Seismic hazard assessment of Peshawar Basin using probabilistic approach

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ABSTRACT: *The area of Peshawar Basin has been divided into grids of 0.15° x 0.15° size for carrying out seismic hazard assessment by using probabilistic approach. Available instrumental data of* $m_b \geq 4.5$ *for the period of 1905 -1998 has been used. Peak Ground Acceleration (PGA) values have been determined for the mid points of each grid applying attenuation equation of the Public Works Research Institute of Japan (1990) for the return periods of 50 and 100 years. ERISA-P software has been used for calculating the PGA's. Contour maps have been prepared for these different return periods of 50 and 100 years and are discussed taking into consideration the geology of the area.*

INTRODUCTION

The region of Pakistan is characterized by its seismic instability and has been the source of a large number of destructive earthquakes. At the same time the country consists of dominantly non-engineered structures that can cause human as well as monetary losses in case of big earthquakes (>4.5 m_b). Considering this serious threat to life and property different methodologies have been adopted to help in mitigating this loss. In the present case, taking Peshawar city as the central point, probabilistic approach based on peak ground accelerations (PGA's) values has been applied within a radius of 200km. This large area comprises various tectonic zones like Kohat/ Potwar plateau, Salt Range, Kurram Cherat Margalla Hill Ranges, Khyber Hazara Metasedimentary Fold and Thrust Belt and Hazara Kashmir Syntaxis alongwith the Peshawar basin. However, in the present paper only the hazard assessment of Peshawar basin is discussed.

Location of the Study Area

The geographic coordinates of the area for which seismic hazard assessment has been discussed are Latitudes 33°45′ to 34°30′ N and Longitudes 71° 15′ to 72° 45′E. (Fig. 1) This area includes Peshawar basin and adjacent areas. The adjacent areas are included so that the earthquake effects on the peripheral grids of the study area may also be incorporated in the calculations. In addition to Peshawar city, this area contains a number of other important cities like Nowshera, Mardan, Charsadda, Swabi, etc. Besides a large number of other towns and villages are also located. Most of the area is heavily populated.

Data Sources and Methodology

A seismicity map of the Peshawar basin and its surroundings has been produced (Fig. 1). The earthquakes shown in Fig. 1 occurred during the period 1905 to 1998 and have magnitude $\geq 4.5\, m_b$. From a total of 3197 events shown in the map, 1950 events occurred within a radius of 200km with 632 of them lying in the Peshawar basin. This data has been obtained from the International Seismological Centre (ISC), Preliminary Determination of Earthquakes (PDE) reports of USGS, Quetta Observatory data, and Water and Power Development Authority (WAPDA) reports compiled by the Tarbela Observatory.

Geological control on natural hazards: earthquakes and mass movement. Khan, M.A., Abbasi, I.A., & Khattak, G.A. (Eds.). Geological Bulletin, University of Peshawar, (Special Issue), Vol. 35, pp. 103–112, 2002

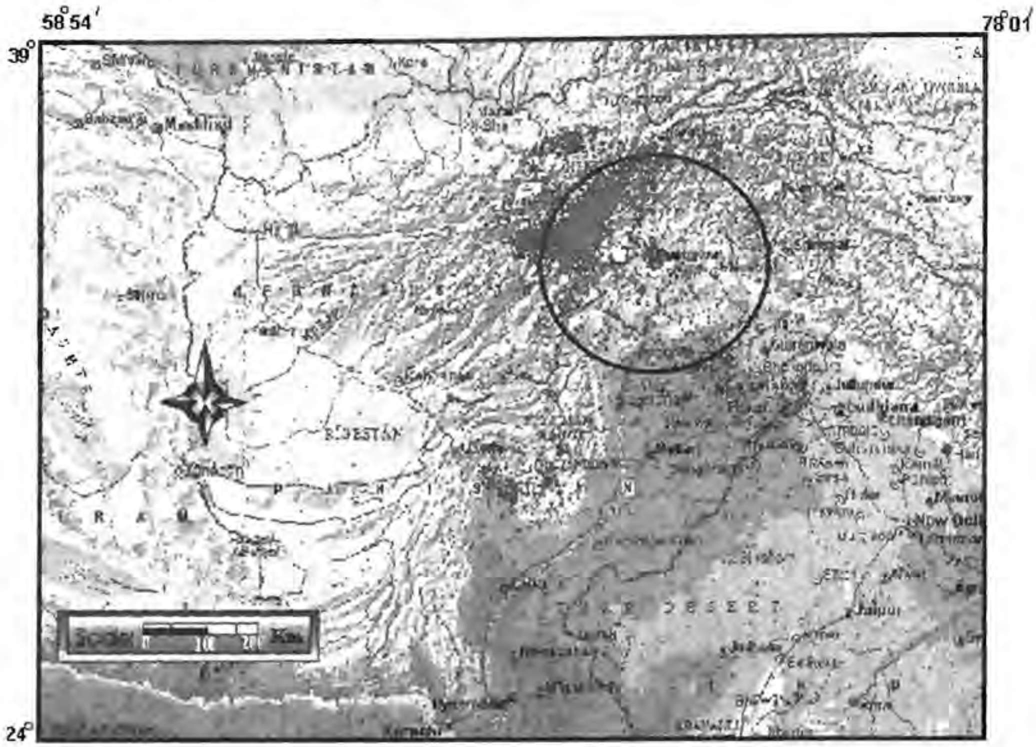

Fig. 1. Location and seismicity within the study and adjoining areas. Circle marks the radius of 200 kms.

1. The area of 200 km radius has been divided into grids of 0.15° x 0.15° with the help of a computer code developed for this purpose. The center of each grid has been considered as a site for which the geographic coordinates were also obtained from the program. From a total of 360 grids, the Peshawar basin is covered by 48 of them.
2. ERISA – P software developed by Tomatsu and Katayama (1991) has been utilized to calculate the Peak Ground Accelerations (PGA's). The major inputs were the earthquake data file that comprises of date, origin time, latitude, longitude and magnitude of 1950 events, geographic coordinates of mid point of each grid, selected radius, attenuation equation and return periods (of 50 and 100 years).
3. The computed PGA values were plotted in the form of contour maps to determine hazardous and safer areas.

GENERAL GEOLOGY AND TECTONICS OF THE AREA

The active fold – and – thrust belt along the northwestern margin of the Indo – Pakistan plate is divisible into two parts – the Sulaiman belt and the NW Himalayan fold and thrust belt. The former is believed to be along a zone of transpression, whereas the latter is associated with the main zone of Himalayan convergence (Jadoon, 1992). In this active zone of convergence (Fig. 2), the Main Karakoram Thrust (MKT), Main Mantle Thrust (MMT), Main Boundary Thrust (MBT) and the Salt Range Thrust (SRT) delineate the major subdivisions of the collision zone (Tahirkheli et al., 1979; Yeats and Lawrence, 1984).

It is believed that the area north of the MKT consisting of Karakoram and Hindukush ranges sutured during the Late Cretaceous – Middle Juras-

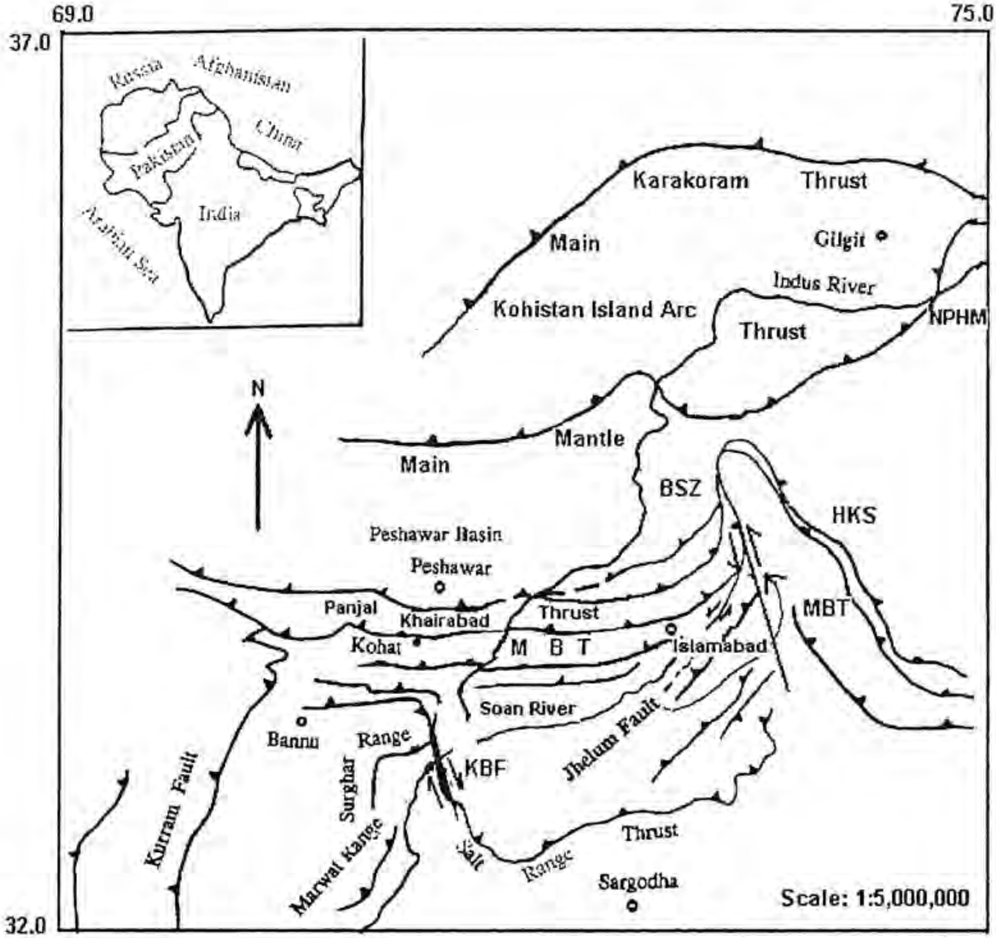

Fig. 2. Structural and tectonic map of the study area and adjoining regions. Here MBT=Main Boundary Thrust. BSZ=Balakot Shear Zone. KBF=Kalabagh Fault. HKS=Hazara Kashmir Syntaxis & NPHM=Nanga Parbat Haramosh Massif.

sic. The Kohistan Island Arc situated between the MKT and MMT sutured in the north (along MKT) about 100 Ma during the Cretaceous (Treloar et al., 1989), whereas the collision at its southern extremity (along MMT) occurred about 50 Ma (Treloar and Rex, 1990). Following the cessation of movement along MMT (3 – 15 Ma according to Zeitler et al., 1980), deformation shifted southwards to MBT. Here the Lower Tertiary rocks are thrusted over Miocene molasse. In the later phases, thrusting propagated south to the SRT. In the Salt Range, deformation as young as 0.5 Ma has been documented by Yeats and Lawrence, 1984.

Peshawar basin covers an area of about 5500 km^2 between the Panjal-Khairabad fault and the MMT. Most of the basin is covered by Plio-Pleistocene basin fill (Burbank and Tahirkheli, 1985) with a Precambrian to Mesozoic sequence underlying it (Hussain et al., 1990; Chaudhry et al., 1999; Kazmi and Jan, 1997; Tahirkheli, 1996). Small outcrops of Paleozoic rocks occur near Mardan and Nowshera (Khwaja and Anwar, 1969), the two cities for which "g" values have been determined. The boundaries of the basin are not well defined. Overall the southern portion has metasediments where as the northern portion contains rift related plutonic-volcanic rocks. Treloar and Rex (1990) refer to the northern part of the basin as a nappe zone.

Hussain et al. (1990), Tahirkheli (1996) and Searle and Khan (1996) have published geological maps of the area. Rafiq et al. (1984) and Tahirkheli (1996) have identified a number of faults in the area. One focal mechanism solution carried out by the authors from near Mardan shows left-lateral strike slip faulting. In both the northern and southern portions, complex folding and thrusts are present. Evidences available suggest that both extensional and compressional structural features occur with the latter predominating.

SELECTION OF RADIUS

The actual radius of 200 km has been selected keeping in view the fact that sufficient number of events must be accommodated within the grids so that the meaningful results are obtained. In other words, the investigated sites (grids) within the study area should contain enough data for carrying out statistical analysis. Fig. 3 shows the distribution of earthquake events in relation to the grids. It can be observed that 10 % of the grids contain less than 25 events, 31% contain between 25 and 50 events and 59% of the grids contain more than 50 events. As such, it can be concluded that very few gaps exist in

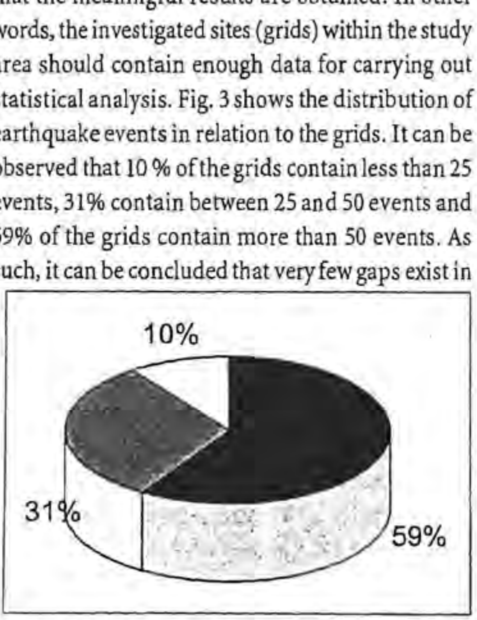

Fig. 3. Distribution of earthquake events in relation to grids.

the present case and the selection of the radius seems to be a correct one.

Another evidence used to infer that the selection of radius is correct has been obtained by applying the attenuation equation (used in the present study) on five randomly chosen grids from within the study area. Fig. 4 shows the PGA values determined for two of these grids for varying radii (from 50 km to 350 km) and for return periods of 50, 100 and 200 years. It is clearly demonstrated from Fig. 4 that PGA values remain constant from about 175 km onwards. Also it can be observed that the number of events may increase for different return periods but are not significantly affected by increase of the radius.

SELECTION OF ATTENUATION EQUATION

A large number of attenuation equations are available in the published literature. These have been compiled by various workers for different regions taking into consideration the seismicity patterns of those particular areas or by incorporating the local geological conditions. Thus the predictive capability of these equations is reduced if applied outside the regions for which they were formulated.

No area of Pakistan has so far been investigated for the formulation of an attenuation equation. Thus, in Pakistan the limited number of studies of this kind that have been undertaken by making use of attenuation equations formulated elsewhere (Pervez, 1998; Ansari, 1995, Monalisa and Khwaja, 2002). In the present study, the equation of the Public Works Research Institute (PWRI) of Japan has been used. Ansari (1995) had previously used it for some areas of Pakistan and given reasons for preferring it. Thus in order to create uniformity in data generation and till such time that an attenuation equation is formulated for the area it has been preferred. This does not imply that other attenuation equations are not applicable. The preferred equations are as follows:

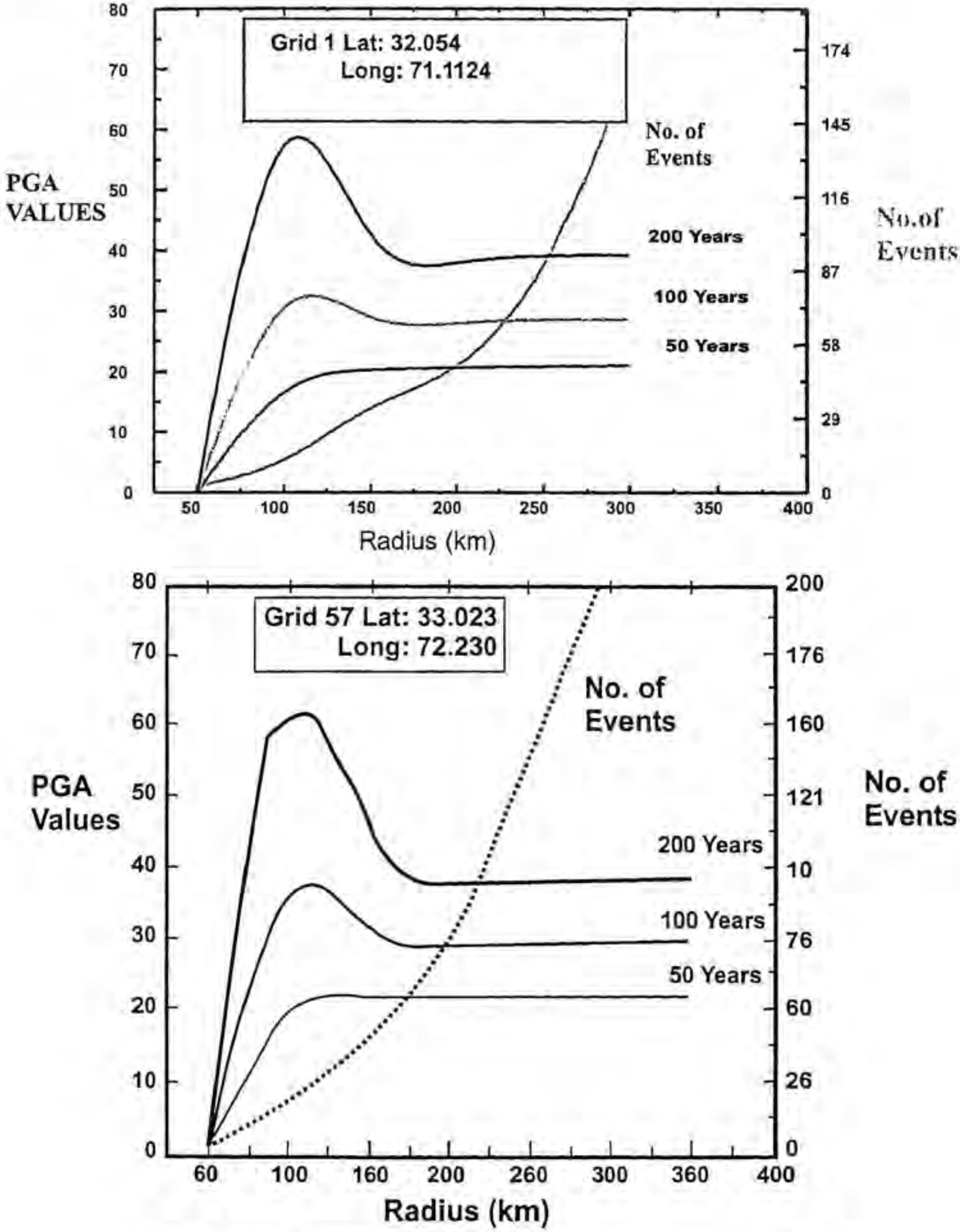

Fig. 4. PGA with increasing radius based on PWRI attenuation model.

$A = 227.3^{*}\ 10^{0.308\,M^{*}}\ (D+30)^{-1.201}$ ... For Alluvium

$A = 1073^{*}\ 10^{0.221\,M^{*}}\ (D+30)^{-1.251}$ ... For Rock

Where A = Acceleration in gals

M = Magnitude

D = Radius in Km

SOFTWARE USED (ERISA-P)

The software used is called ERISA-P developed by Tomatsu and Katayama (1991). The simplified flowchart of this program is shown in Fig. 5. As can

ERISA – P SYSTEM

(EARTHQUAKE RISK ANALYSIS FOR PERSONAL COMPUTER)

START

↓

LOCATION OF THE SITE.

(Geographic coordinate of the mid point of each grid)

↓

DATA PERIOD.

MINIMUM MAGNITUDE.

RADIUS OF THE AREA.

EARTHQUAKE DATA → ↓

SELECTION OF EARTHQUAKES.

↓

SELECTION OF GROUND

MOTION PROPERTY TO BE USED.

ATTENUATION RELATIONSHIP → ↓

SERVICE LIFE (t) → ↓

EXPECTED PGA.

↓

REPEAT FOR ANOTHER GRID

↓

END

Fig. 5. A simplified flow chart of (ERISA –P) system.

be observed from the flow chart, the program starts with the Basic Menu Condition. It requires the input of the location of the site (geographic coordinates of the midpoints of one grid at one time), data period (April, 1905 to April, 1998), minimum magnitude (in our case>4.5 m_b) and radius of area (200 km). Except for the location of the site, the other parameters have been put in a separate data file to be read from there by the program.

Following these inputs the software for statistical analysis, selects the earthquakes. The other relevant information fed is about the ground motion property to be analyzed (i.e. PGA), attenuation equation to be used (in our case PWRI 1990 Equation) and the service life of the structure (e.g. 50/100 years). The expected PGA value is then obtained and the process repeated for each grid.

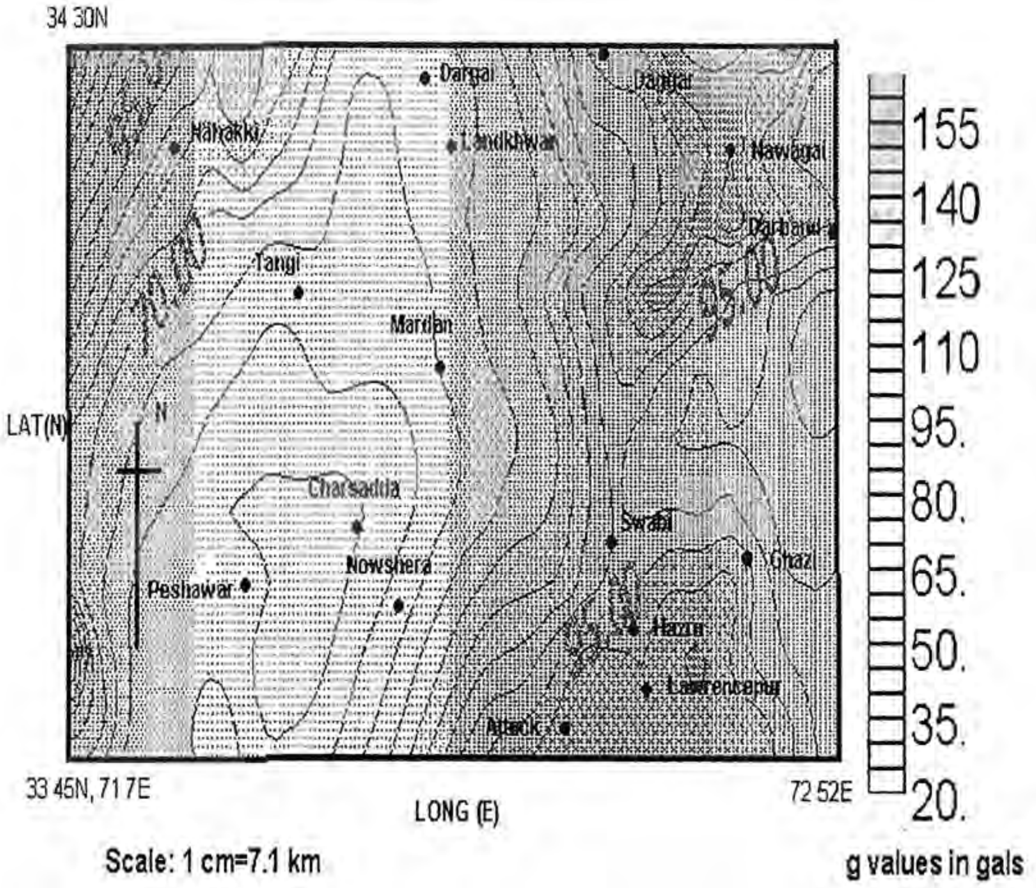

Fig. 6. PGA contour map for 50 years return period.

DISCUSSION

The expected peak acceleration values were calculated for the return periods of 50 and 100 years. The accelerations have been calculated with a non-exceedance probability (Q) of 0.386. This value is for cases where service life of structure is the same as the return period.

PGA contour maps for return periods of 50 and 100 years have been prepared (Figs. 6 and 7). In both the maps, pattern of distribution of contours is similar, the only difference being higher PGA values with increasing return periods. As such, only the 50 years return period map is discussed below in terms of seismic zonation and geology of the area. However values of 'g' for both 50 and 100 years are also shown in Table. 1.

The expected ground accelerations show that the lowest values of about 50 gals are centered on Peshawar City itself (Fig. 6). The city forms part of a narrow zone that slightly broadens towards the NNE and has values of about 70 gals at the margins. This zone till near Dargai is dominantly overlain by Quaternary alluvium. Charsadda, Mardan and Tangi are also situated within this zone of relatively low accelerations.

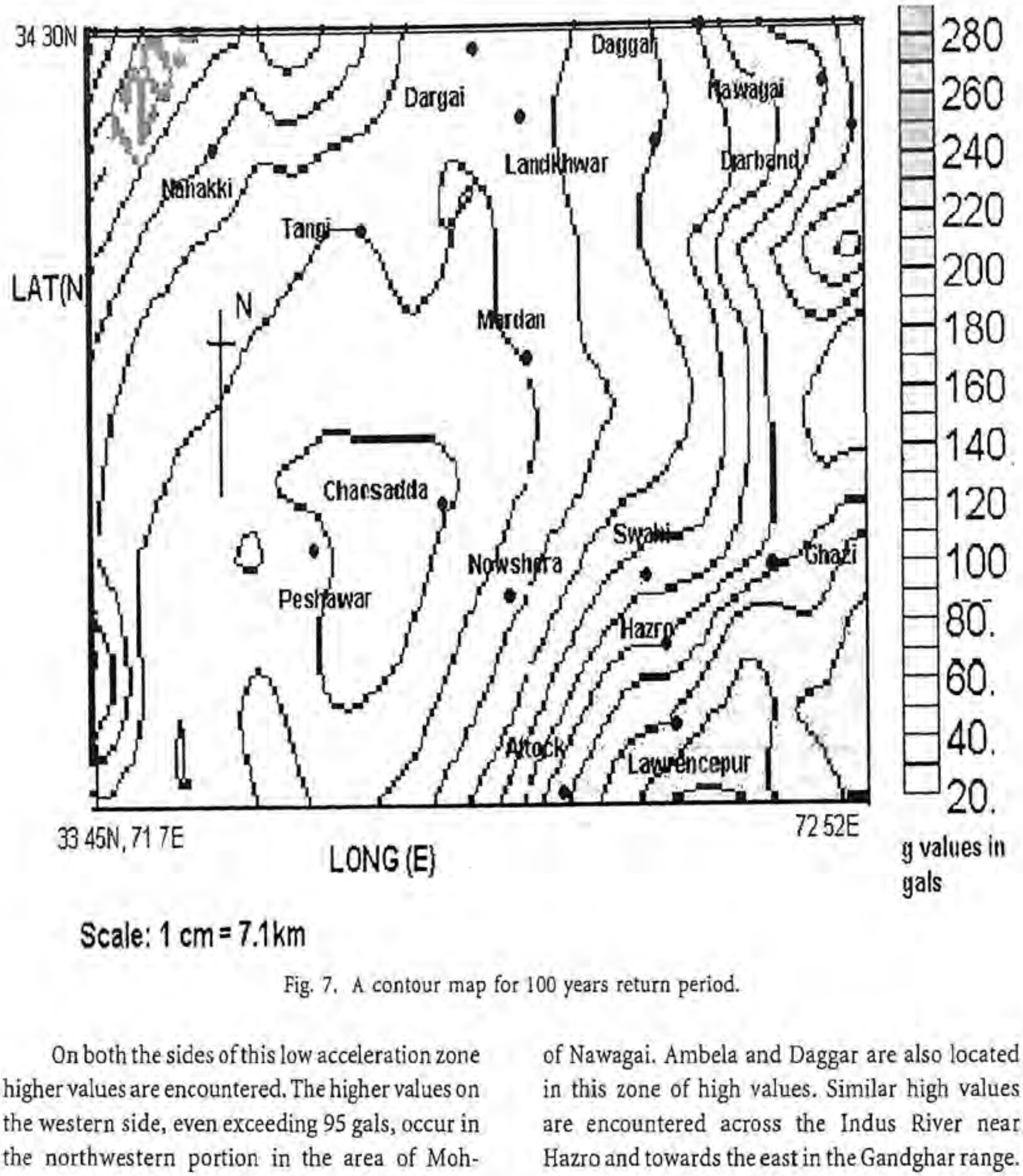

Fig. 7. A contour map for 100 years return period.

On both the sides of this low acceleration zone higher values are encountered. The higher values on the western side, even exceeding 95 gals, occur in the northwestern portion in the area of Mohmand Agency. Structural information is not available. MMT is located a few kilometers north of the area and these values may be a reflection of seismic activity.

In the eastern portion of the map from near Landkhwar, Rustam and Swabi onwards, the acceleration values constantly increase till they reach a maximum of 110 gals near the village of Nawagai. Ambela and Daggar are also located in this zone of high values. Similar high values are encountered across the Indus River near Hazro and towards the east in the Gandghar range. These areas are marked by structural complexity with some faults like the Darband Fault considered as active. Further, Seeber and Armbruster (1979) have documented steeply dipping NW-SE trending faults in this portion. These faults are considered to be active between 8 and 18 km depth by them. Seismicity at deeper levels also exists in this part that is referred to as the Hazara Lower Seismic Zone.

TABLE 1

SOME IMPORTANT CITIES /TOWNS AND THEIR EXPECTED ACCELERATION FOR RETURN PERIOD OF 50 AND 100 YEARS.

Name of cities/villages	Expected PGA	
	50 years	100 years
Peshawar	0.05 g	0.07g
Mardan	0.06 g	0.09g
Swabi	0.085 g	0.12g
Attock	0.100 g	0.15g
Landkhwar	0.065g	0.10g
Dargai	0.085g	0.10g
Tangi	0.06	0.09g
Rustam	0.08	0.10g
Charsadda	0.05	0.07g
Nowshera	0.06	0.09g
Daggar	0.095	0.120g
Hazro	0.09	0.140g
Lawrencepur	0.10	0.150g
Nahakki	0.085	0.10g
Nawagai	0.110	0.130g
Darband	0.08	0.140g
Ghazi	0.065	0.130g

The low and high acceleration zones differentiated on the map help to delineate between safer and more hazardous areas. Also shown in Table 1 are calculated PGA values of some localities. Locations having values of > 0.6g can suffer more damage due to earthquake activity and thus require more attention related to construction and designing of structures.

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