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A Study of Some Seismic Parameters of a Few Cities of Northeast India and Its Adjoining Region

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Abstract Seismic hazard analysis includes the study of ground motions at a selected site due to a seismic event. This is necessary for the purpose of evolving earthquake resistant design of a new structure or for estimating the safety of an existing structure of importance, like dams, nuclear power plants, long-span bridges, high-rise buildings, etc. at that site. Some seismic parameters of eleven cities of the region has been analysed using Poisson's Model. It has been found that return period for different PGA values are the minimum for Tezu. Seismic loading is found to be maximum in Tezu for the same risk level and economic life.
Keywords *Hazard; Seismic Source; Probability; Return Period; PGA Value*

1. Introduction

The North-Eastern part of India has a fascinating diversified landscape having valleys and razor-edged high hills, snow clad mountains and meandering rivers, flat high lands, deep gorges and waterfalls. The seven states of Assam, Nagaland, Mizoram, Meghalaya, Manipur, Tripura and Arunachal Pradesh comprises Northeast India and occupy 2,54,979 sq km of mostly mountainous terrain of which 65% is under dense forest cover (Nandy, 2001). This region is connected to the rest of India only through a narrow corridor (50 km wide) of northern Bengal. Northeast India and its adjoining territories display tectonically distinct geological domains occurring in intimate spatial association. Seismically, Northeast India is one of the six most active seismic regions of the world. Historical records are replete with references of catastrophic earthquakes that caused large scale damage to lives and properties in the Northeastern region of India; but in the absence of instrumentation, the magnitude of these earthquakes cannot be authenticated (Oldham, 1883). This region is characterized by collision tectonics in the North between the Eurasian plate and the Indian plate and subduction tectonics in the East between the Indian plate and the Burmese plate (Nandy, 1983 and 1986a).

In this study we have considered eleven cities of the region which are Agartala, Aizawl, Dibrugarh, Dimapur, Kohima Imphal, Itanagar, Guwahati, Shillong, Tezpur and Tezu. The study region with the eleven cities is shown in Figure 1. The return periods corresponding to different values of peak ground acceleration together with the probability of occurrence of an seismic event exceeding a given PGA value due to the seismic sources were determined for these eleven different cities/towns. Also the relation between economic life, risk level and return period has been analysed for this study.

2. Data Source

The study region taken is between latitudes 22^0N – 30^0N and between longitude 89^0E – 98^0E. The earthquake catalogues of ISC and USGS that are available for the study region has been used for the period 1909 (1^{st} January) – 2012 (31^{st} July).

3. Methodology

The entire region was divided into grids of $\{(1/2)^0 \times (1/2)^0\}$ and the seismic events in each grid is considered together with their respective magnitude for determining the position of the seismogenic sources. The relation used is –

$$X = (m_1x_1 + m_2x_2 + \ldots\ldots + m_nx_n) / (m_1 + m_2 + \ldots\ldots + m_n) \quad \ldots\ldots \quad (1)$$
$$Y = (m_1y_1 + m_2y_2 + \ldots\ldots + m_ny_n) / (m_1 + m_2 + \ldots\ldots + m_n) \ldots\ldots \quad (2)$$

where, X and Y represent the longitude and latitude of the seismogenic sources. (x_1, y_1), (x_2, y_2) ………… (x_n, y_n) are the co-ordinates in terms of longitude and latitude of each seismic event in the grid and n is the number of seismic events of each grid. The magnitude of each seismic event is given by m_1, m_2, m_3 ……..m_n respectively. If the source of earthquakes is closely concentrated in space relative to its distance from the sites it may be assumed to be a point source. Here we have taken thirteen point sources. The depth of each source was computed as an average hypocentral depth of all the earthquakes in the source and earthquakes with no depth information were not included in the averaging process. However, they are considered in determining the location of the seismicity of the sources.

According to Poisson's Model (Shah, et al., 1975), the probability of observing X events above magnitude M in time period t, based on the seismic history of a given source is given by,

$$P_x\,(t) = \frac{exp[-exp(\alpha_1' + \beta_1 M)t][exp(\alpha_2' + \beta_2 M\,)t]^x}{x!} \quad (3)$$

And, the probability that there will be X events of magnitude greater than m in time period t is given by,

$$P_x\,(M > m, t) = \frac{exp[-N'(M)t][N'(M)t]^x}{x!} \quad (4)$$

For engineering purposes one usually determines the probability of at least one event greater than m in time period t. Now, the probability is given by,
P[at least one event of magnitude M > m in time period t] = 1 – P[no of earthquakes of magnitude M > m in time period t]
Hence, from eq. (4) we have-
P[at least one event of magnitude M > m in time period t] = 1 – exp[- $N^{/}$(m)t] ……. (5)
Using,

$$lnN'(M) = \alpha' + \beta M \quad (6)$$

where, $\alpha' = \alpha - \ln(T)$ in eq. (5)
we get the relation for probabilistic determination of PGA at a site due to seismic source as,

$$P(M > m, t) = 1 - \exp[-\exp(\alpha' + \beta M)] \quad (7)$$

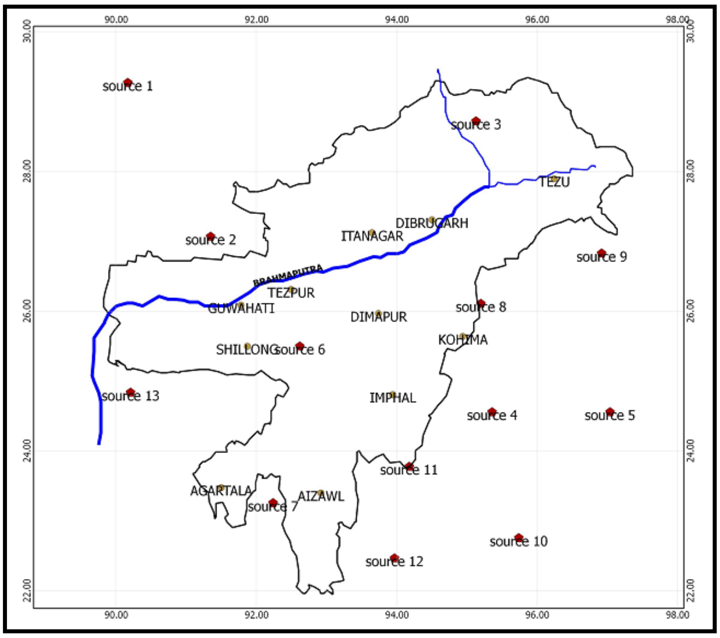


Figure 1: *The Study Region and the Eleven Cities with the Seismic Sources*

The attenuation relation given by Donovan (1973) is-

$$A = \frac{b_1 \exp(b_2 M)}{(R_h + b_4)^{b_3}} \quad (8)$$

The values of the parameters b_1, b_2, b_3 and b_4 have been determined and found to be,

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

For determining the probabilistic distribution of an seismic event having Peak Ground Acceleration, a , we have by using eq. (8)

$$P[A > a] = P\left[\frac{b_1 \exp(b_2 M)}{(R_h + b_4)^{b_3}} > a\right] = P\left[M > \ln\left\{\frac{a}{b_1}(R_h + b_4)^{b_3}\right\}^{\frac{1}{b_2}}\right] \quad (9)$$

Using, eq. (7) and eq. (9) we have,

$$P[A > a] = 1 - \exp\{-\gamma \left(\frac{a}{b_1}\right)^{\delta} (R_h + b_4)^{\rho}\ t\} \quad (10)$$

Here,

$$\gamma = e^{\alpha'}$$

$$\delta = \frac{\beta}{b_2}$$

$$\rho = \delta b_3$$

Eq. (10) gives the probability of peak ground acceleration due to a source located some distance away. But usually a site is surrounded by a number of sources, hence if there are N seismic sources, then the probability distribution is given by,

$$P[A > a] = \ 1 - \exp[-\sum_{i=1}^{N}\{\gamma_i \left(\frac{a}{b_1}\right)^{\delta_i} (R_h + \ b_4)^{\rho_i} \ t\}] \qquad (11)$$

The above equation gives the probability distribution function of peak ground acceleration as function of time and space. Using the probability distribution function given by eq. (11), the probabilities of A > a is determined for the eleven cities. The Bernoulli probability law (Benjamin and Cornell, 1970) was used to calculate the return period of different values of peak ground acceleration at the different cities.

From the Binomial probability law, for independent trials with probability of success P at each trial the probability of y success in n trials is given by-

$$P_y(Y) = \frac{n!}{y!(n-y)!} P^y (1-P)^{n-y} \qquad (12)$$

where, y = 0,1, 2,……..,n.

$$P_y\ (Y) = \binom{n}{y} P^y\ (1-P)^{n-y} \qquad (13)$$

Where, $\binom{n}{y} = \frac{n!}{y!(n-y)!}$

Now, success is defined as that event when the peak ground acceleration for a given trial exceeds the given peak ground acceleration. Thus, the probability of non-exceedance of the given level of peak ground acceleration during the same time is also the same as probability of zero success in the same number of trials.

Hence,

$$P_y\ (0) = \binom{y}{0} P^0\ (1-P)^y \qquad (14)$$

Thus,

Return Period = $\frac{1}{P}$

The graph between peak ground acceleration and return period is called Acceleration Zone Graph. Thus, we have found relationship between the peak ground acceleration and the corresponding return period for different localities but these relations by themselves do not help in selecting a return period for a given acceptable level of risk. Therefore an attempt has been made to obtain a relationship between the economic life of structures and the level of risk and return period consistent with the risk and economic life. From binomial distribution we have-

$$P_n\ (r) = \binom{n}{r} P^r\ (1-P)^{n-r}$$

Where n is the time period of study i.e. economic life of a structure and r is the number of success. For a corresponding period of economic life of a particular city, the probability of success is determined from the acceleration zone graph and return period of the seismic event for which the structure has been built can be determined.

4. Results and Observations

Probabilistic seismic hazard analysis was made by applying Poisson's Model. The seismic events of the entire region were plotted in a map and grouped by dividing it into grids of {(½^{o} X ½^{o})}. Then, the grids having closely concentrated epicenters of earthquakes were identified and considered as a point source. Thirteen such point sources were identified in the entire study regions which are presented in Table 1.

Table 1: *Identified Seismic Sources in the Study Region*

Source	Longitude (deg.)	Latitude (deg.)	No of Events	Average Depth (km)
Source 1	90.17	29.27	147	24.68
Source 2	91.35	27.07	214	34.53
Source 3	95.13	28.72	205	42.28
Source 4	95.36	24.56	302	64.1
Source 5	97.04	24.56	178	30.19
Source 6	92.62	25.5	265	44.77
Source 7	92.24	23.26	179	33.39
Source 8	95.2	26.11	192	60.05
Source 9	96.92	26.83	195	41.56
Source 10	95.74	22.76	58	37.48
Source 11	94.18	23.78	395	67.42
Source 12	93.97	22.47	212	76.69
Source 13	90.21	24.84	147	35.21

The return periods corresponding to different values of peak ground acceleration were determined for eleven different cities/towns of the study region. The cities/town considered are Agartala, Aizawl, Dibrugarh, Dimapur, Kohima Imphal, Itanagar, Guwahati, Shillong, Tezpur and Tezu. The probability of occurrence of a seismic event exceeding a given PGA value due to the seismic sources considered is estimated and shown in Table 2, and their graphical representations are shown in Figure 2. For all the values of PGA, the probability of exceedance was found to be the highest in Tezu followed by Dibrugarh town, while it came out as the minimum in Shillong. Among the hill towns, Kohima shows the second highest values of the probability of exceedance for all the PGA values. Guwahati, the capital city of Assam and the most developed and populated city of Northeast India shows moderate values of the probability of exceedance ranging from 0.001 to 0.335 depending on PGA values. Moderate values of the probability of exceedance are also observed in Agartala and Imphal ranging from 0.001 to 0.39 and 0.004 to 0.344 respectively. Probability of exceedance against different PGA values are in the range of 0.003 - 0.537 in Itanagar, the capital town of Arunachal Pradesh.

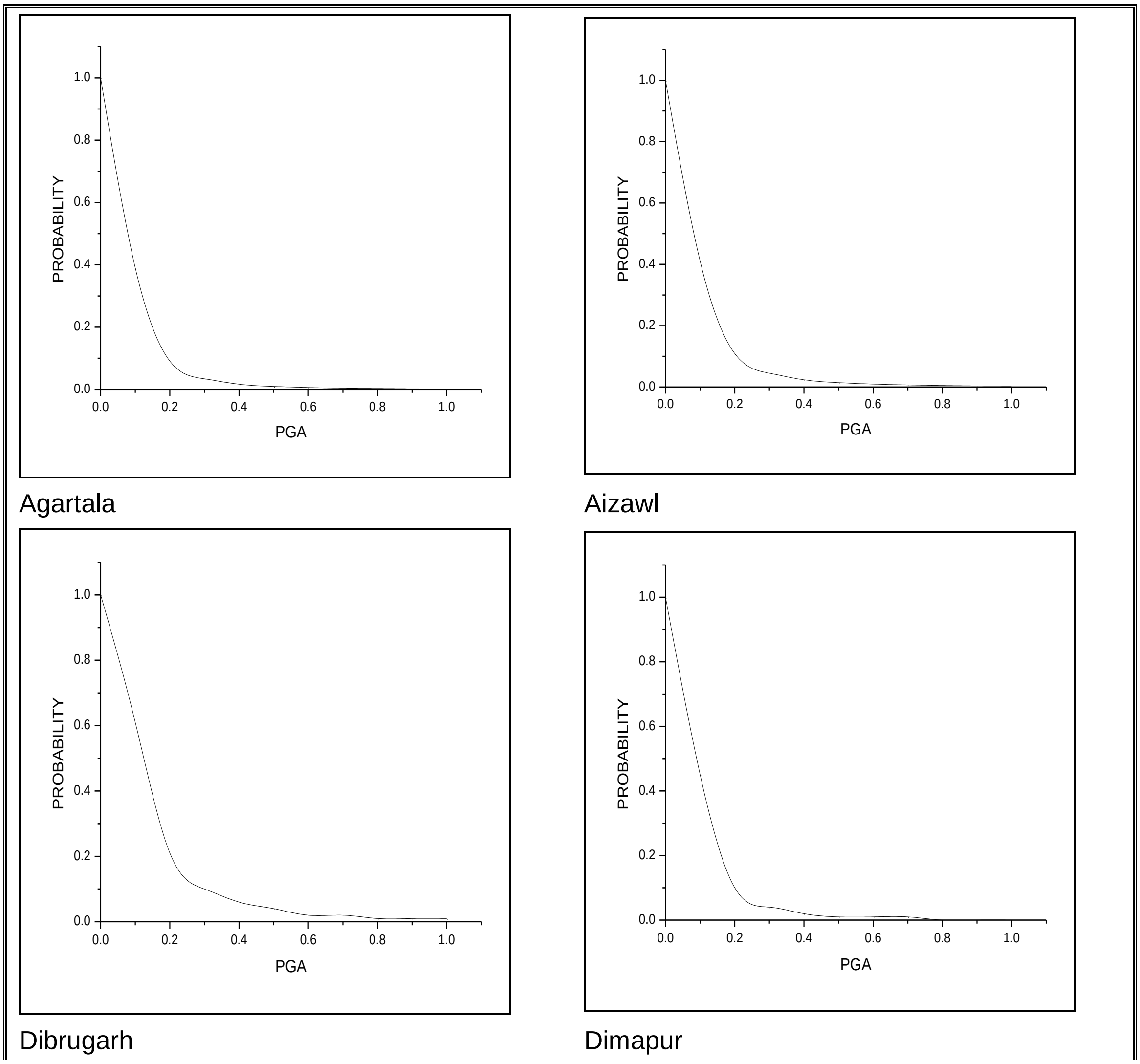
Table 2: *Probability of Exceedance of a given PGA value in the Selected Cities/Towns*

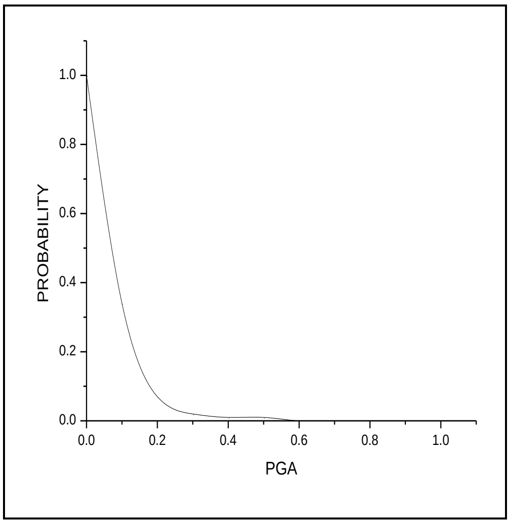
PGA Values	Probability										
	Agartala	Aizawl	Dibrugarh	Dimapur	Kohima	Imphal	Itanagar	Guwahati	Shillong	Tezpur	Tezu
0	1	1	1	1	1	1	1	1	1	1	1
0.1	0.39	0.409	0.612	0.454	0.557	0.344	0.537	0.335	0.189	0.430	0.769
0.2	0.09	0.109	0.214	0.102	0.192	0.105	0.141	0.069	0.027	0.095	0.299
0.3	0.03	0.045	0.099	0.041	0.092	0.049	0.057	0.024	0.008	0.034	0.143

0.4	0.01	0.023	0.056	0.021	0.053	0.028	0.029	0.011	0.003	0.016	0.082
0.5	0.009	0.014	0.035	0.013	0.035	0.018	0.017	0.006	0.001	0.009	0.053
0.6	0.006	0.009	0.024	0.008	0.024	0.012	0.011	0.004	0.001	0.005	0.037
0.7	0.004	0.006	0.017	0.006	0.018	0.009	0.008	0.002	0	0.003	0.027
0.8	0.002	0.005	0.013	0.004	0.014	0.007	0.006	0.001	0	0.002	0.020
0.9	0.002	0.003	0.010	0.003	0.011	0.005	0.004	0.001	0	0.001	0.016
1	0.001	0.003	0.008	0.002	0.009	0.004	0.003	0.001	0	0.001	0.013

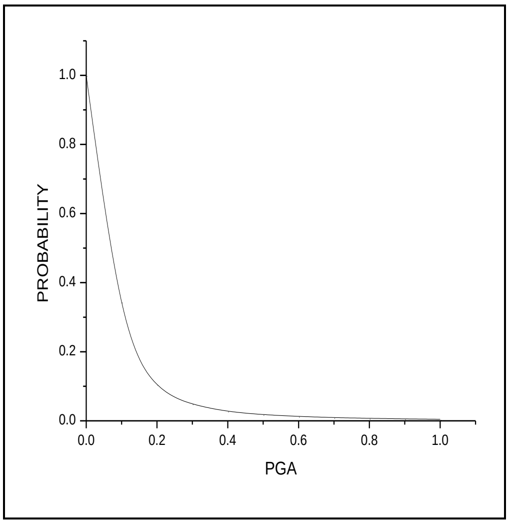
From the graphical representations, return periods of seismic events corresponding to different PGA values for an exposure time of 50 years were determined for each of the selected cities/towns and the results are presented in Table 3 and Figure 3. For example, let us consider the case of Tezu, for an exposure time of 50 years. It is found that (from Figure 2),

$$P_{50}(A>0.1g) = 0.769$$



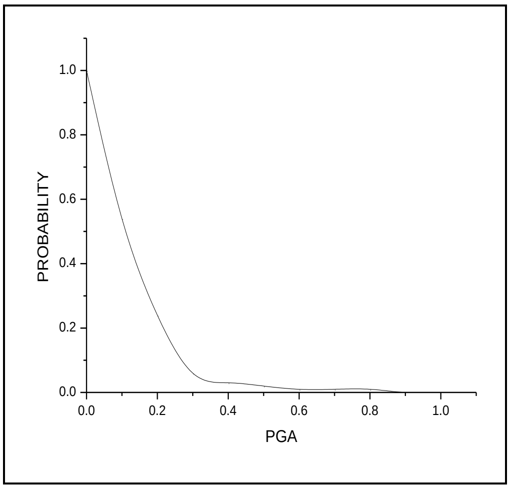


Guwahati

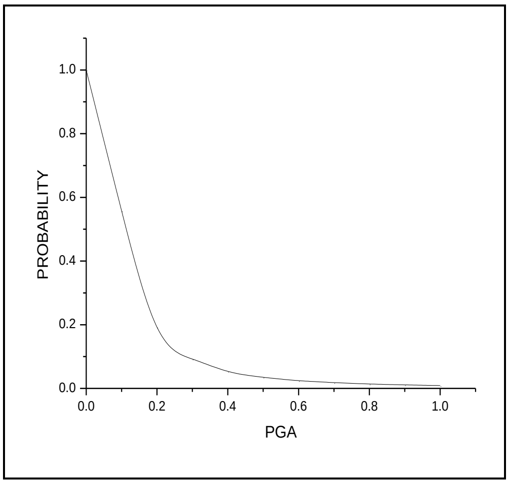


Imphal

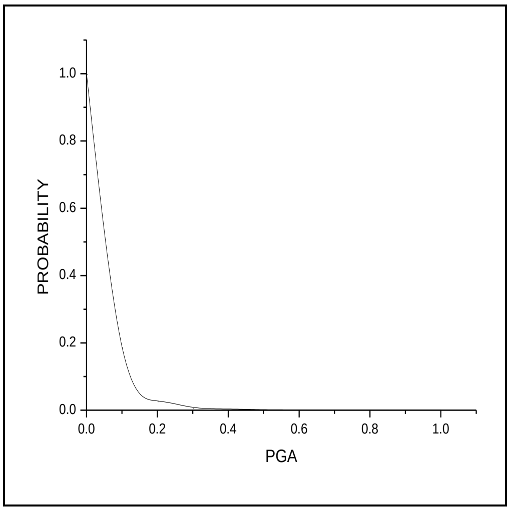
Figure 2: *Graphical Representation of Probability of Exceedance of a given PGA*



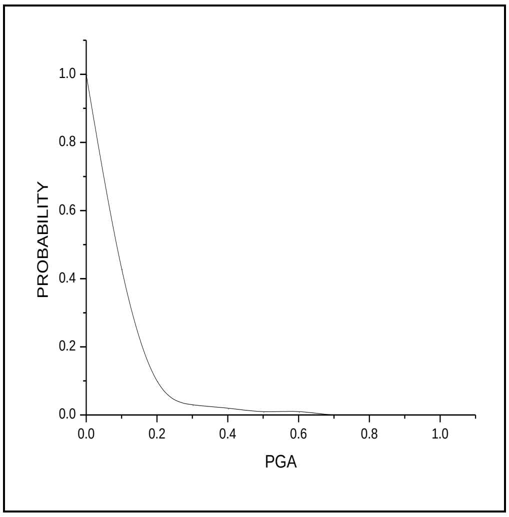
Itanagar



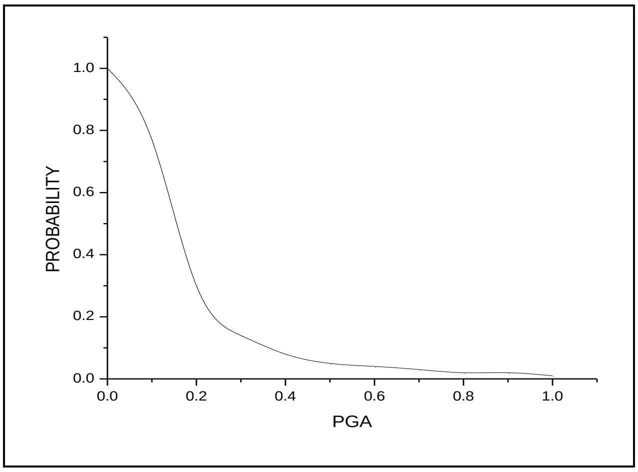
Kohima



Shillong



Tezpur



Tezu

Figure 2 (Contd.): *Graphical Representation of Probability of Exceedance of a given PGA*

i.e. for Tezu there is 76.9% chance that during the next 50 years the PGA of 0.1g will be exceeded at least once. Thus, there is nearly 23% chance that 0.1g will not be exceeded even once in Tezu during the next 50 years. Hence,

P(zero exceedance of 0.1g in 50yrs.) = 0.23

$P_{50}(0) = 0.23 = (1 - P)^{50}$

P = 0.028 and Return Period = 1/P = 34.59 years

Table 3: *Return Period of an Event Exceeding a given PGA in the Selected 11 Cities for Exposure Time of 50 Years*

PGA Values	Return Period (Years)										
	Agartala	Aizawl	Dibrugarh	Dimapur	Kohima	Imphal	Itanagar	Guwahati	Shillong	Tezpur	Tezu
0.0	1	1	1	1	1	1	1	1	1	1	1
0.1	102	95	53	83	62	119	65	123	239	89	35
0.2	524	433	208	464	235	448	329	697	1788	501	141
0.3	1434	1086	477	1189	517	989	851	2010	5777	1429	322
0.4	2947	2086	866	2291	906	1737	1659	4282	13246	3021	579
0.5	5156	3456	1376	3787	1402	2690	2776	7705	25180	5405	913
0.6	8145	5216	2011	5693	2002	3844	4218	12452	42523	8697	1325
0.7	11987	7380	2773	8019	2707	5196	5999	18684	66185	13003	1814
0.8	16751	9960	3663	10775	3515	6744	8130	26548	97051	18424	2382
0.9	22499	12967	4682	13967	4425	8486	10621	36186	13598	25053	3029
1.0	29291	16412	5833	17603	5438	10420	13482	47732	18383	32980	3755

From the graphs of return period of the eleven selected cities/towns expected PGA values for a seismic event having return period of 50 years and 100 years respectively have been ascertained and presented in Table 4. It has been observed that PGA of a seismic event is the maximum at Tezu for return period of 50 years as well as 100 years and the same is the minimum in Shillong. In the capital city of Assam i.e. in Guwahati, the PGA value having return period 50 years and 100 years are 0.03 and 0.08 respectively.

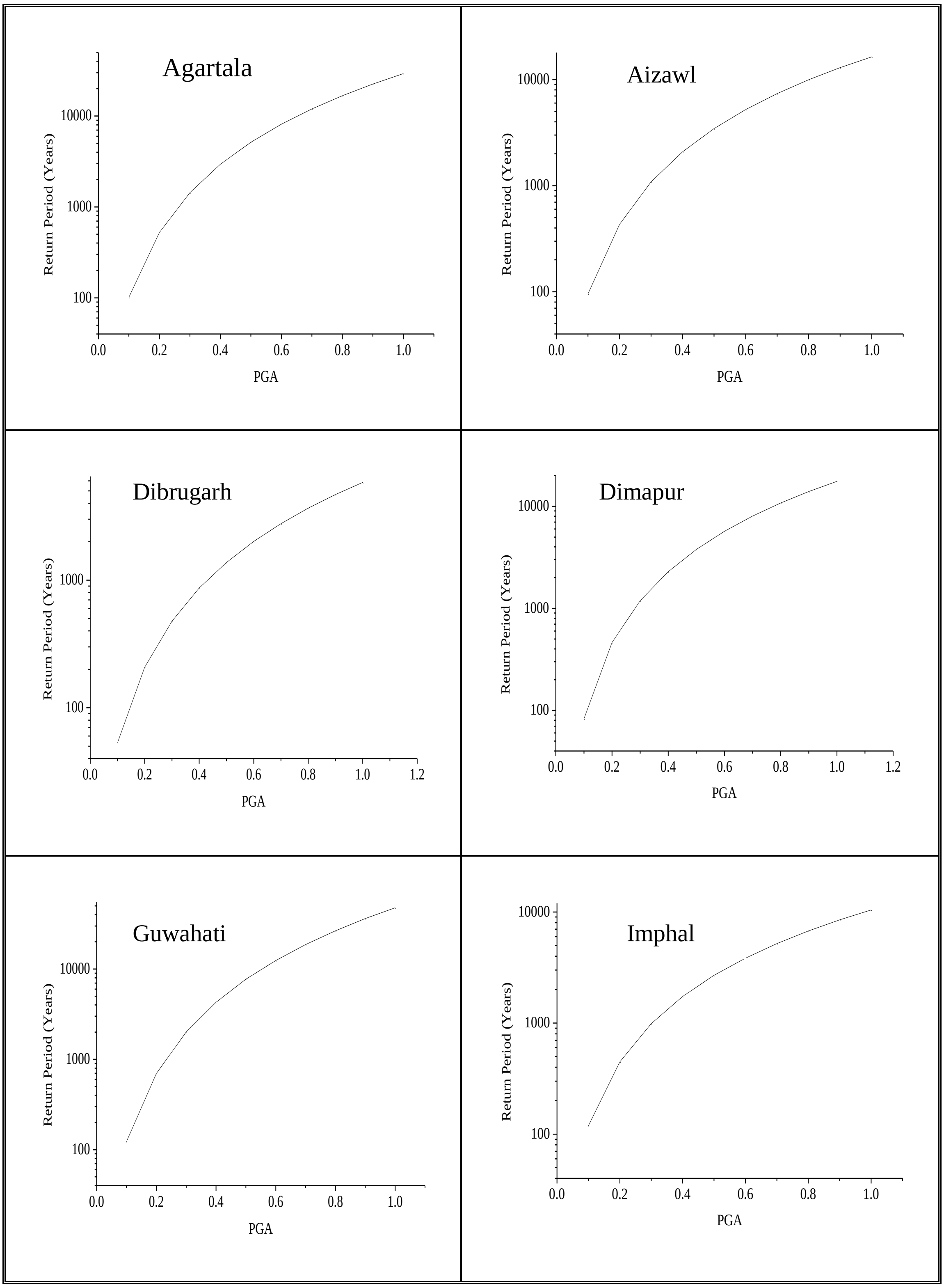


Figure 3: *Curves Showing the Variation of Return Period of an Event Exceeding a given PGA in the Selected Cities for Exposure Time of 50 Years*

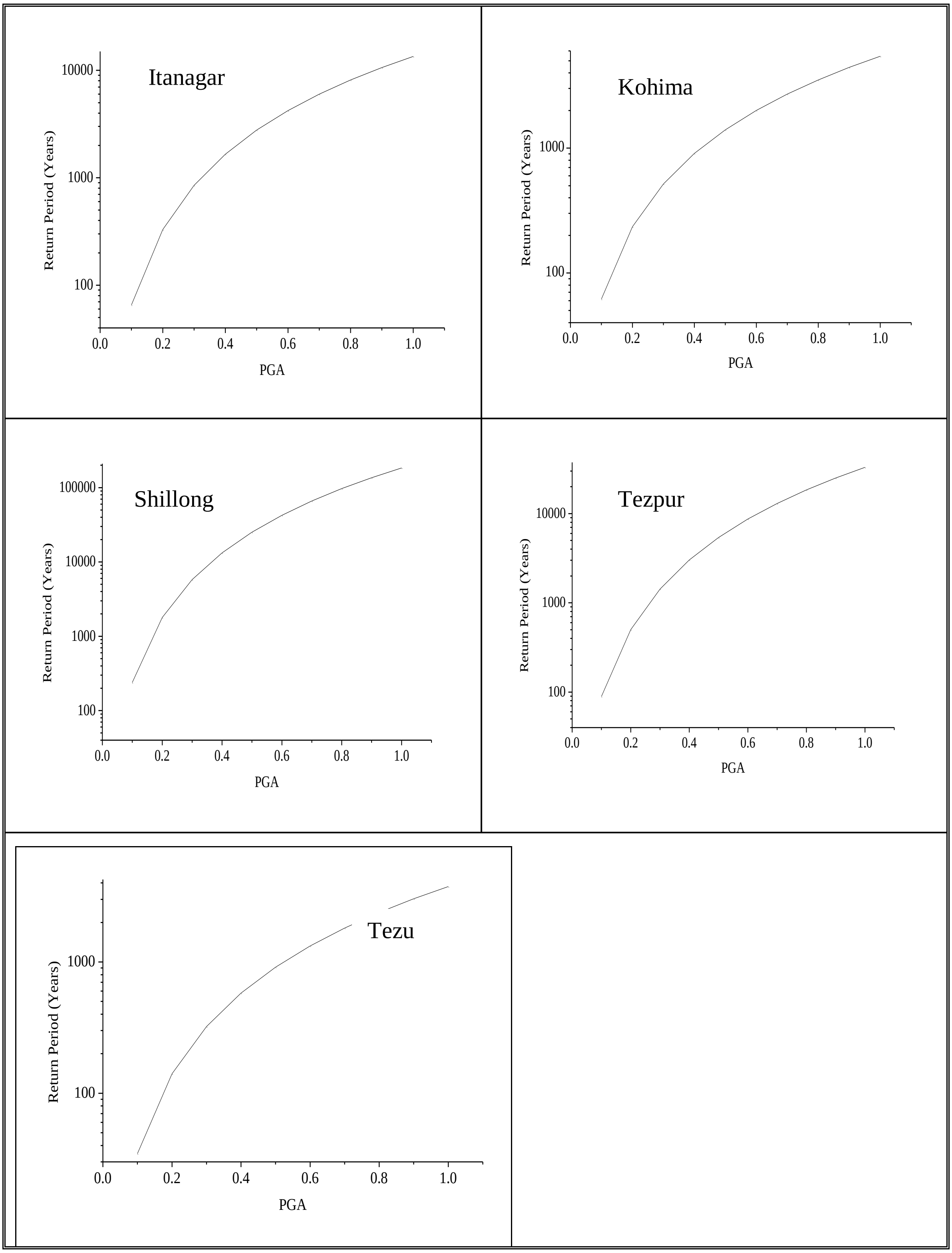


Figure 3 (Contd.): *Curves Showing the Variation of Return Period of an Event Exceeding a given PGA in the Selected Cities for Exposure Time of 50 Years*

Table 4: *Expected Peak Ground Acceleration for a Return Period of 50 Years and 100 Years (From Acceleration Zone Graph)*

Cities/Sites	50 yrs	100 yrs
Agartala	0.04	0.09
Aizawl	0.03	0.1
Dibrugarh	0.09	0.14
Dimapur	0.04	0.1
Kohima	0.07	0.13
Imphal	0.02	0.08
Itanagar	0.07	0.12
Guwahati	0.03	0.08
Shillong	0.02	0.05
Tezpur	0.03	0.11
Tezu	0.13	0.17

Though the relationship between PGA and the corresponding return period was found for different localities, these relations by themselves do not help in selecting a return period for a given acceptable level of risk. Therefore, an attempt has been made to obtain a relationship between the economic life of a structure with return period and probability of exceedance. Suppose the economic life of a structure is 10 years and the probability of no success at 10% level of exceedance is –

P_{10} (0) = (1 – probability of success at 10% level of exceedance) = (1 – 0.1) = 0.9

Hence,
$(1 – P)^{10} = 0.9$
RP = 1/P = 95 years

In this manner return period was determined for different level of exceedance and for different economic life expectancy. The results are presented in Table 5 and graphically in Figure 4.

Results presented in Table 5 and Figure 4 are helpful in seismic design. For example, suppose if the acceptable risk level is 20% for a structure whose economic life is 50 yrs, then the loading level should correspond to a return period of 224.57 yrs ~ 225 yrs (Table 5). If this structure is to be constructed in Shillong based on the graph of return period vs PGA (Figure 3) the corresponding loading is found to be 0.1g. If the same structure is to be built in Tezu for the same risk value then the corresponding PGA value will be 0.26g (from Figure 3). This is the concept of consistent risk design from one seismic region to another region of different seismicity.

Table 5: *Return Period as a Function of Economic Life and Probability of Exceedance*

Probability of Exceedance	Return Period in Years for the Economic Life of					
	10 Year	20 Year	30 Year	40 Year	50 Year	60 Year
10%	95.41	190.32	288.11	380.15	475.06	568.84
20%	45.32	90.13	136.30	179.76	224.57	268.85
30%	28.54	56.57	85.46	112.65	140.68	168.39
40%	20.08	39.65	59.82	78.81	98.38	117.72
50%	14.93	29.36	44.22	58.21	72.64	86.89
60%	11.42	22.33	33.57	44.16	55.07	65.85
70%	8.82	17.12	25.67	33.73	42.03	50.24
80%	6.73	12.93	19.33	25.36	31.57	37.71
90%	4.86	9.20	13.67	17.88	22.22	26.51

The graphs relating to economic life, risk level and return period as presented in Figure 4 are independent of any region and show the return period as function of risk and economic life. Once the acceptable risk level for a given economic life is selected for a given class and use of structure, the corresponding return period can be obtained from figure. Then the seismic loading at a site can be determined on the basis of acceleration zone graph.

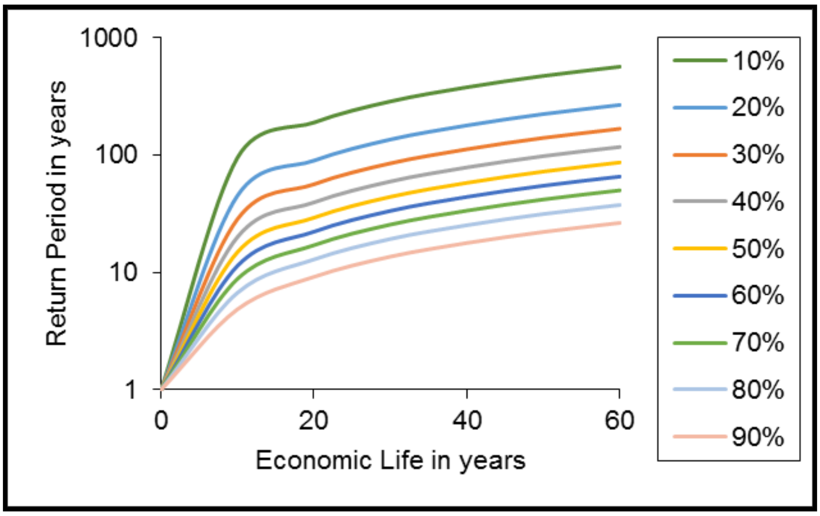


Figure 4: *Return Period as a Function of Economic Life and Probability of Exceedance*

5. Conclusion

The return periods corresponding to different values of peak ground acceleration were determined for eleven different cities/town of the study region. It has been found that return period for different PGA values is the minimum for Tezu. A relationship between the economic life of a structure with return period and probability of exceedance was determined for all the eleven cities. Seismic loading is found to be maximum in Tezu for the same risk level and economic life.

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