



A critical review of the seismic risk zoning and development of Design spectra for Peshawar and adjoining areas

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SUMMARY

Most of the structural engineers in Pakistan refer to UBC code for design of aseismic structures. In its seismic zones of international cities, the UBC code 1997 has placed Peshawar in the most severe earthquake Zone-4 similar to the high earthquake prone cities of California, Alaska, Japan, Chile, Taiwan or Turkey. These places have suffered some of the most destructive earthquakes in the past. Earthquake history of Peshawar, however, doesn't tell us of even moderate devastation. Moreover work done on the seismic zoning of Pakistan by different national and international agencies present quite conflicting picture about the seismic vulnerability of Peshawar. This paper critically reviews almost all of the published work done on seismic zoning, in light of the locally available data, geology, tectonics and earthquake history of Peshawar. Based on the reviewed seismic risk zoning and PGA values the authors also recommend Design Spectra for Peshawar and adjoining areas.

INTRODUCTION

Peshawar one of the oldest historical cities of the Indian sub continent geographically is located at $71^{\circ}, 43.4'$ N latitude and $33^{\circ}, 93.7'$ E Longitude as shown in fig 1 [1]. The total area of the city is 1257 km^2 with population of around 2.5 million including more than half a million Afghan refugees. Peshawar is the most important and the largest city of North West Frontier Province of Pakistan. The city provides key access to the Central Asian States through Afghanistan along the Western borders of Pakistan. Highly Seismic Hindu Kush region is approximately 200 km North West of Peshawar.

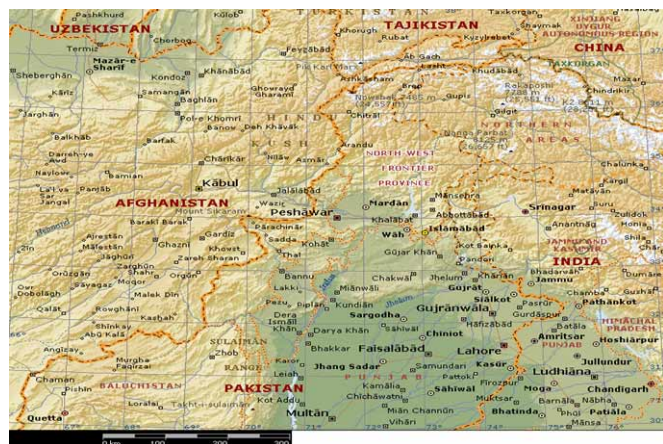


Figure 1: Map of Northern Pakistan showing Peshawar and Hindu Kush Region

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The zone consists of southern part of Eurasian plate and northern part of Indo-Australian plate as shown in fig 2 [1]. Most of the earthquakes felt at Peshawar have their origin in the Hindu Kush region of Afghanistan or Northern areas of Pakistan [2, 3].

Uniform Building Code in its 1997 Edition (UBC-97), for the first time published a list of Seismic Risk Zones for the major cities of the world outside the United States. The List shows Peshawar in the most severe earthquake Zone-4 similar to the high earthquake prone cities of California, Alaska, Japan, Chile, Taiwan or Turkey. These places sitting on active faults have suffered some of the most destructive earthquakes in the past. The case of Peshawar, however, is quite different. The earthquake history of Peshawar doesn't tell us of even moderate damage during the last several hundred years. [2, 3, 4, 5]

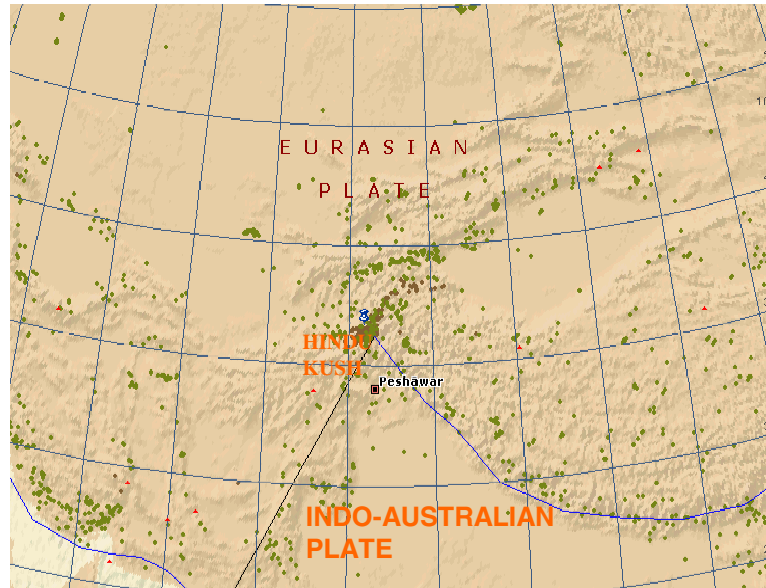


Figure 2: Eurasian and Indo Australian Plates

Placing any region of the world in seismic zones by the universally accepted Uniform Building Code has a number of socio- economic implications. A structure to be build earthquake resistant in zone 4 requires enormous amount of funds. . Limitations of resources in developing and poor countries like Pakistan may not allow its one of the largest cities to bear gargantuan cost of constructing high-tech structures specially when not warranted technically. Also the fear among people may have far reaching psychological consequences in such a situation. In view of the fact that except for Quetta, none of the major cities in Pakistan has the history of large earthquake of magnitude 6.0 and above or any confirmed major recently active fault in the immediate vicinity, geoscientists and earthquake engineers express their reservation at UBC placing Peshawar in the most hazardous zone..

It is worth mentioning that the paper doesn't aim at performing seismic risk analysis of the locality but rather reviews almost all of the published work regarding seismic zoning of Peshawar. In light of the locally available data, geology, tectonics and earthquake history of Peshawar the authors finally recommend a rationale PGA value among that given by different sources. Based on the reviewed seismic risk zoning and PGA values the authors also recommend Design Spectra for Peshawar and adjoining areas.

SEISMIC RISK ZONING OF PESHAWAR CARRIED OUT BY DIFFERENT AGENCIES AND RESEARCHERS

1. Uniform Building Code (UBC)

Pakistan does not have any seismic regulations for buildings till date (2003). Therefore it is not possible to derive lateral strength requirements from local practice. Structural engineers in Pakistan usually refer to UBC code because it is a well respected code commonly adopted outside the United States, including Pakistan. UBC has placed Peshawar in Zone 4 which corresponds to a Peak Ground Acceleration (PGA) of above 4.0 m/sec^2 or 0.4 g [6]. UBC has also placed two other important cities of Pakistan Karachi and Islamabad in Zone 4. In a study conducted with the collaboration of Seismic

Committees of Associated Consulting Engineers Pakistan and Karachi Building Code Authority, seismic risk zoning of Karachi by UBC has already been strongly objected, A.Razzak Loya et.al [7]. The authors in their report finally conclude that Karachi should be placed in Zone 2b instead of Zone 4.

2. United States Department of States Office of Foreign Building Operations (1997)

This report prepared by the consultant Woodward and Clyde in 1985 and a later study in 1992 suggests zone 3 for Peshawar in its seismic hazard zones of international cities [8]

3. United Nation Global Seismic Hazard Assessment Program, UN GSHAP

In order to reduce the risk of disasters to the world population by the earthquakes, United Nations in 1992 launched the “Global Seismic Hazard Assessment Program. It was widely participated by hundreds of geologists and seismologists from all over the world. East Asia including Indo-Pak Subcontinent was also studied in detail. Fig 3 shows UN GSHAP map for Pakistan and Afghanistan with some parts of the neighboring countries [9]. The report and maps of Seismic Risk Zones were published by GSHAP in December 1999.

The map shows color coded scheme for PGA values in m/sec^2 with 10% probability of exceedance in 50 years corresponding to return period of 475 years. The map shows Peshawar in Moderate Hazard Zone corresponding to PGA values of 1.6 to 2.4 m/sec^2 or 0.16g to 0.24 g. The highly seismic Hindu Kush region has been placed in very high hazard zone corresponding to PGA values of above 4.0 m/sec^2 . On average there are four magnitude 5.0 earthquakes per year in this region. Earthquakes in this part of the world have devastated several nearby towns of Badakhshan and Takhar provinces of Afghanistan in the past. Placement of this region in high hazard zone is therefore justified.

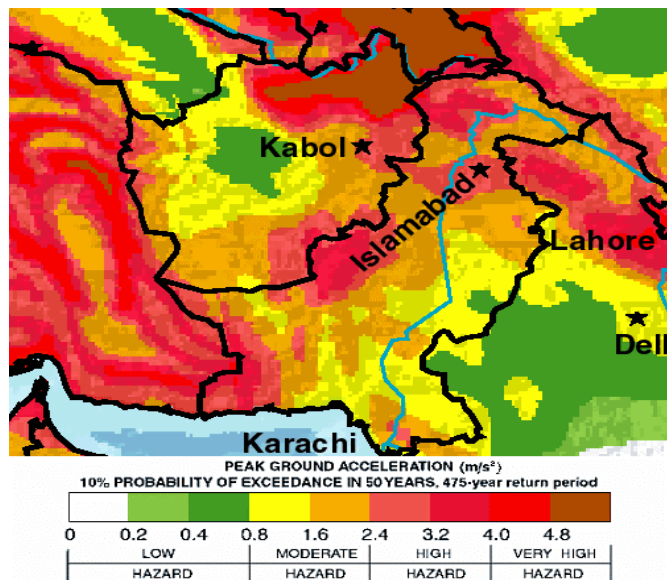


Figure 3: UN GSHAP map for Pakistan and Afghanistan

4. Geological Survey of Pakistan

Seismic Risk map of Northern Pakistan was issued by the National Geo-Data Center Geological Survey of Pakistan, GSP in 1988, Mohammad Ali Mirza et.al [10]. The map does not provide information about peak ground acceleration required by the structural engineers. However the map is of practical use in determining the range of damage in a quantitative sense according to Mercalli scale of earthquake intensity. The map shows Peshawar in a zone of major damage zone. But the map surprisingly shows District Dir, a region of high seismicity, in a zone of moderate damage zone. This makes the authenticity of the map highly questionable. Moreover as GSP doesn't have its own strong motion recording system, the earthquake hazard maps prepared by it can't be recommended for use in earthquake engineering.

5. Geophysical Center Quetta, Met Department of Pakistan

Fig 4 shows a color coded Seismic Zoning map of Pakistan issued by Mohammad Rafiq [11] Geophysical Center Quetta, Met Department of Pakistan.

The map shows Peshawar in a zone of minor damage zone corresponding to PGA value of .0667g to 0.1g. The Geophysical Center Quetta is officially responsible for the collection and dissemination of information regarding natural hazards including earthquakes. The center has a good network of seismometers and few strong motion recorders installed in major cities including Peshawar. The center has put a 100 years record of earthquake history of Pakistan on the net at the web site www.met.gov.pk. Therefore the seismic zoning map prepared by the Geophysical Center Quetta, Met Department of Pakistan can be considered the most reliable earthquake hazard map for Pakistan.

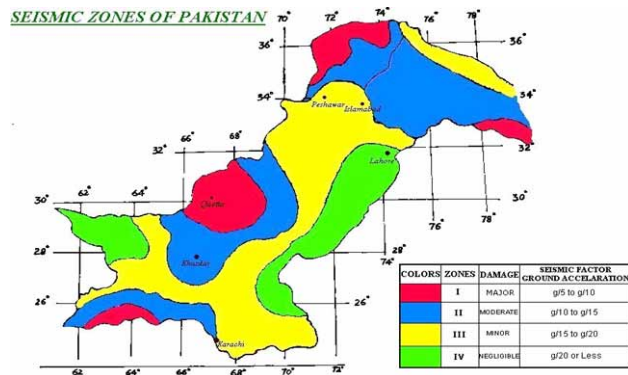


Figure 4: Seismic Zoning map of Pakistan issued by Geophysical Center Quetta, Met Department of Pakistan

6. Independent study carried out by Mona Lisa and Azam A. Khwaja:

As part of this study an area of 200 km around Peshawar has been divided into 2913 grids of 0.0650×0.0650 size for carrying out seismic risk analysis.

Instrumental data of $M_b = 4.5$, mostly taken from the USGS has been used which comprises 2207 events that occurred during 1905 to 1998 as shown in fig 5.

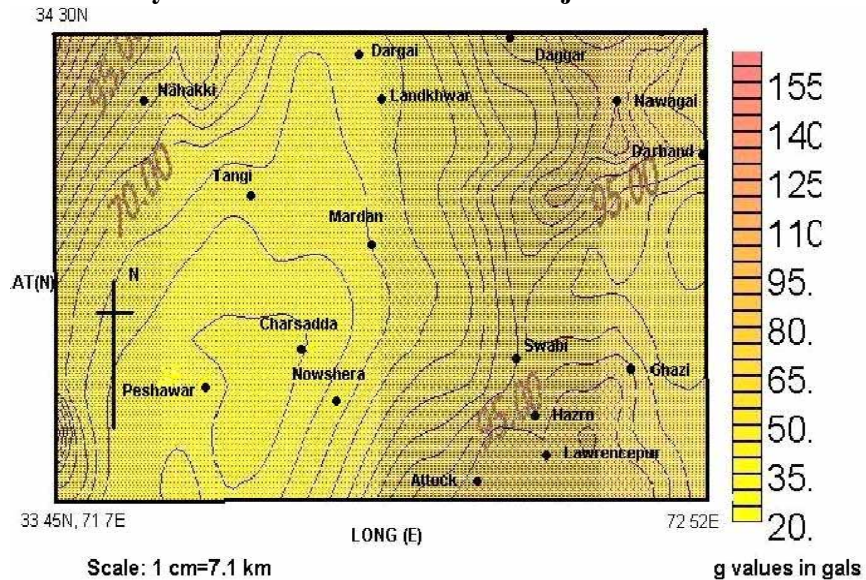


Figure 5: Map showing PGA values in gals (1 gal = 1cm/sec²) for Peshawar and adjoining areas

The study recommends a PGA value of 0.06g for Peshawar and adjoining areas, Mona Lisa and Khwaja [12].

AUTHORS OBSERVATIONS

1. Data obtained from the US Geological Survey and Geophysical Center Quetta, Met Department of Pakistan:

Figs 6, 7, 8, 9, and 10 obtained from National Earthquake Information Center, NEIC, Earthquake Search Results, U.S Geological Survey show earthquakes of magnitude greater than 4, 4.5, 5.0, 5.5 and 6.0 for the duration of 1973 to 2003 with Latitude and longitude range of 32 to 38 and 68 to 78 respectively, covering a wide area around Peshawar and extending north to cover the Hindu Kush region.

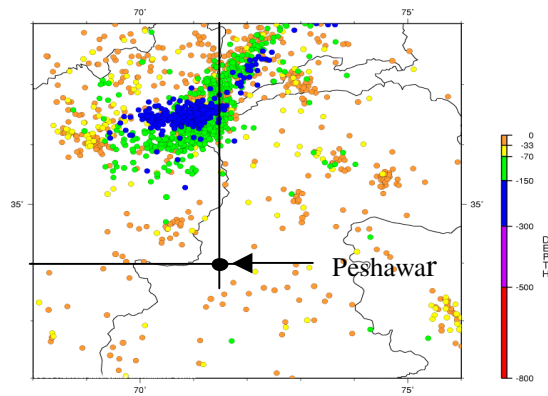


Figure 6: Earthquakes above Magnitude 4; Number of Earthquakes= 3587

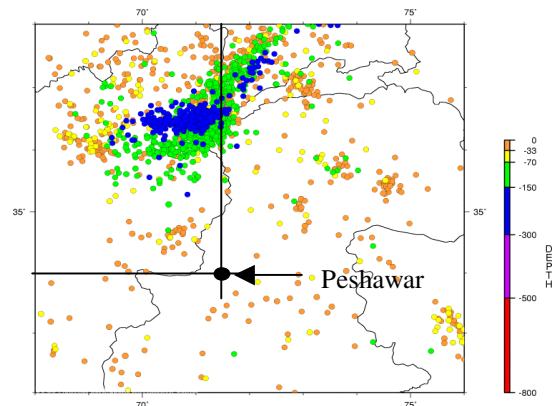


Figure 7: Earthquakes above Magnitude 4.5; Number of Earthquakes= 1691

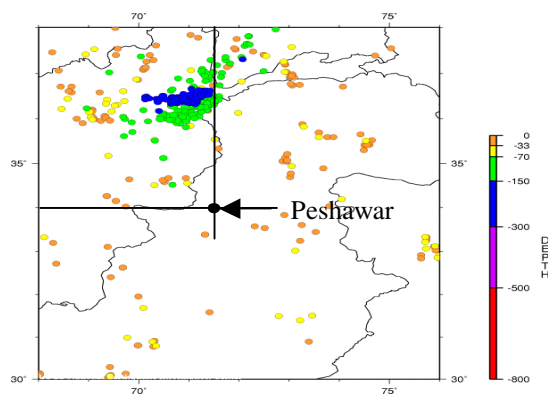


Figure 8: Earthquakes above Magnitude 5; Number of Earthquakes= 404

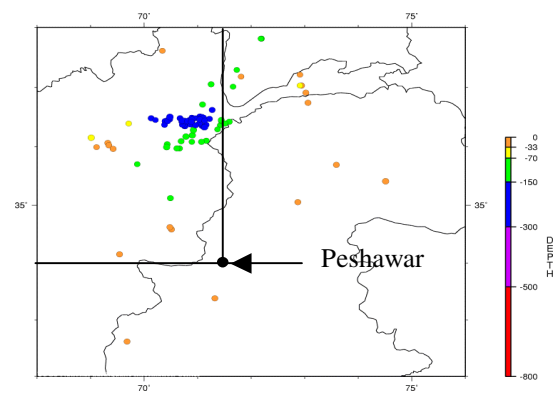


Figure 9: Earthquakes above Magnitude 5.5; Number of Earthquakes= 87

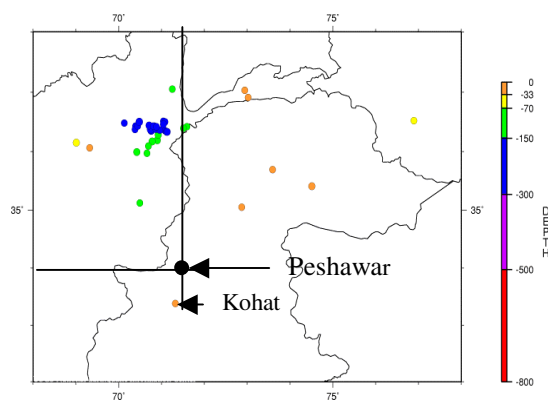


Figure 10: Earthquakes above Magnitude 6; Number of Earthquakes= 38

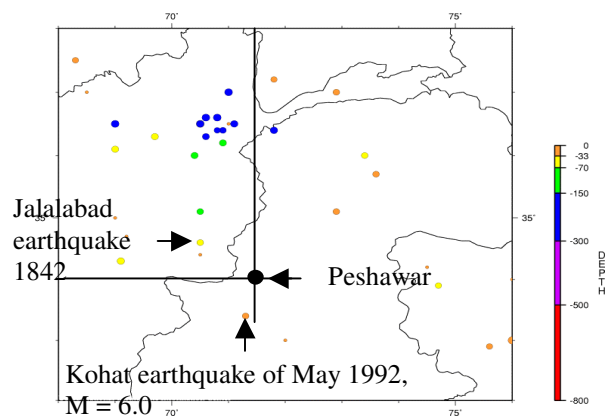


Figure 11: Significant Earthquakes Record from 25 A.D to 1992; Number of Earthquakes= 41

Fig 11 shows results of significant earthquakes for the same ranges of latitude and longitude for duration of 25 A.D to 1992.

It is evident from these figures that though some small magnitude earthquake, less than 4.5 have occurred near the city, no earthquake of magnitude greater than 5.0 has occurred in the close vicinity of the city and none has occurred within the Peshawar valley. This is confirmed by the history of almost no considerable damage to the city in the last several hundred years. All figures however show dense earthquake record in the Hindu Kush region.

Only two earthquakes one of Feb 19, 1842 and other of May 20, 1992, identified in figs 10 and 11 had their epicenters close to Peshawar at Jalal Abad, Afghanistan and Kohat, Pakistan respectively. All other significant earthquakes felt at Peshawar had their epicenters either in the Hindu Kush region of Afghanistan or Northern Areas of Pakistan as far as 200 km from Peshawar. It is pertinent to note however that even moderate damage has not been reported as a result of all of these earthquakes including the two nearby earthquakes of Jalal Abad and Kohat. For example, the Amateur Seismic Center India at the web site www.asc.india.org has given some details of the earthquake of Feb 19, 1842. Quoting one of the references "*Memoir, Extracted and compiled from various sources to illustrate the origin and foundation of the Polluck Medal*", Woolrich, Boddy and Co., Military Publishers, 1875, it reports of heavy casualties in Jalal Abad but surprisingly tells of only minor damages at Peshawar [13]. Similarly the geophysical center Met Department of Pakistan has reported only minor damage at Peshawar due to the earthquake of May 20, 1992 at Kohat as close as 60 km to Peshawar.

A large number of historical buildings and a number of private houses as old as 300 years still standing today is yet another proof of very minor damages as a result of these earthquakes. Figs 12 through 14 show some of these old buildings.



Figure 12: Minaret of Mosque Mahabat Khan constructed during the era of Mogul Emperor Aurang Zeb some 300 years ago. The minaret is about 60 ft high constructed in burnt brick masonry.



Figure 13: A 100 years old house constructed as wooden frame with un-burnt brick infill walls, situated in the center of the walled city

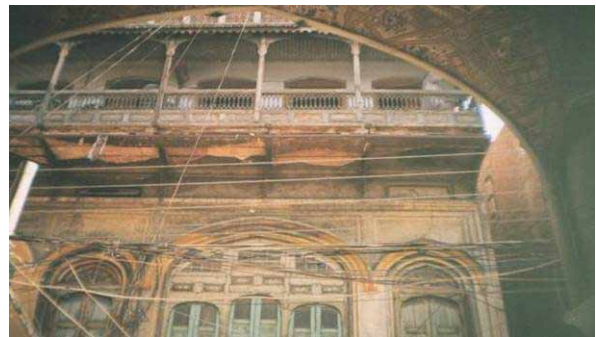


Figure 14: A 100 years old house constructed as wooden frame with un-burnt brick infill walls, situated in the center of the walled city

2. Accelerograms collected from the Upper Air Research Station Khyber Road Peshawar, Met Department of Pakistan

The Peshawar observatory has been operational since 1954. The first accelerograph was installed in 1986. The last 10 years accelerograph record of the earthquakes of magnitude greater than 6.0 is presented in table 1 [14]. Table 1 shows date, actual magnitude of the earthquakes given by USGS and Peak Ground Accelerations recorded on the accelerograms at the Peshawar Met Office. Two typical accelerograms from the original record are shown in fig 15. The record reveals very low PGA values for earthquakes of magnitude even greater than 6.0, having epicenter at Hindu Kush. The highest PGA value is **0.063g**, which corresponds to earthquake of magnitude 6.5 dated June 30, 1994.

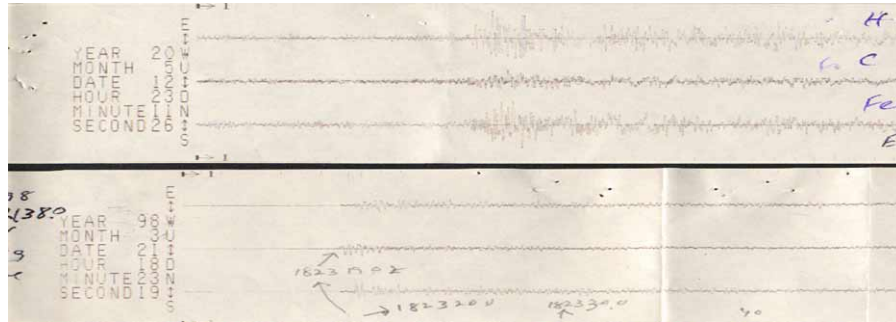


Figure 15: Accelerograms obtained from Met Office, Peshawar, Pakistan

Table 1

Peshawar met office record of earthquakes greater than magnitude 6.0

1993-2003

Date	Earthquake Magnitude on Richter Scale given by USGS	Peak Ground Acceleration recorded at Peshawar Met Office, approximately 250 km from epicenter at Hindu Kush
September 4, 1993	6.0	.024g
September 18, 1993	6.3	*
June 30, 1994	6.5	.063g
October 25, 1994	6.2	.038g
October 18, 1995	6.3	.03g
January 19, 2000	6.0	.015g
May 12, 2000	6.3	.011g
July 17, 2000	6.6	.017g
November 23, 2001	6.1	.004g
January 3, 2002	6.2	.043g
March 3, 2002	6.3	*
March 3, 2002	7.4	0.045g
March 25, 2002	6.2	.005g
November 20, 2002	6.5	*

*Record for these events was not available.

3. Role of local tectonic faults in the Seismicity of Peshawar:

Most of the tectonic faults of Pakistan have no instrumental monitoring to measure their activities to classify them authentically as active faults. In absence of recorded instrumental monitoring, the seismic hazard of the regions adjoining the major faults is generally assessed by historical and recent earthquake data in those regions, and occasional inspection of general topographic, geological and tectonic features of the surroundings by the geologists. In Pakistan some studies have been carried out by Geological Survey of Pakistan and by the geophysicists of other Agencies, for example Richard C. Quitmyer et.al [15] and Ali Hamza Kazmi [16]. These studies however are insufficient for the assessment of the seismic hazard of an area. In case of Peshawar, as all significant earthquakes hitting Peshawar originate from the Hindu Kush region of Afghanistan or Northern Pakistan, the local tectonic faults seem to have a meager role in the seismicity of the city. Moreover the instrumented earthquake record of the USGS for the last 35 years, figs 7 through 12, shows that earthquakes of magnitude less than 4 and 4.5 have occurred in the vicinity of the city. These further confirm a low seismic activity around the city.

RESULTS AND DISCUSSION

The above points highlight the huge conflict among the sources suggesting seismic hazard zoning of Peshawar and adjoining areas. For example the PGA value of 0.4g by UBC and 0.1g by Geophysical Center Met Department of Pakistan has no match. The UN GSHAP adopts a middle way suggesting 0.16g to 0.24g. The two most plausible reasons for the conflict seem to be the scarcity of locally available strong motion data and instrumented study of the seismic activity of the local tectonic faults. Nevertheless the absence of even moderate damage earthquake history of Peshawar provides sufficient evidence that Peshawar and adjoining areas cant' be placed in a seismic hazard Zone at least equivalent to Hindu Kush Region (HKR). On the other hand the facts that Peshawar is regularly rattled by earthquakes originating from HKR and the presence of though low some seismic activity in the vicinity of the city suggests a seismic hazard zoning higher than that recommended by the Geophysical Center Met Department of Pakistan, Mona Lisa and that apparently comprehended from 10 years accelerogram record obtained from Peshawar observatory given in table 1.

In view of the above facts the authors recommend a lower bound value of 0.16g given by the UNGSHAP, with 10% probability of exceedance in 50 years corresponding to return period of 475 years.. This PGA value corresponds to zone 2b of the UBC seismic hazard zones.

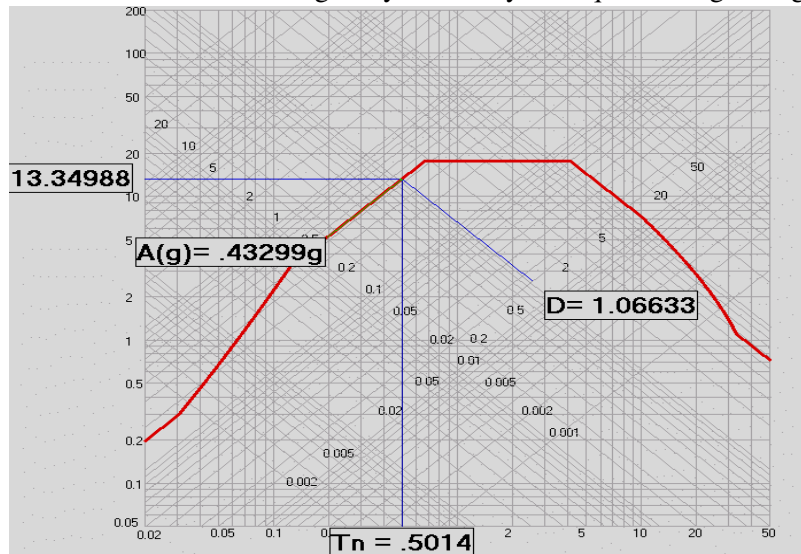


Figure 16: Design Spectra for Peshawar and adjoining areas, corresponding to 5 % damping and PGA of 0.16g

Based on Newmark's model, 5 % damping and PGA value of 0.16g, the authors have developed Design Spectra for Peshawar and adjoining areas as shown in fig 16. It would prove to be very useful for engineers and architects working in the region.

CONCLUSIONS

Based on the work carried out by national and international agencies, independent researchers and available record it seems quite irrational to include Peshawar in a zone of seismic hazard as high as HKR. Though the available record and history of Peshawar entails a PGA value not greater than 0.1g, the same can not be however recommended due to the presence of some low level seismic activity in the close vicinity of the city. Moreover as the authors have not performed either probabilistic or deterministic seismic risk analysis nor was it the purpose of the paper, a PGA value of 0.16g which is a lower bound value adopted by UN GSHAP for Peshawar and adjoining areas has been recommended due to following two reasons.

- According to ground facts it seems the most reliable source due to its exhaustive study of several years, which involved the participation of hundreds of geo physicist, seismologist and engineers from all over the world.
- The records from USGS and Geophysical Center Quetta Met Department of Pakistan, accelerograms collected from Peshawar observatory and the earthquake history of Peshawar all endorse that the structures designed for this PGA value would be safe and economical.

This value corresponds to **zone 2b** of the seismic hazard zones of UBC.

FUTURE RECOMMENDATIONS

In view of the fact that there exists some low level seismic activity in the vicinity of the city, an instrumented study of the local fault system is highly recommended to determine the potential risk posed to the region. Establishing a network of strong motion recorders is also recommended in the northern part of the Province for the construction of attenuation models conforming to local conditions. This would greatly help in the seismic risk study of the whole region.

References

1. Microsoft Encarta Reference Library 2003
2. National Earthquake Information Center, NEIC, Earthquake Search Results, U.S Geological Survey, for the Latitude and longitude range of 32 to 38 and 68 to 78, for earthquake magnitude, $M_b \geq 5.5$ and duration 1973-2003
3. Geophysical Center Quetta, Met Department of Pakistan, Earthquake record from 1905 to 2002
4. Gazetteer of Peshawar District; Library, Department of Archives NWFP Peshawar.
5. National Earthquake Information Center, NEIC, Earthquake Search Results, U.S Geological Survey for the Latitude and longitude range of 32 to 38 and 68 to 78, significant earthquake record Since 25 A.D to 1992
6. Seismic Zones of International cities ,UBC code 1997
7. A. Razzak Loya, Nayyar Alam Zaigham, Muhtaq H. Dawood, "Seismic Zoning of Karachi and Recommendations for Seismic Design of Buildings" , a study conducted with the collaboration of Seismic Committees of Associated Consulting Engineers Pakistan and Karachi Building Code Authority, April 2000.
8. Seismic Hazard Zones of international cities, US Department of states manual, 1997

9. United Nation Global Seismic Hazard Assessment Program (GSHAP/USGS), 1992 to 1999, Reports and maps of World Seismic Hazard, Published by United States Geological Survey, December 15, 1999-Denver Colorado. web site; www.seismo.ethz.ch/GSHAP
10. Mohammad Ali Mirza, M. Zaheeruddin Babar and Kanwar Sabir A. Khan, "Seismic Risk Map of Northern Pakistan", National Geo-Data Center Geological Survey of Pakistan 1988.
11. Mohammad Rafiq Director Geophysical Center Quetta, "Seismic Zones of Pakistan", revised on 25th May 1999, Met Department of Pakistan.
12. Mona Lisa and Azam A. Khwaja, "Seismic Hazard Assessment of Peshawar Basin using Probabilistic Approach". Workshop on Geological Control of Natural Hazards: Earthquakes and mass movement, Baragali, Pakistan, 2002, Abstract p-16: In press Geological Bulletin, University of Peshawar.
13. "Seismicity of Afghanistan /Great Earthquakes / Jalal Abad earthquake of 1842", Amateur Seismic Center India, web site; www.asc.india.org
14. Accelerograms for the duration 1993 to 2003, Upper Air Research Station Khyber Road Peshawar, Met Department of Pakistan.
15. Richard C. Quitmyer, Abul Farah and Klaus H.Jacob, "The seismicity of Pakistan and its relation to surface faults", Geodynamics of Pakistan, Geological Survey of Pakistan, 1979, p.271.
16. Ali Hamza Kazmi, "Active Fault systems in Pakistan", Geodynamics of Pakistan, Geological Survey of Pakistan, 1979, p.285.