SEISMIC VULNERABILITY OF EXISTING BUILDING STOCK IN PAKISTAN

S.T. Maqsood[1] and J. Schwarz[2]

[1] *PhD Scholar, Earthquake Damage Analysis Center, Bauhaus-University Weimar, Germany*
[2] *Head, Earthquake Damage Analysis Center, Bauhaus-University Weimar, Germany*
Email: tariq.maqsood@bauing.uni-weimar.de, schwarz@bauing.uni-weimar.de

ABSTRACT:

Seismic vulnerability is a crucial aspect in the earthquake risk assessment. The detailed survey of damage cases observed in the aftermath of the 7.6 M_w Kashmir Earthquake of October 8, 2005 provides the opportunity to test the vulnerability of the building stock in Pakistan. The survey helps to use GIS-based seismic risk assessment tools and to examine their applicability to earthquake regions of Pakistan. The building stock is reconstructed based on a quick field survey immediately after the earthquake in 2005, a survey after two years in 2007 and also based on interviews with inhabitants, carried out after the earthquake. Typical building types in Pakistan are defined and compared to the standard construction types of the European Macroseismic Scale-98 (EMS-98). The differences in the vulnerabilities of the standard construction types are evaluated resulting in the correction of the vulnerability classes of the EMS-98 for the respective construction types. In the end, damage prognosis at micro level for the city of Muzaffarabad is given, as a test area, by considering the vulnerability of the building stock.

KEYWORDS: Seismic vulnerability, risk assessment, building damage, building types, EMS-98

1. INTRODUCTION

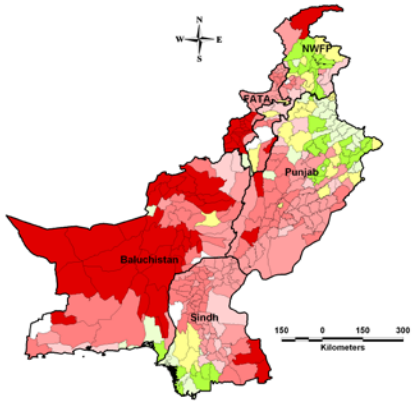
Risk assessment allows ascertaining the damage or loss to built environment and lifelines due to a scenario earthquake, which is important for emergency response and disaster planning by a national authority. The studies can be used for the mitigation of risk through the improvement in the seismic codes for new structures and strengthening and retrofitting of the existing structures.

Vulnerability of the built environment is one of the most important components in assessing the risk. The vulnerability of a structure can be described as its susceptibility to damage by ground shaking of a given intensity. The aim of this paper is to ascertain the vulnerability of Pakistani building stock and to derive the vulnerability classes of the typical building types in Pakistan to forecast the level of damage due to an earthquake [Maqsood, in progress]. Intensity is used as basic seismic impact parameter to simulate the damage distribution, whereas European Macroseismic Scale-98 (EMS-98) [Grünthal *et al.* 1998] is used to describe the damage patterns.

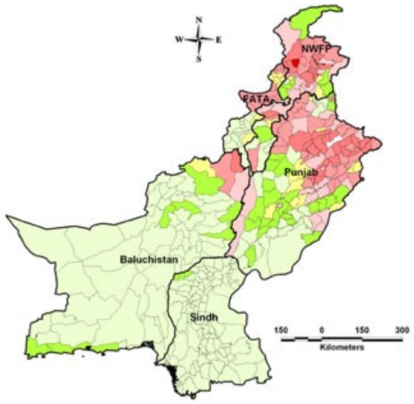
Pakistan is a country with high seismicity on the world scale. Although the country has suffered tremendous damage in the last 70 years, (e.g., in 1935 Quetta earthquake and in 2005 Kashmir earthquake), very less effort has been made to assess the vulnerability of existing buildings in Pakistan. In order to predict the expected loses, it is important to quantify the risk associated with the earthquakes. For the risk assessment, vulnerability of existing building stock to earthquake has to be evaluated. A vulnerability study comprising the whole of Pakistan does not exist. For risk scenarios, either the vulnerability based on expert opinions from other countries should be used or there is a need to define the vulnerability of typical building types in Pakistan.

2. EXISTING BUILDING STOCK IN PAKISTAN

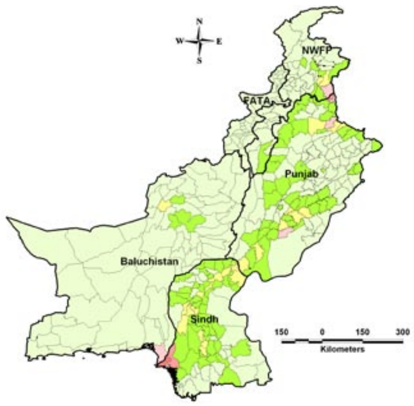
Pakistan has the following provinces/administrative areas: Punjab, Sindh, Baluchistan and North Western Frontier Province (NWFP), Federally Administrative Tribal Area (FATA) and Azad Jammu & Kashmir (AJK), see Figure 1. These provinces/administrative areas are divided into a number of districts which are further subdivided into Tehsils. It is to be noted that Pakistan is a highly populated country, with over 160 millions inhabitants (number 6th in the world ranking). However the population is not scattered in a regular pattern. Baluchistan is the biggest province of Pakistan regarding its area, but at the same time, it is the least populated province, too. Punjab is the most populated province in Pakistan with population over 80 millions.



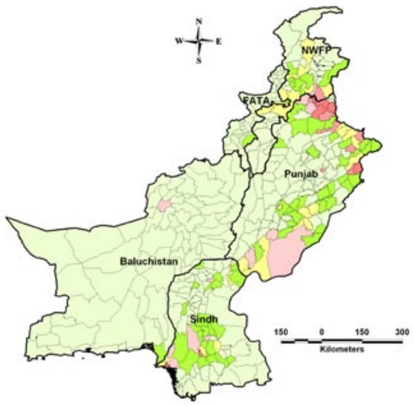
a) Adobe



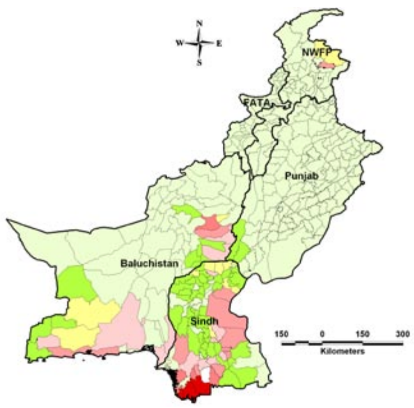
b) Stone masonry

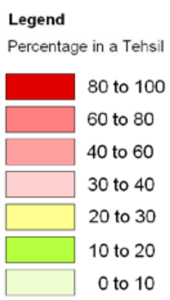


c) Concrete block masonry



d) Brick masonry





e) Timber

Figure 1. Distribution of building types in the Tehsils of Pakistan

The statistics of the building stock of Pakistan are obtained from the last census in 1998 by Ministry of Economic Affairs and Statistics, Government of Pakistan (GoP). The statistical data by GoP is further utilized to obtain the distribution of the building types all over Pakistan. Five typical building types are defined: adobe (36%), stone masonry (24%), concrete block masonry (13%), brick masonry (21%), and timber (5%). The statistics reflect that the dominant building type in Pakistan is masonry. The percentage of reinforced concrete frame structure is not significant, therefore, added in the brick masonry structures.

The distribution of the typical building types in Pakistan at Tehsils level is presented in Figure 1. It has been observed that in Baluchistan province, the majority of buildings are of un-burnt bricks or adobe. Stone masonry is widely used in northern part of Pakistan. Concrete block masonry is found to be used in majority in northern area but also common in central and south Pakistan. Brick masonry is used in urban areas of Pakistan while timber structure is more common in rural areas. It is to be pointed out that reinforced concrete frame structures are built only in urban areas. The percentage of these structures is very less as compared to other types and hence incorporated in brick masonry structures.

3. ASSIGNMENT OF VULNERABILITY CLASS

In the European Macroseismic Scale-98 (EMS-98), for a set of structural types, a most likely vulnerability class with probable and less probable ranges is assigned. It is assumed that the most likely vulnerability class corresponds to a standard structural type. The standard structural types tend to be regular in plan and elevation with medium height. In order to determine to what extent typical Pakistani building types correspond to these standard structural types of the EMS-98, firstly a vulnerability evaluation criteria was defined, secondly, buildings in four test areas in Pakistan were evaluated and then finally vulnerability classes to typical building types were assigned.

3.1. Vulnerability Classes according to EMS-98

The EMS-98 includes six classes of structural vulnerability (A, B, C, D, E, and F). The first two classes A and B represent the most vulnerable building types (buildings most likely not to withstand severe earthquake shaking); and classes C, D, E and F represent building types with less structural vulnerability (buildings most likely to withstand severe earthquake shaking).

The expected damage is also described for each vulnerability class, for intensity greater than V. The number of buildings of one vulnerability class suffering a certain damage grade is defined by the terms few, many and most. The definition of the intensities in the EMS-98 is largely based on building damage surveys. German Taskforce for Earthquakes carried out a number of field surveys after destructive earthquakes, which helped in the definition of intensities and damage grades in the EMS -98 [Schwarz *et al.* 2000]. The EMS-98 defines five damage grades ranging from negligible damage to destruction and typical damage to the structural and non-structural elements is defined for each damage grade.

The vulnerability of the typical building types in the test areas is evaluated by using the vulnerability classification of buildings in terms of the EMS-98, and for different type of structures a most likely vulnerability class and probable ranges are indicated.

The identification of probable uncertainties in the seismic performance of structures is due to the fact that besides the type of structure and construction material there are many other factors affecting the vulnerability of the buildings such as quality and workmanship, geometrical and structural regularity (in plan or in elevation), local site conditions, state of preservation of the buildings, their position with respect to the other buildings, earthquake resistant design (ERD), etc. These factors should be taken into account, when conducting vulnerability assessment.

3.2. Typical building types in Pakistan

Table 1 shows the typical building types in Pakistan, which is a further refinement of typical building types presented in [Maqsood and Schwarz, 2008]. After the 2005 Kashmir earthquake, the use of confined masonry is becoming more common. Reinforced concrete members are used both in concrete block masonry and in brick masonry structures for the purpose of confinement. The building authorities in the affected area have declared the use of confinement as mandatory for the new construction.

a) Stone masonry

b) Unconfined concrete block masonry

c) Concrete block masonry

d) Unconfined brick masonry

e) Confined brick masonry

f) Reinforced concrete frame

Figure 2. Observed damage cases after 2005 earthquake

Table 1: Typical building types in Pakistan and their vulnerability class

Building Type	Description	Vulnerability Class A	B	C	D	E	F	Built in
Adobe	Low strength adobe walls are used with no additional system to restrain the out of plane failure. Wooden logs (beams) with heavy mud roof and straw are used as roof.	○						RA
Stone Masonry	Stone masonry walls are normally used in lean cement sand mortar, often with mud mortar and sometimes even without any mortar. In rural areas, wooden beams with heavy mud roof and straw are used as roof. In urban areas, reinforced concrete roof slab is used.	├	○					RA
Unconfined Concrete Block Masonry	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 300mm x 150mm x 150mm. The roof slab is made of cement or GI sheets which normally has a low weight. Sometimes a 150 mm thick RC slab is also used.	├	○					RA
Confined Concrete Block Masonry	In confined concrete block masonry, reinforced concrete columns are inserted at each corner and junction of the masonry walls. This type of construction is becoming very popular after the Kashmir 2005 earthquakes, especially in northern areas of Pakistan.		├	○	┤			UR
Unconfined Brick Masonry	Clay brick bricks 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 230mm x 115mm x 75mm. The roof slab is made of reinforced concrete having compressive strength of 21 MPa and 150mm thickness. The mixed ratio of concrete is 1:2:4.		├○					UR
Confined Brick Masonry	In urban areas, brick masonry walls are confined with the help of reinforced concrete columns, at each corner and junction of the walls.		├	○	┤			UA
Reinforced Concrete Frames	Reinforced concrete frame structures with infill walls are generally constructed only in urban areas. These four to six storeys RC frame structures are not designed for earthquake loads normally and most of the old structures were designed only for gravity loadings.	├		○	┤			UA
Timber Structures	Timber frames, placed in longitudinal and traverse directions, are filled with masonry walls. 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 & straw are also used as a roof.		├		○			RA

UA: Urban areas RA: Rural areas UR: Urban & rural areas

3.3. Vulnerability of Building Stock in Pakistan

[Maqsood and Schwarz 2008] present 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 [Grünthal *et al*, 1998], see Figure 3. The lower the MVI, the higher the vulnerability of buildings to damage. From [Maqsood and Schwarz 2008], it is observed that buildings in Pakistan have low resistance for earthquake shaking and are vulnerable to damage during an earthquake.

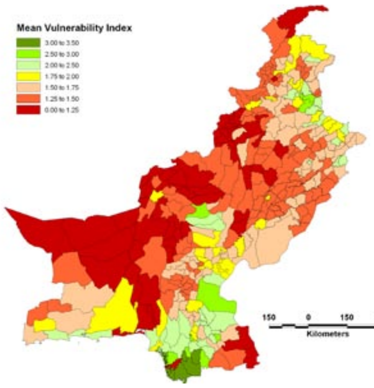


Figure 3. Mean Vulnerability Index, MVI (Maqsood and Schwarz, 2008)

Figure 4. Test areas and provinces of Pakistan

The first survey conducted in October 2005, shows the high vulnerability of structures in terms of severe damage observed after the 2005 Kashmir earthquake, see Figure 2. Keeping in mind the above mentioned factors and by incorporating the building practice and standard in Pakistan, as seen during the filed surveys, a revised vulnerability table has been developed for Pakistan, see Table 1.

4. EVALUATION OF DAMAGE AND RISK ASSESSMENT

Scenarios are used to better understand and help plan for the future. A scenario tells the story of a defined earthquake and its specific impacts [Schwarz *et al.* 2004]. 2005 Kashmir earthquake is used as a scenario event to forecast the damage that would occur, if the earthquake occurs today in the Muzaffarabad city.

4.1. Test Areas

In order to determine to what extent the Pakistani building types correspond to the standard structural types of the EMS-98, building surveys were carried out in typical cities in Pakistan. The selected cities were Islamabad, Muzaffarabad, Sialkot and Jaranawala, see Figure 4. More than 700 buildings were observed and examined in Muzaffarabad in the field survey. Micro level studies on the building types and their vulnerabilities were done. However, for the rest of Pakistan, macro level studies were carried.

Figure 5 shows the building type distribution in the city of Muzaffarabad, as observed in the survey. Most of the structures in the city are used for residential purposes and while some are used for commercial purposes. The majority of structures are either concrete block masonry (confined and unconfined) or brick masonry (confined and unconfined) with reinforced concrete slab roof. Most of the buildings are either single or double storeys, see figure 6.

4.2. Observed damage

Two field surveys were carried out in the affected areas of 2005 Kashmir earthquake: first one in October 2005 and the second one in September 2007. The main goal of the first survey was to record the damage cases in the affected area, which covered the cities of Muzaffarabad, Balakot, Abottabad and Bagh. The focus of second survey was to observe the reconstruction process, after two years of the event. In the second trip, a detailed survey of the building stock in Muzaffarabad was done. Figure 7 shows the results in terms of MDG (D_m) observed during the second survey. In the survey, it was seen that the reconstruction works had been started but despite of the fact, there were still many damaged buildings in the inner city. Some of them were abandoned and were no longer in use, but most of them were in use without any retrofitting measures. The author found hundreds of such buildings during the survey of the inner city. Figure 2 shows the damage cases in the different building types. It is observed that stone and concrete block masonry failed to resist the earthquake forces and most of them suffered heavy damage.

The next step after evaluation of the vulnerability of building stock is to simulate the damages of historical earthquakes. The application would be the zonation of the territory in order to establish the criteria for activation of different levels of the earthquake emergency plan according to the severity of the estimated consequences.

4.3. Damage scenarios

A number of factors influence the damage in a community due to a seismic event, e.g., the severity (intensity) and quality of (spectral acceleration) of ground shaking, site conditions and vulnerability of building stock. [Schwarz *et al.* 2006] presents a methodology and step-wise approaches for estimation of damage, depending upon the availability of information and data.

In the methodology, the level 1 is site-independent approach in which the attenuation of intensity depending upon distance is considered. The level 2 is site-dependent approach, which considers the influence of local site conditions such as geology and topography of the study area. A more refined level (level 3) includes the dynamic building characteristics in the estimation of damage. The estimated damage distribution for the given scenario is described using the Mean Damage Grade (D_m), but can also be illustrated by showing the shares of every single damage grade D_i [Kaufmann and Schwarz, 2008].

Figure 8 presents the result of the simulation of the scenario event of Kashmir earthquake 2005, if they would occur today, by assuming epicentral intensity of VIII and the vulnerability of building stock that was assessed during the second survey in 2007.

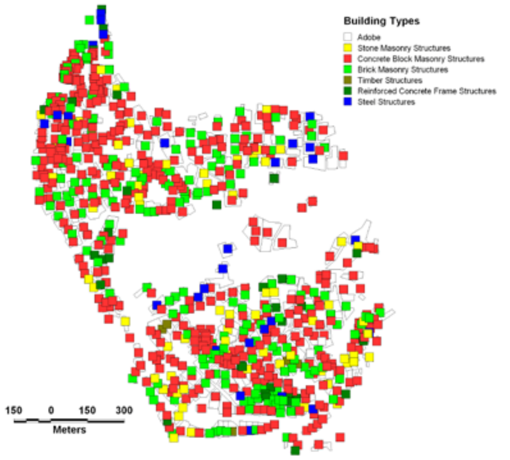


Figure 5. Distribution of building types

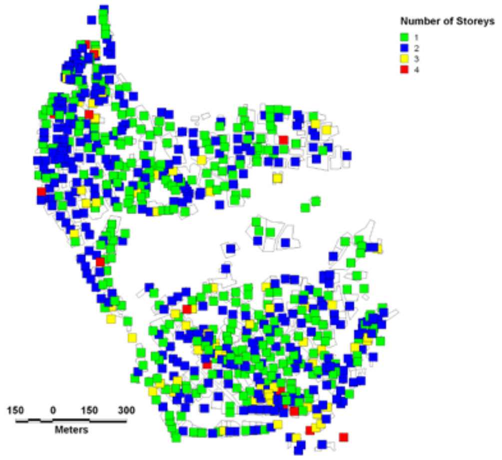


Figure 6. Number of storeys

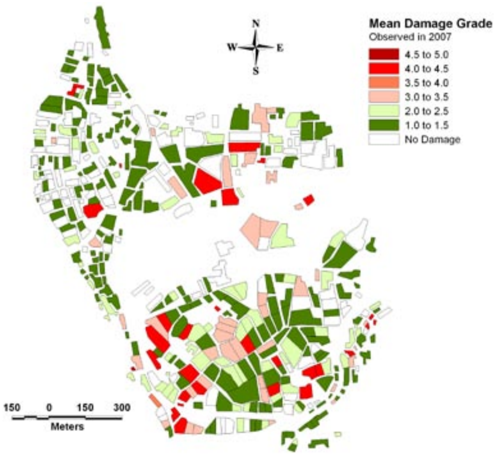


Figure 7. Observed damage in Muzaffarabad (2007)

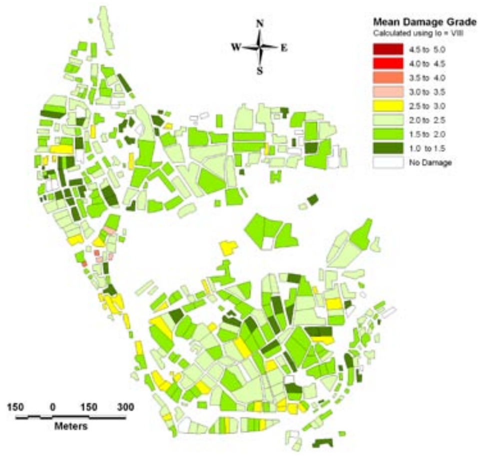


Figure 8. Damage Scenario, I_o = VIII

The result of level I approach does not match exactly with the observation, but requires more refined study. The results shown are simulated by taking into account the seismic vulnerability of the structures only, and the influence of local soil conditions and hydrology was not taken into account, on regards of the availability of the data. Also, the geology and topography of the area play an important role in the damage prognosis. The ground motion characteristics have to be evaluated and incorporated in the model for more detailed investigation.

In the present study, the vulnerability of a structure is assessed as a free standing building; however the influence of adjacent structures could lead to an increase in the resistance of the structure to horizontal forces. Therefore, the results are subjected to more reinfinement, but, nevertheless, gives an indication of the expected damage due to the high vulnerability of the structures.

5. SUMMARY

It is emphasized through the field surveys which were conducted after the 2005 Kashmir earthquakes that the majority of building stock in Pakistan is made of adobe and masonry. The resistance of buildings to earthquake loads is low and the buildings are vulnerable to damage in any moderate to severe earthquake, as seen in 1935 Quetta earthquake and in 2005 Kashmir earthquake.

Micro and macro level studies have been carried out to evaluate the building types and their vulnerabilities. Damage prognosis is given for the city of Muzaffarabad on the basis of 2005 Kashmir earthquake.

From the present study, it can be concluded that more detailed studies should be carried out to refine and improve the vulnerability studies. The ongoing studies are focused to assess the structural vulnerability of Pakistani building stock by analytical and experimental ways, which would lead to more precise risk assessment of the whole the area. Scenario studies in other damage prone areas will also be done and Mean Damage Ratio, MDR (indicating the loss as a percentage of the replacement value) will be calculated from the Mean Damage Grades (D_m).

The output of the study could be the loss calculation due to an earthquake event. Losses will be estimated by using the Mean Damage Ratio, MDR and the asset values of the building stock.

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