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"Research Note"

PROBABILISTIC SEISMIC HAZARD ANALYSIS OF QUETTA PAKISTAN*

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Abstract– Pakistan is a seismically prone country and its provincial capital city Quetta is bordered by a number of faults. Traditionally Peak Ground Acceleration (PGA) is calculated, and is further used in design calculations for structures. However, PGA alone doesnot amply define the seismic load and modern building code emphasis on use of spectral acceleration values. Seismic hazard analysis has been carried out for Quetta city and design parameters required by codes to define seismic loading have been derived. The maps are developed for 0.2 second (Ss) and 1.0 second spectral acceleration (S_1) values for 2% probability of exceedance in 50 years, equivalent to 2500 years of return period. The proposed maps have been recommended to be included in Building Code of Pakistan.

Keywords– Seismic hazard analysis, Quetta, Baluchistan, Ss and S_1 mapping

1. INTRODUCTION

Pakistan's high earthquake risk and vulnerability is evident from the fact that about 59 percent of Pakistan's land area could face moderate to severe earthquakes. During the Oct 8, 2005 earthquake more than 1 lakh lives were lost due to this major earthquake, which also caused enormous damage to property and public infrastructures. The earthquake near Dalbandin, Baluchistan of magnitude Mw 7.2 recorded on January 18th, 2011 and near Quetta, of magnitude Mw 6.4 on October 29th, 2008 with aftershocks show the very high and active seismic vulnerability of the region in recent years. After the strong setback observed in the Quetta Earthquake (1935), construction work has been restricted to very high seismic limits in the area. Traditionally Peak Ground Acceleration (PGA) is used in design calculations for lateral loads on structures [1, 2]. However, PGA alone does not amply define the seismic load and modern international building codes emphasis on the use of spectral acceleration values, PGA is not sufficient to design or to account for the emphasis of earthquake resistant structures. But such parameters do not exist for major cities of Pakistan [3].

2. SEISMIC SOURCE ZONES

The computation grid was limited to administrative boundaries of Quetta district and some portions of Pishin, Kuchlak. Increasing the size of the grid increments in the calculation done by Crisis (2007) increases the processing time, which results in a heavy output file; the disaggregation results are saved in '*.des' and '*.res' output file [4, 5]. Four corners of the selected grid are defined by the following coordinates;

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(1)	*Longitude*	66.7	and	*Latitude*	29.85
(2)	*Longitude*	67.3	and	*Latitude*	29.85
(3)	*Longitude*	67.3	and	*Latitude*	30.65
(4)	*Longitude*	66.7	and	*Latitude*	30.65

The area where the hazard was to be calculated was divided into 60 longitudinal lines and 80 lateral lines making 4800 squares spaced at 1 km both ways. The hazard was calculated at four corners of each square and interpolation was done for intermediate locations. A separate list of earthquakes occurring in each source zone was prepared through the software, The plotting of the earthquakes and faults was done using the projected Geographic coordinate system, (World Geodetic System) WGS 1984, (Universal Transverse Mercator) UTM zone 43N; Earthquake sources can be modeled as point source, line source or area source; volcanoes are point sources, Faults as line sources etc.

The area was divided into six zones as shown in Fig 1. The *b*-value for each area seismic source zone was calculated using linear regression through least square method. The minimum magnitude for each area source zone was selected from the magnitude frequency curve based on completeness checks [6].

Zone 1

It covers most of the areas of Quetta district. The coordinates of the zone are as follows: (29.007 N, 66.253 E), (29.520 N, 66.021 E), (30.386 N, 67.143 E), (29.977 N, 67.329 E) and (29.254 N, 67.011 E). Location of various faults in the zone are shown in Fig. 1. It covers the Northern Boundary of Kirther Fold Belt, the Chaman fault boundary and some areas of the Sibi trough.

Administrative boundary of Mastung and Noshki and the main Lakhpass Highway are included in this area. A total of 28 earthquakes are reported in the catalogue, out of which the range of earthquake is from 4 - 4.9. The famous Quetta Earthquake, May, 1935 also occurred in this zone with an intensity of 7.5 Mw. Almost all earthquakes are shallow with focal depth ranging from 20 to 40 km.

Zone 2

It covers Northern portions of Quetta and also includes Pishin, Gulistan and the Western Pak-Afghanistan border. The coordinates of the zone are as follows: (29.520 N, 66.021 E), (30.994 N, 66.358 E), (31.026 N, 66.726 E) and (30.386 N, 67.143 E) shown in Fig. 1. The significant seismicity is from Chaman fault near the Pak-Afghanistan Border. 50 events are reported in the catalogue in this area, the majority of which have a magnitude greater than 4.0. The maximum recorded earthquake magnitude is 6.7 on 3rd Oct, 1975.

Zone 3

This zone mainly covers the city of Chaman, some areas of Quetta and Pashtun inhabited areas. The coordinates are: (31.026 N, 66.726 E), (31.104 N, 67.610 E), (30.845N, 68.322 E) and (30.386 N, 67.143 E) as shown in Fig. 1. This zone contains the continuity of the transform and thrust fault of Zone 1, and the region rests over the Bela-Chaman Fault Zone and the Ophiolite Belt, in the Tectonic map of Pakistan [7]. This region is named Kakar Khorasan flysch basin. A total of 45 earthquakes are reported, out of which 15 are of magnitude less than 4. The zone also records a few intense earthquakes of magnitude 6.4 recorded in Oct, 2008.

Zone 4

The region covers majority areas of the Sibi trough. It includes high seismic areas of Ziarat, Harnai and Sibi. Coordinates are: (67.143 N, 30.386 E), (30.845 N, 68.322 E), (29.409 N, 69.070 E), (29.087 N, 68.544 E), (29.341 N, 68.061 E) and (29.977 N, 67.329E). Many transform and Thrust faults are located in this zone (Fig. 1). It contains the Western tip of the Sulaiman Fold Belt and is connected with Sibi Trough.

This is a weak area for the release of energy. A total of 541 events have been reported in the region, the records of the region show intense earthquakes which date back to 21st Oct, 1909, when the villages of Baga, Shahpur and Bellpat were destroyed, and the notable Ziarat earthquake in 2008, in which almost all of Ziarat was destroyed. The Zone remained highly active in 2008, 90% of the earthquakes in this region are shallow. This is the most active region surrounding Quetta.

Zone 5

This zone includes seismicity from Kachi Fordeep, Kirthar Fold belt, and the Sibi Trough. Areas of Sibi, Dhadar and Mach district are covered in this zone. Coordinates are: (29.997 N, 67.329 E), (29.341 N, 68.061 E), (28.360 N, 67.043 E) and (29.254 N, 67.011 E) as shown in Fig. 1. Thrust faults on Kirthar fordeep are hosted by this zone. A total of 39 earthquakes are reported in PMD catalogue, out of which 4 are of magnitude less than 4. Maximum recorded earthquake is 7.0 on 27 Aug, 1931. Earthquakes in this region are shallow with focal depth less than 40 km.

Zone 6

This zone covers the district of Kalat, portions of Surab district, and other Baloch inhabited areas, its coordinates are as follows: (29.007 N, 66.253 E), (29.254 N, 67.011E), (28.360 N, 67.043 E), (27.981 N, 66.292 E) and (28.592 N, 65.811 E) as shown in Fig. 1. This area connects to the Chaman fault, and the main transform faults cause earthquakes in regions of Khuzdar and the surrounding area. A total of 52 earthquakes are reported out of which 44 events are of magnitude greater than 4.0. Maximum recorded earthquake is 6.4 on 4 March 1990. This area is seismically active, and rests over the Kirthar Fold belt and the Chaman fault zone.

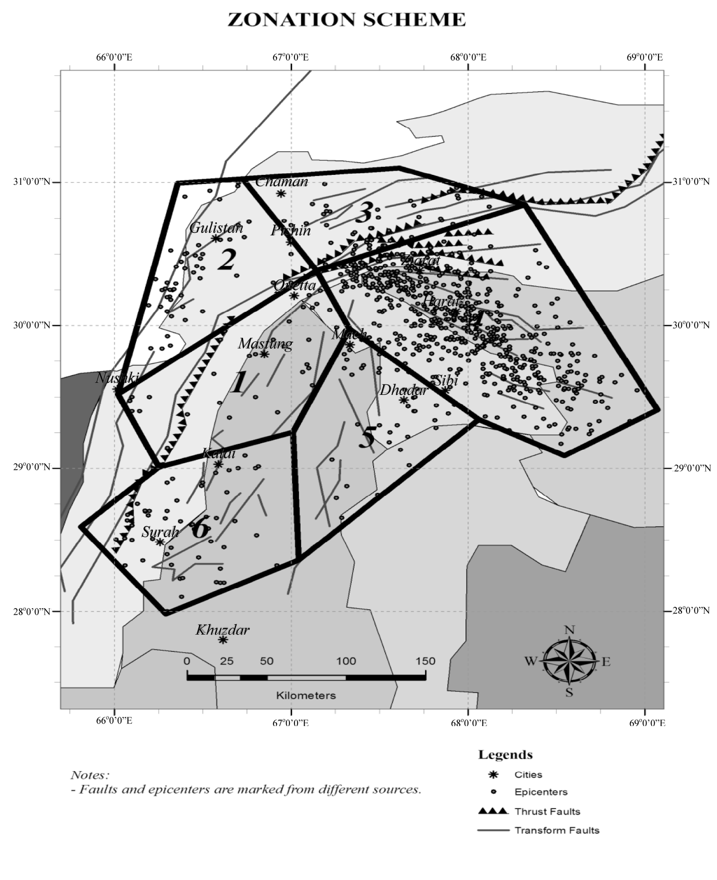

Fig. 1. Micro-zonation scheme for the area; marking of epicenters and faults in each seismic source zone

3. PROBABILISTIC SEISMIC HAZARD ANALYSIS (PSHA) OF QUETTA

Peak Ground Acceleration (PGA) has been calculated by many researchers. However PGA alone does not fully describe the characteristics of an earthquake. We have plotted these values for Quetta. Short period spectral acceleration at 0.2 second (Ss) and one second spectral acceleration (S_1) apply to a deeper concept of structural response [8].

Structural engineers sometimes prefer a so-called "spectral" motion, the response of a damped pendulum with a specific natural period (say, 1.0-second or 0.2-second period with 5 percent damping), because it can simulate the response of an idealized building as shown in Figs. 2 and 3. An engineer might wish to design a building that is strong enough to have a reasonably small chance of seismic damage in the next few decades, say a 10-percent chance of damage in 50 years [9]. The calculations are shown in Figs. 2 and 3. (0.2 second and 1.0 second spectral acceleration values for 2% probability of exceedance in 50 years equivalent to 2500 years of return period.). The proposed maps have been recommended to be included in Building Code of Pakistan.

4. CONCLUSION

Quetta city has a 2 percent chance in 50 years of exceeding a peak ground acceleration of 67 percent g, which is a the highest value observed and a 10-percent chance in 50 years of exceeding a peak ground acceleration of 40 percent g (3.96m/s^2). This value was compared to the value estimated by PMD and NORSAR (2006), in their report the PGA value for 10 percent probability of exceedance in 50 years is 39.28 percent g (3.85m/s^2), which also confirms Zone 4, having PGA greater than 0.32g in Building Code of Pakistan and UBC 97.

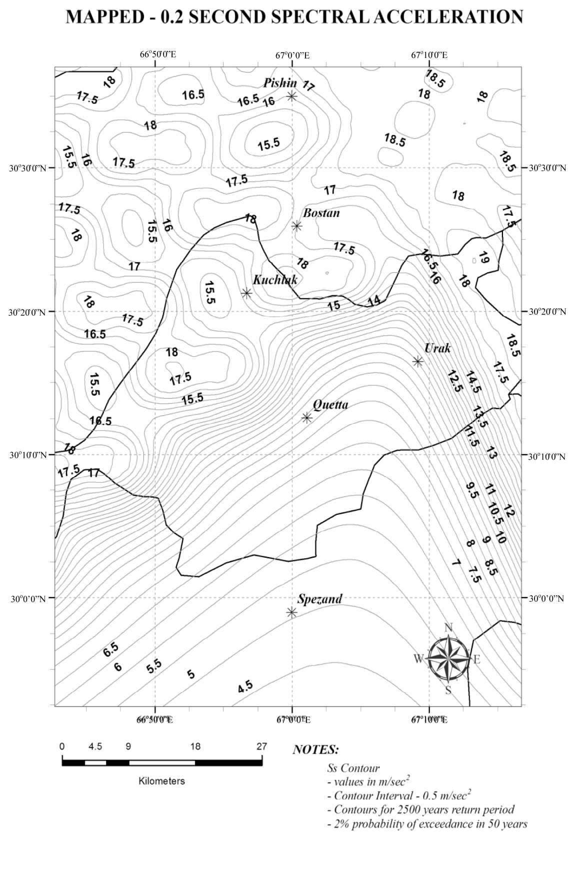

Fig. 2. 0.2-second spectral acceleration contours for 2500 years return period

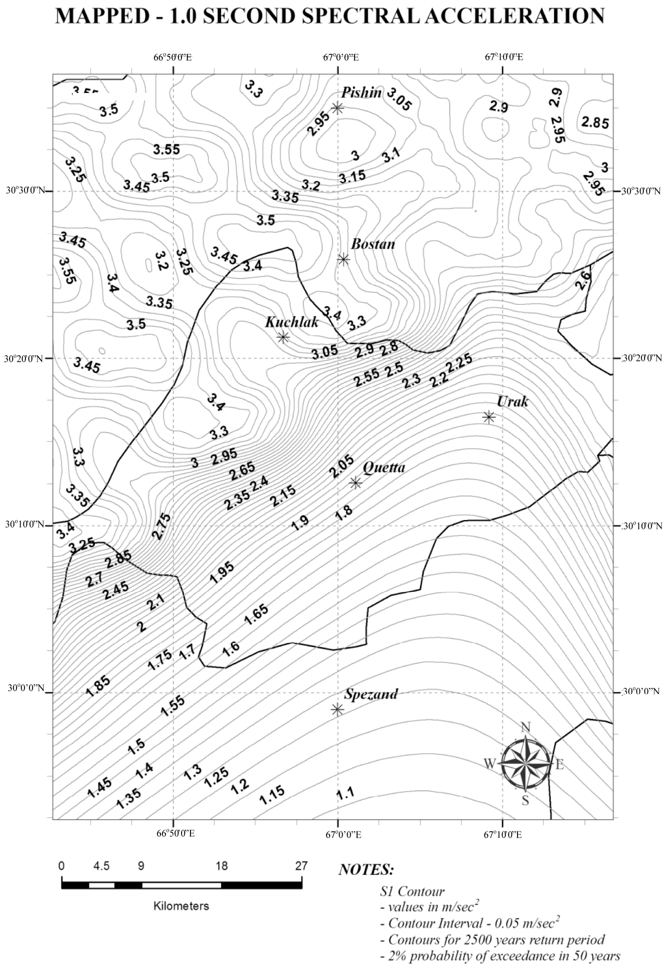

Fig. 3. 1-second spectral acceleration contours for 2500 years return period

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