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Earthquake Hazard and Risk Assessment in Pakistan

Earthquake Risk Assessment of Quetta

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Abstract

Quetta is the capital of the state of Balochistan with a population of around 2.8 million. Quetta is a very important cultural and economical hub for the region as it lies in the trade routes between Afghanistan and Pakistan. The city of Quetta is located in the most active seismic zone of Pakistan with shallow focus earthquakes recorded very close to the city. The vital role of the city in the cultural and economical life of the region combined with the region's active seismicity stipulates the need for a reliable earthquake damage and loss assessment of the city.

The present report summarizes the damage and loss assessment of Quetta and surroundings due to potential future earthquakes in the region. Quetta is divided into 13 zones based on building typology, population, soil type, and socioeconomic conditions. Three earthquake scenarios with magnitudes 6.5, 6.9, and 7.3 with epicenters that are 105, 21 and 66 km away from the center of the city of Quetta, respectively were used in the damage and loss assessment. The exposure, earthquake scenarios and vulnerability information was fed into SELENA (Seismic Loss Estimation using a Logic Tree Approach) to estimate the potential damage and social losses under these three earthquake scenarios.

Of the three earthquake scenarios, the first scenario is estimated to pose no threat to the building stock and the population of the city of Quetta. The second and third earthquake scenarios lead to very similar damage and casualty estimates. Of the six available building typologies, adobe and wet-mud stone buildings are the most vulnerable. Under the earthquake scenarios two and three, New Hazara Town district of Quetta is estimated to suffer the highest damage. This is assessed to be a result of three factors: (1) The district is one of the closest to the epicenters of both earthquakes which leads to higher ground motion parameters; (2) the district has one of the most vulnerable soil conditions in the city and (3) adobe buildings, which are the most vulnerable typology, is very prominent in the district.

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1 Introduction

The city of Quetta is the capital of the state of Balochistan and is located approximately 70 km east of the Afghanistan-Pakistan border (Figure 1). Apart from being the state capital, Quetta has been a trade center and commercial hub of the region for decades and since it is located on a main trade route between Pakistan and Afghanistan.



Figure 1 - Location of the city of Quetta

The city of Quetta and its surroundings is arguably the most earthquake active zone of Pakistan and have experienced several devastating earthquakes throughout the history. One of these major earthquakes occurred on the early morning of 31 May 1935. The 1935 Quetta earthquake, with an estimated magnitude 7.7, was reported to last around three minutes. The epicentre of the earthquake was established to be 4-kilometres south-west of the town of Ali Jaan in Balochistan, some 153-kilometres away from Quetta. The earthquake caused destruction in almost all the towns close to Quetta including the city itself and

tremors were felt as far as Agra, India. As many as 35,000 are estimated to have died during the 1935 earthquake.

The region had experienced two major earthquakes only four years earlier: The first of these near Sharigh, Mw 6.8 24 August 1931, was followed by the Mach, Mw 7.3, earthquake on 27 August 1931. Both these earthquakes caused severe damage and loss of lives, though not comparable in devastation with the 1935 earthquake.

Since 1935, the region was rather silent and did not suffer any major earthquake. Due partly to its importance in economic and cultural life of the region and partly due to the seismic activity of the region, Quetta has been selected as the target city of the earthquake risk assessment.

The main purpose of the earthquake risk assessment is to assess the potential damage and losses that can be created by potential future earthquakes and inform the authorities and the public about the risk their city and its residents face. A reliable earthquake risk assessment also helps identify the most vulnerable building typologies, which, if used properly, can lead to a targeted and economically viable strengthening strategy.

This report summarizes the earthquake risk assessment conducted for the city of Quetta. The second chapter summarizes the technical details of the risk assessment method used in the analysis, while demarcation of the city is summarized in the third chapter. The available building typologies and creation of the building database is summarized in the fourth chapter while, in the fifth chapter, the capacity curves and the vulnerability functions of each building typology are summarized. The results of the damage and loss assessment is presented and discussed in the sixth chapter.

2 Risk Assessment Method

The risk assessment SELENA is based on the HAZUS methodology that has been developed as a multi-hazard risk assessment tool for the US (FEMA, 2004). While the HAZUS approach is attractive from a scientific/technical perspective, the fact that it is tailored so intimately to U.S. situations and to a specific GIS software makes it difficult to apply in other environments and geographical regions.

Aware of the importance of a proper seismic risk estimation, NORSAR/ICG (Norway) and the University of Alicante (Spain), has developed a software in order to compute the seismic risk in urban areas using the capacity spectrum method named SELENA (SEimic Loss Estimation using a logic tree Approach; Molina et al., 2010). The user supplies built area or number of buildings in the different model building types, earthquake sources, empirical ground-motion prediction relationships, soil maps and corresponding ground-motion amplification factors, capacity curves and fragility curves corresponding to each of the model building types and finally cost models for building repair or replacement. This tool will compute the probability of damage in each one of the four damage states (slight, moderate, extensive, and complete) for the given building types. This probability is subsequently used with the built area or the number of buildings to express the results in terms of damaged area (square meters) or number of damaged buildings. Finally, using a simplified economic model, the damage is converted to economic losses in the respective input currency and human casualties in terms of different injury types and casualties are computed (Molina et al. 2010).

The algorithm is transparent in writing and loading the input files and getting the final results. One main innovation of this tool is the implementation of the computation under a logic tree scheme, allowing the consideration of epistemic uncertainties related with the different input parameters to be properly included, and the final results are provided with corresponding confidence levels.

The basic approach is often called the *capacity-spectrum method*, because it combines the ground motion input in terms of response spectra (see, for example, the spectral acceleration versus spectral displacement illustrated in Figure 2

Figure 2 - The methodology is based on presenting the ground-motion response spectral ordinates (at given damping levels) of spectral acceleration versus spectral displacement

with the building's specific capacity curve).

The philosophy is that any building is structurally damaged by its maximum displacement (and not by the acceleration by itself). For each building and

building type the inter-story drift (relative drift of the stories within a multistory structure) is a function of the applied lateral force that can be analytically determined and transformed into building capacity curves. Building capacity curves naturally vary from building type to building type, and also from region to region reflecting local building regulations as well as local construction practice. Under the HAZUS-umbrella FEMA developed capacity curves for 36 U.S. building types for four earthquake code regimes (reflecting the variation in building regulations as a function of time across the U.S.). These 144 capacity curves are developed analytically, but adjusted so that empirical knowledge is incorporated in the curves whenever possible.



Figure 2 - The methodology is based on presenting the ground-motion response spectral ordinates (at given damping levels) of spectral acceleration versus spectral displacement



Figure 3 - The principle of the building specific capacity spectrum intersected by the demand spectrum representing the seismic demand

The building capacity curve is defined through three control points: Design, Yield and Ultimate capacity (Figure 3). Up to the yield point, the building capacity curve is assumed to behave linearly elastic. From the yield point to the ultimate point, the capacity curve changes from an elastic to a fully plastic state (curved form), and the curve is assumed to remain fully plastic past the ultimate point. A bi-linear representation (two linear parts) is sometimes used to simplify the model shown in Figure 3.

The fragility functions are developed as log-normal probability distributions of damage from the capacity curves (see the illustration in Figure 4).



Figure 4 - Example fragility curves showing the probabilities $P(d_s | S_d)$ of being in or exceeding the different damage states, ds, for building type C1M as given in HAZUS

The structural damage states are (as in most other proposed schemes and neglecting the state no damage) divided into four damage states: "slight", "moderate", "extensive", and "complete". A detailed description of these damage states are found in many places. For example, the description of damage states for concrete frame buildings are:

slight: Flexural or shear type hairline cracks in some beams and columns near joints or within joints.

moderate: Most beams and columns exhibit hairline cracks. In ductile frames some of the frame elements have reached yield capacity indicated by larger flexural cracks and some concrete spalling. Non-ductile frames may exhibit larger shear cracks and spalling.

extensive: Some of the frame elements have reached their ultimate capacity indicated in ductile frames by large flexural cracks, spalled concrete and buckled main reinforcement; non-ductile frame elements may have suffered shear

failures or bond failures at reinforcement splices, or broken ties or buckled main reinforcement in columns which may result in partial collapse.

complete: Structure is collapsed or in imminent danger of collapse due to brittle failure of nonductile frame elements or loss of frame stability. Approximately 13% (low-rise), 10% (mid-rise) or 5% (high-rise) of the total buildings in this building typology with complete damage is expected to be collapsed.

The physical damage estimates are then converted to economic loss and casualty estimates using the HAZUS methodology. Detailed information on how the economic loss and casualties are computed can be found in SELENA manual (<u>http://selena.sourceforge.net/userman.shtml</u>) as well as HAZUS manual (FEMA, 2004).

3 Demarcation of the Study Area

The first step of any damage and loss assessment study is to get an overview of the size and dimension of the study area. For a reliable earthquake loss and risk assessment at the scale of a city, the study area must be divided into smaller geographical units (geounits). A geounit is the smallest geographical unit for which the input information including the building inventory, population information, soil classification, etc will be provided. The results of the risk assessment will also be obtained and presented at these geounits. The accuracy of the input information as well as the risk assessment results increases as the number of geounits increase. However, an increase in the geographical units also increases the time that needs to be spent to prepare the input data as well as the computation time. Hence, the number of geounits should be:

- so many that local variations in damage and loss estimates can be identified and a certain level of detailedness and resolution is provided,
- so few that their number can be handled during the course of the project.

In an urban environment, a geounit is related to a conglomerate of building blocks or smaller city districts such as sectors. For rural areas, a geounit may cover an entire village or a conglomerate of several separately located settlements.

A geounit, in general, shall cover an area of homogenous conditions. This with respect to:

- geology (local subsoil conditions that affect the amplification characteristics during earthquake motion),
- topography (plane surface (basin), foothill, slope, ridge or hilltop),
- era of construction which is strongly connected to different code design levels and certain building typologies,
- socio-economic conditions which is related to the quality of construction, state of building maintenance, population density and social resilience.

With these criteria in mind, the city has been divided into 13 zones. The main criterion in this division was the socio-economic conditions, which significantly affect the distribution of building typologies. Figure 5 depicts the demarcation of the city of Quetta into thirteen zones according to the socio-economic conditions. These thirteen zones were then divided into smaller geounits (119 geounits in total) to have a more refined and accurate analysis; Figure 6.



Figure 5 - Demarcation of the city of Quetta into 13 zones according to the socio-economic conditions.



Figure 6 - Demarcation of the city of Quetta into 119 geounits.

4 Building Database

A total of 278,938 buildings distributed into six different buildings constitute the building stock of the city of Quetta. Most of the buildings have been constructed without paying too much attention to the seismic design principles. A total of six building typologies are available in the city of Quetta. Table 1 summarizes the building typologies available.

No. final	Index final	HAZUS mbt	story no.	comments
1	RC_L	C3L	1-3	concrete frame with unreinforced masonry
2	RC_M	C3M	4-6	infill walls
3	WMS	-	1	Unreinforced wet-mudstone buildings
4	AD	AD	1	Adobe; unreinforced sun-baked mudstone buildings
5	WD	-	1	Wood buildings
6	BrMs	-	1-2	Unreinforced brick masonry

Table 1 - Classification scheme for available building typologies in Quetta

Once the classification of the available building typologies has been complicated, the percentage distribution of the buildings into each building typology for each zone was estimated by the local experts who currently live or has lived in the city of Quetta. As a result, the following table (Table 2) was obtained. Using the information in Table 2, the total number of buildings in each geounit and its distribution among the building typologies was computed. Figure 7 presents the final distribution of the total building stock in different building typologies.

As Figure 7 depicts, low-rise reinforced concrete frame with unreinforced masonry infill walls is the most prominent building typology with more than half of the buildings falling in this building typology. Wet-mudstone and unreinforced brick masonry buildings are also very common with approximately 25% and 15% share of the total building stock, respectively. Mid-rise reinforced concrete (RC_M) and wood buildings, although exist, are very few and together they constitute only 0.42% of the building stock.

Building Typology									
Zone	Remarks	RC_L	RC_M	WMS	AD	WD	BrMs	Population in %	
Zone1 Satellite Town	Relatively new; rich residents	98	0	0	0	0	2	12	
Zone 2 Pashtonabad	Poor neighborhood; one room buildings	20	0	40	15	0	25	18	
Zone 3 Centrum	Administrative buildings	89	1	0	0	0	10	24	
Zone 4 Quetta Cantt	Military zone; on the foothills (possibly rock)	70	0	2	0	1	27	8	
Zone 5 Jinnah Town	Rich neighborhood	97	0	0	0	0	3	4	
Zone 6 Kharot Abad	Poor neighborhood; one room buildings	2	0	80	5	0	13	8	
Zone 7 Salim Town	Rich neighborhood	85	5	5	3	0	2	2	
Zone 8 Sariab	Buildings constructed without approval	20	0	70	5	0	5	9	
Zone 9 Hazara Town	Both rich and poor reside	60	0	15	6	0	19	3	
Zone 10 Samugli	Both rich and poor reside	50	0	40	2	0	8	4	
Zone 11 Quetta North	Rich neighborhood	97	0	0	0	0	3	3	
Zone 12 Hazarganji	Both rich and poor reside	8	0	30	2	0	60	2	
Zone 13 Quetta East	Both rich and poor reside	35	0	60	0	0	5	3	

Table 2 - Percentage building distribution in different zones of the city of Quetta



Figure 7 - Distribution of the total stock building among typologies.

Figure 8, Figure 9 and Figure 10 present the distribution of low-rise reinforced-concrete, wet mud-stone and unreinforced brick masonry buildings in the city of Quetta, respectively. As Figure 8 depicts, low-rise reinforced-concrete buildings are prominent in the entire city but they form almost the entire building

stock in the mid-section of the city where the socio-economic level of the residents is higher compared to the outskirts of the city. On the contrary, building typologies such as wet-mud stone and unreinforced masonry, which are often constructed by the residents of the buildings themselves, are more prominent in the outskirts of the town where the residents have lower income compared to the mid-section of the city.



Figure 8 - Geographical distribution of low-rise reinforced-concrete buildings in the city of Quetta



Figure 9 - Geographical distribution of wet-mud stone buildings in the city of Quetta



Figure 10 - Geographical distribution of unreinforced brick masonry buildings in the city of Quetta

The total population of Quetta in 2012 is estimated to be 2,831,364. Figure 11 presents the geographical distribution of the population throughout the city.



Figure 11 - Population distribution in the city of Quetta

Finally, Figure 12 presents the soil classification of the city of Quetta according to NEHRP soil classification scheme (FEMA 1997; Table 3). In Figure 12, blue color indicates soil type B, dark blue color indicates soil type C, and green and yellow colors indicate soil types A and D, respectively.



Figure 12 - Soil classification of the city of Quetta according to NEHRP soil classification scheme

Table 3 - NEHRP soil classification scheme.

Code	NEHRP site class	Site class description	Shear-wave velocity Vs,30 [m/s]
1	А	Hard rock	>1500
2	В	Rock	760-1500
3	С	Very dense soil and sof rock	360-760
4	D	Stiff soil	180-360
5	E	Soft soil	<180

5 Capacity Curves and Fragility Functions

5.1 General

For analytical risk computation applying the Capacity Spectrum Method (CSM; Freeman et al., 1975; Freeman, 1998) the provision of reliable capacity curves and vulnerability functions for the prevalent building types is one of the most important issues.

Unfortunately, there are no vulnerability functions that have been developed specifically for Pakistan and developing such functions is not possible within the time frame and resources of this project. As such, the vulnerability functions for this study has been selected from the functions provided by HAZUS (FEMA, 1999) Even though these curves were not specifically developed for Pakistani buildings, it is believed that these curves can be applied in order to represent the damage behavior of these typologies.

5.2 Applied (pushover) capacity curves

For each of the 6 defined model building types, Table 4 lists the respective parameters describing the capacity curve. Figure 13 schematically illustrates the main parameters of a capacity curve as defined by the HAZUS Manual (FEMA 2004).



Spectral Displacement (inches)



No.	Index final	No of stories N	Reference (Authors)	D _y [<i>mm</i>]	A _y [m/s ²]	D _u [<i>mm</i>]	A _u [m/s ²]
1	RC_L	1-3	C3L-pre (HAZUS)	3.05	0.98	13.24	2.21
2	RC_M	4-6	C3M-pre (HAZUS)	6.60	0.81	19.13	1.84
3	WMS	1	M2-1 (Cattari et al., 2004)	1.01	1.41	10.70	1.41
4	AD	1	M2-1 (Cattari et al., 2004)	1.01	1.41	10.70	1.41
5	WD	1	W1-pre (Gencturk et al., 2007)	10.41	1.57	133.60	2.75
6	BrMs	1-2	RM1L (HAZUS)	4.06	1.30	18.84	2.62

Table 4 - Parameters of the applied capacity curves to the available building typologies

5.3 Applied fragility functions

The conditional probability of being in, or exceeding a discrete damage state, ds, given by the spectral displacement S_d (or other seismic demand parameter) is defined by the following equation:

$$P\left[ds|S_{d}\right] = \Phi \cdot \left[\frac{1}{\beta_{ds}} \cdot \ln\left(\frac{S_{d}}{\overline{S}_{d,ds}}\right)\right]$$

in which:

 $\overline{S}_{d,ds}$ median value of spectral displacement at which the building reaches the threshold of damage state ds,

 β_{ds} - standard deviation of the natural logarithm of spectral displacement for damage state ds,

 Φ - standard normal cumulative distribution function.

Both parameters, mean displacement threshold of damage state $S_{d,ds}$ and its corresponding standard deviation β_{ds} are given in Table 7. It should be regarded that the parameters defining the fragility functions for a certain building type are closely connected to its respective capacity curve.

No.	Index final	Reference (Authors)	-S _{d,slight} [mm]	eta_{slight}	—S _{d,mod} [mm]	eta_{mod}	- S_{d,ext} [mm]	β_{ext}	- S_{d, comp} [mm]	eta_{comp}
1	RC_L	C3L-pre (HAZUS)	10.92	1.19	21.84	1.15	54.86	1.15	128.02	0.92
2	RC_M	C3M-pre (HAZUS)	18.29	0.9	36.58	0.86	91.44	0.9	213.36	0.96
3	WMS	M2-1 (Cattari et al., 2004)	0.6	1.11	1.4	1.11	5.9	1.11	10.8	1.11
4	AD	M2-1 (Cattari et al., 2004)	0.6	1.11	1.4	1.11	5.9	1.11	10.8	1.11
5	WD	W1-pre (Gencturk et al., 2007)	12.7	0.92	40.89	0.87	81.03	0.86	114.55	0.84
6	BrMs	RM1L (HAZUS)	14.73	1.2	23.37	1.17	58.67	1.17	160.02	0.94

Table 5 - Parameters of the fragility functions applied to the available building typologies



Figure 14 - Fragility functions for available building typologies

6 Results of Damage Assessment

6.1 Scenario Earthquakes:

Damage assessment of the city of Quetta has been repeated for three earthquakes. The first earthquake (EQ1) is a magnitude M6.5 earthquake with an epicenter approximately 105 km northeast of the city of Quetta. The second earthquake (EQ) is a magnitude M6.9 earthquake approximately 21 km west of the city and, the final earthquake (EQ3; M7.3) is approximately 66km south-west of the city. EQ3 represents the 1935 Balochistan earthquake that has reportedly claimed around 35,000 lives. Figure 15 depicts the locations of the epicenters of the three scenario earthquakes with respect to the location of the city of Quetta.



Figure 15 - Epicenters of the three scenario earthquakes with respect to the location of the city of Quetta

The ground motion was represented by a IBC type design spectrum and the ground motion parameters was computed using Campbell and Bozorgnia (2003) ground motion prediction equation.

6.2 General Overview of the Damage and Casualty Estimates

Figure 16 depicts the estimated number of buildings in each damage state for the three scenario earthquakes defined previously. The damage estimates shown in Figure 16 suggest that scenario earthquake with a magnitude of M6.5 and an epicenter that is approximately 105 km away from the center of the city of Quetta poses virtually no risk to the city of Quetta with almost all of the buildings surviving the earthquake with none or slight damage. On the other hand, the remaining two scenarios, namely EQ2 with a magnitude of M6.9 and an epicenter 21 km away and EQ3 with a magnitude M7.3 and an epicenter 66 km away from the city, are estimated to create significant damage in the city of Quetta.



Figure 16 - Damage statistics for the three scenario earthquakes

The injury estimates shown in Figure 17 also provide a similar picture: No persons are estimated to be injured for EQ1 while EQ2 and EQ3 are estimated to result in injuries and casualties by the thousands. As in most, if not all, earthquake damage estimates, the most dangerous time for an earthquake to occur is in the early morning hours of the day (represented by 2:00 in this study), when most of the people is expected to be indoors while an earthquake during the commuting hours (ca 17:00) leads to the lowest injury estimates since, of the three

earthquake occurrence times, least number of people is expected to be indoors at 17:00.



Figure 17 - Injury estimates for the three scenario earthquakes with three different occurrence times

The damage and injury estimates shown in Figure 16 and Figure 17 respectively suggest that earthquake scenarios 2 and 3 warrant further investigation while earthquake scenario 1, which is estimated to pose no risk to the building stock and community of the city of Quetta, can be omitted in the detailed investigation. As such, the following discussion will be focused on only EQ2 and EQ3.

6.3 Damage Estimates for Earthquake Scenario 2.

The second earthquake scenario (EQ2), which has an epicenter 21 km west of the city of Quetta and a magnitude of M6.9, is estimated to lead to the highest damage and casual estimates among the three earthquake scenarios considered in this study. Despite the fact that EQ2 has a smaller magnitude than EQ3, M6.9 compared to M7.3, it leads to slightly higher damage estimates since it has an epicenter much closer to the city center compared to EQ3; 21 km as compared to 66km.

Figure 18 presents the damage estimates for individual building typologies under EQ2. Of the building typologies available, mid-rise and wood buildings are very seldom and their statistics can barely be seen in the figure. Of the prominent building typologies, wet-mud stone buildings and adobe buildings seem to be most



vulnerable while low-rise reinforced and brick masonry buildings exhibit comparatively favorable behavior.

Figure 18 - Damage statistics for individual building typologies under EQ2

Figure 19 to Figure 22 depict the damage estimates of low-rise reinforced concrete (Figure 19), wet-mud stone (Figure 20), adobe (Figure 21) and brick masonry (Figure 22) buildings under EQ2. The figures indicate that, the buildings located in the south-west region of the city, particularly New Hazara Town region is expected to suffer the highest damage (Figure 21). This can be attributed to the close proximity of this region to the epicenter of the earthquake as well as the soft soil conditions in this region, Figure 12. On the other hand, while Kharotabad region is also located on the western part of the city of Quetta, this region is expected to suffer less damage compared to the New Hazara Town region (Figure 20 and Figure 21). This difference can be attributed to the fact that the soil conditions in Kharotabad region is generally rock (class A) while the soil conditions in New Hazara Town is stiff soil (class D); Figure 12. Earthquake scenario 2, if it occurs in the early morning hours, is estimated to result in approximately 15,000 casualties (Figure 17). This estimate drops to approximately 12,000 and 6,000 for earthquake occurring at 10:00 and 17:00, respectively.



Figure 19 - Damage estimates of RC_L buildings under EQ2



Figure 20 - Damage estimates of wet-mud stone buildings under EQ2



Figure 21 - Damage estimates of adobe buildings under EQ2



Figure 22 - Damage estimates of brick masonry buildings under EQ2.

6.4 Damage Earthquakes for Scenario 3

Figure 23 presents the damage estimates for individual building typologies under the earthquake scenario 3, which represents the 1935 Balochistan earthquake and has a magnitude of 7.3 and has an epicenter that is 66 km away from the center of the city of Quetta. Figure 18 and Figure 23 show that damage estimates for both EQ2 and EQ3 are very similar to each other.



Figure 23 - Damage estimates for individual building typologies under EQ3.

The geographical distribution of the damage estimates for different building typologies under EQ3 plotted in Figure 24 to Figure 27 also show strong similarities to the same figures plotted for EQ2 (Figure 19 to Figure 22). Under EQ3, New Hazara Town is estimated to suffer the highest damage, mainly to the adobe buildings (Figure 26). This again can be attributed to the unfavorable soil conditions and to the fact that adobe buildings, which are the most vulnerable building typology together with the wet-mud stone buildings, are the dominant building typology in this region. The damage distribution among the other parts of the city seems to be evenly distributed. Finally, the casualty estimates from EQ3 are also very similar to EQ2 with approximately 15,000 estimated casualties if the earthquake occurs at 02:00.



Figure 24 - Damage estimates of RC_L buildings under EQ3



Figure 25 - Damage estimates of wet-mud stone buildings under EQ3



Figure 26 - Damage estimates of adobe buildings under EQ3



Figure 27 - Damage estimates of brick masonry buildings under EQ3

7 Conclusion

The city of Quetta is located in one of the seismically most active zones in Pakistan. Quetta has been struck many damaging earthquakes in the history, most devastating being the 1935 earthquake which claimed approximately 35,000 lives. Quetta has been selected as the target city of the earthquake damage and loss assessment studies due to its significance in the social and economical livelihood of the region as well as its proximity to several active faults with the capacity to produce strong earthquakes.

Damage and loss assessment of Quetta was conducted under three different scenario earthquakes: A M6.5 event approximately 105 km away from the city, a M6.9 approximately 21 km away from the city and finally, a M7.3 event approximately 66km away from the city. The third scenario earthquake is aimed to duplicate the 1935 Balochistan earthquake. As a result of the simulations the following conclusions have been drawn:

- Scenario earthquake one is not estimated to pose a significant risk to the city of Quetta. Almost all of the buildings are expected to survive the EQ1 with none or slight damage with no expected casualties.
- The second scenario earthquake is estimated to cause the highest damage and loss in the city despite it has a lower magnitude than earthquake scenario three. This can be attributed to the epicenter of the earthquake scenario 2 being much closer to the city center compared to that of the earthquake scenario 3; 21 km as opposed to 66km. However, it should be noted that the damage and loss estimates of these two earthquake scenarios are very close to each other.
- Under both earthquake scenarios 2 and 3, adobe and wet-mud stone buildings, that are generally constructed by the owners of the buildings themselves or laymen that have no experience or knowledge about earthquake resistant construction, are expected to suffer the highest damage.
- Both scenarios are estimated to lead to approximately 15,000 casualties in case the earthquake occurs around 02:00. This number drops to 12,000 and 6,000 for earthquake occurring at 10:00 and 17:00, respectively.

- The southwest region of the city, called New Hazara Town, is estimated to suffer the highest damage in the two earthquake scenarios considered (scenarios 2 and 3). This can be explained as a combined result of three factors. First, location wise, New Hazara Town is one of the closest districts to the epicenter of both earthquakes compared to the other parts. Second, this district has one of the most unfavorable soil conditions in the city of Quetta. Finally, there are several adobe buildings in this region, which have very high vulnerability.
- It should be noted that this report presents a first attempt to provide an estimate of the damage and loss that can be expected in the city of Quetta. Due to the sensitive security situation in the city of Quetta, it was not possible to obtain a more accurate building database and information about the vulnerability of the buildings could not be compiled. As such, the damage and loss assessment reported in this study is based on crude data. Moreover, the earthquakes that were used in the analysis are three scenarios of possible many, each of which can have significantly different characteristics compared to the considered earthquakes. Therefore, it should be noted that the results presented in this study can deviate from the observed damage and losses after a real earthquake. Further efforts should focus on refining and improving the databases that will lead to better and more accurate damage and loss estimates.

References

- Campbell K.W. and Y. Bozorgnia (2003). Updated near-source ground-motion (attenuation) relations for the horizontal and vertical components of peak ground acceleration and acceleration response spectra. Bulletin of the Seismological Society of America, pages 314-331.
- Cattari, S., Curti, E., Giovinazzi, S., Lagomarsino, S, Parodi, S., and Penna, A. (2004). Un modello meccanico per l'analisi di vulnerabilità del costruito in muratura a scala urbana, VI Congreso nazionale "L'ingegneria Sismica in Italia", Genova 25-29 gennaio 2004.
- Federal Emergency Management Agency (FEMA). (2004). HAZUS-MH Multi-hazard Loss Estimation Methodology, Earthquake Model, Advanced Engineering Building Module. FEMA, Washington DC
- Federal Emergency Management Agency (FEMA). (1997). NEHRP recommended provisions for seismic regulations for new buildings, FEMA 222A. Technical report. Washington DC.
- Freeman, S.A., Nicoletti, J.P., and Tyrell, J.V. (1975). Evaluations of existing buildings for seismic risk - A case study of Puget Sound Naval Shipyard, Bremerton, Washington', Proc. 1st National Conf. Earthquake Engng., EERI, Berkeley, 1975, 113-122.
- Freeman, S.A. (1998). Development and use of capacity spectrum method, Proc. 6th National Conf. Earthquake Engng., Seattle, EERI, Oakland, 1998.
- Gencturk, B., Elnashai, A.S., and Song, J. (2007). Fragility relationships for populations of building based on inelastic response. Technical report, Mid-America Earthquake Center, Urbana, Illinois, U.S., August 2007, 194 pp.
- Molina, S., Lang, D.H., and Lindholm, C.D. (2010). SELENA An open-source tool for seismic risk and loss assessment using a logic tree computation procedure. Computer and Geosciencies 36: 257-269, doi:10.1016/j.cageo.2009.07.006.