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PROPOSAL FOR A NEW SEISMIC ZONING MAP FOR BANGLADESH

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ABSTRACT: This paper estimates the seismic hazards in Bangladesh. Due to the lack of a proper seismotectonic map in the region under consideration, insufficiency of data and high uncertainties in seismic source parameters, a simple model for earthquake occurrence using a newly developed earthquake catalogue is used in this paper. Using the simple catalogue based model, the seismic hazard at 42 points in Bangladesh is estimated. The seismic hazard maps are presented as contour maps in terms of horizontal Peak Ground Acceleration (PGA) based on 50, 100, 200 years return period and 10% probability of exceedance in a design life of 50 years. A return period seismic hazard map for PGA≥150 cm/s^2 is also presented. By comparing the seismic base shear coefficients with the values of the hazard maps, a new seismic zoning map for short period structures are proposed based on the 200 year PGA. Similar to the BNBC 1993 seismic zoning map, the proposed map has three seismic zones. But it assigns higher seismicity to some areas that have been assigned low seismicity in the seismic zoning map of BNBC 1993. The findings of this study show that considerable seismic hazard exists for major parts of the country.

KEYWORDS: Earthquake Hazard, Peak Ground Acceleration, Attenuation, Seismic Zoning

INTRODUCTION

Earthquake is one of the most deadly natural disasters that may affect the human environment. Even a relatively moderate earthquake can lead to a very large number of deaths. Although in recent past no major earthquake has affected this country, a major event may affect the country any moment. It may be noted that the 1897 Great Indian earthquake with a magnitude of 8.7 and considered to be one of the strongest earthquakes in the world, originated at a epicentral distance of only 230 km from Dhaka. While the earthquake affected almost whole of Bangladesh, damages were very severe particularly in Sylhet, Rangpur and Mymensingh. In the city of Dhaka most of the brick masonry buildings either collapsed or were severely damaged (Oldham, 1899). The first step in reducing the risk of the society from earthquake hazard is an assessment of the hazard itself. Both the seismic hazard analysis and the establishment of seismic hazard maps were made difficult in Bangladesh due to the lack of homogeneous, accurate and complete data. Today, after the re-evaluation of the seismicity of Bangladesh and adjacent regions (Sharfuddin, 2001), it became possible to produce these maps. For this purpose, this paper intends to assess the seismic hazard and to produce earthquake hazard maps in

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Bangladesh. An seismic-zoning map for engineering purposes is a map that specifies the levels of the maximum ground motions (forces) for earthquake-resistant design. Earthquake hazard maps are practical tools in seismic design of structures because they provide important guidance when it is not feasible to do the earthquake hazard assessment at particular sites. These maps give a good indication on the areal extent of expected strong shaking for large earthquakes.

The findings of this study should be an integral part of the whole process of economic and social development in Bangladesh. They constitute a fundamental means which should guide officials at the national and regional levels in the formulation of development strategies in seismically active zones, land use management, revision and enforcement of appropriate building codes and decision-making of policies for preventive measures against earthquake risk affecting the region considered.

METHODOLOGY

Numerous methods for earthquake hazard assessment in a given site are available today. Lomnitz and Epstein (1966) employed the Poisson process for the occurrence of large earthquakes which is still used. Cornell (1968) and Esteva (1968) derived the general basis for the most complete analysis of the whole seismic hazard problem with the inclusion of the propagation mechanism of the ground motion. Shah and Vagliente (1972) used the Markov model of earthquake prediction in seismic hazard analysis. A methodology for seismic hazard estimation based on historical earthquake occurrences is presented in detail in Tomatsu and Katayama (1988) and Molas and Yamazaki (1994). The seismic hazard evaluation at a specified site depends upon the definition of the following four conditions:

(a) *An earthquake source model.* It is based on geological evidence, seismic sources are identified and modelled as a point, line, area or dipping plane. In this study, a point source model is used.

(b) *A seismicity model.* The seismicity of each of the modelled sources is first determined from past data available. The recurrence relationship relating the size of the past events in terms of Peak Ground Acceleration (PGA) is derived. The seismicity model used in Tomatsu and Katayama (1988) and Molas and Yamazaki (1994) is usually taken as

$$\log(\bullet) = a + b\log(y) \quad (1)$$

where y is the peak ground acceleration, • is its occurrence rate and a and b are regression constants. This relation can be written as

$$\log(y) = (-\log(T) - a)/b \quad (2)$$

where T (=1/•) is the return period of T yr. Thus, Eq (2) represents the peak ground acceleration earthquakes with a return period of T yr.

(c) *An attenuation model of ground motion information.* This describes the transfer of ground motions from the source to a particular site as a function of magnitude, distance and soil conditions. Here, the peak ground acceleration is used to characterize the ground motion; the attenuation law is in the form

$$log(y) = b_1 + b_2 (Ms) - b_3 \log (r) - b_4 (r) \quad (3)$$

where $r^2 = d^2 + h^2$, r is the hypocentral distance (km), d is the epicentral distance (km), h is the focal depth (km), y is the peak ground acceleration, and M_s is the surface-wave magnitude. This attenuation law is required to determine the regression constants a and b. Then, a linear regression fitting is carried out at each given site within the region under consideration.

(d) *A recurrence forecasting model.* Various statistical models have been tested in research papers; however, for practical purposes, earthquakes are considered to be random events, and the Poisson process is used, which implies assumptions of stability and independence over time. Since hazard analysis defines the occurrence of ground motions equal to or larger than a specified value, the probability of exceedance is used. For a Poisson process this may be expressed as

$$p= 1-exp(- \upsilon t) \quad (4)$$

ZONE UNDER INVESTIGATION

In this study, an attempt is made to assess the seismicity of Bangladesh (20 - 28° north latitude and 86 - 95° east longitude). The region under study has similar geological process and similar historical development. Similarities in population settlements, building stock characteristics and socio-economic and demographic conditions, etc., are very important parameters in the whole process of seismic hazard studies in the region. Table 1 shows the latitude and longitude of 42 selected points. Figure 1 shows the geographical locations of the investigated sites.

ATTENUATION LAW OF PEAK GROUND ACCELERATION

The quantitative assessment of seismic hazard at any particular site within a region requires an attenuation law for the Peak Ground Acceleration (PGA). The maximum ground motion to be expected in the site constitutes a crucial problem in earthquake engineering. For Bangladesh, as in many other parts of the world, no PGA attenuation law has been developed, due mainly to the shortage of strong motion data. To assess the seismic hazard in this region, an attenuation law was adopted. A great amount of PGA attenuation relationships, predicting strong ground motions in terms of magnitudes, distance, site geology, and in some cases other factors, using various models and data sets are established for different parts of the world. Reviews of these laws are presented in Campbell (1985) and Joyner and Boore (1988). Some of the published attenuation laws are presented in Table 2.

Table 1. Latitude and longitude of 42 selected sites for hazard analysis

Grid Point	Latitude	Longitude	Grid Point	Latitude	Longitude
1	26.5	88.5	22	23.8	90.3
2	25.5	88.5	23	22.8	89.6
3	25.5	89.5	24	22.7	90.3
4	24.5	88	25	22.35	91.75
5	24.5	89.5	26	26.5	89.5
6	24.5	90.5	27	26.5	90.5
7	24.5	91.5	28	26.5	91.5
8	23.5	89	29	26.5	92.5
9	23.5	89.5	30	25.5	90.5
10	23.5	90.5	31	25.5	91.5
11	23.5	92	32	25.5	92.5
12	22.5	89	33	23.5	91.5
13	22.5	90	34	21.5	91.5
14	22.5	91	35	24.85	93
15	22.5	92	36	24	92
16	22.5	92.5	37	24	93
17	21.5	92	38	23	93
18	21.5	92.5	39	22	93
19	20.5	92.25	40	21	93
20	24.42	88.5	41	26	88
21	24.85	91.8	42	25	88

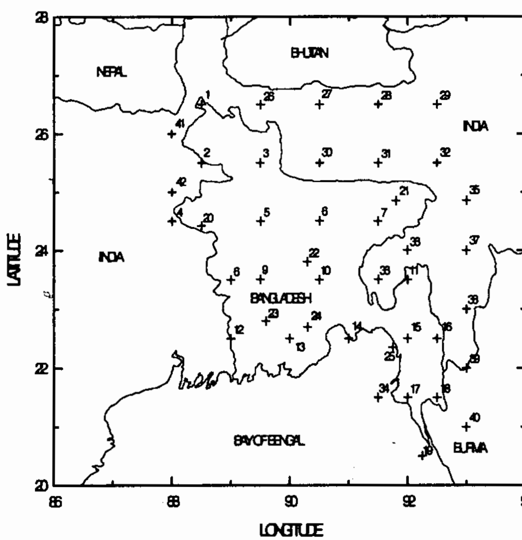

Fig. 1. Map showing the limits of Bangladesh and adjacent region

Table 2. Attenuation laws (after Sharfuddin, 2001)

Author	Law
Esteva	$y=1230e^{3M}(d+25)^{-2}$
Esteva & Rosenblueth	$y=110e^{0.8M}r^{-1.6}$
Duggal	$y=227x10^{0.308M}(d+30)^{-1.2}$
McGuire	$y=0.0306e^{0.89M}r^{-1.17}e^{-0.2S}$ where S=0 for rock and S=1 for alluvium
Katayama	Logy=2.308-1 637log(r+30)+0.411M
WoodwardClyde Consultants	$y=276e^{(0.68M)}*(r+c)^{-1.2}$ $C=0.864e^{0.463M}$
Ambraseys	Logy=-1.43+0.245Ms-0.001r-0.786logr $r=(d^2+2.7^2)^{1/2}$

where y=PGA; M=magnitude; d=epicentral distance; r=hypocentral distance.

In this paper, the attenuation law for alluvial soil proposed by Public Works Research Institute (PWRI) in Japan (Duggal, 1989) has been used. This is due to the fact that the soil of Bangladesh is similar to the type of soil used in the above law.

This equation is presented below:

$$y=227.3x10^{0.308M}(d+30)^{-1.201} \text{ (in cm/s}^2\text{)}$$

where *M* is the magnitude and d is the epicentral distance (km), and y is the PGA (cm/s^2).

SELECTION OF EARTHQUAKES AROUND THE SITE

To estimate the seismic hazard in any particular site within a region requires a selection of earthquakes that affect significantly the value of the hazard output. However, there is no strict rule for selecting the maximum epicentral distance to the site. A sensitivity study for different maximum epicentral distances, for three sites in the region considered, was carried out to show the influence on the seismic hazard evaluation, as shown in Figure 2. A small area around the site results in a smaller number of earthquakes to be considered and some events outside the zone considered may affect the hazard in the site. This, naturally, will decrease the data set for regression. On the other hand, a too large area may include earthquakes that do not affect the seismic hazard in the site and are thus useless. The findings show that for an epicentral distance of 200 km and beyond, the b-coefficient of the Gutenberg-Richter formula is relatively stable. Thus, it is assumed that significant earthquakes are equally likely to occur anywhere in the area of 200 km in radius surrounding the sites under consideration. Figure 3 shows the regression curve fitting for a site. The evaluation of seismic hazard at a site is carried out only if the number of earthquakes in the area considered (200 km radius) is larger than 10 and the surface-wave magnitude is equal to or greater than 4.0.

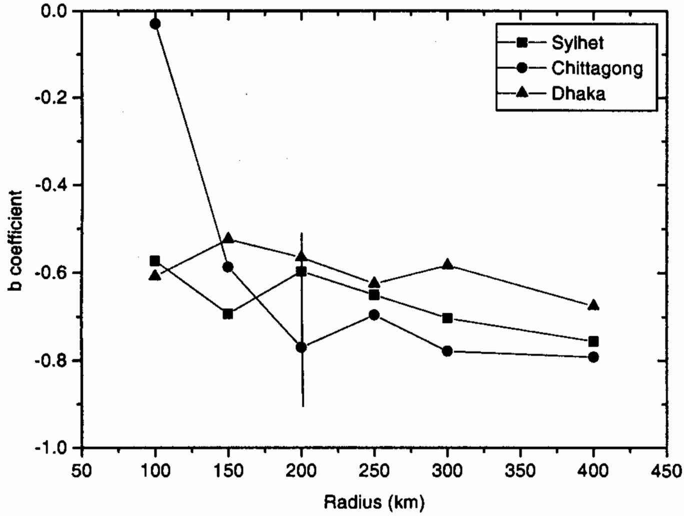

Fig. 2. Sensitivity of b-coefficient to the increase in radius

REGRESSION ANALYSIS

In applying linear regression to each site which is taken as the centre of an area of 200 km radius where past earthquakes are likely to occur again, it was found that very high peak ground accelerations are calculated in some very low seismicity zones. It was found that the fitting curve of peak ground acceleration and its occurrence rate do not fit the data accurately. This is due to the high mean annual occurrence rate of small peak ground acceleration. To solve this problem, some sites where unusually high values of the PGA are found and some other random sites were studied. Figure 3 shows the regression curve fitting for a site where high PGA was calculated. It can be clearly seen that taking into account so many small accelerations tend to flatten the regression line and thus affect seriously the earthquake hazard in the site.

The findings of this study suggest that these small events be removed from the analysis by cutting the regression at $\upsilon=1$ (i.e. disregarding data with occurrence rates greater than 1.0 per year) be applied to the evaluation of seismic hazard of this region. A good fit of the new regression line with the data sample with a cut off at $\upsilon=1$ is also shown in Fig. 3. Obviously cutting the data samples for these sites will tend to decrease the value of the predicted PGA. This will be more visible if only a small number of high PGA occurred at the site.

EARTHQUAKE HAZARD MAPS

Bangladesh, as defined in Fig. 1, has been first divided into 42 grids having sides of one degree. Earthquake hazard is estimated in terms of (1) expected peak ground horizontal accelerations for 50, 100 and 200 year return periods, (2) 10% probability of exceedance in a design life of 50 years (3) return period in years for PGA≥150 cm/s^2 which is considered as an important value in engineering purposes.

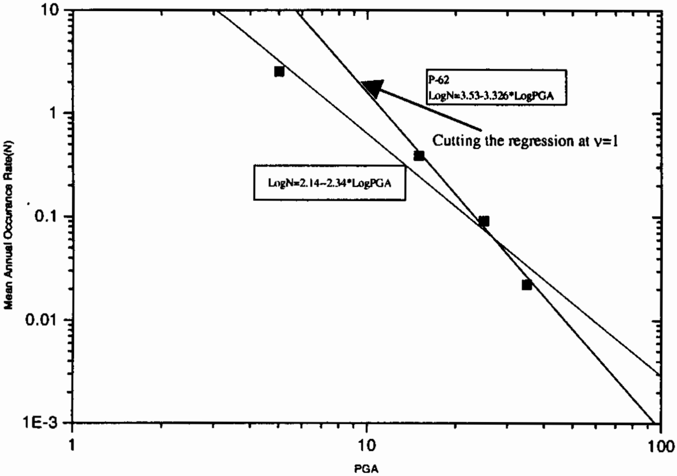

Fig. 3. PGA versus Mean Occurrence Rate for a Site

The earthquake hazard maps using the above criteria are shown in Figures 4 to 8. It can be seen that higher seismic hazard is observed especially in Sylhet, Chittagong Hill Tracts and northern part of Bangladesh. These regions were struck by several damaging earthquakes during the last and the current centuries which are 1869 Cachar earthquake, 1885 Bengal earthquake, 1897 Great Indian earthquake, 1918 Srimangal earthquake, 1930 Dhubri earthquake and 1934 Bihar-Nepal earthquake. The south-western area of Bangladesh is almost an earthquake free zone; it is of interest to mention that very few earthquakes were reported and no seismic lineament can be clearly observed in this region. Based on the above hazard maps, an updated seismic zoning map of Bangladesh is proposed as shown in Fig. 9.

COMPARATIVE ANALYSIS OF BNBC 1993 AND THE PROPOSED SEISMIC MAP

Similar to the BNBC 1993 seismic zoning map, the proposed map has three seismic zones. The proposed seismic zoning map assigns higher seismicity to Bandarban, Faridpur, Kustia, Natore, Nilphamari, Panchogarh, Rajshahi, Sandwip and significant part of Bogra, Cox'sbazar, Khagrachari, Noakhali, Rangamati and Rangpur. These areas have been assigned low seismicity in the seismic zoning map of

BNBC 1993. Figure 10 compares the proposed seismic zoning map with the existing seismic zoning map of Bangladesh (BNBC 1993). Table 3 presents a comparison between the BNBC 1993 and the proposed seismic zoning maps with respect to area and population (based on the 1991 Population Census data) which falls within the three different seismic zone boundaries.

Table 3. Comparison between BNBC 1993 and the Proposed Seismic Zoning Maps

Zone	Assigned PGA (cm/s^2)	BNBC 1993		Proposed	
		% Area	Population in Millions	% Area	Population in Millions
1: liable to slight damage	75	36	34	23	19
2: liable to moderate damage	150	38	50	39	52
3: liable to severe damage	250	26	29	38	42

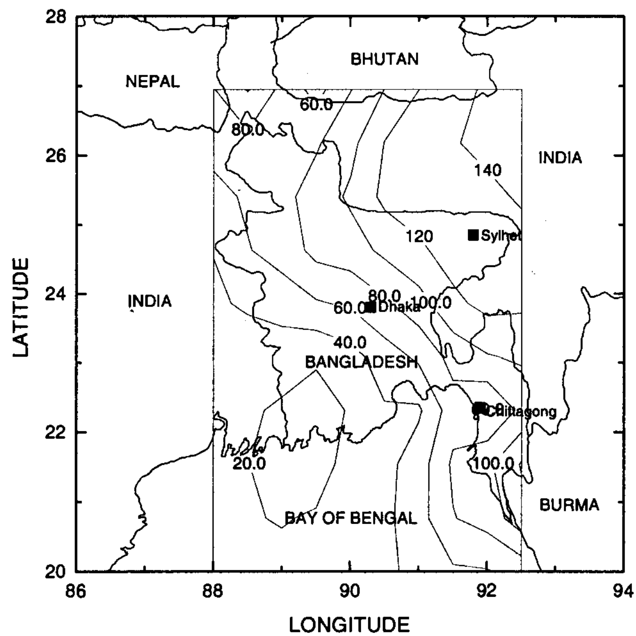

Fig. 4. Hazard Map Showing 50 Year Ground Surface Acceleration Based on the Attenuation Law of Duggal (1989)

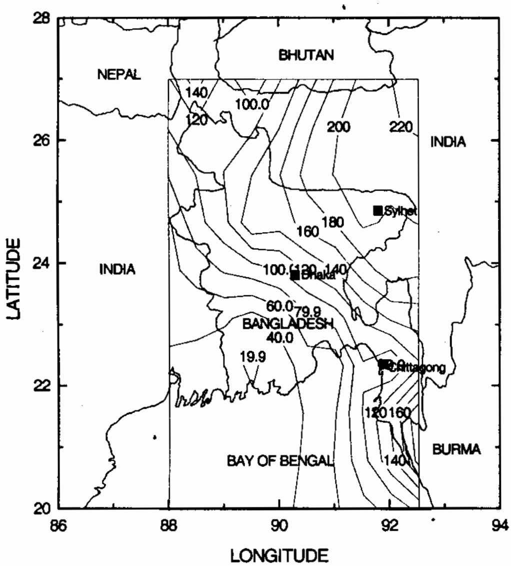

Fig. 5. Hazard Map Showing 100 Year Ground Surface Acceleration Based on the Attenuation Law of Duggal (1989)

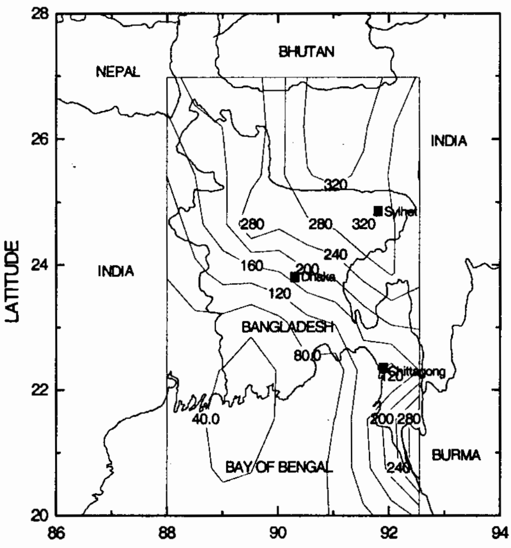

Fig. 6. *Hazard Map Showing 200 Year Ground Surface Acceleration Based on the Attenuation Law of Duggal (1989)*

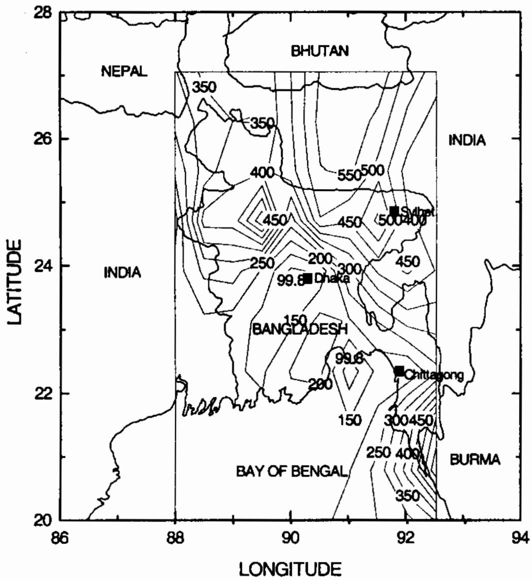

Fig. 7. Seismic Map of Bangladesh and Surrounding Area for a 10% Probability of Exceedance in an Economic Life of 50 year Based on the Attenuation Law of Duggal (1989)

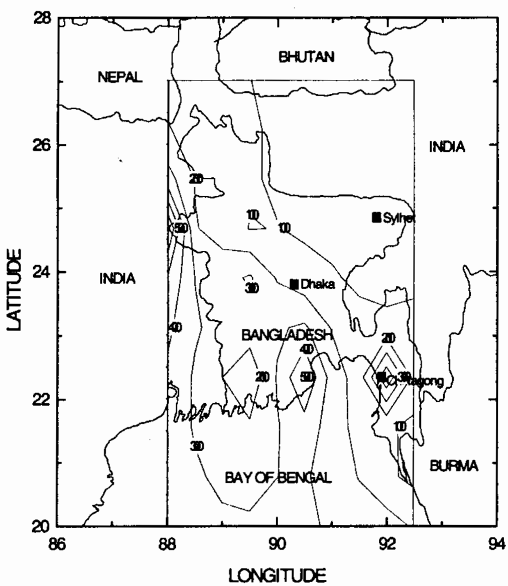

Fig. 8. Seismic Map of Bangladesh and Surrounding Area in Terms of Return Period in Years for PGA≥150 cm/s² based on the Attenuation Law of Duggal (1989)

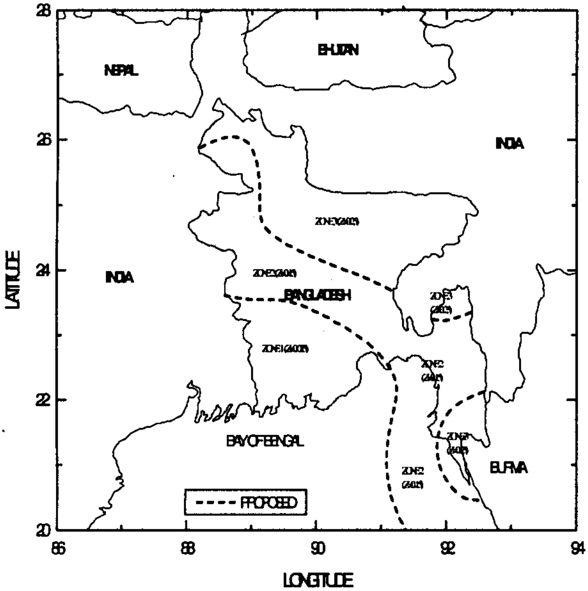

Fig. 9. Proposed Seismic Zoning Map of Bangladesh

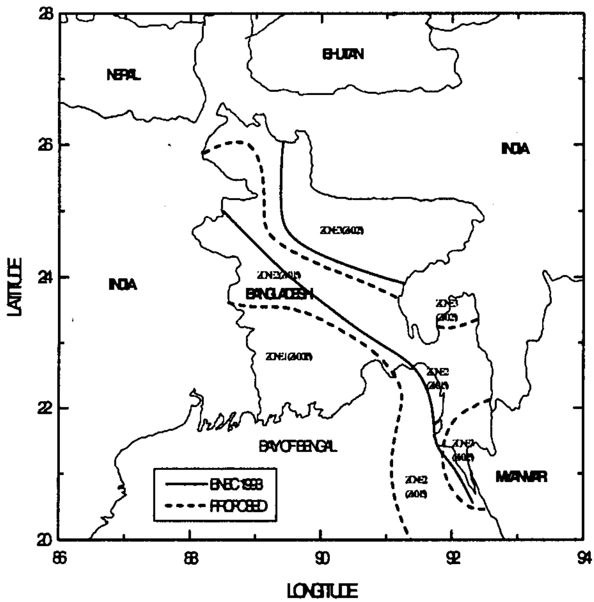

Fig. 10. Comparison between Proposed Seismic Zoning Map of Bangladesh and BNBC 1993

CONCLUSIONS

In this paper seismic hazards in Bangladesh has been evaluated and presented as seismic hazard maps. For this purpose, a simple model for earthquake occurrence is used. Using this model, the seismic hazard at 42 points in Bangladesh is estimated. The seismic hazard maps are presented as contour maps in terms of horizontal Peak Ground Acceleration (PGA) based on 50, 100, 200 years return period and 10% probability of exceedance in a design life of 50 years. A return period seismic hazard map for PGA≥150 cm/s^2 is also presented. A new seismic zoning map for short period structures is also proposed. Similar to the BNBC 1993 seismic zoning map, the proposed map has three seismic zones. But the proposed map assigns higher seismicity to some areas that have been assigned low seismicity in the existing zoning map. The findings of this study shows that considerable seismic hazard exists for major parts of the country. Based on the 1991 Census data and proposed seismic zoning map, about 42 million people, representing one third of the total population live in Zone 3 (38% area), i.e. areas which may be classified as "liable to severe damage", another 52 million (i.e. approx. 46% of the population) live in Zone 2 (39% area), i.e. areas "liable to moderate damage" and the rest 19 million population live in Zone 1 (23% area), i.e. areas "liable to slight damage". The outcome of this study, coupled with vulnerability studies, must guide, stimulate and facilitate the efforts of the respective government, the earthquake engineering and the disaster mitigation planning communities to take specific practical preventive measures to reduce seismic risk of Bangladesh.

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NOTATIONS

•	occurrence rate
y	peak ground acceleration
a & b	regression constants
M_s	surface-wave magnitude
r	hypocentral distance
d	epicentral distance
h	depth