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# A Review on Probabilistic Seismic Hazard Analysis of Upper Himalayas Region Using Moment Releases Constraint Method

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***Abstract*— The Upper Himalayas Region is located in most seismic active zone of Himalayan that exhibits many moderate to large size earthquake. In this study eleven seismic zones are identify in and around of Upper Himalayas Region and the entire area has been divided into 0.2°×0.2° grid size, and the hazard level has been assessed for each grid by considering the seismicity within a 350-km radius around the grid. Using the past earthquake data the seismicity for the area around each grid has been estimated by defining a and b value of the Gutenberg-Richter recurrence relationship and annual occurrence rate has been estimated by constant seismicity and seismic moment release constraints method. Uniform hazard contours for peak ground acceleration as the hazard parameter have been obtained for an exposure time of 50 years and for 90% and 98% confidence level at 0.01s natural periods using constant seismicity and moment release constraint. The trends reflected by these contours are broadly consistent with the major seismotectonic features in the region.***

***Keywords*— Upper Himalayas, earthquake, recurrence relationship, peak ground acceleration, annual occurrence rate.**

## I. INTRODUCTION

Seismic hazard is the characterisation of various natural effects of earthquakes occurrence that have enough potential to cause loss of life and property. Seismic hazard is determined from historical, geological and instrumental observations it occurs naturally without any control over it. Hazard analysis should consider all uncertainties in input data and parameters to have high confidence in the estimated hazard levels. The major earthquake along the Himalayan are shown in Fig.1

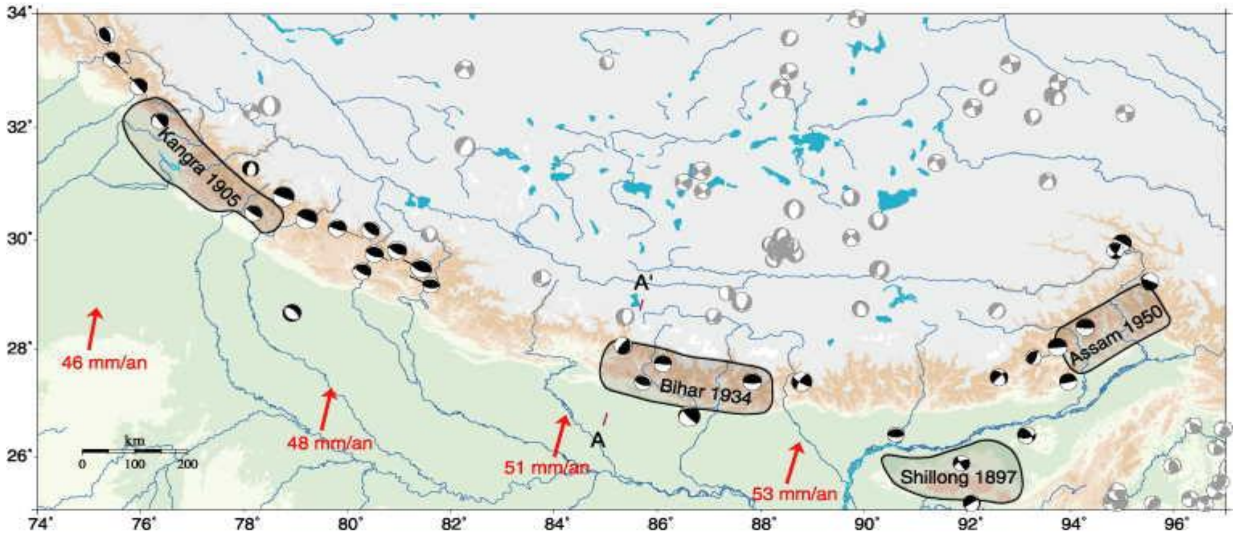


*Fig.1 Major Earthquake along the Himalayan arc*

The Upper Himalaya Region lies between latitude 25.0º N to 44.0º N and longitude 68.0º E to 104.0º E. It falls in high seismically active zones IV and V as per IS Code [IS 1893 (Part 1):2002]. The most well-known moderate earthquakes in the region are Himalaya earthquake 1991 (magnitude 6.8). Several studies have been carried out in the past to determine the seismic hazard in the vicinity of main central thrust (MCT) and main boundary thrust (MBT) of Himalayan region by using various models and Hazard analysis method. Two methods namely, And Fig.2 has shown the tectonics features of Himalayas to his adjoring boundaries.

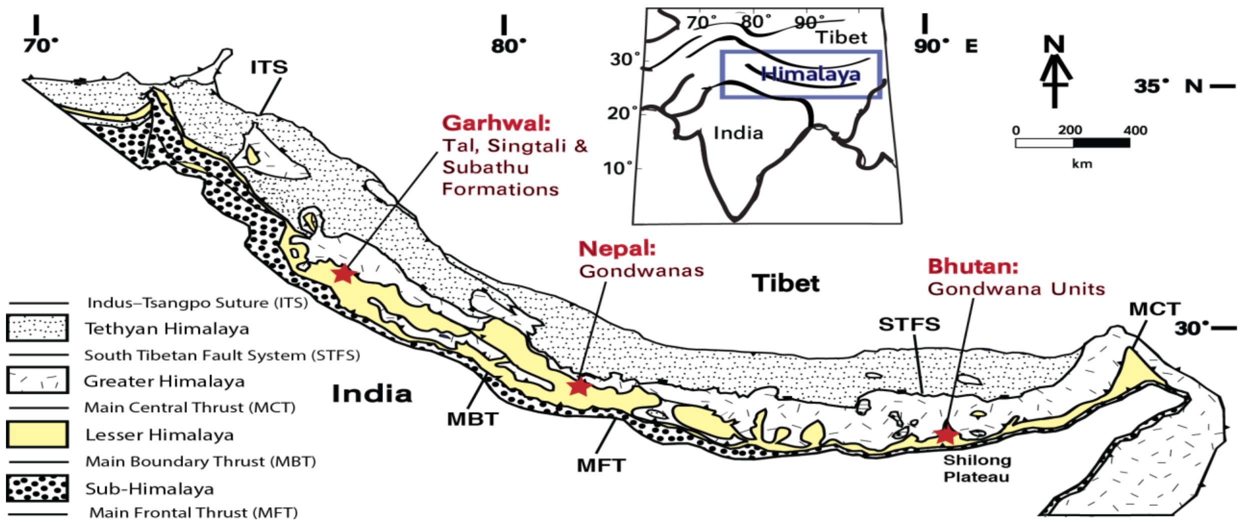


*Fig.2 Tectonic features of Himalayan Region*

Deterministic Seismic Hazard Analysis (DSHA) and Probabilistic Seismic Hazard Analysis (PSHA) are used for determining hazard .This paper reviews the probabilistic analysis of seismic data of the North Himalayan region with seismic moment release constraint. Poisson's distributions exponential Model, Recurrence relation and attenuation relationship are used to estimated Hazard [1]. The moment release rate $M_0$ is used to determine the strength of a seismic source. Therefore, it is necessary to estimate the seismic moment release rate to constraint the scaling and distribution parameters (a and b value), that define the recurrence relationship for estimating Hazard.

In this study earthquake data have been analyzed using ZMAP software to determine the source characteristics. A broad area bounded by longitudes $68^o$ to $104^o$ E and latitudes $26^o$ to $42^o$ N has been taken for the digitization of tectonic features, plotting and distribution of earthquakes magnitude-wise, creation of seismogenic source zones, zone boundary co-ordinates. For this purpose, the software Surfer has been used.

Basically seismic hazard can be represented most frequently in terms of probability of peak accelerations, peak velocities, peak displacements or the complete response spectrum. Two approaches are commonly used for determining seismic hazard, namely:

i) Probabilistic Seismic Hazard Analysis (PSHA)
ii) Deterministic seismic Hazard analysis (DSHA)

Seismic hazard is defined by ground motion with very low probability of exceedance. Probabilistic method considers the uncertainties in location, size and rate of occurrence. The objective of PSHA is to quantify these uncertainties, and provide description about distribution of future Earthquake shaking that may occur at different sites.

Generally probabilistic approach is most reliable than deterministic. Most of the parameters in DSHA are fixed which is reality are random. So PSHA method is commonly used for Hazard analysis. Also Probabilistic seismic hazard analysis (PSHA) considers all magnitude earthquakes greater than $M$min for all the distances of the site for ground motion which influence the Hazard [2].

## II. SEISMOTECTONICS AND SEISMIC SOURCES

Northern Himalayas is high seismicity region. It is falling in between the seismic gap of 1934 Bihar–Nepal earthquake and 1905 Kangra earthquake in the central Himalaya active region [3].

### A. *Tectonics and Tectonic Map*

The data on past seismicity shows that the various tectonic features such as faults, folds, shear zones, lineaments, etc. are most important components required to describe the seismic sources and prediction of the future earthquakes. The mostly used tectonic units are faults and thrusts considered for seismic hazard.

### B. *Earthquake Catalogue*

Instrumentally recorded seismic data for this study was obtained from as many sources as possible as this is the primary requirement for undertaking study of this nature. The main sources of such data were:

i) MSSP Seismic Data Base
ii) ISC Earthquake Catalogue
iii) USGS Seismic Data Base
**iv)** MSSP Technical Reports.

This area has very ancient cultural history therefore from archeological sites, some evidences about large earthquakes have been identified e.g. Taxila Earthquake of year 25 A.D. Geological and seismotectonic evidences have also dictated about some earthquake sources. Damages to some monumental construction have also contributed to the information of large earthquakes. Historic notes also contain information of some damaging earthquakes. Out of 12 large significant earthquakes documented earlier, only one large damaging earthquake found occurring near Himalaya [4].

### C. *Correlation of Seismicity with Tectonics*

The seismicity of the region is due to the continued convergence of the Indian plate against the Eurasian plate. Due to this convergence motion of Indian plate towards Eurasian plate large seismicity occurs in this zone and it leads to the formation of thrusts, i.e. The Main Central Thrust (MCT), The Main Boundary Thrust (MBT), Southern Tibetan detachment and Main Frontal thrust (MFT), and several other thrust and lineaments along the entire Himalaya.

### D. *Identification of seismogenic source zones*

For the estimation of PSHA of the North Himalayan region, a region boundary from latitude $26^o$ to $44^o$ and longitude $68^o$ to $104^o$ has to be selected and earthquake data can be extracted from the Eathquake Catalogue. After plotting this earthquake data with the tectonic map, the region is to be divided into several seismogenic source zones based on geologic conditions, tectonic features and seismicity.

## III. RECURRENCE RELATIONSHIP

### *A. Declustering of Catalogue*

The earthquake catalogue consists of all earthquakes foreshocks, main shocks and aftershocks. For seismic hazard analysis earthquake catalogue must have the independent main shocks following Poisson's distribution. The foreshocks and aftershocks being dependent on the main shocks tend to cluster in space and time close to the locations and times of occurrence of the main shocks.

### *B. Completeness Analysis*

The methods of completeness and seismicity analysis can be done by using ZMAP. The code is available with software package ZMAP Wiemer, 2001) [5], which is a written in Mathtype software MATLAB (http://www.mathworks.com ). For the completeness analysis slope method is used [14].In this analysis we draw time history by using ZMAP software for the different minimum magnitudes and estimate the duration for which the earthquake is complete and the slope is constant.

Upper Himalayas has been divided into 33 Seismic Zones which has been shown in Fig 3.

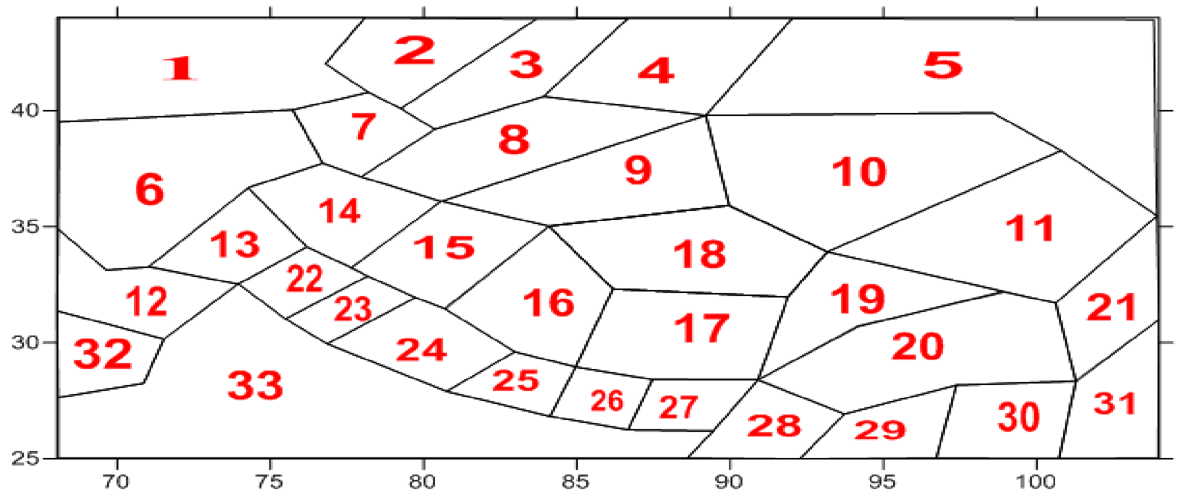


*Fig.3 Division of Upper Himalayas Regions into 33 Seismic Zones*

TABLE I

SOME SEISMIC FEATURES OF SOURCE ZONE

| Source | Area (km$^2$) | Total No EQ | No of Earthquake for different Magnitude | | | | | | Big Event time | Highest magnitude |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | <4.0 | 4-4.9 | 5-5.9 | 6-6.9 | 7-7.9 | >8.0 | | |
| Reg 1 | 477451 | 124 | 8 | 70 | 42 | 4 | 0 | 0 | 2013 | 6.2 |
| Reg 2 | 181456 | 125 | 8 | 71 | 42 | 4 | 0 | 0 | 2013 | 6.2 |
| Reg 3 | 187393 | 114 | 11 | 71 | 30 | 2 | 0 | 0 | 1966 | 6.7 |
| Reg 4 | 261259 | 88 | 3 | 48 | 32 | 5 | 0 | 0 | 1992 | 6.5 |
| Reg 5 | 801424 | 60 | 1 | 42 | 16 | 1 | 0 | 0 | 1986 | 6.1 |
| Reg 6 | 481418 | 14240 | 539 | 12056 | 1368 | 239 | 33 | 5 | 1985 | 8.3 |
| Reg 7 | 114319 | 914 | 42 | 751 | 107 | 11 | 2 | 1 | 1961 | 8.5 |
| Reg 8 | 155550 | 110 | 7 | 87 | 16 | 0 | 0 | 0 | 1963 | 5.8 |
| Reg 9 | 282380 | 203 | 8 | 151 | 34 | 8 | 2 | 0 | 1924 | 6.5 |
| Reg 10 | 535007 | 699 | 20 | 526 | 132 | 17 | 4 | 1 | 2001 | 8 |
| Reg 11 | 432729 | 262 | 6 | 193 | 49 | 11 | 3 | 0 | 1947 | 7.7 |
| Reg 12 | 129851 | 1640 | 71 | 1373 | 167 | 19 | 9 | 1 | 1555 | 8.5 |
| Reg 13 | 185093 | 688 | 25 | 594 | 59 | 9 | 1 | 0 | 1996 | 7 |
| Reg 14 | 306758 | 707 | 24 | 609 | 59 | 12 | 3 | 0 | 1961 | 7.7 |
| Reg 15 | 223535 | 588 | 18 | 487 | 59 | 24 | 0 | 0 | 1902 | 6.7 |
| Reg 16 | 298152 | 826 | 22 | 679 | 112 | 12 | 1 | 0 | 1986 | 7 |
| Reg 17 | 265876 | 843 | 35 | 676 | 110 | 19 | 2 | 1 | 1951 | 8 |
| Reg 18 | 199012 | 391 | 10 | 294 | 78 | 7 | 2 | 0 | 1952 | 7.5 |
| Reg 19 | 383587 | 963 | 11 | 718 | 149 | 78 | 6 | 1 | 2013 | 8.5 |
| Reg 20 | 160138 | 145 | 13 | 102 | 25 | 4 | 1 | 0 | 2008 | 8 |
| Reg 21 | 160422 | 279 | 16 | 216 | 39 | 6 | 2 | 0 | 1831 | 7 |
| Reg 22 | 79189 | 304 | 17 | 247 | 35 | 2 | 2 | 1 | 1905 | 8 |
| Reg 23 | 68868 | 211 | 8 | 161 | 34 | 5 | 3 | 0 | 1294 | 7.5 |
| Reg 24 | 154724 | 611 | 26 | 458 | 100 | 23 | 4 | 0 | 1916 | 7.5 |
| Reg 25 | 79642 | 121 | 6 | 94 | 14 | 6 | 1 | 0 | 1936 | 7 |
| Reg 26 | 80590 | 218 | 5 | 166 | 38 | 6 | 2 | 1 | 1833 | 8.5 |
| Reg 27 | 84077 | 220 | 19 | 147 | 45 | 7 | 1 | 1 | 2012 | 8.3 |
| Reg 28 | 122589 | 490 | 16 | 350 | 109 | 11 | 3 | 1 | 1897 | 8.1 |
| Reg 29 | 118230 | 764 | 20 | 575 | 124 | 39 | 6 | 0 | 2013 | 7.5 |
| Reg 30 | 157001 | 366 | 9 | 243 | 90 | 22 | 2 | 0 | 1961 | 7.6 |
| Reg 31 | 166035 | 121 | 6 | 88 | 26 | 1 | 0 | 0 | 1962 | 6 |
| Reg 32 | 110142 | 755 | 30 | 607 | 98 | 18 | 1 | 1 | 1997 | 8.3 |
| Reg 33 | 905715 | 198 | 16 | 132 | 41 | 8 | 1 | 0 | 1905 | 7.1 |

*C. Estimation of Recurrence Parameter 'a' and 'b'*

The recurrence parameter 'a' and 'b' represents the frequency-magnitude relationship. Generally occurrence of earthquakes follows Gutenberg Richter relation (G-R relationship) [6] expressed as:

$$\log N(M) = a - bM \quad (1)$$

where N(M) is the cumulative frequency or annual occurrence rate of earthquakes of magnitude greater than and equal to M, and a and b are both constants. The 'a' value indicates the overall rate of earthquakes in a region, and the 'b' value indicates the change in occurrence rate with magnitudes. The parameter 'b' is related to $\beta$; $\beta = b \times ln10$ (2)

The parameter β can then be evaluated by using the maximum likelihood method as

$$\beta = \frac{1}{\bar{M} - M_C} \quad (3)$$

$$\bar{M} = \frac{\sum M_i \times n_i}{N} \quad (4)$$

where, N = total number of earthquake

Ni = number of earthquake for different lower threshold magnitude

$M_c$= magnitude for different period of completeness.

*D. Recurrence Relation with Constant Seismicity*

In the constant seismicity method, the recurrence rate depends on the upper bound magnitude $M_{\max}$ as well as lower bound magnitude $M_{\min}$ . For the computational purpose $M_{\min}$ has been taken as 4 in this study and maximum magnitude $M_{\max}$ can be determined by the relationship given by Kijko [6] expressed as:

$$M_{\max} = M_{\max}(obs) + \frac{E_1(n_1) - E_1(n_2)}{\beta \times \exp(-n_2)} + M_{\min} \times \exp(-n) \quad (5)$$

where, $M_{\max}$ = maximum magnitude of earthquake

$M_{\max}(obs)$ = observed maximum earthquake magnitude

$M_{\min}$ = minimum magnitude of completeness

n = number of earthquakes equal or greater than $M_{\min}$

TABLE II

MAXIMUM MAGNITUDE OF EACH SOURCE ZONE

| Region | a Value | b Value | β Value | $M_{max}$ (obs) | Catalogue Period | $M_{max}$ using T =500 | $M_{max}$ for Catalogue Period | $M_{max}$ Adopted |
|---|---|---|---|---|---|---|---|---|
| Zreg 1 | 3.761336 | 0.746268 | 1.718346 | 6.2 | 48 | 6.5186 | 6.6561 | 6.7 |
| Zreg 2 | 3.595079 | 0.60722 | 1.398176 | 6.2 | 48 | 6.2016 | 6.2163 | 6.3 |
| Zreg 3 | 3.916712 | 0.795608 | 1.831956 | 6.7 | 53 | 6.7144 | 6.815 | 6.8 |
| Zreg 4 | 3.000492 | 0.576797 | 1.328125 | 6.5 | 48 | 6.5084 | 6.672 | 6.7 |
| Zreg 5 | 2.656065 | 0.614694 | 1.415385 | 6.1 | 80 | 6.1195 | 6.2085 | 6.2 |
| Zreg 6 | 5.821699 | 0.97871 | 1.253564 | 8.3 | 513 | 8.3523 | 8.4222 | 8.3 |
| Zreg 7 | 4.794831 | 0.95227 | 1.192683 | 8.5 | 94 | 9.4862 | 10.0451 | 8.3 |
| Zreg 8 | 3.755037 | 0.671315 | 1.545759 | 5.8 | 89 | 5.8049 | 5.8266 | 5.9 |
| Zreg 9 | 3.984006 | 0.826703 | 1.903553 | 6.5 | 89 | 7.2485 | 7.4087 | 7.4 |
| Zreg 10 | 3.760575 | 0.761556 | 1.753548 | 8 | 404 | 7.8475 | 7.9966 | 8 |
| Zreg 11 | 3.281333 | 0.593676 | 1.36699 | 7.7 | 105 | 7.7374 | 7.854 | 7.8 |
| Zreg 12 | 3.435724 | 0.503882 | 1.160232 | 8.5 | 461 | 9.1287 | 9.1655 | 8.3 |
| Zreg 13 | 3.715054 | 0.627633 | 1.445178 | 7 | 343 | 7.0087 | 7.0404 | 7 |
| Zreg 14 | 4.263113 | 0.522954 | 1.204147 | 7.7 | 93 | 7.7018 | 7.7098 | 7.7 |
| Zreg 15 | 2.964664 | 0.57936 | 1.334025 | 6.7 | 111 | 6.7086 | 6.7374 | 6.7 |
| Zreg 16 | 4.215132 | 0.487722 | 1.123021 | 7 | 94 | 7.1 | 7.0021 | 7.1 |
| Zreg 17 | 1.974302 | 0.469185 | 1.080339 | 8 | 602 | 7.7391 | 7.8566 | 7.8 |
| Zreg 18 | 3.313862 | 0.61612 | 1.418668 | 7.5 | 98 | 7.5335 | 7.6475 | 7.6 |
| Zreg 19 | 3.993302 | 0.734805 | 1.69195 | 8.5 | 171 | 8.6071 | 8.851 | 8.3 |
| Zreg 20 | 4.211394 | 0.792397 | 1.824561 | 8 | 53 | 8.0679 | 8.3915 | 8 |
| Zreg 21 | 2.486356 | 0.511313 | 1.177342 | 7 | 180 | 7.0227 | 7.0599 | 7 |
| Zreg 22 | 4.013023 | 0.845184 | 1.946108 | 8 | 186 | 8.2045 | 8.4036 | 8.2 |
| Zreg 23 | 3.667058 | 0.771236 | 1.775837 | 7.5 | 185 | 8.2276 | 8.6085 | 8.2 |
| Zreg 24 | 4.155058 | 0.819218 | 1.886319 | 7.5 | 262 | 7.5566 | 7.6208 | 7.6 |
| Zreg 25 | 3.441879 | 0.806987 | 1.858156 | 7 | 180 | 7.0754 | 7.3293 | 7.3 |
| Zreg 26 | 3.589825 | 0.806313 | 1.856604 | 8.5 | 191 | 9.1293 | 9.6294 | 8.3 |
| Zreg 27 | 2.930145 | 0.595325 | 1.370787 | 8.3 | 171 | 8.4227 | 8.5947 | 8.3 |
| Zreg 28 | 5.214013 | 0.051193 | 1.420462 | 8.1 | 350 | 10.5315 | 13.6196 | 8.3 |
| Zreg 29 | 3.954968 | 0.802756 | 1.848413 | 7.5 | 465 | 7.5613 | 7.654 | 7.6 |
| Zreg 30 | 3.580337 | 0.651442 | 1.5 | 7.6 | 325 | 7.6314 | 7.7512 | 7.7 |
| Zreg 31 | 3.306221 | 0.60099 | 1.383831 | 6 | 51 | 6.0038 | 6.0356 | 6 |
| Zreg 32 | 4.157374 | 0.614874 | 1.415799 | 8.3 | 151 | 8.3181 | 8.3569 | 8.3 |
| Zreg 33 | 3.21895 | 0.601161 | 1.384224 | 7.1 | 496 | 7.6904 | 7.7903 | 7.8 |

*E. Recurrence Relations with Moment Release Constraint*

Before the estimation of recurrence rate by Seismic Moment Release Constraint method we have to determine the seismic moment associated with the sources. According to the Kostrove, 1974 the seismic moment associated with any volume is given by the relation:

$$\dot{M}_0 = 2\mu DLW\dot{\varepsilon} \qquad (6)$$

Where, L = length in km

D = depth in km

μ = shear modulus in dyne/cm$^2$

W = width in km

$\dot{\varepsilon}$ = strain rate in terms of per year

$\dot{M}_0$ = seismic moment using slip in moment ratio

This seismic moment is depend on the strain rate for all sources. So the accurate measurement of the strain rate is necessary.

*F. Annual Occurrence Rate*

For the estimation of occurrence rate through seismic moment release rate, initially we have to bound the upper limit seismic moment released during the earthquakes, which can also be related to the magnitude by an expression $\dot{M}_0(M) = \mathrm{c} + \mathrm{dM}$ where c = 16.0 and d= 1.5 for $\dot{M}_0$ in units of dyne-cm [7]. The annual occurrence rate $N(M_{\min})$ is determined by:

$$N(M_{\min}) = \frac{\dot{M}_0(M)}{e^{-\beta(M-M_{\min})} \times \dot{M}_0(M_{\max}) \times \frac{b}{d-b}} \quad (7)$$

TABLE III

ANNUAL OCCURANCE RATE USING SEISMIC MOMENT RELEASE CONSTRAINT

| Source | Occurrence rate using constant seismicity $N(M_{min})$ | Occurrence rate using Moment release | | |
|---|---|---|---|---|
| | | $N(M_{min})$ for $M=M_{max}$ | $N(M_{min})$ for $M=M_{max}$ -0.3 | $N(M_{min})$ for $M=M_{max}$ +0.3 |
| Zreg 1 | 4.396757 | 1.142748 | 1.918071 | 6.80063 |
| Zreg 2 | 18.51122 | 0.392143 | 0.718866 | 2.131215 |
| Zreg 3 | 10.28144 | 0.222822 | 0.361842 | 1.37112 |
| Zreg 4 | 4.725236 | 0.22506 | 0.422835 | 1.19508 |
| Zreg 5 | 1.305392 | 0.984524 | 1.793266 | 5.382509 |
| Zreg 6 | 245.1535 | 0.275454 | 0.394846 | 1.921615 |
| Zreg 7 | 83.44515 | 0.064433 | 0.094063 | 0.441364 |
| Zreg 8 | 3.940966 | 0.921133 | 1.608604 | 5.244959 |
| Zreg 9 | 8.746526 | 0.145737 | 0.231932 | 0.915576 |
| Zreg 10 | 17.31794 | 0.043465 | 0.072371 | 0.261021 |
| Zreg 11 | 5.814126 | 0.023671 | 0.044207 | 0.126686 |
| Zreg 12 | 21.55045 | 0.001403 | 0.002788 | 0.00706 |
| Zreg 13 | 11.83534 | 0.051148 | 0.093117 | 0.280606 |
| Zreg 14 | 76.41332 | 0.009574 | 0.018751 | 0.048847 |
| Zreg 15 | 6.131901 | 0.153779 | 0.288433 | 0.817963 |
| Zreg 16 | 129.0936 | 0.028644 | 0.057226 | 0.143073 |
| Zreg 17 | 2.427034 | 0.008093 | 0.016434 | 0.039814 |
| Zreg 18 | 5.713142 | 0.0484 | 0.088986 | 0.263108 |
| Zreg 19 | 18.86778 | 0.006774 | 0.011489 | 0.039931 |
| Zreg 20 | 21.20073 | 0.054964 | 0.089593 | 0.337171 |
| Zreg 21 | 2.415375 | 0.028186 | 0.055411 | 0.143073 |
| Zreg 22 | 8.463206 | 0.01701 | 0.026738 | 0.108216 |
| Zreg 23 | 4.193445 | 0.008823 | 0.014593 | 0.053335 |
| Zreg 24 | 12.44981 | 0.07326 | 0.117207 | 0.457838 |
| Zreg 25 | 3.283647 | 0.059409 | 0.095825 | 0.368223 |
| Zreg 26 | 2.873866 | 0.016291 | 0.026303 | 0.100893 |
| Zreg 27 | 3.676204 | 0.002702 | 0.005045 | 0.014472 |
| Zreg 28 | 1.256858 | 0.172374 | 0.235023 | 1.264248 |
| Zreg 29 | 10.20206 | 0.041889 | 0.06778 | 0.258831 |
| Zreg 30 | 8.950299 | 0.016212 | 0.029104 | 0.090272 |
| Zreg 31 | 5.663223 | 0.373162 | 0.682785 | 2.027489 |
| Zreg 32 | 33.40476 | 0.002927 | 0.005391 | 0.015886 |
| Zreg 33 | 2.057188 | 0.103083 | 0.191539 | 0.554526 |

## IV. ESTIMATION AND REPRESENTATION OF SEISMIC HAZARD

In the seismic hazard analysis we have estimated the peak ground acceleration (PGA) at a closely spaced grid of sites covering upper Himalayas. These PGA values are used to draw hazard zoning map in the form of contour. The hazard zoning maps are prepared for 90% and 98% probability of not occurrence (10% and 2% probability of exceeding) in next 50 years. The occurrence rate for desire probability of exceeding the PGA>z is determine by the summation of all recurrence rate υ ($M_j$ , $R_i$) multiplied with their individual probability $q(Z > z \mid \mathrm{M}_j, R_i)$ over the j magnitude range and i distances for each magnitude. For the computation purpose the parameters a, b, $M_{max}$, N($M_{min}$) and attenuation models are used for input in the programme and PGA is estimated by using attenuation model (Abrahamson and Silva, 1997). PGA ordinates are calculated for 500 and 2500 year return period.

## V. CONCLUSION

In the study of Upper Himalayas Region, Probabilistic Seismic Hazard Analysis (PSHA) method is used to estimate the PGA using the constant seismicity and Seismic Moment release constraint by the analysis on the earthquake catalogue and slip rates data. The current literature on PSHA approach is used to prepare the hazard zoning maps for ground motion parameter PGA. The hazard has been estimated for the 90% and 98% probability of not occurrence (500 year and 2500 year return period) in exposure period 50 year.

TABLE IV

IMPORTANT PGA VALUES

| Maximum Magnitude | Return Period | Used Model | PGA in terms of g | | | | |
|---|---|---|---|---|---|---|---|
| | | | North | West | South | East | Central region |
| $M_{max}$ | 500year | Constant seismicity | 0.24-0.27 | 0.3-0.33 | 0.12-0.24 | 0.3-0.45 | 0.27-0.30 |
| | | Moment release | 0.34-0.39 | 0.44-0.49 | 0.14-0.34 | 0.44-0.54 | 0.39-0.44 |
| | 2500years | Constant seismicity | 0.4-0.45 | 0.50-0.55 | 0.20-0.40 | 0.50-0.70 | 0.45-0.50 |
| | | Moment release | 0.54-0.6 | 0.66-0.72 | 0.24-0.54 | 0.66-0.78 | 0.60-0.66 |
| $M_{max}$-0.3 | 500year | Constant seismicity | 0.22-o.26 | 0.30-0.34 | 0.10-0.22 | 0.30-0.42 | 0.26-0.30 |
| | | Moment release | 0.39-0.44 | 0.49-0.54 | 0.14-0.39 | 0.49-0.59 | 0.44-0.49 |
| | 2500years | Constant seismicity | 0.43-0.48 | 0.48-0.53 | 0.18-0.38 | 0.48-0.68 | 0.43-0.48 |
| | | Moment release | 0.6-0.68 | 0.76-0.84 | 0.20-0.60 | 0.76-0.84 | 0.68-0.76 |
| $M_{max}$+0.3 | 500year | Constant seismicity | 0.24-0.28 | 0.32-0.36 | 0.12-0.24 | 0.32-0.44 | 0.28-0.32 |
| | | Moment release | 0.3-0.34 | 0.38-0.42 | 0.14-0.30 | 0.38-0.42 | 0.34-0.38 |
| | 2500years | Constant seismicity | 0.42-0.47 | 0.52-0.57 | 0.22-0.42 | 0.52-0.72 | 0.47-0.52 |
| | | Moment release | 0.48-0.54 | 0.60-0.66 | 0.24-0.48 | 0.60-0.72 | 0.54-0.60 |

The value of PGA, obtained from the constant seismicity varies between 0.1 to 0.45g for 500 year return period and 0.2 to 0.72g for the 2500 year return period. These PGA values is increases with increase in the upper bound magnitude $M_{max}$ while these PGA values lies between 0.15 to 0.54g for 500 year return period and 0.2 to 0.84g for 2500 year return period with Constant Seismic Moment Release Constraint and this peak ground acceleration decreases with increase in the maximum magnitude $M_{max}$.

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