Codal provisions of seismic hazard in Northeast India

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Seismic hazard maps have been prepared for Northeast India in the form of uniform hazard contours for pseudo-spectral acceleration at stiff sites. These maps are for the horizontal component of ground motion and for different values of exposure time, confidence level and natural period. A comparison with the codal provisions given by the Bureau of Indian Standards code (IS 1893 (Part 1): 2002) shows that the pseudo-spectral accelerations specified in the code for Northeast India are broadly consistent with the hazard level corresponding to 10% probability of exceedance and 50 years service life, and that the present practice of specifying seismic hazard through peak ground acceleration and a fixed spectral shape may be inappropriate for structures in most areas of the region.

Keywords: Codal provisions, Northeast India, PSHA, uniform hazard contours.

DAS *et al.*[1] have carried out a probabilistic seismic hazard analysis (PSHA) of Northeast India based on a regionalization-free seismicity model and by adopting the PSHA formulation of Anderson and Trifunac[2,3]. They have obtained significantly varying seismic hazard levels over the region in the form of pseudo-spectral acceleration (PSA) response for both horizontal and vertical motions. Their study is first of its kind for the region, as it attempts to directly estimate the hazard levels in terms of structural response. This article compares the findings of their analysis with the hazard levels specified by the Indian standard code[4], IS 1893 (Part 1): 2002. According to this code, the seismic hazard levels in Northeast India are specified via MCE levels of effective peak ground acceleration (PGA) for seismic zone V, and a fixed spectral shape. Though it is not explicitly clear, it appears from the foreword of the code that the MCE level is assumed to correspond to 100 years exposure time and 50% confidence level. Comparisons are carried out by considering uniform hazard contours for (i) 50 years exposure time and 90% confidence level, and (ii) 100 years exposure time and 50% confidence level, at ten different natural periods. A brief review of the procedure followed by Das *et al.*[1] is given first for the sake of completeness. This is followed by comparison with the codal provisions.

PSHA procedure: a brief review

PSHA is based on evaluating the probability distribution function for the amplitude z of a hazard parameter Z, at a site due to all the earthquakes expected to occur during an exposure period of Y years in the region around the site. Under the Poissonian assumption, this probability distribution is defined as

$$P(Z > z) = 1 - \exp\{-Yn(z)\}, \qquad (1)$$

where $n(z)$ is the average occurrence rate of the earthquake events. It is defined as

$$n(z) = \sum_{i=1}^{I} \sum_{j=1}^{J} q(z \mid M_j, R_i) n(M_j, R_i), \qquad (2)$$

where $q(z|M_j, R_i)$ is the probability of exceeding z due to an event of size M_j at distance R_i. It is obtained from the attenuation relationship for the hazard parameter Z. This relationship has been developed by Das *et al.*[1] for 5% damping pseudo-spectral velocity (PSV) spectrum with the help of 261 accelerograms recorded at stiff sites for six earthquake events. The relationship is given as:

$$\begin{aligned}\log[\mathrm{PSV}(p,T)] &= c_1'(T) + c_2'(T)M + c_3'(T)h \\ &\quad + c_4'(T)\log(\sqrt{R^2+h^2}) + c_5'(T)v + e(p,T),\end{aligned} \qquad (3)$$

where M is the magnitude of the earthquake event, R the epicentral distance, h the focal depth, c_is the estimated regression coefficients, $n = 0$ for horizontal motions, and $e(p, T)$ is the normally distributed error residual term. For a given z, $e(p, T)$ is determined corresponding to $M = M_j$ and $R = R_i$. This leads to p on using the normal distribution parameters given by Das *et al.*[1], and thus to $q(z|M_j, R_i) = 1 - p$.

In eq. (2), the quantity $n(M_j, R_i)$ is the annual rate of occurrence of the (M_j, R_i) event. As the magnitude and distance are both continuous variables, for practical applications, they are discretized into small intervals with central values, M_j and R_i. Summations over i and j in eq. (2) are thus taken over the total number of distance intervals, I, and the magnitude intervals, J respectively. Following is the procedure used for obtaining the seismicity $n(M_j, R_i)$.

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A regionalization-free approach is adopted to define the seismicity of Northeast India. Figure 1 shows the significant earthquakes (magnitude above 5.0) with the major tectonic features in Northeast India[5]. The entire area lying between 21–30° lat. and 88–97° long. is sub-divided into a 0.1° lat. and 0.1° long. grid. The seismicity, $n(M_j, R_i)$, for each site is now evaluated by fitting the G–R recurrence relation[6]

$$\log N(M) = a - bM, \tag{4}$$

to the past earthquake data within a circular area of 300 km radius around the site. In eq. (4), $N(M)$ is the annual occurrence rate of earthquakes with magnitudes greater than or equal to M, and a and b are the constants obtained for the area of 300 km radius around each of the grid points by fitting a least square straight line. The earthquake catalogue used covers the period from 1458 to 2000, where the data up to 1979 are taken from Bapat *et al.*[7], and from the USGS website for the subsequent period. To minimize the effects of incompleteness of the catalogue, the empirical method proposed by Stepp[8] has been adopted.

Table 1 shows the values of a and b for selected grid points that are located at the interval of 1° in both directions. Also shown in Table 1 are the values of root-mean-square (rms) error in log $N(M)$ associated with the use of eq. (4). Figure 2 shows a comparison of the actual values of log $N(M)$ with estimates based on eq. (4) in case of the grid point at 27° lat. and 94° long.

The annual rate, $N(M)$, is determined for different values of magnitude from $M_{\min} = 4.0$ to $M_{\max} = 8.5$. These are used to obtain the number of earthquakes, $N(M_j)$, with magnitudes between $M_j - dM_j/2$ and $M_j + dM_j/2$ as

$$N(M_j) = N\left(M_j - \frac{dM_j}{2}\right) - N\left(M_j + \frac{dM_j}{2}\right), \tag{5}$$

which is then spatially distributed based on the smoothened observed probability distribution function of the epicen-

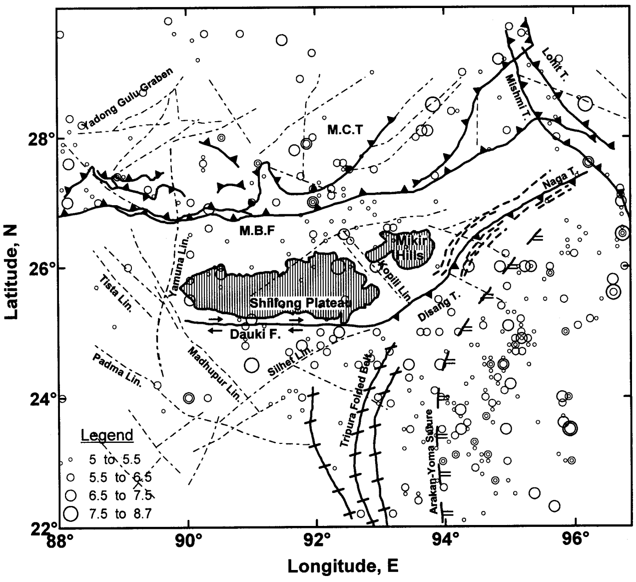

Figure 1. Epicentres of past earthquakes with major tectonic features in Northeast Indian region (after Verma *et al.*[5]).

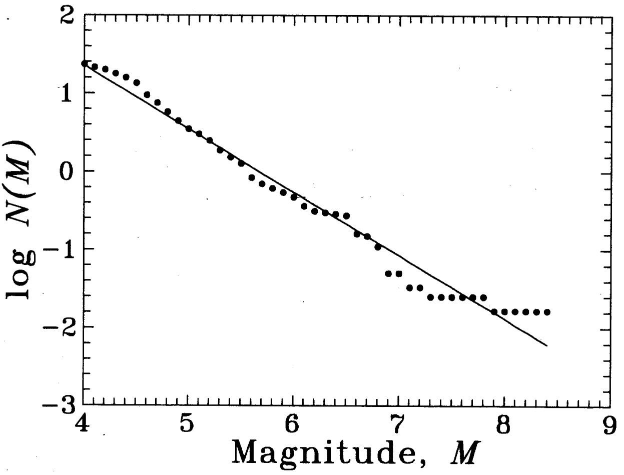

Figure 2. Fitting of G–R relationship to the observed variation of log $N(M)$ with M in case of the grid point at 27° lat. and 94° long.

Table 1. Values of a and b with rms error in case of 30 grid points

Latitude (in degrees)	Longitude (in degrees)	a	b	rms error
22	93	5.3930	0.9831	0.0805
23	93	5.0640	0.8961	0.1135
24	92	4.8090	0.8668	0.1202
24	93	5.1830	0.9039	0.1075
24	94	5.1800	0.8924	0.0830
25	92	4.7580	0.8590	0.1168
25	93	5.2310	0.9133	0.1111
25	94	5.1540	0.8869	0.0762
26	90	4.1170	0.7819	0.1235
26	91	4.3560	0.8105	0.0612
26	92	4.5980	0.8378	0.1159
26	93	4.9730	0.8698	0.0874
26	94	5.0810	0.8831	0.0488
26	95	4.8450	0.8364	0.0730
27	90	4.3200	0.8132	0.1501
27	91	4.3230	0.8048	0.1146
27	92	4.2800	0.7851	0.0797
27	93	4.6370	0.8383	0.1236
27	94	4.5930	0.8097	0.1563
27	95	4.8040	0.8489	0.0857
27	96	4.4830	0.8098	0.0905
28	92	4.3570	0.8065	0.0836
28	93	4.8720	0.9137	0.0993
28	94	4.6150	0.8397	0.1305
28	95	4.5400	0.8267	0.1314
28	96	4.2020	0.7784	0.1306
28	97	3.9220	0.7426	0.1171
29	94	4.2560	0.7931	0.1411
29	95	4.0680	0.7846	0.2351
29	96	3.9840	0.7635	0.1910

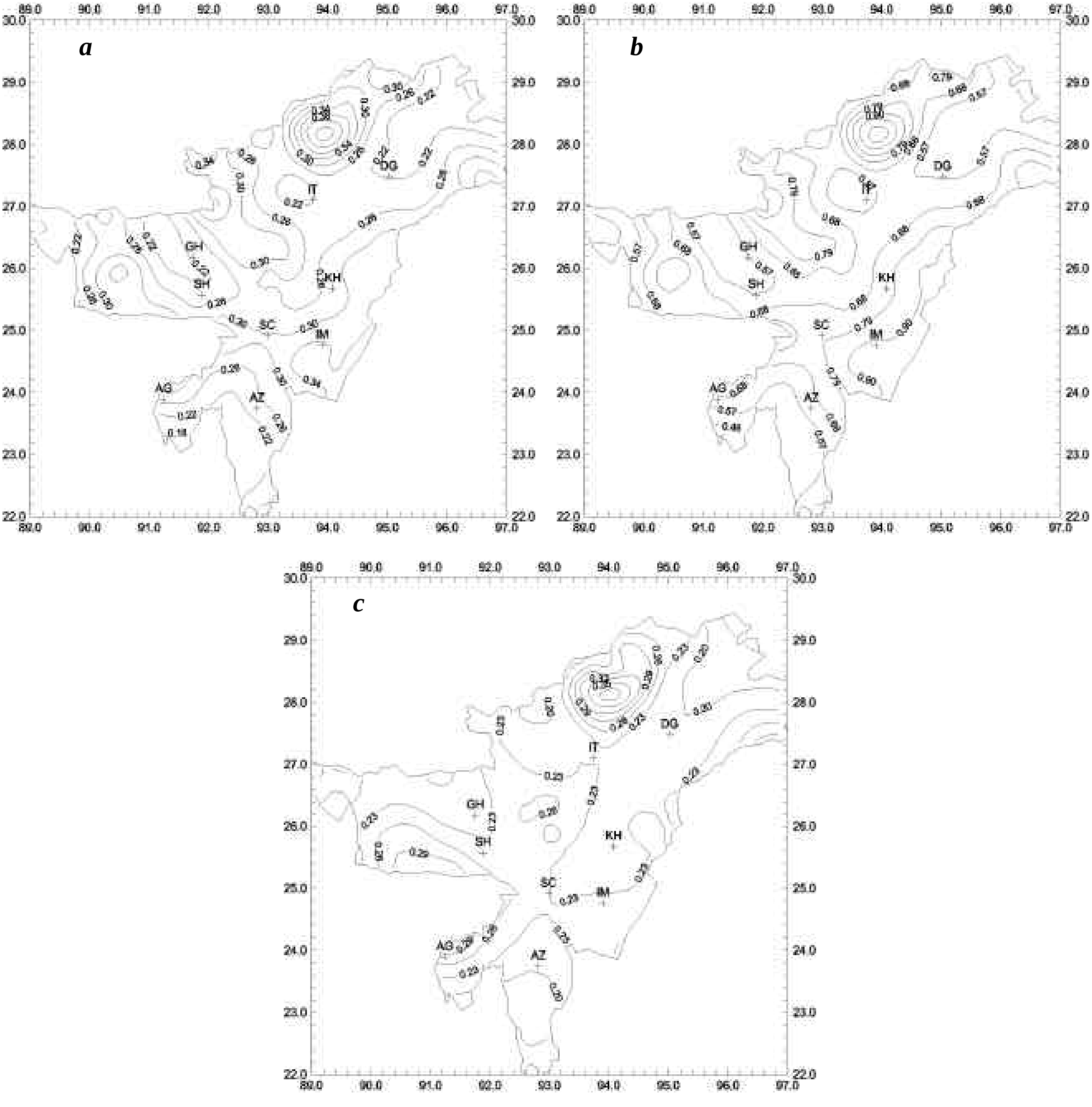

Figure 3. Hazard map for horizontal PSA (in g) at $T = 0.04$ s (***a***), $T = 0.17$ s (***b***), $T = 1.0$ s and (***c***) in case of $Y = 100$ years and $P = 0.5$.

tral distance, $F(R)$. The expected rate of events in a distance range $(R_i - dR_i/2, R_i + dR_i/2)$ is finally obtained as

$$n(M_j, R_i) = N(M_j)[F(R_i + dR_i/2) - F(R_i - dR_i/2)]. \qquad (6)$$

Earthquake magnitude is discretized into nine intervals with central magnitudes $M_j = 4.25,\ 4.75,\ 5.25, \ldots, 8.25$ and $dM_j = 0.5$ for all the intervals. Further, the 300 km radius circular area around the site is sub-divided into 50 annular elements, equispaced on logarithmic scale, with R_i as the radius of the median circle of the annular ring.

Once the probability distribution $P(Z > z)$ (see eq. (1)) is determined, UHS are obtained for all the grid points and seismic hazard maps are drawn in terms of Z contours. Here, we obtain the UHS for PSV spectrum at natural period, T and determine the seismic hazard maps in terms of PSA (in g) contours.

Comparison with Indian standard provisions

According to the Indian Standard code[4], IS 1893 (Part 1): 2002, the entire Northeast Indian region falls under seismic

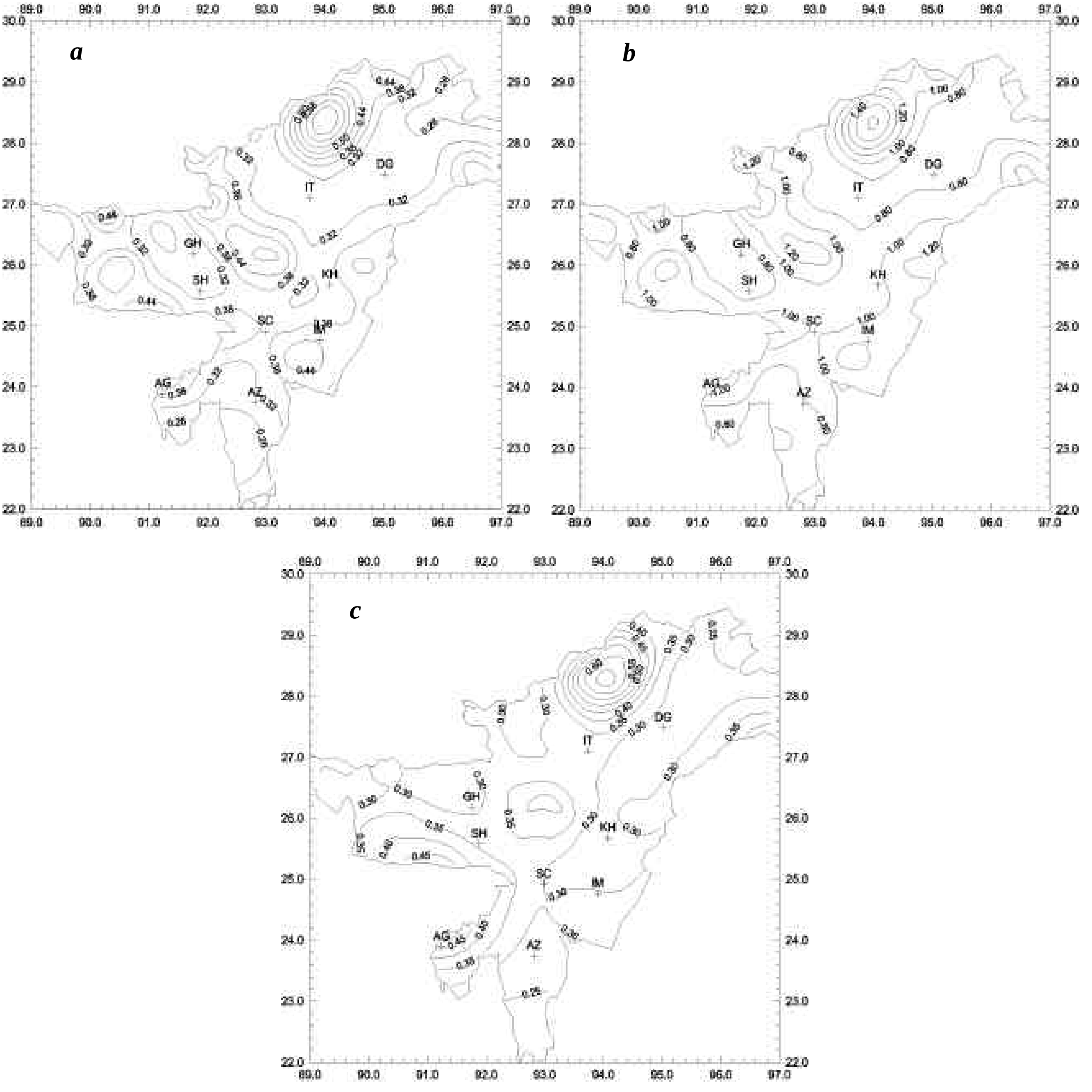

Figure 4. Hazard map for horizontal PSA (in g) at $T = 0.04$ s (***a***), $T = 0.17$ s (***b***), $T = 1.0$ s and (***c***) in case of $Y = 50$ years and $P = 0.1$.

zone V associated with the highest hazard level in India. For this region, the hazard levels (in terms of 5% damping horizontal PSA) are specified via the multiplication of zone factor equal to 0.36 with a spectral shape (normalized to unit PGA). This leads to PSA values at ten different time periods, as shown in Table 2 for all stiff sites of Northeast India. The zone factor used for these values corresponds to the MCE level which is apparently assumed to correspond to 100 years exposure time and 50% confidence level, i.e. 144 years return period.

Figure 3 *a–c* shows hazard maps for 5% damping PSA at $T = 0.04$, 0.17, and 1.0 s respectively, for $Y = 100$ years, $P = 0.5$ and horizontal component of ground motion. It may be observed from Figure 3 that the difference between the minimum and maximum hazard levels in any of the maps is about 45% of the maximum. Considering that the difference between the zone factor for seismic zone IV is two-thirds of that for seismic zone V, the hazard levels in Northeast India according to PSHA correspond to two seismic zones instead of just one. Thus, considering the entire Northeast India in a single zone V with uniform hazard levels may not be justified. Further, the maximum codal value of hazard in Northeast India is 0.9 g (see Table 2), which is close to the highest PSHA value of 1.1 g only

Table 2. Comparison of PSHA and codal PSA values (in *g*) for horizontal component at different time periods

	PSHA values for $P = 0.1$ and $Y = 50$ yrs									
Period T (s)	GH	IT	KH	DG	SH	SC	IM	AZ	AG	Codal value
0.04	0.28	0.28	0.35	0.28	0.30	0.38	0.43	0.29	0.41	0.54
0.06	0.37	0.37	0.47	0.37	0.39	0.52	0.57	0.39	0.53	0.72
0.08	0.51	0.51	0.65	0.52	0.53	0.69	0.79	0.55	0.69	0.81
0.12	0.64	0.64	0.84	0.66	0.67	0.89	1.02	0.70	0.87	0.90
0.17	0.70	0.72	0.94	0.75	0.74	0.99	1.16	0.77	1.00	0.90
0.24	0.60	0.65	0.85	0.67	0.66	0.85	1.03	0.67	0.90	0.90
0.34	0.45	0.52	0.66	0.56	0.50	0.62	0.74	0.52	0.70	0.90
0.48	0.31	0.37	0.43	0.38	0.36	0.41	0.47	0.37	0.48	0.86
0.70	0.30	0.32	0.33	0.30	0.34	0.34	0.37	0.30	0.47	0.49
1.00	0.29	0.32	0.28	0.28	0.34	0.30	0.31	0.28	0.46	0.36

GH, Guwahati; IT, Itanagar; KH, Kohima; DG, Dibrugarh; SH, Shillong; SC, Silchar; IM, Imphal; AZ, Aizawl; AG, Agartala.

for a small area near 28.5° lat. and 94° long. grid point at $T = 0.17$ s (see Figure 3 *b*). For most parts of the region, the maximum PSHA values are much lower (say by about 30%) than the maximum codal value.

Considering that it is a worldwide practice to consider the return period of 475 years for seismic zoning, the hazard maps have also been obtained for $P = 0.1$ and $Y = 50$ years. Figure 4 *a–c* shows the contour plots of horizontal PSA in case of $Y = 50$ years and $P = 0.1$ for $T = 0.04$, 0.17 and 1.0 s respectively. For convenience, Table 2 shows the PSHA values of PSA along with those prescribed by the code for major towns of the Northeast Indian region, viz. Guwahati, Itanagar, Kohima, Dibrugarh, Shillong, Silchar, Imphal, Aizawl, and Agartala, in case of $T = 0.04$, 0.06, 0.08, 0.12, 0.17, 0.24, 0.34, 0.48, 0.70 and 1.0 s. It may be observed that the codal values are now much closer to the PSHA values at several time periods and in most of the sites, though there is an overestimation of hazard at Guwahati by 177% for 0.48 s period structures on one extreme and there is an underestimation at Imphal by 23% for 0.17 s period structures on the other extreme (in case of big cities). The observed discrepancies (within these two extremes) between the codal and estimated values are due to the choice of a fixed spectral shape and due to specifying the same zone factor for the entire Northeast region in the code. The standard spectral shape in the code causes the peak hazard levels to remain unchanged up to $T = 0.45$ s, whereas the estimated PSA values start falling after $T = 0.24$ s. Moreover, a hazard level corresponding to zone V is specified uniformly at all sites, though the region has seismicity varying from somewhere between zone IV and zone V (say, at Guwahati) to that higher than zone V (say, at Imphal) according to PSHA. It is thus obvious that the seismic hazard levels specified by IS 1893 (Part 1): 2002 correspond to much higher levels than those for $P = 0.5$ and $Y = 100$ years, and that the period-independent zoning map together with the use of a single spectral shape are inadequate.

Conclusion

A comparison of the hazard maps based on PSHA has been carried out with those specified by IS 1893 (Part I): 2002 in case of 5% damping PSA as the hazard parameter. This shows that the zoning map together with a single spectral shape in the code corresponds to the comparable levels of seismic hazard from PSHA, provided the zone factors given in the code correspond to $P = 0.1$ and $Y = 50$ years (or 475 years of return period). Further, it is unrealistic to describe seismic hazard for structures of varying time periods in the entire Northeast Indian region using a single zone factor and a single spectral shape. The spectral shape in general may change from location to location and the proposed maps provide a basis to obtain the spectral shape specific to any particular location.

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