AN ESTIMATE OF SEISMIC RISK IN THE NORTHEAST INDIAN REGION

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SUMMARY

Seismic risk in terms of probabilistic estimate of maximum ground acceleration to be expected from earthquakes occurring in the northeast Indian region has been studied by dividing the region into a number of elementary point sources. From the distribution of earthquakes in these elementary point sources, the distribution of acceleration is computed for each grid centre of $\frac{1}{2}^{\circ} \times \frac{1}{2}^{\circ}$ area of the region. Probabilistic acceleration contours with a 50-year return period and 90% probable extreme acceleration in a 50-year period are then drawn. This gives a picture of relative seismic risk at various parts of the region.

INTRODUCTION

Estimation of seismic risk in a region is very important from engineering point of view as it gives the probability of experiencing a given earthquake during the design period of a structure in the region. Since designing a earthquake resistant structure adds substantially to the cost of construction, it is necessary to identify the seismic risk areas of a region, so that cost can be adjusted according to the magnitude of risk. For this purpose, a comprehensive geological and seismological study of the region is essential.

In this research, an analysis of seismic risk has been made for the northeast Indian region, lying between 22°N to 30°N latitude and 89°E to 98°E longitude, using a method developed and used by Algermissen and Parkin (Ref.1) for the United States. The risk, as defined by them is the probability that the peak ground acceleration as a particular site due to an earthquake on its neighbourhood exceeds a given value at least once during a specified time interval. The earthquake data used for this analysis are taken from EARTHQUAKE DATA FILE of U.S. Coast and Geodetic Survey (NOAA), Bulletins of Indian Meteorological Department and the earthquake list of Tandon and Shrivastava (Ref.2).

METHOD OF ANALYSIS

The method of Algermissen and Parkin is based on three main steps :

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(i) delineation of seismic source areas based on historical seismicity and available geological and tectonic informations.

(ii) analysis of statistical characteristics of the historical earthquakes in the seismic source area.

(iii) calculation and mapping of the extreme cumulative probability $F_{max,t}(a)$ of acceleration for time, t.

After the distribution of the source areas, the magnitude-frequency relationship of the form,

$$\log N = a - bM \qquad \ldots (1)$$

are determined for each source area. Here N is the number of earthquakes of magnitude M or greater, 'a' and 'b' are constants. The activity in a source area is generally assumed to be uniform. Therefore if a source area is divided into 'n' smaller sub-divisions and if the number of earthquakes likely to occur in a magnitude class M in the source area is N(M), then the number of earthquakes likely to occur in the magnitude class M in each small division of the source is

$$\frac{N(M)}{n} \qquad \ldots (2)$$

But if it is observed that due to some geophysical or geological reasons some parts of a source are more active than the other parts, the activity can be increased or decreased accordingly. In doing so, the slope of the log N,M curve, 'b' remains constant for the entire source area but the intercept 'a' varies over the area. The only restriction is that the resulting total number of earthquakes in a magnitude class can not exceed the number estimated for the same magnitude class from the magnitude-frequency relationship for the source area (Ref.3).

After distributing the earthquakes in each small division of the source, the effect at each site due to the occurrence of earthquakes in each small division of the source can be computed using suitable magnitude-distance-acceleration relationship. In practice, the region is devided into a grid pattern and the centres of the grids are generally considered as the sites where the effects are to be computed. The earthquake source areas are also included in the grid pattern.

Following Algermissen and Parkins, the peak acceleration corresponding to some extreme probability is calculated from the distribution of expected number of occurrences as follows:

Let the peak acceleration be 'a', then,

$$F(a) = P(A \leq a \mid M \geq M_{min}) \qquad \ldots (3)$$

is the probability that an observed acceleration A is less than or equal to the value a, given that an earthquake with magnitude M greater than some minimum magnitude of interest has occurred. The calculation at a point is performed for every acceleration 'a' using,

$$F(a) = \frac{\text{expected number of occurrences with } A \leq a,\ M \geq M_{min}}{\text{total expected number of occurrence } (M \geq M_{min})} \quad \ldots (4)$$

The term 'return period' is then defined as,

$$Ry(a) = \frac{R(a)}{\text{expected number of earthquakes per year } (M \geq M_{min})} \quad \ldots (5)$$

where $$R(a) = \frac{1}{1 - F(a)} \quad \ldots (6)$$

is the average number of events that must occur to get an acceleration exceeding 'a'.

Assuming N independent events with accompanying accelerations A_i, the cumulative distribution of the maximum acceleration of the set of N accelerations is given by

$F_{max}(a)$ = P (the largest of the N accelerations is less than or equal to a

= P (each of the N accelerations is less than or equal to a)

= $P(A \leq a)\ P(A_2 \leq a) \ldots\ldots\ldots P(A_n \leq a)$,
since the events are independent.

= $F(A)^N$, if the events are identically distributed ...(7)

If N itself is a random variable,

$$F_{max}(a) = F(a)^0 . P(N=0) + F(a)' . P(N=1) + \ldots\ldots + F(a)^j . P(N=j) + \ldots\ldots$$

$$= \sum_{j=0}^{\infty} F(a)^j . P(N=j) \quad \ldots (8)$$

If N has a Poisson distribution with mean rate K

$$F_{max}(a) = \sum_{j=0}^{\infty} F(a)^j \frac{K^j e^{-K}}{j!} = e^{-K} \sum_{j=0}^{\infty} \frac{(KF(a))^j}{j!} = e^{-K} e^{KF(a)}$$

$$= e^{-K(1-F(a))} \quad \ldots (9)$$

Now, if K = Bt, where B is the mean rate of occurrence of earthquakes $M \geq M_{min}$ per year and t is the number of years in a period of interest, then,

$$F_{max,t}(a) = e^{-Bt(1-F(a))}$$

In actual procedure, a table of a and F(a) is constructed. For a particular $t = T$, $F_{max,t}(a)$ is calculated, and the value of $\underline{a}$ for a given extreme probability, for example $F_{max,t}(a) = 0.9$ is found by interpolation

Now from the concept of return period,

$$Bt\ (\ 1 - F(a)\ ) = \frac{t}{Ry(a)}$$

thus, $$F_{max,t}(a) = e^{-t/Ry(a)}$$

and $$\ln(F_{max,t}(a)\ ) = -\frac{t}{Ry(a)}$$

If $t = 50$ year and $F_{max,t}(a) = 0.90$

$$\ln\ (0.90) = -\frac{50}{Ry(a)}$$

or $$Ry(a) = \frac{50}{0.1054} = 475 \text{ years}$$

Similarly, if $Bt\ (1 - F(a)\ ) = 1$

$$Bt = \frac{1}{1 - F(a)} = R(a)$$

or $$t = \frac{R(a)}{B} = Ry(a)$$

so that when $t = Ry(a)$, $F_{max,t}(a) = \frac{1}{e} = 0.37$. That is, under Poisson assumption, the acceleration with return period t years has a probability $1 - F_{max,t}(a) = 1 - \frac{1}{e} = 0.63$, of being exceeded in t years.

Accordingly, for each grid point, 50 year return period acceleration (acceleration with 63% chance of being exceeded in 50 years) and also the 90% probable extreme acceleration (acceleration with 10% chance of being exceeded in 50 years) can be calculated using relations (5) and (6).

APPLICATION OF THE METHOD TO THE NORTHEAST INDIAN REGION.

(i) The northeast Indian region is divided into six tectonic blocks based on the available knowledge of geological, tectonic and seismological history of the region (Ref.4).
(ii) Based upon the earthquake history of the region, the magnitude frequency relationships for the six tectonic blocks are determined. Test for incompleteness of data are also made (Ref.5). For each tectonic block a maximum magnitude is assumed which is taken to be the maximum known in that block. The constants 'a' and 'b' of the recurrence relation and the maximum magnitude of the six tectonic blocks are given in Table I.

Table I

Tectonic blocks and other parameters

Tectonic block	a	b	M_{max}
The eastern Himalayas :	3.51	0.66	8.5
The Naga hills and the Patkai synclinorium :	3.20	0.68	7.5
The Brahmaputra Valley :	2.12	0.55	6.5
The Shillong plateau and the Mikir hills :	3.12	0.60	8.7
The Bengal basin and the Surma Valley :	2.40	0.57	7.6
The Arakan Yoma ranges :	3.90	0.71	7.3

(iii) It has been observed that due to some seismological or geological reason some parts of a block are more active than the other parts. Therefore the seismic activity in a block is weighted, remembering the conditions to be maintained as described in the "method of analysis". This is done as follows :

The northeast Indian region is divided into $\frac{1}{2}^{\circ} \times \frac{1}{2}^{\circ}$ grid pattern. Then the number of earthquakes that occurred within each $\frac{1}{2}^{\circ} \times \frac{1}{2}^{\circ}$ grid area during a 100 year period (1879 to 1978) is determined. These numbers are then plotted at the centres of each grid and then contoured. From the resulting contours four areas are selected in accordance with the number of earthquakes that occurred during the 100 year period in each grid. These are as follows:

Area I – more than or equal to 9 earthquakes.
Area II – more than or equal to 6 but less than or equal to 8 earthquakes.
Area III – more than or equal to 3 but less than or equal to 5 earthquakes.
Area IV – less than or equal to 2 earthquakes.

These areas along with the tectonic blocks are shown in figure 1. It is observed that each tectonic block includes at least two or more areas as defined above. These areas in a tectonic block are assumed to be uniform in seismic activity.

(iv) The distribution of earthquakes in a source area within a tectonic block is determined in proportion to the ratio of the observed number of earthquakes in that area to the total number of observed earthquakes in the tectonic block (For example, let x be the observed number of earthquakes in the area, y be the total number of earthquakes in the tectonic block and z, the number of earthquakes obtained from log N,M curve for the tectonic block, then the weighted number of earthquakes in that area is $(x/y)z$).

(v) The whole region is defined by a large number of point sources. Here in this research the point sources are the centres of $\frac{1}{2}^{\circ} \times \frac{1}{2}^{\circ}$ grids of the region. At each grid point the distribution of earthquakes is decided upon from the distribution of the respective parent source area. If a certain grid contains parts of two or more areas then an average distribution is assumed for that grid.

(vi) After distributing the earthquakes within the grid points, the elementary point sources, the accelerations associated with the earthquakes for each magnitude class of all grid points of the region are computed at each grid point. For this purpose Esteva's (1974) magnitude-distance acceleration relationship is used (Ref.6).

(vii) The resulting accelerations in step vi are then contoured as 50 - year return period acceleration map and 90% probable extreme acceleration map in a 50 year period. These are shown in figure 2 and figure 3 respectively.

DISCUSSION

In figure 2 the contours represent accelerations (in percentage of gravity) with 37% probability of not being exceeded in 50 years while in figure 3 they represent accelerations with 90% probability of not being exceeded in 50 years. That is, in figure 2, the exceedance probability of acceleration is 63% and in figure 3 the chance is only 10%.

Acceleration values for 63% chance of being exceeded in a 50 year period ranges from 0.05 g to 0.4 g according to figure 2. The highest acceleration contours (0.4 g) in this figure encloses an area of north-eastern part of the eastern Himalayas and an area of the northern part of the Arakan Yoma ranges. In the entire Indo-Burma border, the Shillong plateau including a part of the Brahmaputra Valley and a mid part of the eastern Himalayas, the acceleration value is 0.3 g.

Similar results are observed in figure 3, where acceleration contou-rs ranges from 0.5 g to 0.8 g. This shows that the acceleration values for 10% chance of being exceeded in a 50 year period is high for the entire region. The relative risk in the region is higher over the Shillong plateau, the eastern part of the eastern Himalayas and to the upper half of the Arakan Yoma ranges; and that the lowest risk is over the eastern part of the Brahmaputra Valley and to the south-west of Bengal basin.

CONCLUSION

The probabilistic acceleration maps presented here provide only a preliminary estimate of the relative risk in the various parts of the region. The attenuation relationship used here may not be truely appropriate for this region. But, due to the lack of sufficient information no such attenuation relationship could be developed for this region. Again no consideration of the soil and rock type of the region has been made in this study. Therefore, although there is enough scope to improve this analysis, the usefulness of these maps can not be ruled out as it provides insights into the relative risk in differant parts of the north-east Indian region.

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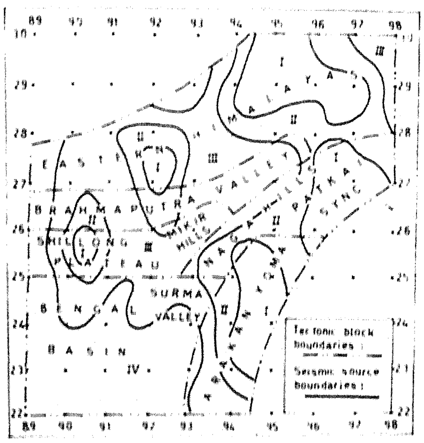

Figure 1: The six tectonic blocks of the northeast Indian region and the earthquake source area.

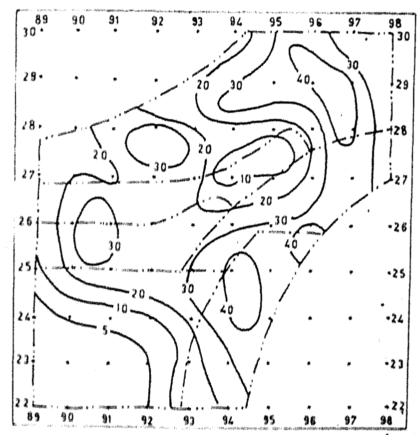

Figure 2: Accelerations (in percentage of gravity) in the northeast Indian region with 50 year return period.

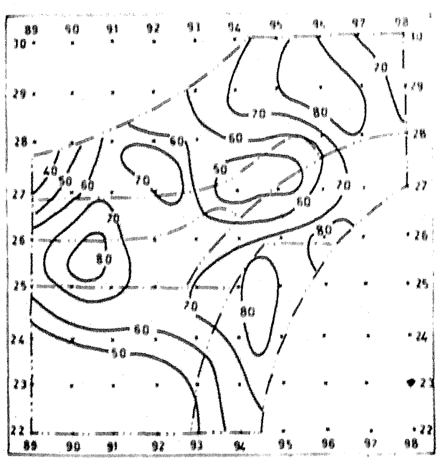

Figure 3: 90% probable acceleration(in percentage of gravity) in the northeast Indian region in a 50 year period.