15.7
Punjab	31.4	34.8	11.2	21.9	0.7
NWFP	39.8	32.5	9.1	16.4	2.3
Balochistan	73.0	3.9	5.7	5.2	12.2
FATA	59.2	32.3	2.9	3.4	2.2

houses in the areas covered by the authors during the field visit, were primarily due to ground shaking and not due to ground failures.

A significant portion of the failure of multistory reinforced concrete buildings resulted from the collapse of soft ground floors, which were left open and without infill walls to be used as shops. In most cases, the upper floors of these buildings remained intact because of the effect of added lateral stiffness due to the presence of masonry infills.

Noncompliance with seismic provisions in the building design, as well as the lack of quality control in construction, seem to be dominant factors in causing widespread damage and failure of building structures, resulting in numerous casualties.

The main causes of collapse of masonry structures were the heavy weight of the roof, absence of ring beam or lintel beam, absence of vertical wooden or concrete post, and the poor quality of cement-sand mortar.

The vulnerability of the existing building stock should be critically assessed, and measures should be taken to improve it to avoid major damage in the future.

A modern national seismic building code, related to the typical building types and including basic rules for existing building types, should be developed. The code should provide guidance to private users and owners to ensure at least a minimum level of earthquake resistance by means of simple rules related to the traditional building types.

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