Deterministic Seismic Hazard Assessment of Quetta, Pakistan

M.A. Shah
Micro Seismic Studies Programme, Islamabad, Pakistan
Pakistan Institute of Engineering and Applied Sciences, Islamabad, Pakistan

M. Qaisar
Centre for Earthquake Studies, National Centre for Physics, Islamabad, Pakistan

J. Iqbal & S. Ahmed
Micro Seismic Studies Programme, Islamabad, Pakistan

SUMMARY:
The deterministic seismic hazard assessment (DSHA) study was carried out for the provincial capital of Baluchistan, Pakistan – Quetta. DSHA of Quetta was carried out considering the identification, characterization of earthquake sources, consideration of suitable tectonic model, source-to-site distance determination, selection of the controlling earthquake and evaluation of ground motion hazard parameters such as PGA and v_{max}. It was concluded from the results that maximum magnitude potential for different faults results a maximum value for Chaman Fault while Quetta has revealed the seismic hazard on the basis of deterministic approach as having a g-value of 0.35g and v_{max} of 45 cm/sec.

Keywords: Deterministic, Seismic Hazard Assessment, Maximum Magnitude Potential, PGA, Quetta

1. INTRODUCTION

Science is advancing day by day by leaps and bounds but still we feel ourselves helpless against many of the natural disasters phenomena. Earthquake is a natural phenomenon and is one of them. Earthquakes can occur at any time at about any place. But scientists and engineers have tried their best to predict or at least estimate them and their ground motions at the places of interest.

Earthquake ground motion hazard evaluation is mainly of two types: deterministically or probabilistically. From the very early days of geotechnical earthquake engineering, deterministic seismic hazard assessment (DSHA) was commonly used. Still many researchers prefer it over probabilistic seismic hazard assessment due to a number of reasons. For nuclear engineering structures, use of DSHA is also well-established though the probabilistic approach is gradually getting a vote of confidence and appreciation. Probabilistic techniques for estimation of seismic hazard are more useful when there is abundant availability of seismic data; however, for regions with enough active faults but having less seismic data, pragmatic results cannot normally be estimated probabilistically.

In this study, seismic hazard assessment (SHA) for Quetta, the Provincial Capital of Baluchistan, Pakistan, using the deterministic approach was carried out.

2. METHODOLOGY

In DSHA, there is mainly the development of a specific seismic scenario. Hazard evaluation of ground motion has its basis on this scenario. This seismic scenario comprises the postulate that any earthquake having a specific size occurs at a particular location. A characteristic illustration of DSHA can be given as following four-step process (Reiter, 1990):

i) Earthquake sources identification and characterization: all the earthquake sources which can produce certain ground motion somewhere are identified and they are characterized by their geometry and potential.

ii) Source-site distance selection: Shortest distance determined from each source upto a certain site is selected. It may be hypocentral distance or epicentral distance but it depends upon the distance measure in predictive empirical relationship(s) used in the following step.

ii) Controlling earthquake selection: It is basically the selection of earthquake corresponding to the expected strongest shaking. Various ground motion parameters commonly express this shaking at a particular site. The selection is made by comparing the levels of shaking produced by earthquakes (identified in step i) assumed then to occur at the distances identified in step ii. The controlling earthquake is portrayed by its size (generally expressed as magnitude) and its displacement from site.

iv) Hazard at a particular site is properly defined, typically by ground motions expected at that site locality by controlling earthquake. Its characteristics are usually described by one or more ground motion parameters obtained from predictive empirical relationships for ground motion parameters. Seismic hazard is usually characterized by Peak acceleration, peak velocity, and response spectrum ordinates etc.

The DSHA procedure is presented schematically in Fig. 2.1. Expressed in these four compact steps, DSHA appears to be a quite simplified procedure, and in many respects it is. DSHA normally evaluates the worst case scenario and is much suitable for vital structures whose destruction or failure is supposed to be not of no question. Nonetheless, it does not present any information on likelihood of occurrence of the controlling earthquake, likelihood of it occurring where it has been assumed to occur, the level of shaking that might be expected during a while (such as the useful lifetime of a particular structure or facility), or the effects of uncertainties in the different steps required to compute the resulting ground motion characteristics (Kramer, 1996).

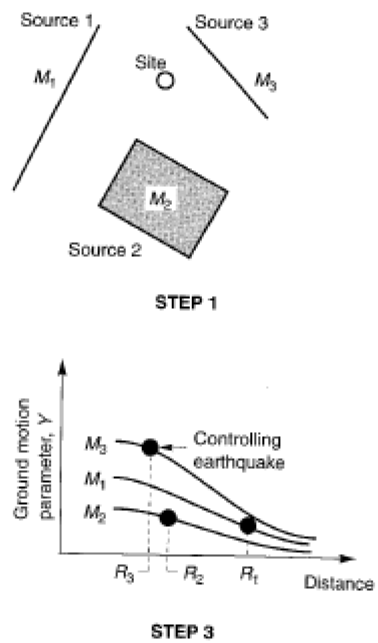

Figure 2.1. Four-steps process of a deterministic seismic hazard assessment

3. CASE STUDY OF QUETTA

As a case study, DSHA of Quetta was determined. Quetta is the most populous city and provincial capital of Baluchistan province of Pakistan (See its location in Fig. 3.1 with red star). It is considered to be the most earthquake prone area of the country. It has already experienced many significant earthquakes in past.

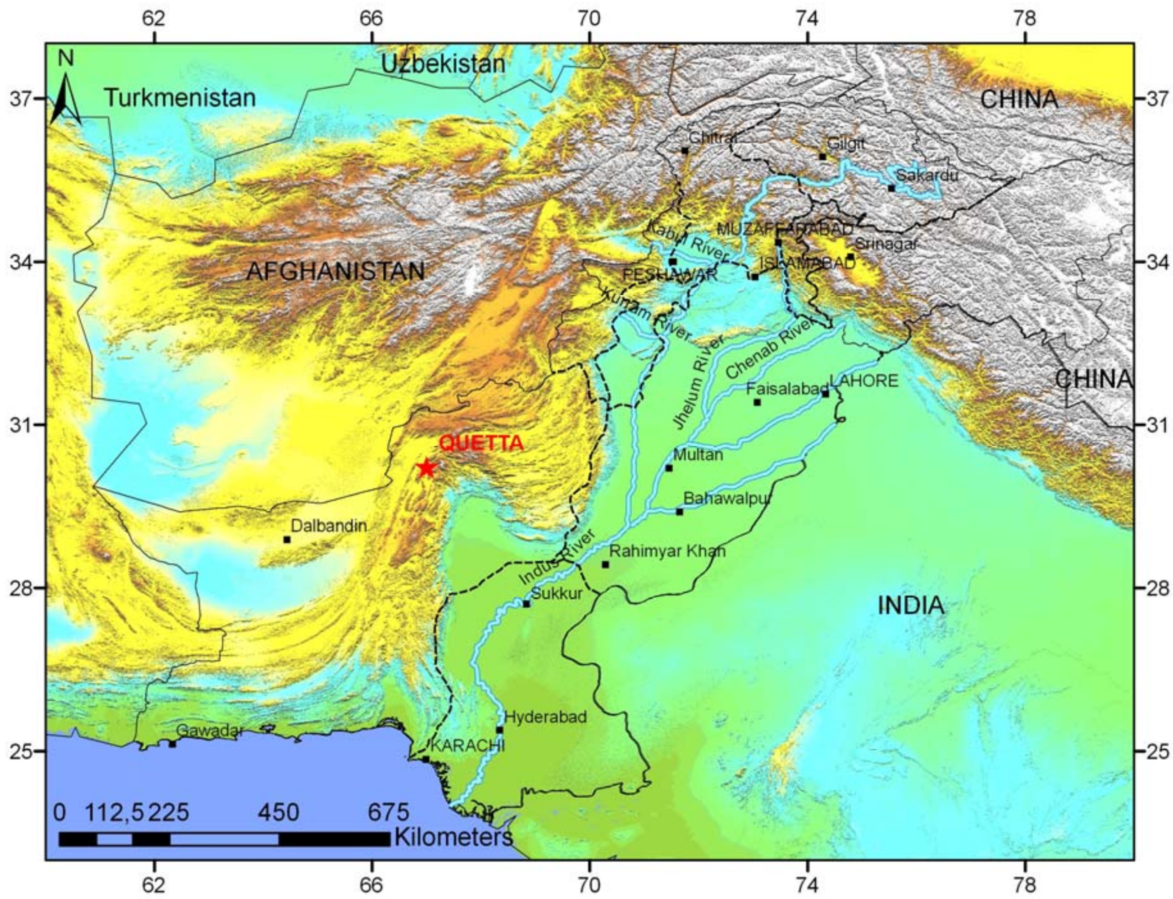

Figure 3.1. Location of Quetta, Pakistan

3.1. Earthquake Sources Identification and Characterization

This step of identification as well as characterization of earthquake sources involved the definition of seismic sources and their potential. For this purpose, either line (i.e. fault) or area sources were used for modeling. Quetta is situated near many active faults and it was assumed to contain geological faults as the seismic sources. Faults model adopted for the study based upon the faults presented by many sources, especially the National Geo-data Centre, GSP (Geological Survey of Pakistan) and Khan et al. (2003). At present, a number of methods were available for assigning a maximum magnitude to a given tectonic fault. These methods are based upon empirically derived correlations between magnitude and key parameters of faults such as fault displacement, fault rupture length, rupture area etc. Geological as well as seismological studies describe these fault parameters. The results of field studies of tectonic features in an area provide the data on fault rupture length, and fault displacement. The most useful regression relations involving magnitude and fault displacement fault rupture length or rupture area, were those given by Bonilla et al. (1984), Slemmons et al. (1989) alongwith Wells and Coppersmith (1994). For the fault characteristic model, the maximum magnitude of the fault was calculated by taking 50% fault length rupture. The Chaman Fault yielded maximum magnitude potential M_w = 8.3. Results of this step concerning maximum magnitude potential assigning were given in the Table 3.1.

Table 3.1. Critical Tectonic Faults and their Maximum Magnitude Potential

Tectonic Feature	Fault Length (km)	Maximum Magnitude Potential			Selected Maximum Magnitude, M_w
		Wells and Coppersmith (1994)	Slemmons et al. (1989)	Bonilla et al. (1984)	
Chaman Fault	326	8.1	8.3	8.0	8.3
Chilton Fault	91	7.3	7.6	7.5	7.6
Ghazaband Fault	187	7.7	8.0	7.8	8.0
Mach Fault	93	7.3	7.6	7.5	7.6
Kolpur Fault	61	7.1	7.3	7.3	7.3

3.2. Source-to-Site Distance

The step of determination of source-site distance involved the allocation of shortest distance from a seismic source and a site under study. For the application of predictive empirical relationships in the next step, maximum magnitude potential and shortest distances from the causative sources to the site were used. Based on the field studies of the faults and interpretation of local seismicity, the shortest distance was assigned to the causative sources for evaluation of PGA. The source-to-site distances, represented by the minimum between any part of each source and Quetta were given in Table 3.2.

Table 3.2. Source-to-Site Distances

Sources (Faults)	Distance (km)
Chaman Fault	30
Chilton Fault	34
Ghazaband Fault	60
Mach Fault	32
Kolpur Fault	32

3.3. Selection of the Controlling Earthquake

This step of selection of controlling earthquake involved the evaluation of Peak Ground Acceleration due to different sources at the site of interest. Actually if the shaking level was assumed to be characterized sufficiently by PHA, then a suitable attenuation relation could be utilized for controlling earthquake selection. On the basis of maximum magnitude potential of causative source and shortest distance from the project sites, the horizontal accelerations expected at site were determined utilizing certain attenuation laws. As no authenticated attenuation law had yet been developed due to absence of enough strong motion data concerning the areas of interest, the attenuation laws developed for other regions of similar geology have been adopted here. The maximum horizontal accelerations were determined by using attenuation laws proposed by Campbell and Bozorgnia (2003), Boore et al. (1997), Sadigh et al. (1997) and Ambraseys (1995). These acceleration values along with shortest distance to the five most significant seismic sources were summarized in Table 3.3. From this analysis, it was concluded that the critical tectonic structure for Quetta is Chaman Fault that can generate the controlling earthquake of magnitude 8.3 at 30km.

Table 3.3. Critical Tectonic Faults and their Maximum Magnitude Potential

Tectonic Feature	Maximum Magnitude (M_w)	Source-to-site distance (km)	Peak Horizontal Acceleration (g)				
			Campbell and Bozorgnia (2003)	Boore et al. (1997)	Sadigh et al. (1997)	Ambraseys (1995)	Average
Chaman Fault	8.3	30	0.50	0.3	0.39	0.22	0.35
Chilton Fault	7.6	34	0.33	0.2	0.2	0.14	0.22
Ghazaband Fault	8.0	60	0.23	0.16	0.13	0.10	0.15
Mach Fault	7.6	32	0.35	0.21	0.22	0.15	0.23
Kolpur Fault	7.3	32	0.31	0.19	0.18	0.13	0.20

3.4. Evaluation of Ground Motion Hazard Parameters

This step of evaluation of ground motion hazard parameters in this particular study involved the depiction of PGA expected at a place and evaluation of corresponding maximum velocity. The hazard would be taken as that which would result from a 8.3 magnitude earthquake occurring at a distance about 30 km. This motion would produce average Mean + s.d.(σ) maximum ground accelerations at Quetta of 0.35g which would be generated by Chaman Fault for its 50% rupture. Other ground motion parameters could be obtained from the predictive empirical relationships described in the literature. For example, based on the values of v_{max} and a_{max} for Loma Prieta Earthquake of 1989 having Magnitude 7.1 recording at 22.8 km distance from the epicenter at Gilroy No.2 (soil) site, the ratio of v_{max} and a_{max} was estimated to be 0.124 sec (Kramer, 1996). The ratio v_{max}/a_{max} was correlated with the distance and earthquake magnitude as it is a measure regarding frequency content of a ground motion. Several investigators studied this dependence, with a summary of their results presented by McGuire (1978). He proposed the magnitude and distance dependences in the form of Table 3.4, which indicated that the ratio v_{max}/a_{max} was directly proportional to source-site distance and earthquake magnitude. Using soil site conditions and considering the fact that v_{max}/a_{max} was also proportional to these relationships, v_{max} was estimated to be 45 cm/sec for Quetta.

Seismic hazard values at Quetta are in the high range. Unified Building Code (UBC, 1997) and latest Building Code of Pakistan - Seismic Provisions, 2007 (NESPAK, 2007) have also put Quetta in Zone 4 with high seismic hazard, validating these results.

Table 3.4. Magnitude and Distance Dependence of v_{max}/a_{max}*

Site Condition	Magnitude Dependence	Distance Dependence
Rock site	$e^{0.40M}$	$R^{0.12}$
Soil site	$e^{0.15M}$	$R^{0.23}$

* The ratio of v_{max}/a_{max} is proportional to these dependence relationships.

4. CONCLUSIONS

Following points were concluded from the results of DSHA of Quetta:

- Maximum magnitude potential determination for different faults around Quetta area resulted in the maximum value for Chaman Fault.
- Quetta revealed the maximum value of seismic hazard from the Chaman Fault.
- Depending upon the seismic hazard values calculated at Quetta and keeping in view different codes, it is deduced that Quetta is situated at a high seismic hazard location.

4. FUTURE RECOMMENDATIONS

In the final section, following recommendations are made as a reference to future works. It is quite a fundamental aspect.

- More study on the dimensions of tectonic features of the area can improve the deterministic seismic hazard characteristics determination as it results in more realistic maximum magnitude potential findings for different faults and their better source-to-site distance calculations.
- More advanced and area specific attenuation relationship should be incorporated to make the results even better and refined.
- The results of this study are a ready reference for any future DSHA work conducted in the area.
- The results can be employed for a guideline when results of DSHA are to be used for different future projects such as construction of Nuclear Power Plants or other related facilities.
- These DSHA work can be used for comparative studies with any future Probabilistic Seismic Hazard Assessment studies.

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