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SEISMIC RISK ASSESSMENT OF BUILT ENVIRONMENT IN PAKISTAN

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ABSTRACT

Pakistan is situated at the triple junction of Arabian, Eurasian and Indian plates. The tectonic settings of Pakistan have made it a seismically active region. Based on the history of seismicity in Pakistan, the country is divided into five seismic zones each zones has its defined probability of peak ground acceleration that ranges from 0.05g to < 0.32g. This paper tried to estimate the risk level of various types of buildings of Pakistan in defined seismic zones using GIS software. Damage Probability Matrix (DPM) has been developed for the identified types of existing building in Pakistan using Population & Housing Census, 1998. It was found that more than 50% buildings of Pakistan are located in seismic zone 2A, which have chance of intensity is about VI so the average probability of damage is about 8.16% of total buildings. Among these 8.16% buildings, Stone Masonry type has more than 11% chance of damage, followed by Adobe Masonry, with the highest chance of collapse which is about 18% of total adobe structure in the zone 2A. 3.63% of the buildings of Pakistan pertain to very high seismic zone i.e. zone 4 with a chance of observing intensity ranges from VII to XII. Hence more than 8 hundred thousand building according to estimated buildings in 2013 are on very high risk; among them merely RC buildings has only 17% probability of survival but only at intensity up to X.

INTRODUCTION

Pakistan has about 200 million inhabitants living in approximately 23 million housing units till 2013 according to estimation of latest Population & Housing Census of Pakistan including Azad Kahsmir and Gilgit Baltistan (Census, 2001). A regional heterogeneity in the proportion of existing buildings in Pakistan can clearly be observed (Ahmed, 2013). The availability of raw materials and the local expertise in construction is in direct relation to the number of buildings of specific type found in the region (Ahmed, 2013). The general percentage of existing buildings in Pakistan using the latest census report of Pakistan is shown Figure 1(Census, 2001).

Figure 1 clearly shows that more than 62% of total buildings in Pakistan comprise brick masonry buildings, while in the remaining 38%, the most dominant type is Adobe masonry, again non-engineering structures which constitutes around 15% of the total buildings. On the other hand Reinforced Concrete structures that may be constructed as per engineering standards share only 7.64% of the total buildings of Pakistan and they may frequently found in large urban areas like Karachi, Islamabad and Lahore etc.

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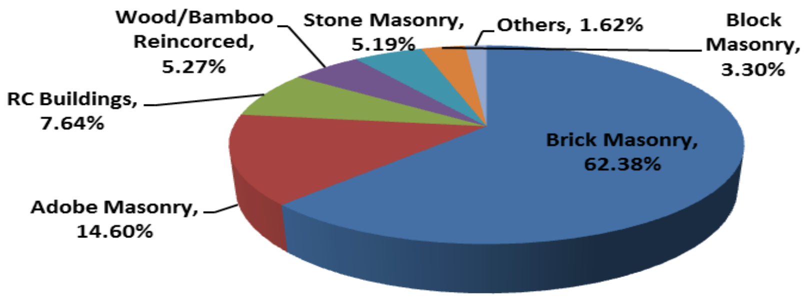

Figure 1 Percentage of Existing Building Types of Pakistan

This Census information regarding building typology has transformed into GIS based grid format by Ahmed, et al., 2012. The transformation of the information into GIS based grid format is based upon the estimated number of population in a grid of 1 km x 1 km over the inhabited region in each district. The district level population and building to population ratio of 1998 Population and Housing census were used as based values for estimating the current population and number of existing types of buildings in each cell of the grid. Figure 2 shows a sample of GIS based grid format map of building typology and population distribution map of Pakistan (Ahmed, et al., 2012).

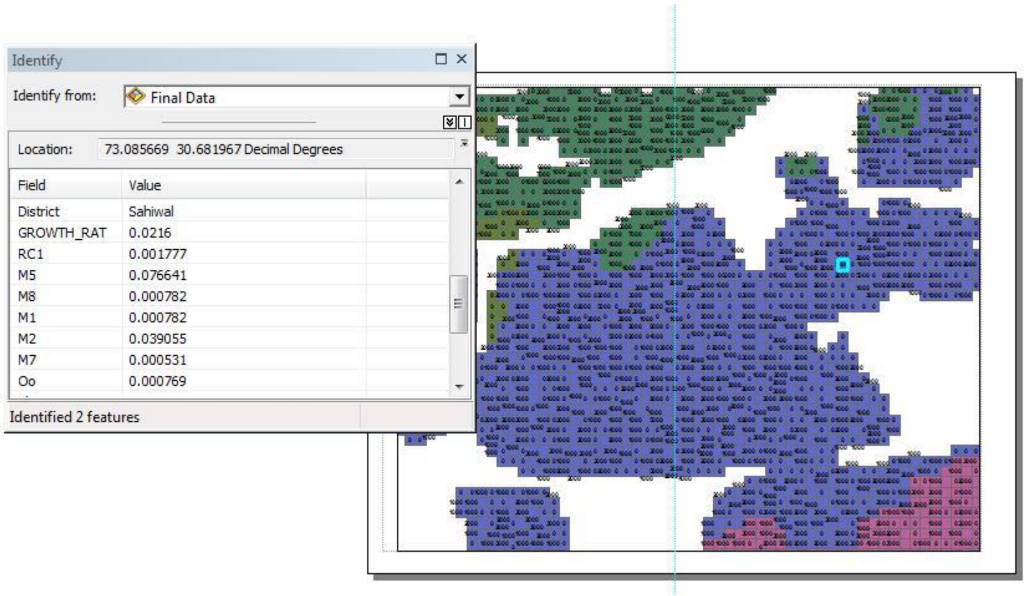

Figure 2 Sample of GIS map of building and population distribution of Pakistan (Ahmed, 2013).

Pakistan is located at highly seismically active region since the region has experiences various earthquakes in the past which results in high rate of damages and killed thousands of people. Historically, the earthquakes have threatened several areas of Pakistan and left deeper impacts. Highly active fault lines are located in this region that could make the population of about 200 million vulnerable to this disaster (Ahmed, 2013). Northern and western sections of Pakistan are more sensitive to earthquake activity than the other sections because they are surrounded by the micro plates of Afghanistan and Iranian and Indian plate. Chaman fault is located in the western section that goes along the northern Makran range, passes Quetta and then to Afghanistan. A fault also run along the Makran coast and it is found to be of the same nature as the West Coast fault along the coast of Maharashtra, India (Kazmi & Qasimjan, 1997). Based upon the observed peak ground acceleration (PGA) of pervious experiences of earthquake in different areas of Pakistan, the country has divided into five seismic zones that range from 0.05g to > 0.32g (MoHW, 2008). Figure 3 shows the Seismic Zones Map of Pakistan while Table 1 shows the PGA ranges for each seismic zone of Pakistan. The PGA values are for rock site condition with shear wave velocity (Vs_{30}) of 760 m/s at depth of 100 meter, where "g" is the acceleration due to gravity (MoHW, 2008).

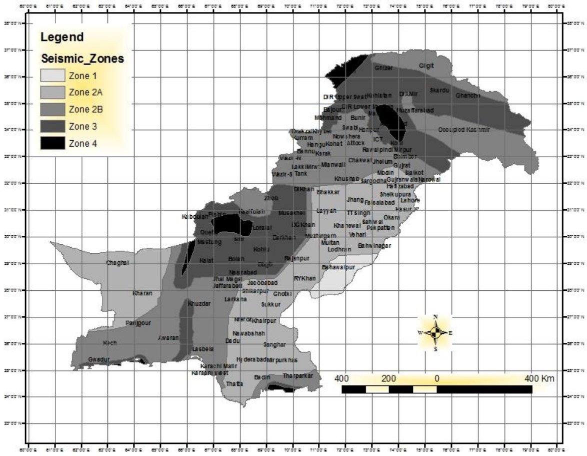

Figure 3 The Seismic Zonation Map of Pakistan (MoHW, 2008)

Table 1 PGA Ranges for Each Seismic Zone

Seismic Zone	PGA Range
Zone 1	0.05 to 0.08g
Zone 2A	0.08 to 0.16g
Zone 2B	0.16 to 0.24g
Zone 3	0.24 to 0.32g
Zone 4	> 0.32g

METHDOLOGY

In order to perform pre-loss estimation anywhere in Pakistan, it is necessary to calculate expected intensities in each seismic zone using the given respective PGA values. Damage Probability Matrix (DPM) is developed to find the probability of damages of existing types of buildings at expected intensities in each seismic zone.

Spatial distributions of existing types of buildings of different areas of Pakistan (Figure 2) were correlated with their respective seismic zone as shown in Figure 3 for Earthquake pre-loss estimation. Seismic zone that reflects the range of peak ground acceleration (PGA) shown in Table 1; PGA value of each zone is further associated with EMS-98 intensity levels using the equation 1(Wong, 2010), for calculating expected range of intensities as shown in Table 2.

An empirical method, a macro-seismic method has been used to develop damage probability matrices for the existing buildings of Pakistan. This method has been suggested by Giovinzai in 2005 (Giovinazzi, 2005). This method requires post-earthquake damage data from previous earthquakes for the development of damage probability matrices. The earthquake of Kashmir 2005 has been the most disastrous earthquakes in the history of Pakistan (Ali, et al., 2009). Being recent the damages from the earthquake have been well documented both by the government and private sector (NESPAK, 2005). Hence, post-earthquake damage data from Kashmir earthquake 2005 has been acquired and used to develop the damage probability matrices for existing buildings of Pakistan. Besides the post-earthquake damage data, this method requires identification of building typology and selection of an intensity scale. Existing building typology for Pakistan has already been derived from the population and census data 1998 while EMS-98 (Grünthal, 1998) has been selected as the intensity scale as most of the researchers have mentioned intensities of different regions in terms of EMS-98 for Kashmir earthquake 2005.

EMPIRICAL RELATIONSHIP BETWEEN INTENSITY AND PGA

The Intensity, observed by an area due to an earthquake shaking, widely depends upon the geology and tectonic properties of the region, but different approaches were carried out around the world to estimate the empirical relationship between Intensity and Peak Ground Acceleration (Wong, 2010). In the present study a relationship as shown in equation 1, formulated by Baron Wong for European buildings, is employed for the calculation of expected ranges of intensities as per EMS-98 in each seismic zone of Pakistan.

$$I=1.51+2.24\text{Log}(PGA)$$ ----------------------------Equation 1(Wong, 2010).

Table 2: PGA range for each Seismic Zone with Possible Intensities

Seismic Zone	Peak Horizontal Ground Acceleration	EMS-98 Intensity
1	0.05 to 0.08g	V to VI
2A	0.08 to 0.16g	VI
2B	0.16 to 0.24g	VI to VII
3	0.24 to 0.32g	VII
4	> 0.32g	VII to XII

DAMAGE PROBABILITY MATRIX

EMS-98 has developed the damage probability matrices (DPM) for each class of the building. Numbers of buildings in each damage grade were represented as few, many and most (Grünthal, 1998). This kind of assessment is qualitative in nature and may result in incomplete and imprecise DPM's. It is, therefore necessary to introduce a distribution which could compensate for the shortcoming. Furthermore based upon the model suggested by Giovinazzi (Giovinazzi, 2005), Alam modified the DPM's provided by EMS-98 for Pakistan using Kashmir damage data as an input as shown in Table 3. (Alam, 2012)

Table 2 Probability of Damage in Percentages at Different Intensity Level for Distinct Building Types (Alam, 2012)

Building Type	V	VI	VII	VIII	IX	X	XI	XII
Reinforce Concrete	0.23	0.97	4.86	20.75	53.06	83.32	96.32	99.26
Stone Masonry	2.35	11.41	37.38	71.60	92.49	98.51	99.66	99.90
Adobe Masonry	3.99	17.82	48.74	80.50	95.52	99.10	99.78	99.93
Brick Masonry	1.40	7.06	27.22	61.28	87.92	97.50	99.47	99.86
Wood/Bamboo Masonry	0.92	4.62	19.96	51.94	82.62	96.13	99.22	99.80
Concrete Block Masonry	1.40	7.06	27.22	61.28	87.92	97.50	99.47	99.86
Average	1.72	8.16	27.56	57.89	83.25	95.34	98.99	99.77

Table 3 shows the probability of damage at different intensities for identified types of building in Pakistan; the probability shown in Table 3 is the cumulative percentage of damage grades from moderate to complete damages.

ASSOCIATION OF DISTRIBUTED BUILDINGS WITH SEISMIC ZONES

The seismic zonation map of Pakistan was obtained from Building Codes of Pakistan (MoHW, 2008). This map was electronically geo-referenced first and then digitized by using geo-spatial analysis software ArcGIS (ESRI, 2011) to obtain spatial extents of the various zones in Pakistan as shown in Figure 3. This map was then overlaid onto a grid map as shown in Figure 2, as described above a grid containing cells of 1x1 km, where each cell has a number of distinct kind of buildings associated with population in Pakistan. At this juncture the grid map is spatially joined with the seismic zonation map of Pakistan to identify the proportions of distinct kind of buildings in the defined seismic zones of Pakistan as shown Figure 4. Table 4 shows the proportions of Area, Population, Buildings and average probability of damages in each seismic zone of Pakistan.

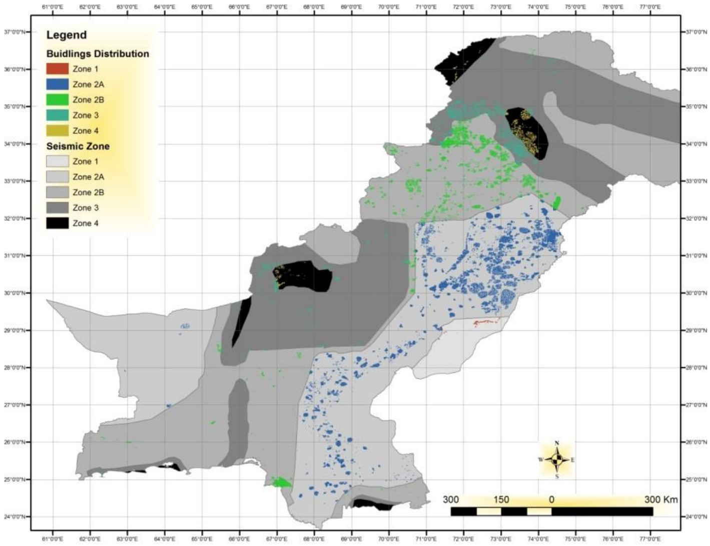

Figure 4 Association of Buildings Distribution with Seismic Zones of Pakistan

Table 3 Element at Risk and Average Probability of Damages in Seismic Zones of Pakistan

Zone	Area	Buildings	Population	DPM	
				Avg_Min	Avg_Max
Zone 1	2.168%	0.499%	0.484%	1.720%	8.160%
Zone 2A	32.082%	60.955%	56.932%	8.160%	8.160%
Zone 2B	35.240%	27.188%	30.339%	8.160%	27.560%
Zone 3	27.057%	9.035%	10.053%	27.560%	27.560%
Zone 4	3.454%	2.323%	2.191%	27.560%	99.770%
Grand Total	100%	100%	100%	-	-

RISK ASSESSMENT IN ZONE 1

Seismic zone 1 shares around 2.17 % land of Pakistan, and is the least seismic over the entire Country. The maximum range of expected intensity is up to VI and at intensity VI the average probability of damages of buildings in Pakistan is around 8.16% of the total buildings, while the minimum expected damage is about 1.72% of total building stock of the region. Figure 5 clearly shows that Brick Masonry is the predominant construction type, with 87% of total buildings of the zone. According to Table 2 seismic zone 1 has expected range of intensity between V and VI. From Table 3 it can be seen that Brick Masonry buildings have a minimum probability of damage, around 1.40% of total buildings and maximum probability is about 7.06% in the zone. The zone has around 11,000 buildings for 9 lac people, and shares 0.5% of total buildings and 0.5% of total population of Pakistan. The proportions of different types of building in the zone are shown in Figure 7.1. The most notable places within this zone are Bahawalpur, Bahwlnagar and Rahimyar Khan.

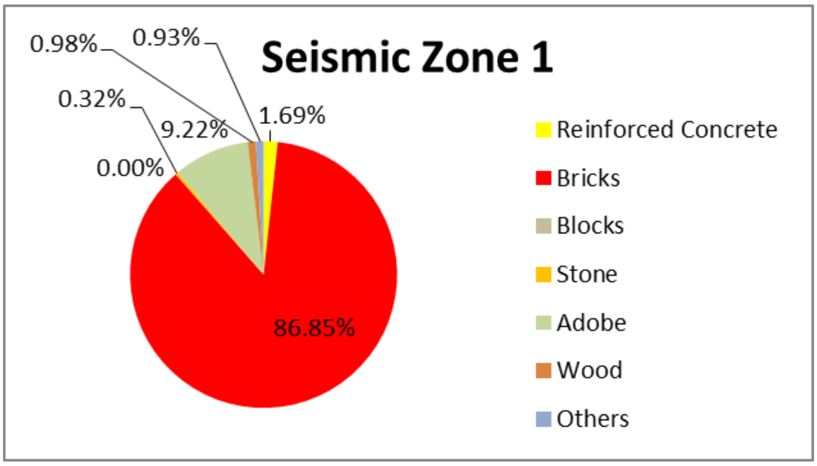

Figure 5 The proportions of different types of building in Seismic Zone 1

RISK ASSESSMENT IN ZONE 2A

More than 50% of the total population of Pakistan lives in zone 2A. This zone is relatively less seismic and has does not observe intensities exceeding VI. As more than 50% of the population lives in this zone, the zone has the largest share of total building stock of Pakistan, which is around 60%. Table 3 shows that at intensity VI the average probability of damage is 8.16% of total buildings of this zone. Figure 6 shows the proportions of the different buildings in the zone, which clearly shows that Brick Masonry is again the leading one, whereas Adobe buildings are found with second highest proportion. Adobe constructions are the most vulnerable kinds of building in the zone, and their probability of damage is around 17.82%. The zone covers most parts of the Punjab and almost all of Sindh excluding Karachi. The important cities of the zones are Lahore, Faisalabad, Hyderabad, Multan, Kasur etc.

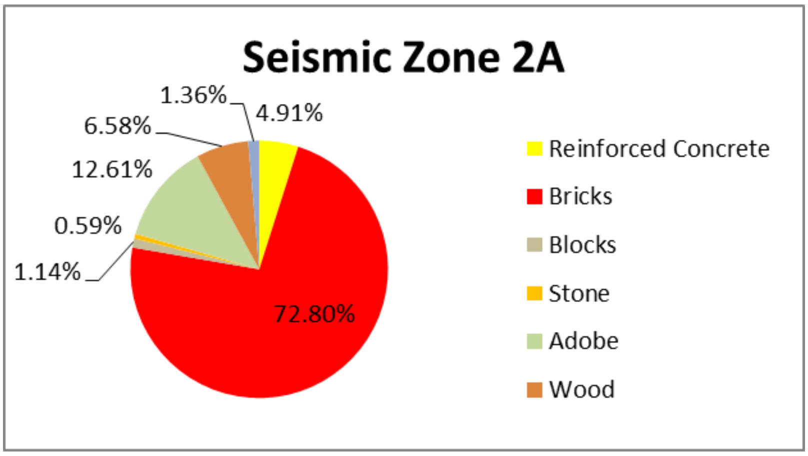

Figure 6 The Proportions of Different Types of Building in Seismic Zone 2A

RISK ASSESSMENT IN ZONE 2B

The largest zone in term of area, this includes Karachi, Islamabad, and Peshawar etc. This zone shares 27% buildings and 30% population of the Country. On average basis from 8.16% to 27.56% of total buildings of the zone are at high risk. Figure 7 shows 17% reinforced concrete buildings in the zone; however these 17% of total RC buildings are located mainly in Karachi and Islamabad. Reinforced the least probability of damage for RC buildings in this zone is 4.86%, while maximum probability of damage is 20.75%. Like Zone 1 and Zone 2A, this zone also has the greatest share of brick buildings and such kind of buildings stocks found in Khyber Pakhtunkhwa and some part of upper Punjab region. In this zone bricks buildings have a minimum probability of damage of about 27.22% whereas 61.28% is the maximum probability of damage in the zone for the type of buildings.

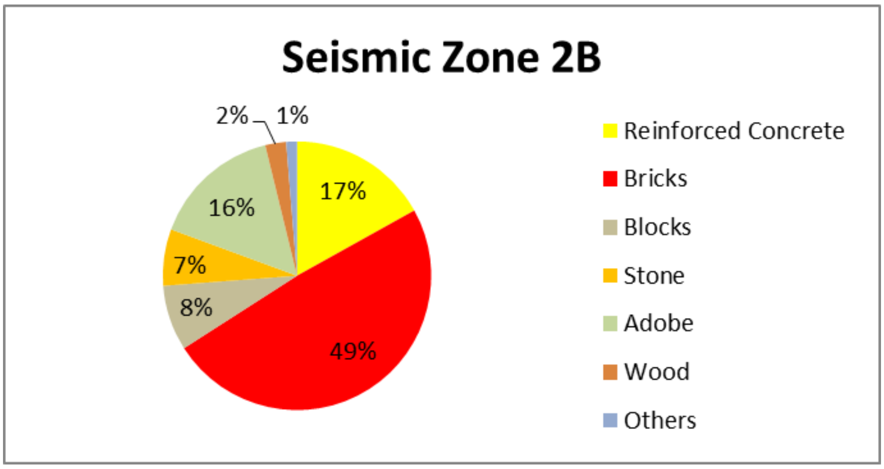

Figure 7 The Proportions of Different Types of Building in Seismic Zone 2B

RISK ASSESSMENT IN ZONE 3

The Zone of relatively higher seismicity is such where intensity of up to VII can be observed. At intensity VII the average probability of damage of the buildings of Pakistan is about 27.56% of total buildings in the Zone. The zone shares around 27.56% in the total land area of Pakistan, while it houses around 10% of the country's population in 9% of the total buildings of Pakistan. In contrast with others zones the Zone has minimum share in total bricks buildings of the country; however in the Zone it has the greatest share of 31%. Overall, the Zone contains almost all kinds of building types that are common to Pakistan in significant proportions, especially Reinforced Concrete and Stone Masonry. Bricks masonry buildings are dominant in Hazara division and part of Azad Kashmir while Stone masonry has a high share in FATA and Gilgit-Baltistan region. The most notable places for the distribution of reinforced concrete buildings are Rawalpindi, DG Khan, Quetta, Gawadur, Gilgit and Abotabad. Figure 7.4 shows the proportions of distinct kind of buildings that exist in the Zone.

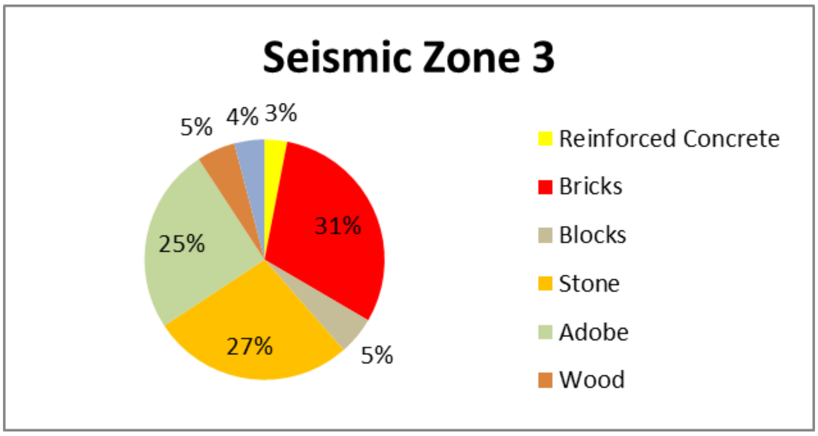

Figure 8 The Proportions of Different Types of Building in Seismic Zone 3

RISK ASSESSMENT IN ZONE 4

The zone experienced very high seismic activity, especially the recent one of Kashmir Earthquake 2005 and 1935 Quetta Earthquake. From the experience of last earthquake it can be predicted that this Zone has a probability of observing maximum intensity, which is XII on the EMS-

98 scale. Intensity XII means totally collapse and there is very little probability of survival for any kind of building. However if the maximum possible intensity is assumed to be X then only 4.66% of the buildings on average can survive. At intensity X only reinforced concrete buildings can survive, up to 17% of total buildings. The notable areas within this zone include Muzfarabad, Quetta, Gawadar and Tharparkar. The proportions of the different kinds of buildings in the Zone are shown in Figure 9.

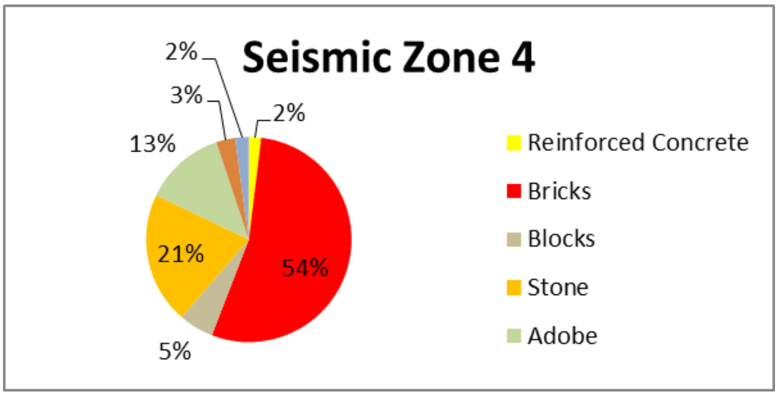

Figure 9 The Proportions of Different Types of Building in Seismic Zone 4

CONCLUSIONS

To conclude overall risk of building stock of Pakistan; distributed buildings of Pakistan were correlated with seismic zone as delimited in Building Code of Pakistan it was found that 50% buildings of Pakistan are located in seismic zone 2A, which have probability of observing intensity is about VI so the average probability of damage is about 9.59% of total buildings in the zone. Among 9.59% Stone Masonry has chance of damage is more than 11% followed by Adobe Masonry, which has the highest chance of collapse which is about 18% of total adobe structure in the zone 2A. Buildings of Pakistan shares about 2.32% in very high seismic zone i.e. zone 4 which have a chance of observing intensity ranges from VII to XII. Hence more than 0.8 million building according to estimated building of 2013 based upon Population and Housing Census, 1998 is on very high risk. Among them only RC buildings has only 17% probability of survival but at intensity up to X. Henceforward it is recommend that buildings should be constructed either according to seismic zone of the region or constructed using lightweight materials such as wooden-bamboo, adobe etc. to save human life during any instance of ground shaking. . Existing building stocks, that are located in high seismic region of Pakistan, are necessarily to be inspected thoroughly and made best possible action for their retrofitting.

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