HAZARD AND RISK

In earthquake engineering, the two terms seismic hazard and seismic risk are regarded as one and the same thing. But actually, the two terms convey different meanings. At a meeting in Paris (25-28 April, 1972) of a working group on the statistical study of Natural hazards (Karnik and Algermissen, 1978), seismic hazard has been defined as the expected occurrence of a future seismic event, whereas seismic risk has been defined as the expected consequence of a future seismic event such as loss of life, economic loss, etc.

Mario Panhizza (1991) has defined environmental hazard, which includes earthquake hazard also, as the probability that a certain phenomenon will occur in a certain territory in a given period of time. He defined environmental risk as probability that the economic and social consequences of a particular hazard phenomenon will exceed a determined threshold. He has elaborately discussed the relation between earthquake hazard and earthquake risk.

In this study, seismic hazard of north-east Indian region has been analysed with the help of Gumbel's extreme value method.
WHAT IS EXTREME VALUE OF ANY VARIABLE

If \( F(x,t) \) is an arbitrary stochastic process, where \( x \) is some variable, it is evident that a complete knowledge of the process \( F(x,t) \) also includes its maximum and minimum values of the variables. But sometimes complete data are not available for the process. In that case, if the whole time scale is divided into equally spaced time intervals and the value \( y = x_{\max} \) which the variable \( x \) reaches within each time interval then \( y \) is called extreme value of the variables \( x \) for that interval. The variable also forms a regular point process imbedded in the original process \( F(x,t) \).

Gumbel (1930) originally applied this extreme value method for the analysis of flood. Nordquist (1945) was the first to apply the "theory of extreme values" in seismology. Epstein and Lomnitz (1966) proposed a probability model for evaluating the characteristics of earthquake activity using the first Gumbel distribution. Yegulalp and Kuo (1974) established a model of the third Gumbel distribution for the occurrence of maximum magnitude earthquakes. Number of workers have used the extreme value method. Therefore, Gumbel extreme value theory has found extensive application to the problem of seismic hazard evaluation. Dick (1965) applied the theory for Newzeland earthquakes, Karnik and Hubernova (1968) and Schenkova and Karnik (1970) for European area Shakal and Willis (1972) for the north Circum Pacific Seismic Belt, Howell (1979a, 1980) for earthquakes of Pennsylvania and Central U.S., Weichart and Milne (1979) for Canadian

Laike M. Asfaw (1992) has studied Gumbel's Type I and Type III distribution of extreme value theory to find the seismic risk at a site in the East African Rift System.

Howell (1993) compared the Gumbel's extreme value theory with Gutenberg - Richter formulae to estimate earthquakes recurrence-rate and found Gumbel's method sometimes more accurate.

Bormann P. (1994) has also studied Gumbel's Type III distribution of extreme to assess the seismic hazard of Germany in the European context.

All these studies tend to show that the return period of various magnitude earthquakes of the region depend on the area considered and the number of earthquake used in the study. In this study, the region under consideration is divided into two tectonic blocks and return period has been calculated individually for each block and also for the region as a whole. The number of years considered in this study is 63 years from 1929 to 1991.

THEORY

The extreme value theory is formulated under the following assumptions (Gumbel, 1958).

(1) The prevailing conditions must be valid in future.
(2) The observed largest values are independent of each other.

The earthquake magnitude $M$ is considered as a random variable described by cumulative distribution function

$$ F(M) = 1 - e^{-\beta M} \quad M > 0 \quad \ldots (16) $$

When the random character of the earthquake occurrence is taken into account, it is possible to consider the largest annual earthquake magnitude in a given time period as a random series with distribution $P(M' < M)$. 
In most cases, the initial distribution $F(M)$ is not known. So it is necessary to deal with the asymptotic forms of distributions introduced by Gumbel, who considered three asymptotic distributions of extreme values known as Type I, Type II and Type III distributions. The Type I distribution assumes that the variable is unlimited while Type II indicates a lower limit and Type III, an upper limit of the variables, (Karnik and Algermissen, 1978).

In this study, for finding out return period for various magnitude earthquakes, Type I and Type III distributions are generally used. Type II distribution is not proper in our case because it assumes a lower limit of extreme values.

Considering the earthquake magnitude to be an independent variable with a cumulative exponential distribution function the Type I distribution may be used to estimate the probability that the magnitude of the largest yearly earthquake ($M'$) will be less than $M$ such that

$$ P (M' < M) = \exp \left[ - \exp \{ - \beta (M - u) \} \right] \quad \ldots \quad (17) $$

where $\beta$ and $u$ are constants to be determined. These constants are generally estimated from a square fit of the relationship

$$ M = u - \frac{1}{\beta} \ln (- \ln P) \quad \ldots \quad (18) $$

found out by taking double logarithms of equation (17) and solving for $M$. 
Here $P$ represents $P (M' < M)$.

In order to find $B$ and $u$, the largest annually observed earthquake magnitude $M_1$, $M_2$, $M_3$, ..., $M_N$ are arranged in order of increasing magnitude. Then the values of $P$ are estimated using the plotting rule

$$P = \frac{n}{N+1} \quad \ldots \quad (19)$$

where $n$ varies from 1 to $N$.

This plotting rule for $P$ has been criticised by Knopoff and Kagan (1977) as this rule is significantly biased for large magnitude earthquakes. They suggested another plotting rule,

$$P = \frac{n - 0.5}{N} \quad \ldots \quad (20)$$

where $n$ varies from 1 to $N$.

In this research both the plotting rules have been used for finding the return period as well as for the occurrence of largest magnitude earthquake in the north-east India.

The return period of extremes has been found from the following equation

$$T_M = \frac{1}{1 - P} \quad \ldots \quad (21)$$

The Type I distribution does not provide an upper
threshold magnitude for any given region. The Type III distribution, which introduces an upper limit of variable, has been used when there is a upper limit of magnitude for a specific region. Type III distribution states that if $M_{\text{max}}$ is the maximum magnitude of the possible earthquake in a region then the probability that the largest earthquake magnitude $M'$ in any year will have a magnitude less than $M$ is given by

$$P (M' < M) = \exp \left[-\left\{\frac{(M_{\text{max}} - M)}{(M_{\text{max}} - u)}\right\}^k\right] \quad \ldots \quad (22)$$

where $k$ and $u$ are constants.

Now solving equation 22 for $M$ it is found that

$$M = M_{\text{max}} - (M_{\text{max}} - u) (-\ln P)^{1/k} \quad \ldots \quad (23)$$

where $P$ represents $P (M' < M)$.

Further manipulation of the equation 23 gives

$$\ln (M_{\text{max}} - M) = \frac{1}{k} \ln (-\ln P) + \ln (M_{\text{max}} - u) \quad \ldots \quad (24)$$

This equation is of the form

$$Y = AX + B$$

where,

$$Y = \ln (M_{\text{max}} - M)$$

$$X = -\ln (-\ln P)$$

$$A = -\frac{1}{k}$$

and

$$B = \ln (M_{\text{max}} - u)$$

The value of the constant $k = -\frac{1}{A}$ and $u = M_{\text{max}} e^{-B}$
can be found out by least square fitting, associating $N$ successively smaller observed values of $Y = \ln (M_{\text{max}} - M)$.

If $M_{\text{max}}$ is not known, all three of $M_{\text{max}}$, $1/k$ and $u$ can be found by trial and error using successively larger values of $M_{\text{max}}$ beginning with a value slightly larger than largest observed $M$ and proceeding until the minimum error of fit is found.

APPLICATION TO THE NORTH-EAST INDIA AND ITS RESULT

Based on the geotectonic features and seismicity, the north-east Indian region has been divided into two block (Chapter III).

Type I and Type III distribution of Gumbel with two different plotting rules [ equations (19) and (20) ] have been applied to the north-east Indian region as a whole and also separately to the two tectonic blocks.

The largest annual magnitude have been taken from USCGS data file and Indian Meterological Department. In the earthquake catalogue from USCGS, the data from 1963 in given as body wave magnitude and the type of magnitude before 1963 is not mentioned in the catalogue. But these have been assumed to be surface wave magnitudes in the research. The body wave magnitude ($M_b$) from 1963 to 1991 have been converted to surface wave magnitude ($M_s$) by the relation (Richter, 1958).

$$M_s = 1.59 M_b - 3.97 \quad \ldots \quad (25)$$
For the whole north-east Indian region the largest annual earthquakes magnitude have taken from 1929 and 1991 i.e. for a period of 63 years and for the two blocks data have been taken from 1946 to 1991 due to discontinuity of data and have been arranged in the increasing order of magnitudes. Next the probability distribution $P$ has been calculated using the two different rules [ equations (19) and (20) ]. The yearly largest earthquake magnitudes are then plotted against the corresponding values of probability $P$ for the whole region and two different blocks as shown in figures 27 (a,b), 28 (a,b) and 29 (a,b) respectively. In all these figures the pair of straight lines represent the 95% confidence intervals for the estimated magnitudes according to the Type I distribution whereas the pair of curve lines represent the 95% confidence intervals for the Type III distribution. For Type III distribution the maximum magnitude $M_{\text{max}}$ is taken as 9.1 which is the world's largest earthquake magnitude as obtained by Howell (1979b). The 95% confidence limits for earthquake magnitude is being determined by using 't test' [ Li (1957) ].

Application of the extreme value theory gives the following equations for north-east India.

**REGION AS A WHOLE**

When the plotting rules is

$$P = \frac{n}{N + 1}$$
FIG. 27a: EXTREME VALUE DISTRIBUTIONS EARTHQUAKES (1929-1991) OF THE NORTH-EAST INDIA WITH 95 PERCENT CONFIDENCE LIMITS USING THE PLOTTING RULE \( P = \frac{n}{N+1} \)
FIG. 27b: EXTREME VALUE DISTRIBUTIONS FOR THE EARTHQUAKES (1929-1991) OF THE NORTH-EAST INDIA WITH 95 PERCENT CONFIDENCE LIMITS USING THE PLOTTING RULE \( P = \frac{n - 0.5}{N} \)
FIG. 28a: EXTREME VALUE DISTRIBUTIONS FOR THE EARTHQUAKES (1946-1991) OF BLOCK I WITH 95 PERCENT CONFIDENCE LIMITS USING PLOTTING RULE $P = \frac{n}{N+1}$
FIG. 28b: EXTREME VALUE DISTRIBUTIONS. FOR THE EARTHQUAKES (1946-1991) OF BLOCK I WITH 95 PERCENT CONFIDENCE LIMITS USING PLOTTING RULE
\[ p = \frac{n - 0.5}{N} \]
AVERAGE RETURN PERIOD IN YEARS

\[ p = \frac{n}{N+1} \]

FIG. 29a: EXTREME VALUE DISTRIBUTIONS FOR THE EARTHQUAKES (1946-1991) OF BLOCK II WITH 95 PERCENT CONFIDENCE LIMITS USING PLOTTING RULE

ANNUAL PROBABILITY OF NONEXCEEDANCE

FIG. 29a: EXTREME VALUE DISTRIBUTIONS FOR THE EARTHQUAKES (1946-1991) OF BLOCK II WITH 95 PERCENT CONFIDENCE LIMITS USING PLOTTING RULE \( p = \frac{n}{N+1} \)
Fig. 29b : Extreme value distributions for the earthquakes (1946-1991) of Block II with 95 percent confidence limits using plotting rule $P = (n-0.5)/N$. 

$$P = \frac{n-0.5}{N}$$
the corresponding equation for the Type I distribution is

\[ M = 5.24 - 0.956 \ln (\ln (1/P)) \] .... \( (26) \)

and for Type III distribution the equation is

\[ M = 9.1 - 3.945 (\ln (1/P))^{0.35} \] .... \( (27) \)

when the plotting rule is

\[ p = \frac{n - 0.5}{N} \]

the equation for the Type I distribution is

\[ M = 5.25 - 0.896 \ln (\ln (1/P)) \] .... \( (28) \)

and for Type III distribution the equation is

\[ M = 9.1 - 3.932 (\ln (1/P))^{0.32} \] .... \( (29) \)

Using the equations given above from 26 to 29 the probability for various magnitude earthquakes are found out and these probabilities are used to find out return period \( (T_M = \frac{1}{1-p}) \) of various magnitude earthquakes (Table - 5) and the most probable largest magnitude earthquakes for various return periods have been calculated and presented in the Table - 6.

From Table - 5 it has been observed that the return period for 8 or greater magnitude earthquake for the whole north-east Indian region considering both the plotting rules for Type I distribution is nearly 20 years whereas for Type
TABLE - 5
PREDICTED AVERAGE RETURN PERIOD IN YEARS FOR VARIOUS MAGNITUDE EARTHQUAKES IN THE NORTH-EAST INDIAN REGION AS A WHOLE

<table>
<thead>
<tr>
<th>SURFACE MAGNITUDE (Ms)</th>
<th>( p = \frac{n}{N + 1} )</th>
<th>( p = \frac{n - 0.5}{N} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TYPE - I (± 0.46)</td>
<td>TYPE - III (± 0.33)</td>
</tr>
<tr>
<td>4.0</td>
<td>1.03</td>
<td>1.14</td>
</tr>
<tr>
<td>4.5</td>
<td>1.13</td>
<td>1.26</td>
</tr>
<tr>
<td>5.0</td>
<td>1.38</td>
<td>1.48</td>
</tr>
<tr>
<td>5.5</td>
<td>1.87</td>
<td>1.86</td>
</tr>
<tr>
<td>5.0</td>
<td>2.75</td>
<td>2.53</td>
</tr>
<tr>
<td>6.5</td>
<td>4.25</td>
<td>3.81</td>
</tr>
<tr>
<td>7.0</td>
<td>6.80</td>
<td>6.57</td>
</tr>
<tr>
<td>7.5</td>
<td>11.11</td>
<td>13.68</td>
</tr>
<tr>
<td>8.0</td>
<td>18.44</td>
<td>38.91</td>
</tr>
</tbody>
</table>

N.B. : VALUES GIVEN WITHIN BRACKETS ARE THE R.M.S ERRORS OF FIT.
TABLE - 6

PREDICTED LARGEST EARTHQUAKE MAGNITUDE, FOR VARIOUS RETURN PERIODS THAT MAY OCCUR IN THE NORTH-EAST INDIAN REGION AS A WHOLE, USING EXTREME VALUE METHOD

<table>
<thead>
<tr>
<th>RETURN PERIODS IN YEARS</th>
<th>( P = \frac{n}{N + 1} )</th>
<th>( P = \frac{n - 0.5}{N} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TYPE - I</td>
<td>TYPE - III</td>
</tr>
<tr>
<td>25</td>
<td>8.3 ± 0.4</td>
<td>7.8 ± 0.4</td>
</tr>
<tr>
<td>50</td>
<td>8.9 ± 0.5</td>
<td>8.1 ± 0.4</td>
</tr>
<tr>
<td>100</td>
<td>9.6 ± 0.5</td>
<td>8.3 ± 0.4</td>
</tr>
</tbody>
</table>

N.B. : NUMBERS GIVEN AS PLUS MINUS VALUES REPRESENT THE 95 PERCENT CONFIDENCE LIMITS OF THE ESTIMATED MAGNITUDE.
period for both distributions is around 31 years.

Comparison of this return period with the historical earthquakes of north-east Indian region (Gait, 1967) shows fairly good agreement. The magnitude of the historical earthquakes mentioned by Gait which caused severe damage to the north-east Indian region have been assumed to be 7 or greater.

By using two plotting rules in Type I distribution, the maximum magnitude earthquake that may occur in the interval of 25 years is found to be $8.3 \pm 0.4$ and $8.1 \pm 0.4$ respectively in the confidence interval of 95%. Similarly, the estimates for the magnitude range of earthquakes expected to occur once in every 50 years is about 8.3 to 9.3 and for every 100 years is 9.1 to 10.0.

Since the Type I distribution does not provide an upper threshold magnitude for any given region, one can be selected by choosing a probability level for the largest possible magnitude using a very low probability of exceedance, e.g. 1 per cent or less (Karnik and Algermissen, 1978). In north-east Indian region consideration of 1 per cent probability of exceedance given largest possible earthquakes of magnitude 9.1 and 8.9 according to the plotting rule given by equations 19 and 30 respectively. Therefore $M_{\text{max}}$ for the north-east India cannot be greater than 9.1 which is slightly greater than world's largest earthquake magnitude of 8.9.
The Type III distribution predicts, according to both the plotting rules together, that the earthquakes of lowest and highest magnitudes expected to occur once in every 25 years 7.3 and 8.2 respectively and in every 50 years are 7.6 and 8.5 and in every 100 years are 7.8 and 8.7 respectively.

Now, the north-east India has been divided into two tectonic blocks. It has been observed that the number of earthquake that the number of earthquake epicentres has been decreased and also due to discontinuity of data the study for two blocks have been done only for 46 years and simultaneously the 95% confidence intervals increased. This may give more uncertainty in calculating the return period and the probable largest earthquake which may occur in the two blocks.

The resulting equations for Type I and Type III distribution using two plotting rules in two blocks are given separately below:

**BLOCK I**

When the plotting rule is

\[ p = \frac{n}{N + 1} \]

the corresponding equation for Type I distribution is

\[ M = 4.49 - 0.908 \left[ \ln \left( \ln \frac{1}{p} \right) \right] \]  

(30)

and for the Type III distribution the equation is
When the plotting rule is
\[ p = \frac{n - 0.5}{N} \]
the equation for Type I distribution is
\[ M = 9.1 - 4.542 \left( \ln \frac{1}{P} \right)^{2.5} \] \hspace{1cm} (31)
and the equation for Type III distribution is
\[ M = 9.1 - 4.519 \left( \ln \frac{1}{P} \right)^{0.23} \] \hspace{1cm} (32)

**BLOCK II**

When the plotting rule is
\[ p = \frac{n}{N + 1} \]
the corresponding equation for Type I distribution is
\[ M = 4.48 - 0.883 \left[ \ln \left( \ln \frac{1}{P} \right) \right] \] \hspace{1cm} (34)
and for Type III distribution the equation is
\[ M = 9.1 - 4.607 \left( \ln \frac{1}{P} \right)^{0.34} \] \hspace{1cm} (35)

When the plotting rule is
\[ p = \frac{n - 0.5}{N} \]
the equation for Type I distribution is
\[ M = 4.49 - 0.902 \left[ \ln \left( \ln \frac{1}{P} \right) \right] \] \hspace{1cm} (36)
and for Type III distribution the equation is
\[ M = 9.1 - 4.596 \left( \ln \frac{1}{P} \right)^{0.32} \] \hspace{1cm} (37)
TABLE - 7

PREDICTED AVERAGE RETURN PERIOD IN YEARS FOR VARIOUS MAGNITUDE EARTHQUAKES IN BLOCK - I

<table>
<thead>
<tr>
<th>SURFACE MAGNITUDE (Ms)</th>
<th>p = ( \frac{n}{N + 1} )</th>
<th>p = ( \frac{n - 0.5}{N} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TYPE - I (± 0.31)</td>
<td>TYPE - III (± 0.24)</td>
</tr>
<tr>
<td></td>
<td>TYPE - I (± 0.43)</td>
<td>TYPE - III (± 0.26)</td>
</tr>
<tr>
<td>4.0</td>
<td>1.22</td>
<td>1.26</td>
</tr>
<tr>
<td>4.5</td>
<td>1.59</td>
<td>1.54</td>
</tr>
<tr>
<td>5.0</td>
<td>2.30</td>
<td>1.80</td>
</tr>
<tr>
<td>5.5</td>
<td>3.57</td>
<td>3.04</td>
</tr>
<tr>
<td>6.0</td>
<td>5.79</td>
<td>5.04</td>
</tr>
<tr>
<td>6.5</td>
<td>9.66</td>
<td>9.58</td>
</tr>
<tr>
<td>7.0</td>
<td>16.37</td>
<td>21.59</td>
</tr>
<tr>
<td>7.5</td>
<td>28.01</td>
<td>62.11</td>
</tr>
<tr>
<td>8.0</td>
<td>48.08</td>
<td>272.27</td>
</tr>
</tbody>
</table>

N.B. : VALUES GIVEN WITHIN BRACKETS ARE THE r.m.s. ERRORS OF FIT.
TABLE - 8

PREDICTED LARGEST EARTHQUAKE MAGNITUDE, FOR VARIOUS RETURN PERIODS THAT MAY OCCUR IN BLOCK - I, USING EXTREME VALUE METHOD

<table>
<thead>
<tr>
<th>RETURN PERIODS IN YEARS</th>
<th>( p = \frac{n}{N+1} )</th>
<th>( p = \frac{n - 0.5}{N} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TYPE - I</td>
<td>TYPE - III</td>
</tr>
<tr>
<td>25</td>
<td>7.4 ± 0.5</td>
<td>7.1 ± 0.5</td>
</tr>
<tr>
<td>50</td>
<td>8.0 ± 0.5</td>
<td>7.4 ± 0.5</td>
</tr>
<tr>
<td>100</td>
<td>8.6 ± 0.5</td>
<td>7.7 ± 0.5</td>
</tr>
</tbody>
</table>

N.B. : NUMBERS GIVEN AS PLUS MINUS VALUES REPRESENT THE 95 PERCENT CONFIDENCE LIMITS OF THE ESTIMATED MAGNITUDE.
<table>
<thead>
<tr>
<th>SURFACE MAGNITUDE (Ms)</th>
<th>( p = \frac{n}{N + 1} )</th>
<th>( p = \frac{n - 0.5}{N} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPE - I (± 0.30)</td>
<td>TYPE - III (± 0.54)</td>
<td>TYPE - I (± 0.29)</td>
</tr>
<tr>
<td>4.0</td>
<td>1.25</td>
<td>1.35</td>
</tr>
<tr>
<td>4.5</td>
<td>1.63</td>
<td>1.59</td>
</tr>
<tr>
<td>5.0</td>
<td>2.39</td>
<td>1.97</td>
</tr>
<tr>
<td>5.5</td>
<td>3.45</td>
<td>2.60</td>
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<tr>
<td>6.0</td>
<td>5.41</td>
<td>3.72</td>
</tr>
<tr>
<td>6.5</td>
<td>8.68</td>
<td>5.87</td>
</tr>
<tr>
<td>7.0</td>
<td>14.16</td>
<td>10.51</td>
</tr>
<tr>
<td>7.5</td>
<td>23.25</td>
<td>22.73</td>
</tr>
<tr>
<td>8.0</td>
<td>38.46</td>
<td>66.66</td>
</tr>
</tbody>
</table>

N.B. : VALUES GIVEN WITHIN BRACKETS ARE THE r.m.s. ERRORS OF FIT.
### TABLE - 10

PREDICTED LARGEST EARTHQUAKE MAGNITUDE, FOR VARIOUS RETURN PERIODS THAT MAY OCCUR IN BLOCK - II, USING EXTREME VALUE METHOD

<table>
<thead>
<tr>
<th>RETURN PERIODS IN YEARS</th>
<th>( p = \frac{n}{N + 1} ) TYPE - I</th>
<th>( p = \frac{n - 0.5}{N} ) TYPE - I</th>
<th>( p = \frac{n}{N + 1} ) TYPE - III</th>
<th>( p = \frac{n - 0.5}{N} ) TYPE - III</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>7.6 ± 0.4</td>
<td>7.4 ± 0.5</td>
<td>7.5 ± 0.5</td>
<td>7.5 ± 0.4</td>
</tr>
<tr>
<td>50</td>
<td>8.2 ± 0.4</td>
<td>8.0 ± 0.5</td>
<td>7.9 ± 0.5</td>
<td>7.8 ± 0.5</td>
</tr>
<tr>
<td>100</td>
<td>8.9 ± 0.4</td>
<td>8.6 ± 0.5</td>
<td>8.1 ± 0.5</td>
<td>8.1 ± 0.5</td>
</tr>
</tbody>
</table>

N.B. : NUMBERS GIVEN AS PLUS MINUS VALUES REPRESENT THE 95 PERCENT CONFIDENCE LIMITS OF THE ESTIMATED MAGNITUDE.
The predicted return period and the most probable largest magnitude earthquake for various return periods using the equations from (32) to (37) and equation (18) have been presented in tables 7 and 8 for block I and in tables 9 and 10 for block II respectively.

Comparison of the return periods of the two blocks for different magnitudes shows that the return periods of block II for various magnitude earthquakes are low compared to block I which seems to indicate that the block II is more hazardous than block I.

SEISMIC RISK

Seismic risk estimation and hence seismic zoning in a particular region depends on various factors such as seismicity, tectonics, geology and soil types of the region. But most important factor is seismicity. The Indian standard in 1970 produced a map dividing the country into five zones with increasing intensity based on seismicity and geotectonic set up of the country. The whole of north-east India was grouped in zone V with maximum Modified Mercali Intensity of IX and above. However, it has been found that the earthquakes occurrence in north-east India is not uniform because of its complex geology. Hence a finer seismic zoning map is necessary for the north-east Indian region.

For seismic risk estimation, the basic quantity to be computed from earthquake data is Peak Ground Acceleration.
(PGA) and then application of statistical method to find the probability of occurrence of particular values of peak ground acceleration for a single or many design periods. Several statistical methods such as Poison, Bayesian, Algermissen-Perkin methods have been used for this region (Sarmah, 1989 and Goswami, 1982) based on earthquake data upto 1978. But it seems that the method given by Lomnitz (1974) with attenuation relation of Donovan (1973) is a relatively simple one and give results similar to those obtained by other workers.

The earthquake data used in this study is mainly taken from USCGS from the period 1897 to 1991. Some data which are not recorded in the data file have been taken from the Bulletin of Meteorological Department. The lowest magnitude considered is 4 ($M_s$).

THEORY

To estimate seismic risk at any point, an earthquake is selected capable of producing accelerations in excess of 0.1 $g_m$. Then a list of earthquake epicentres in the region over a period $T > D$ where $D$ is the design period for which risk is to be calculated is determined and defined some grid points covering the region. At each grid point the probability $P_{ij}$ may be calculated as

$$P_{ij} = 1 - \exp (-\beta M_j) \quad \ldots \quad (38)$$

where $\beta = 1/\tilde{M}$, $\tilde{M}$ being the mean magnitude of the region.
under consideration and $M_j$ is the magnitude which if released at the $j$th epicentre will produce an acceleration of 0.1 gm at the grid point. Here $P_{ij}$ represents the probability that the design earthquake will not occur at epicentre $j$ during a period of $T$ years. Hence the earthquake risk at the grid point $i$ may be written as

$$R_T(i) = 1 - \prod_{j} P_{ij} \quad \ldots \ldots \quad (39)$$

Finally the earthquake risk $R_D$ for the design period $D$ is given by the relation

$$\log (1 - R_D) = D/T \log (1 - R_T) \quad \ldots \ldots \quad (40)$$

Here the acceleration is determined using Donovan's (1973) magnitude-distance-acceleration relationship

$$a = \frac{b_1 \exp (b_2 M)}{(R_h + b_4)^{b_3}} \quad \ldots \ldots \quad (41)$$

where

- $a =$ Peak ground acceleration in cm/sec$^2$
- $R_h =$ Hypocentral distance from source to site (in km.)
- $M =$ Surface magnitude

$b_1$, $b_2$, $b_3$ and $b_4$ are constants and the values of the constants are

$$b_1 = 1080; \quad b_2 = 0.5$$
$$b_3 = 1.32 \quad \text{and} \quad b_4 = 25$$

as developed by Donovan (1973).
Thus the relation (41) becomes

\[ a = \frac{1080 \exp(0.5) M}{(R_h + 25) 1.32} \]  

\[ \text{(42)} \]

APPLICATION TO NORTH-EAST INDIA

To apply the Lomnitz method of risk estimation to north-east Indian region, the region is divided into \( \frac{1^\circ}{2} \times \frac{1^\circ}{2} \) grids. All the earthquake magnitude which can produce 0.1 gm of acceleration at the epicentre have been selected for a period of 95 years from 1897 to 1991 and the acceleration due to an earthquake has been calculated using equation (42) and found that minimum magnitude \( M_s \) to produce atleast 0.1 gm of acceleration is 4.

Using the relations (38), (39) and (40) the seismic risk, that is the probability of exceeding a given value of peak ground acceleration (0.1 gm) during a design period of 50 years have been computed at each grid point. The computation shows that higher the acceleration probability, greater is the risk. The result obtained are contoured and the contoured map thus obtained is shown in figure 30. The contours represent the probability (in per cent) of occurrence of an earthquake of minimum acceleration 0.1 gm during a design period of 50 years.

RESULT

The contour map shows different seismic risk probability over the entire study region.
FIG. 30: EARTHQUAKE RISK MAP OF THE NORTH-EAST INDIA. CONTOURS REPRESENT THE PROBABILITY (IN PERCENTAGE) OF OCCURRENCE OF AN EARTHQUAKE OF MINIMUM ACCELERATION 0.1g DURING A DESIGN PERIOD OF 50 YEARS.
The observations from west to east or left to right of the contour map show that along the Dhubri fault and its adjoining region the risk is 70 to 40 per cent, and in Arunachal Pradesh - Assam area the risk is 80 to 20 per cent. The risk in the north-east corner of the region is from 90 per cent to 40 per cent. The entire Indo-Burma region shows seismic risk from 90 to 50 per cent. The Indo-Bangladesh border (i.e. Tripura and Surma valley) shows low seismic risk compare to other region ranging from 60 to 30 per cent.

Therefore, it has been found that the whole Indo-Burma border and north-east corner of the region show higher seismic risk compare to other part of the region. The Indo-Burma border which is free from earthquake of magnitude greater than 7.5 (upto 1994) shows higher seismic risk compare to other regions like Shillong plateau, the area of Dhubri earthquake and the area of great earthquake of 1950.

Therefore, it can be concluded from the risk map that risk is maximum towards the area where earthquakes occurrence are frequent rather than the area where earthquake frequency is less even though one or two great earthquakes occurred in those regions. Similar observations were also made by Lomnitz (1974) in California area.

This study is based on the occurrence of past earthquakes in the north-east India. Nothing can be drawn about the occurrence of high magnitude earthquakes in the low risk
regions obtained in this study such as Surma valley and parts of Brahmaputra valley.