Design Ground Motion Prediction update for Lahore and Surrounding Region of Pakistan

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ABSTRACT :

Being second largest city of Pakistan, Lahore has emerged as a major industrial and population centre and its growth is rapid. To mitigate the consequences of possible earthquake in future, a realistic seismic hazard assessment and design ground motion for new infrastructures are necessary. To meet this need for developers and designers in this region, design ground motion for Lahore and surrounding region is evaluated on the basis of seismic hazard assessment with updated data. The most significant seismogenic sources for this region are Western Himalaya and Sargodha High source zones. Peak Ground Acceleration (PGA), expected for city of Lahore with 10% probability of exceedance in 50 and 100 years, is estimated to be 0.1g and 0.12g. Design Ground Motion, for expected ground acceleration at 10%/50 years on the basis of updated data, is presented in the form of design response spectra and compatible time histories.

KEYWORDS: Lahore, Seismic Hazard Assessment, Design Ground Motion, Peak Ground Acceleration, Design Response Spectra, Compatible Time Histories

1. INTRODUCTION

Risk of earthquake devastations for Pakistani cities should be realized as it is situated at the junction of three tectonic plates (Powell, 1979), namely Indian, Eurasian and Arabian (Figure 1). Near past has resulted in a number of major seismic events and hence has just emphasized that seismic hazard assessment for the major urban centers of the country should be carried out. At these major population centers, seismic hazards are not being considered so important to be taken into account while designing and constructing multistoried buildings. This paper is another step to the already done work towards gaining the goal of earthquake risk determination in the major cities to facilitate seismic resistant design and construction to avoid any devastation in future. Target area of this study is central Punjab province of Pakistan where three major industrial hubs, namely Lahore, Faisalabad and Gujranwala, are situated.

Lahore is the capital of Punjab Province and has a current population of around 10 million It has experienced many earthquakes in past and its rich documented history tells us a lot about the information regarding these seismic events. Quittmeyer and Jacob (1979) have also given listing of the significant earthquakes among them. From these historical documents, a number of examples of damage to the historic buildings caused by earthquakes can be found. About twelve significant large documented earthquakes are listed in Table 1.1. Among these, two damaging earthquakes experienced at Lahore have worth mentioning examples – First is the damage to the minarets of famous Badshahi Mosque by earthquake of 1827 and second is the damage to Town Hall building of Lahore due to Kangra Earthquake of 1905.

Table 1.1 Significant documented earthquakes of the study area

Date	Location	Intensity.	Eqv. Magnitude	Related Zone
25 AD	33.7 N, 72.9 E	IX	7.5	Hazara-Potohar
Jun. 23, 1669	33.9 N, 72.3 E	VIII-IX	7.5	Hazara-Potohar
Sep. 24, 1827	31.6 N, 74.4 E	VIII-IX	7.5	Lahore Fault
Jun. 06, 1828	34.1 N, 74.8 E	IX-X	8.0	Western Himalayas
Nov. 10, 1868	33.0 N, 70.6 E	VII-VIII	7.0	Kohat-Chirat
Apr. 1869	34.0 N, 71.6 E	VII-VIII	7.0	Bannu Basin
Dec. 20, 1869	33.8 N, 72.2 E	VII-VIII	7.0	Hazara-Potohar zone
Dec. 12, 1875	33.5 N, 73.0 E	VII-VIII	7.0	Hazara-Potohar zone
Mar. 02, 1878	33.6 N, 71.4 E	VII-VIII	7.0	Kohat-Chirat
May 30, 1885	34.3 N, 74.5 E	VIII	7.0	Western Himalayas
Jun. 06, 1885	34.0 N, 74.5 E	IX	7.5	Western Himalayas
Apr. 04, 1905	32.0 N, 76.3 E	X	8.0	Western Himalayas

Lahore does not posses many and strong earthquake generating source in close proximity but distant seismic sources are strong and active, as frequent moderate level of shakings were felt from earthquake occurring in far flung areas like Hindukush region. Above two examples of building damage in Lahore hints that urban building in general and high rise buildings in particular can be damaged by distant earthquakes. So considering the recent trend of multistoried construction, the importance of seismic resistant construction becomes more important in view of capital intensive nature of construction and above two historic examples of damage to relatively high rise structures. Soil strata in the region consists of very thick alluvium deposits therefore site amplification of low frequency seismic waves even from distant earthquakes, puts multistoried construction at risk of earthquake damage similar to the situation arose during 1985 Mexico Earthquake (Gomez et al., 1989).

In this document earthquake generating sources around the target area have been identified which have potential to generate ground motion so intense to cause damage to the constructed environment. These seismotectonic zones are identified on basis of geological and seismological evidences. The seismological data has been obtained from many sources to account for the formation of these zones and further analysis.

Uniform Building Code (UBC, 1997) has put forward the methodology for evaluating design ground motion for major cities world wide, and has presented the seismic zone factor for these cities. From Pakistan four cities, namely Karachi, Lahore, Quetta and Peshawar are included in the list of UBC. Even though UBC (1997) has assigned the seismic zone "2A" for Lahore to meet the requirement of construction industry for seismic resistant construction, yet a realistic seismic hazard assessment and thus design ground motion prediction for Lahore and surrounding region is needed for proper construction and design of multistoried buildings and Industrial units. This paper is based on seismic hazard analysis for Lahore and surrounding region using probabilistic approach and design ground motion prediction on the basis of different methodologies and their compatible time histories. Many researches have already been done by many teams like GSHAP (Zhang et al., 1999) and Khan et al. (2004) to have a realistic evaluation of the seismic hazard and design ground motion. This paper is a modification and improvement of the later one.

The region under study (Figures 1 and 2) is a part of the vast Indus Basin, situating in the west of the Indian Shield. Based upon differences in structure, sedimentary facieses development, and chrono-stratigraphic sequences, the Indus Basin can be subdivided as following four basins (Bender and Raza, 1995):

i)	Upper Indus Basin	ii)	Central Lower Indus Basin and
iii)	Northern Lower Indus Basin	iv)	Southern Lower Indus Basin.

The target area of this study lies in the northern part of Northern Lower Indus Basin south of Sargodha High (bulge). Thickness of sediments decreases from more than 5000m to less than 1000m. (Bender and Raza, 1995). Base rock outcrops through the sediment blankets near towns of Shahkot, Sangla, Chiniot and Sargodha. Topographic features of the upper part of this sedimentary plane consist of five rivers, tributaries of river Indus. The land between two rivers is called Doab and different doabs situated in the area have been named as Bari, Rachna, Chaj and Thal Doabs as shown in Figure 2.

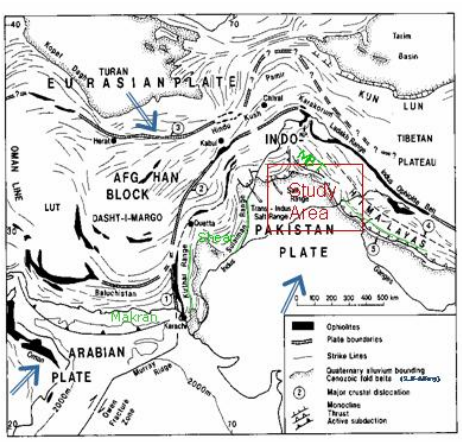

Figure 1 Tectonic plates active in region

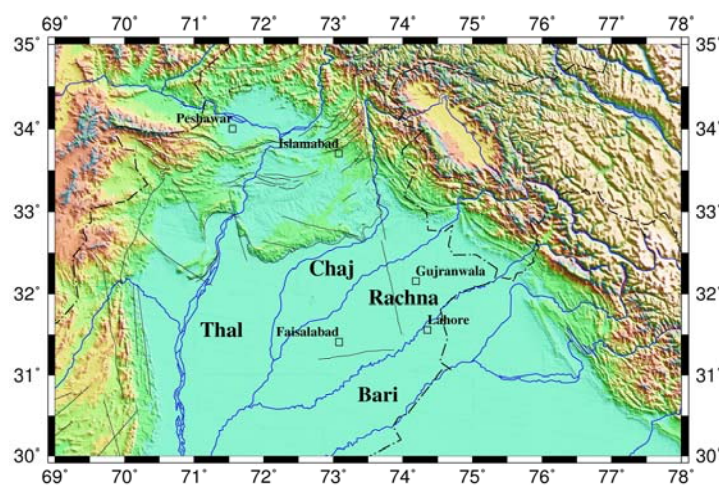

Figure 2 Geographical settings of the region

2. METHODOLOGY AND PARAMETERS AFFECTING THE STUDY

Design ground motion and compatible time histories prediction depend a lot on the seismic hazard estimate at a certain place. The probabilistic estimate of seismic hazard requires information on seismic activity, geotectonics and appropriate ground motion attenuation characteristics of the region. Main steps, parameters and the methodology employed are described briefly in the following sections:

2.1. Earthquake Catalogue

Instrumentally recorded seismic data for this study was obtained from as many sources as possible as this is the primary requirement for undertaking study of this nature. The main sources of such data were:

i) MSSP Seismic Data Base
ii) ISC Earthquake Catalogue
iii) USGS Seismic Data Base
iv) MSSP Technical Reports.

This area has very ancient cultural history therefore from archeological sites, some evidences about large earthquakes have been identified e.g. Taxila Earthquake of year 25 A.D. Geological and seismotectonic evidences have also dictated about some earthquake sources. Damages to some monumental construction have also contributed to the information of large earthquakes. Historic notes also contain information of some damaging earthquakes. Out of 12 large significant earthquakes documented earlier, only one large damaging earthquake found occurring near Lahore (Oldham, 1882).

2.2. Seismogenic Zones

The study area is located in Indus-Basin within Indo-Pakistani plate south of Himalayas and Salt Range and east of the predominantly northward trending mountains of western Pakistan. As mentioned earlier, earthquake generating sources in close proximity to Lahore are very few and weak but distant sources are strong and active. In this document, earthquake generating sources around the target area which has potential to generate ground motion so intense to cause damage to the constructed environment, have been identified. On the basis of geological and seismological evidences, fourteen seismogenic zones have been identified around the target area (Figures 3 and 4). Seismological data for this purpose was obtained from Oldham (1882) and Ambraseys (1975) for historic records and for instrumental record, USGS, ISC and MSSP data base (1976 to date) have been searched. The seismogenic zones identified around the study area are:

1 Lahore Fault Source Zone
2 Hafizabad Fault Source Zone
3 Sargodha High Source Zone
4 Western Himalaya Source Zone
5 Indian Border Region Source Zone
6 Salt Range Source Zone
7 Bannu Basin Faults Source Zone
8 Bhakkar Fault Source Zone
9 Kalabagh Region Source Zone
10 Kohat-Chirat Source Zone
11 Hazara-Potohar Source zone
12 Diffused Seismicity Zone
13 Southern Punjab Source Zone
14 Suleiman Range Source Zone

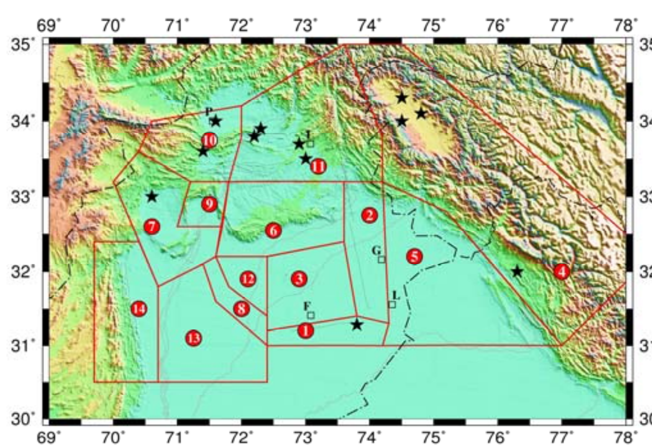

Figure 3 Seismogenic zones identified in the area

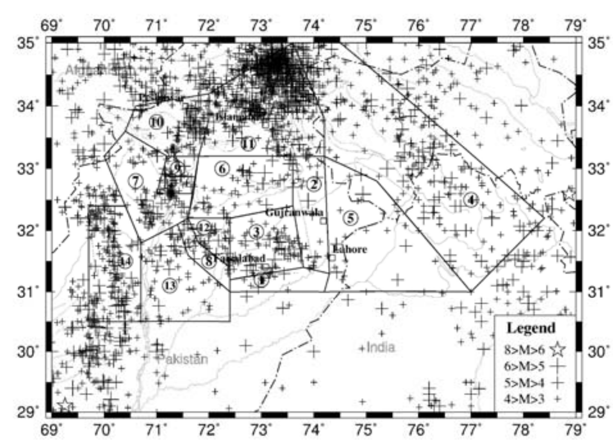

Figure 4 Seismicity with source zones during last 30 yrs.

Some of the identified zones contain a number of seismotectonic sources. Due to locations of these sources far from the target area they are combined together in the form of single seismogenic zone. In the probabilistic approach for hazard estimation, basic recurrence relation (Richter, 1958) of the form, given in Eqn. 2.1, was used to determine the cumulative distribution of magnitude for the fourteen seismogenic source zones recognized in the area.

$$\log N = a - bM \tag{2.1}$$

Here N is the number of the earthquake above magnitude M and **a** and b are the characteristics of the region. The plots of b-values for the zones have been drawn. Parameters, a and b-values along with the others characteristics of these zones have been used as input to computer program SEISRISK III and some of them are listed in the Table 2.1.

Table 2.1 Characteristic parameters of various seismogenic sources identified for analysis

	Name of Source Zones	Threshold Magnitude.	No. of Events above Threshold	Period of data	a-value	b-value
1	Lahore Fault	3	26	32	3.82	0.76
2	Hafizabad Fault	3	44	31	3.49	0.63
3	Sargodha High	3	92	31	4.03	0.67
4	Western Himalaya	5	53	43	5.69	0.95
5	Indian Border Region	3	38	25	3.89	0.74
6	Salt Range	3	68	32	4.42	0.81
7	Bannu Basin Faults	3	108	31	4.48	0.79
8	Bhakkar Fault	3	35	32	4.25	0.90
9	Kalabagh Region	3	94	32	4.18	0.73
10	Kohat-Chirat	3	137	31	4.55	0.75
11	Hazara-Potohar	3	632	31	5.98	0.87
12	Diffused Seismicity	3	55	30	5.03	1.07
13	Southern Punjab	3	68	32	4.52	0.88
14	Suleiman Range	3	240	32	4.56	0.70

2.3. Attenuation Equations

Authentic attenuation relationships for the South Asian Region could not be developed so far due to lack of sufficient strong motion data covering a larger range of magnitudes and distances. A number of attenuation equations have been developed from strong motion data collected in other parts of the world. For Probabilistic Seismic Hazard Assessment (PSHA), the attenuation equations of Boore et al. (1997), Campbell (1981), Ambraseys and Bommer(1991) and Ambraseys (1995) have been used. First two attenuation equations have been preferred as shallow earthquakes were of more concern for this hazard analysis, attenuation equations developed for such conditions were considered for use in the hazard analysis. The last two attenuation equations have been preferred because of the authors who have developed these relations with claims that they have used 3% data from Pakistan. Attenuation equations have been used in PSHA by giving equal weightage (25%) to each equation. Ground motion amplitudes obtained by these equations are generally same as obtained by using Boore et al. (1997) equation only.

2.4. Seismic Hazard Analysis

The probabilistic seismic hazard analysis has many applications from earthquake engineering point of view, apart from risk mitigation and planning for post disaster risk management. It results in estimates of the probability of exceedance of various levels of ground motion. This analysis considers uncertainties in the location, size and recurrence of earthquake. Cornell (1968) introduces this method as a quantitative method for seismic hazard analysis.

The updated composite seismic data contain magnitude values in the form of different magnitude types. Since each attenuation relationship is based on magnitude of given type, a single type must be selected. For data to be used in seismic hazard analysis, all the magnitudes were therefore converted to moment magnitude (M_w). PSHA was carried out using software SEISRISK III (Bender and Perkins, 1989). It is a computer program to compute seismic hazard using a probability model to consider the occurrence and distribution of earthquakes. For this purpose, cumulative number of earthquakes against magnitude are plotted for each zone to obtain b-values and other related parameters to be utilized in the programme.

2.5. Design Ground Motion

Design Ground Motion can be evaluated in many ways but in this paper, it has been evaluated in the form of Design Response Spectra according to the three different guideline, namely United States Nuclear Regulatory Guides (USNRC, 1973), Method of Newmark and Hall (1969) and UBC (1997). Uniform Building Code of 1997 has been used due to its consideration of Lahore in seismic zone “2A”. Design Response Spectra and their Compatible time histories can be utilized for dynamic analysis of structures of interest.

3. RESULTS AND CONCLUSIONS

Due to the away proximity of the earthquake generating sources, the variation of ground motion parameters in this area is not very complex. Results of seismic hazard assessment are presented in the form of Peak Ground Acceleration (PGA) variation with return periods of 50 and 100 years as shown in Figure 5 and Figure 6 respectively.

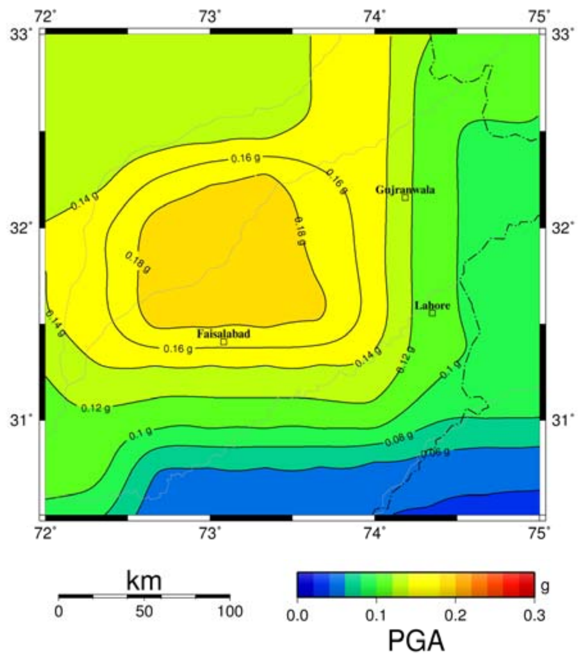

Figure 5 PGA Map with Return Period of 50 years

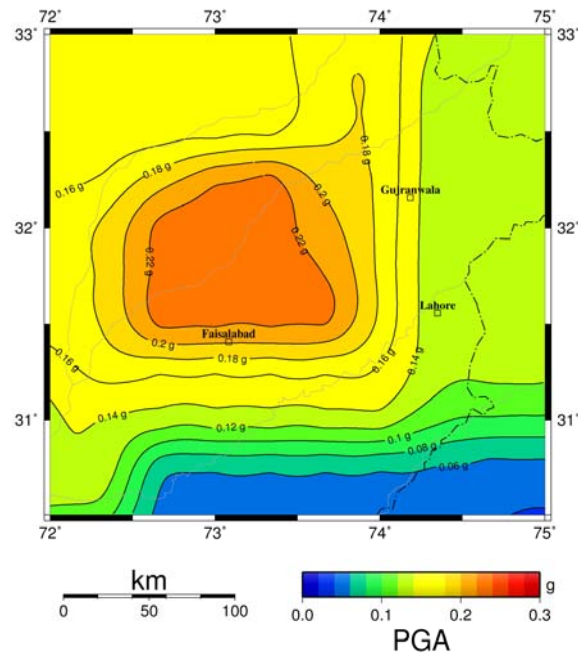

Figure 6 PGA Map with Return Period of 100 years

Peak ground acceleration for three cities of the region with return period of 50 and 100 years are listed in Table 3.1. The trend of variation of expected PGA shows that the two most significant earthquake source zones for the target area are the Western Himalayas, where Kangra earthquake of 1905 occurred and the Sargodha High which has large potential of damaging earthquake due to proximity to the target area.

Table 3.1 Peak Ground Acceleration (PGA) for three cities in the region

Cities \ Return Period	50 years	100 years
Lahore	0.10 g	0.12 g
Faisalabad	0.12 g	0.14 g
Gujranwala	0.16 g	0.20 g

Figures 7 to 9 show the design ground motion presented in the form of response spectrum and compatible time histories of Displacement, Velocity and Acceleration for Lahore based upon three methods mentioned earlier and for expected PGA with 10% probability of exceedance in 50 years. Predicted design response spectra for Lahore based upon three methods mentioned above have been compared in Figure 10.

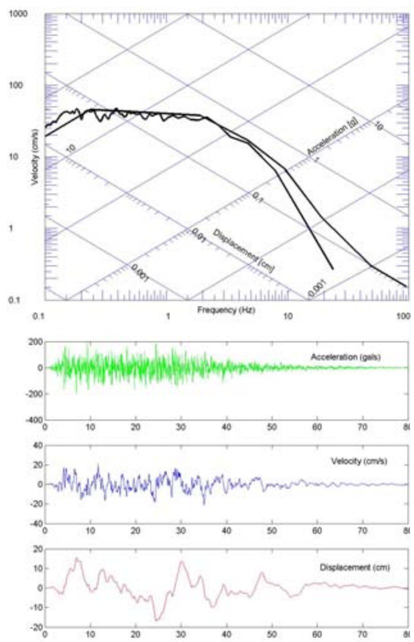

Figure 7 USNRC Design Response Spectrum and compatible time histories

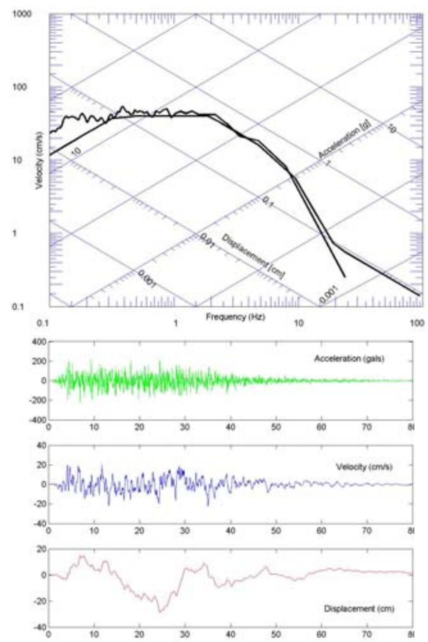

Figure 8 Newmark and Hall Design Response Spectrum and compatible time histories

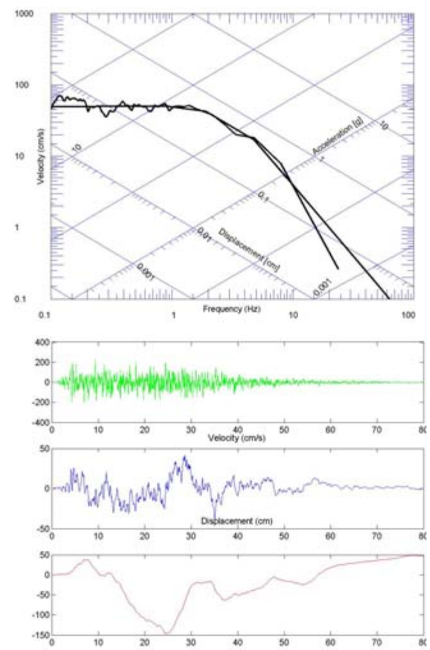

Figure 9 UBC Design Response Spectrum and compatible time histories

The results indicate that the three industrial cities of the region fall in the medium to low risk category, as the PGA values with 90% probability of non-exceedance are not quite significant and in agreement with UBC, which has placed Lahore in low seismic zone. Damage to tall structure of minarets of Badshahi Mosque and Town Hall can be regarded as exceptional cases as no considerable damage to other structures was reported in the city of Lahore. This may be attributed to any one or combination of poor design, soil amplification and internal resonance of low frequency seismic waves from distant earthquakes. Site amplification of low frequency seismic waves from distant earthquakes should not be underestimated as the soil strata in the region consist of very thick alluvium deposits and it may put multistoried construction at risk of earthquake damage similar to the situation which arose during the 1985 Mexico Earthquake. Predicted Design Ground Motions from different methods are also close to each other making them viable to be used for further purposes like dynamic analysis.

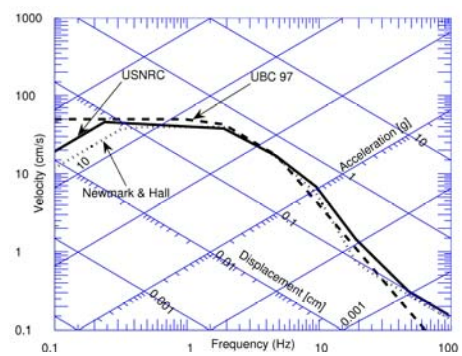

Figure 14 Comparison of Design Response Spectra

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