Journal of the Institute of Engineering
Volume 17, No. 1
ISSN: 1810-3383
Published: April 2023

Response Spectra for Nepal through Probabilistic Approach

Sunita Ghimire [a], Hari Ram Parajuli [b]

[a,b] *Pulchowk Campus, Institute of Engineering, Tribhuvan University, Nepal*
Corresponding Author: [b]hariparajuli@ioe.edu.np

Received: 2021-12-16 Revised:2023-01-01 Accepted: 2023-03-19

Abstract:
In this study, a rectangular area surrounding Nepal, bounded by the coordinates (N 25° 30' 00", E 78° 30' 00"), (N 31° 30' 00", E 89 ° 30' 00") has been considered. Study area has been divided into five hundred areas by defining the grids at the interval of 0.5 degree along longitude and 0.25 degree along latitude. By preparing detailed earthquake catalogue and defining areal seismic sources, probabilistic seismic hazard analysis has been done in terms of peak ground acceleration. The completeness of the data has been done by using Stepp's procedure. Seismicity in four regions of study area has been evaluated by defining 'a' and 'b' parameters of Gutenberg Richter recurrence relationship. Average hazard spectrum for 10% probability of exceedence in fifty years in five percent damped condition is obtained and then normalized to obtain design spectra and seismic zoning factor 'Z' is obtained in terms of contour for all areas of Nepal.

Keywords: Earthquake catalogue, Probabilistic seismic hazard analysis, Seismic hazard map, Design spectra

1.Introduction

Nepal is a mountainous country that lies in subduction zone between two active tectonic plates Indo- Australian and Eurasian Plates. The evidences of historical earthquakes in Nepal recorded since 1255A.D, show that this zone is very active seismically. Even the geographical configuration like formation of Himalayas, formation of lakes and its disappearance etc. are also related to seismic activities. There are four major identified fault lines throughout the country along the longitude and ninety two other small faults. There are more than twelve hundred independent events of magnitude greater than 4.5, recorded since 1255 in Nepal. Due to complexity in geology, soil type also varies from region to region. The mountainous region of Nepal consists of rocky strata whereas Terai region of Nepal consists of lacustrine and alluvial loose soil deposits. Due to such complex geological pattern, the level of shaking during earthquake varies radically during the events.

The hazard caused due to uncertain events like earthquake is difficult to assess In order to approach for level of shaking due to future earthquakes in any region, we need to conduct probabilistic seismic hazard analysis (PSHA) by defining all the seismic, geological, geotechnical, hydrological and other necessary parameters. PSHA gives the hazard potential of the site under consideration in terms of PGA or PGV or PGD. Once obtained the value of PGA's at all sites from hazard analysis, it's necessary to know the response of structures through response spectra. Response spectra are the maximum response quantities (displacement, velocity and acceleration) of a SDOF plotted as a function of its period for a given earthquake record. For design purposes, an average set of spectra that describes the general trends and characteristics of the original one is used. These can be built from basic parameters describing the seismic vulnerability, site conditions and importance of the structure.

2. Literature

Due to the spatial uncertainty, the earthquake source may be modeled as point, linear, areal or volumetric sources depending on the information on tectonics of region. One an earthquake source is defined it should be assigned by the probable earthquakes in given period of time, which is well described by recurrence law. Gutenberg and Richter(1944), defined the relationship of the annual rate of exceedance of earthquake of certain magnitude with the magnitude itself on the basis of southern California records. They divided number of exceedences of each magnitude by length of time period and defined mean annual rate of exceedence λ_m of an earthquake of magnitude m and constants 'a' and 'b'. In case of Nepal, Parajuli et. al. (2008) have proposed a magnitude frequency relationship by arranging limited available earthquake data in magnitudes and years and concluded that available data are insufficient to estimate model the seismic sources. Then, they developed the recurrence law from available data and considering 50% intra plate slip rate to satisfy the rate of occurrences.

There are several attenuation relationships developed for subduction zone. Based in the 476 strong motion records from 164 earthquakes that occurred in subduction zones i.e. Alaska, Chile, Cascadia, Japan, Mexico, Peru and Solomon Islands with magnitude ranging from 5.0 to 8.2 moment magnitude (Mw), Young’s et al. (1997) developed an attenuation relationship. Distance to rupture plane as well as hypo-central distance for some data was taken as the distance parameter ranging from 15 to 450 km. Focal depth used in the analysis was between 10 km to 229 km. Kanno et al. (2006) considered a database of whole Japanese strong ground motion records between 1963 and 2003 is established in order to identify a new standard attenuation relation for Japan, for response acceleration as well as peak value. They have used earthquake magnitude, shortest distance to the seismic fault plane and focal depth as three variables and developed an attenuation relationship for response acceleration as well as peak value. To improve the predictions given by the model, site correction terms are adopted and additional terms for correcting regional anomalous seismic intensity with respect to the base model are determined. Zhao et al. (2006) have presented a spectral acceleration attenuation model for Japan using a very large number of strong ground motion database up to 2003.For subduction slab effects, a simple distance modification factor is employed to achieve plausible and unbiased predictions. Maskey and Mishra (2004) have concluded that the attenuation law proposed by Young’s et al. (1997 is one of the suitable law for Nepal region unless a better alternative is found. Maskey and Datta (2004) have generated risk consistent response spectrum for typical locations of Kathmandu valley. Both linear and nonlinear behavior of soil is considered to plot hazard curves and response spectrum.

In Nepal, BECA (1993) had conducted probabilistic seismic hazard analysis of Nepal and risk assessment of Nepal. They divided the total area into three parts and developed a seismicity model. They used Kawashima (1984) ground motion attenuation model and conducted hazard analysis by using a computer program named 'HAZARD'. The seismic hazard maps were prepared and there came uniform hazard spectra for different structural periods for return period of 500 years. Design seismic forces for the Nepal Standard are another outcome of this project. Also, an attempt has been made to access potential secondary seismic hazards in Kathmandu Valley.

Pandey et. al. (2002) conducted PSHA by using CRISIS99 software. and prepared seismic hazard map of Nepal. The seismic sources were characterized keeping in view the seismo tectonic model and by adopting the characteristic fault model for PSHA. They have collected a micro seismic database of more than 5000 local earthquakes of magnitude greater than two occurring within the country and near the vicinity in the 8 years of operation since March 1994 to 2002.The frequency magnitude relationship have been derived for eastern and western seismic belts of higher Himalaya. The attenuation relationship given by Young's et al (1997) was used to obtain peak ground acceleration. They considered M8.2 earthquake with a return period of 500 years in the assumption that it represents the matured seismic gap in the central Himalaya. The contour of PGA for bedrock condition has been compiled for this return period such that the significant moment magnitude is greater than M5 for all sources. But contribution of northern sources in PSHA is ignored. Gupta et. al. (2006) had prepared seismic hazard maps of Northeast India based on the uniform hazard response spectra for absolute acceleration at stiff sites. A new attenuation model for pseudo-spectral velocity scaling has been developed by using 261 recorded accelerograms in Northeast India. The entire area of Northeast India has been divided into 0.1° grid size, and the hazard level has been assessed for each node of this grid by considering the seismicity within a 300-km radius around the node.

Using the past earthquake data, the seismicity for the area around each node has been evaluated by defining 'a' and 'b' values of the Gutenberg-Richter recurrence relationship, while accounting for the incompleteness of the earthquake catalogue. To consider the spatial distribution of seismicity around each node, a spatially smoothed probability distribution function of the observed epicentral distances has been used. Uniform hazard contours for pseudo-spectral acceleration as the hazard parameter have been obtained for an exposure time of 100 years and for 50% confidence level at different natural periods for both horizontal and vertical components of ground motion. The trends reflected by these contours shown are consistent with the major seismo tectonic features in the region.

3. Procedures

3.1 Probabilistic Seismic Hazard Analysis

Probabilistic seismic hazard analysis is carried out as the steps described below.

3.1.1 Earthquake Catalogue

Historical earthquake recordsin the rectangular area bounded by coordinates (78° 30' 00'' E, 25° 30' 00'' N) and (89° 30' 00'' E, 31° 30' 00N) is taken from literatures (Rana B. S. J. R., 1935) and website of USGS archive. There are total 1228 events greater than magnitude 4.5 in this area. The magnitude of these events are converted to moment magnitude using the conversions as per (Ambraseys ,N.N., Douglas, J. & Smith, P.M., 2004), (Gutenberg, B. & Richter, C.F., 1944), (Hanks, T. & Kanamori, H., 1979) and (Scordilis, 2006). The defined earthquakes are then plotted within study area. To make the earthquake distribution, a Poissonian, aftershock events are removed based on the space and time, (Gardner J.K. & Knopoff L., 1974). There remain total 827 independent events. Due to insufficiency of historical earthquake data, it is necessary to conduct completeness analysis for the best fit of frequency formula. For completeness analysis, earthquakes are grouped in magnitude range of 0.5M and are judged separately The completeness analysis as done above gives the best fit for the magnitude frequency relation.

3.1.2 Uncertainty consideration

Magnitude Uncertainty

To address the uncertainty associated with earthquake magnitude, each discretized cell in the study area is assumed to have uniform seismicity. Magnitude frequency relationship is accommodated. The recurrence relation is, (Gutenberg, B. & Richter, C.F., 1944),

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

Where, λ_m= mean annual rate of exceedence of magnitude, M

10^a = mean yearly number of earthquakes of magnitude greater than or equal to zero

b = relative likelihood of large and small earthquakes

We are concerned with the earthquakes greater than magnitude M 4.5 since greater size earthquake produces maximum level of shaking generally. So, bounded recurrence relation law is used to express the certain maximum magnitude mmax associated with each source zone the value of which is greater than minimum magnitude mmin. The probability density function for Gutenberg Richter law with lower and upper bound magnitude is given by,

$$f(m) = \frac{\beta\ exp[-\beta(m-m_{min})}{1-\beta\ exp[-\beta(m-m_{min})} \qquad \ldots(2)$$

Temporal Uncertainty

The temporal uncertainty of an earthquake is modeled by using Poisson’s model. For a Poisson’s process, Similarly, probability of exceedence of particular parameter y* in a time period 't' is given by

$$p[y \geq y^*] = 1 - e^{-\lambda_{Y^*} t} \qquad \ldots(3)$$

3.1.3 Attenuation of ground motion

As Nepal lies in the subduction zone, the attenuation laws developed for subduction zone is used to develop the peak ground acceleration (PGA) and spectral acceleration (SA). These empirical relations given by (Young's et al, 1997), (Kanno et al., 2006), (Zhao et al., 1997) have been used.

3.1.4 Seismic Hazard Curve

Seismic hazard curve is the plot of mean annual rate of exceedence versus peak ground acceleration. Seismic hazard curve for individual source zone is obtained at first and they are combined to get the hazard for particular site. . The probability of exceedence of certain ground motion P(Y >y*) is estimated by assuming probability distribution of ground motion. For a site with possible numbers of earthquakes N_M with magnitudes mj, at different source to site distances N_R, then mean rate of exceedence can be obtained as:

Where,

$$\lambda_{y^*} = \sum_{i=1}^{N_s}\sum_{j=1}^{N_M}\sum_{k=1}^{N_R} \nu_i P[Y > y^* | m_j, r_k] p[M = m_j] p[R = r_k] \quad \ldots(4)$$

$$m_j = m_{min} + (j - 0.5)(m_{max} - m_{min}) / N_M. \quad \ldots(5)$$

$$r_k = r_{min} + (k - 0.5)(r_{max} - r_{min}) / N_R \quad \ldots(6)$$

$$\Delta m = (m_{max} - m_{min}) / N_m, \Delta r = (r_{max} - r_{min}) / N_R \ldots(7)$$

Where, r_{max}, r_{min}: source to site distances and m_{max}, m_{min} : Maximum and minimum magnitudes

3.1.5 Uniform Density Model

Uniform density model distributes earthquake densities equally irrespective of whether there is earthquakes or not. Maximum magnitudes for these area sources are assessed from an extrapolation of historical seismicity of the region. Uniform density model forgets faulting and assumes uniform geology and gives the equal weightage to all the area capable of producing earthquake.

3.2 Derivation of seismic design forces

There are many factors which influence the seismic design forces like seismic hazard, foundation soil type, structural period, structure type, available ductility, construction materials, damping property, importance of building, philosophy objectives and economic considerations. In this research, it is desired to obtain the terms CT(i) and Z in order to recommend the seismic design spectrum as defined in existing National Building Code of Nepal, (NBC 105, 2060).

$$C_d T_{(i)} = CT_{(i)} ZIK \quad \ldots(8)$$

Where, $C_d T_{(i)}$ is the ordinate of the normalized, 5% damped, hazard spectrum or the basic design spectrum for translational structural period Ti and the appropriate subsoil type.
Z is the spectrum scaling factor or seismic zoning factor.,I is the importance factor. And K is the structural performance factor.

The product $CT_{(i)}$ Z is proportional to the 5% damped hazard spectrum which has the probability of exceedence consistent with meeting the requirements of part of the objective that structures should be able to resist moderate earthquakes without significant structural damage.
In the case of Nepal the design life adopted is nearly 30 to 50 years for simple structures. And the earthquake considered for design is the one having 10% probability of exceedence in 50 years. This is equivalent to the earthquake having return period on 475 years. For deriving C(Ti) and Z, hazard spectra for various locations in Nepal are obtained for the return period of 475 years for each subsoil type considered (i.e. soft, medium and hard soil type). The nature of spectra is analyzed in all the locations. Average spectral accelerations for all nineteen sites that lie in Nepal are obtained. The averaged spectra are normalized at time of zero period.
The value of Z for each site is average accelerations of nineteen numbers of sites of Nepal in this case) at a normalized structural period. Z is then plotted in the form of contour. The contour may be plotted from the adjusted plot of the obtained return period, 5% damping, peak structural responses for a structural period on which spectra is normalized and suitable subsoil type. In this study, normalization has been done on medium subsoil type.
Adopt three basic design spectra for Nepal, one for each subsoil type.

4. Results

Out of total collected 1228 events greater than 4.5 MW , since 1255 A.D., 401 events were removed and remaining 827 main events are presented with delineation of seismic source into four seismic source zones.

Table 1: Seismicity in four zones

Area	a	b	M_{max}
1	5.18	-1.27	6.6 in 1833
2	5.04	-0.91	8.1 in 1934
3	6.3	-1.16	8.2 in 1505
4	5.86	-1.18	7.2 in 1934

Gutenberg Richter recurrence relationship was developed to access the seismicity of four source zones. Table 1 shows the coefficients for this relation and maximum magnitude ever occurred in these source zones.After accessing the seismicity of source zones hazard analysis was conducted through the program in Matlab. Uniform density model was adopted to define earthquake density. Three attenuation laws by Young's et al (1997), Zhao et al (2006) and Kanno et al (2006) were considered and PGA and spectral accelerations were calculated for eight time periods in three soil types for four return periods. While doing so, it was observed that there was maximum PGA at site 21 (82.2°E, 28.7°N), considering uniform density model. Highest PGA value is found on soft soil and lowest is on hard soil. The PGA value for design purpose seems well if we use PGA around 0.56g (i.e. Peak value among hard, medium and soft soil for averaged spectra) however it depends on type of structure, economy and local site conditions.

Figure 1 contains seismic hazard curve at site of maximum accleration for soft, medium and hard soil conditions respectively. We can obtain the probability of exceedence of certain PGA values through these curves.

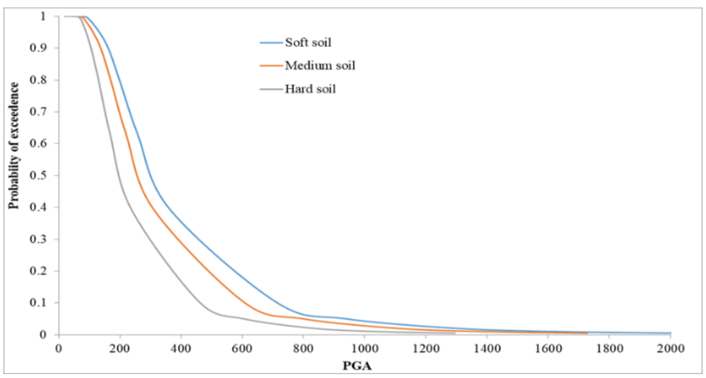

Figure 1: Seismic Hazard curve for site producing maximum acceleration

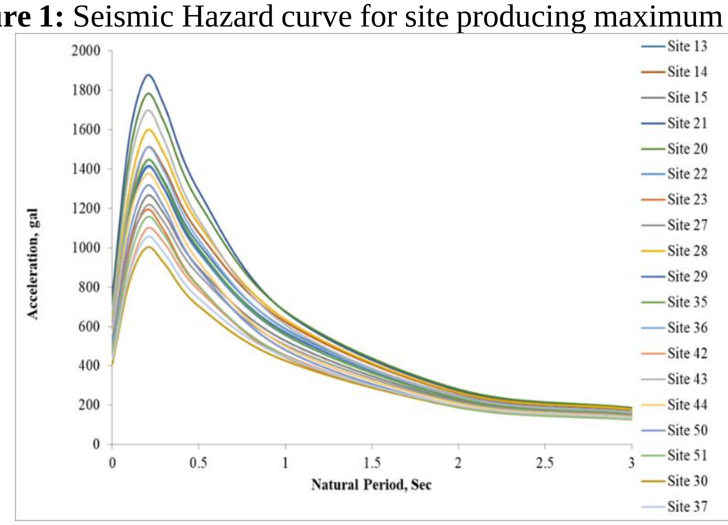

Figure 2: Hazard Spectra for various sites of Nepal 10% probability of exceedence in 50 years

for soft soil (5% damping)

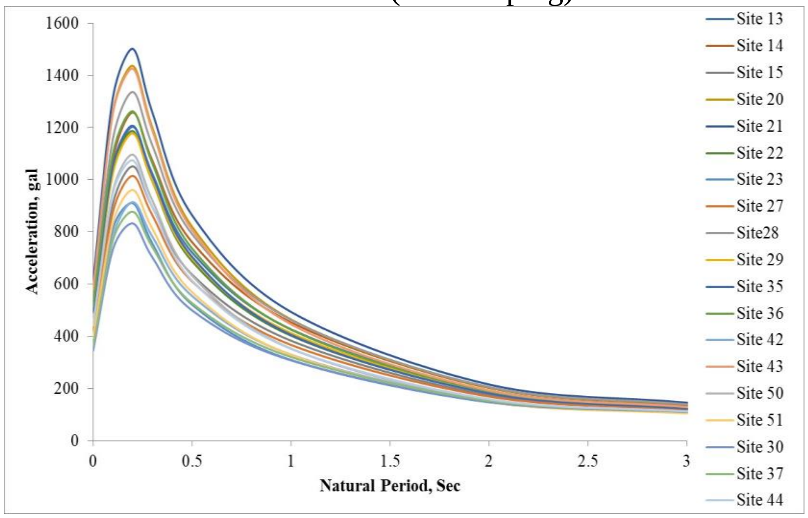

Figure 3: Hazard Spectra at various sites of Nepal for 10% probability of exceedence in 50 years for medium soil (5% damping)

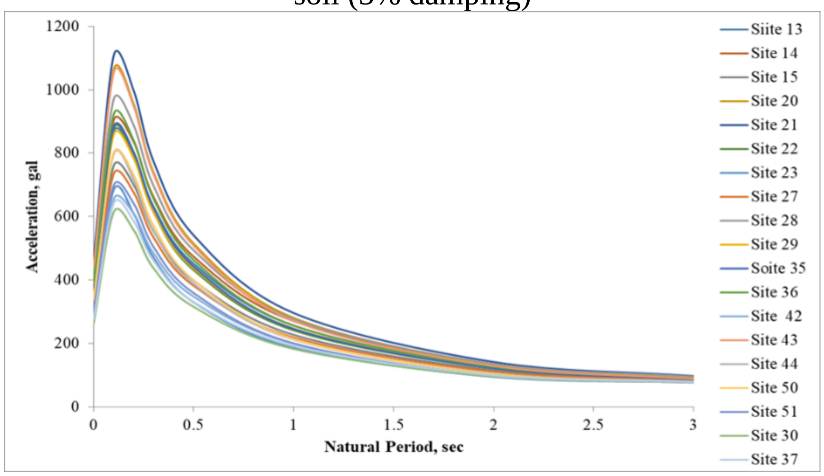

Figure 4: Hazard Spectra at various sites of Nepal for 10% probability of exceedence in 50 years for hard soil (5% damping)

Figure 2 to 4 plots the hazard spectra at seventeen different sites in Nepal for soft, medium and hard soil conditions respectively.

To derive design response spectra it is necessary to choose design PGA. Selection of PGA is done by taking the average value from nineteen different sites lying over Nepal. So, the average spectral accelerations are obtained for 19 different sites of Nepal is plotted in figure 5. Hence normalization (at time = 0 second) of this spectrum is done to obtain normalized spectra in figure 6.

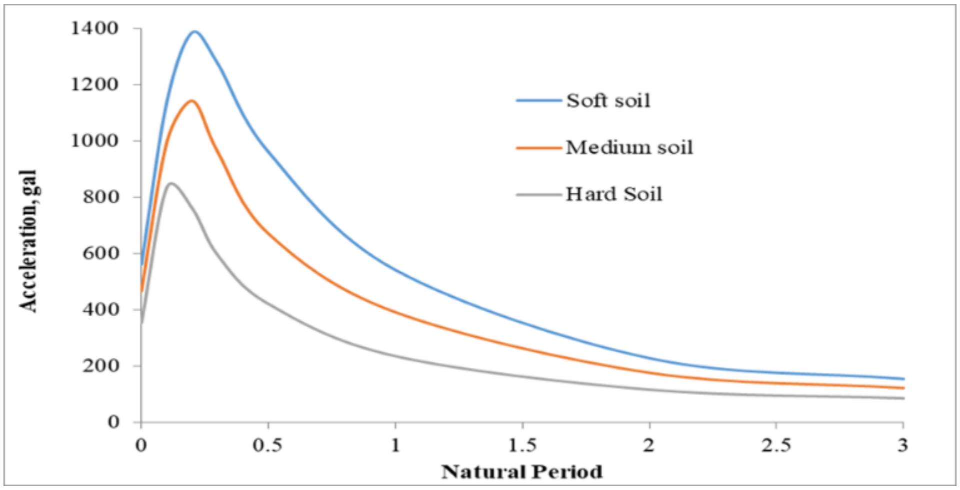

Figure 5: Average Uniform Hazard Spectra for all sites of Nepal, for 10% probability of exceedence in 50years

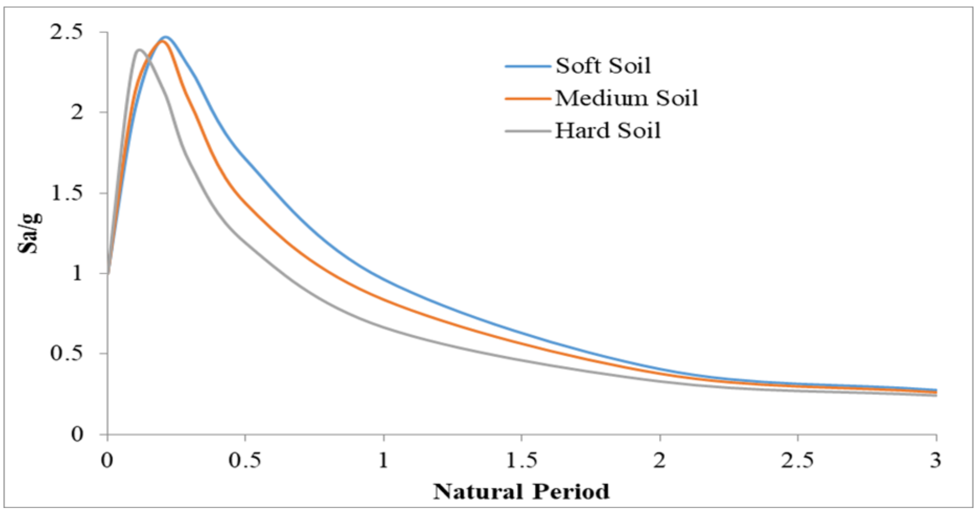

Figure 6: Normalized design spectra for Nepal for 10% probability of exceedence in 50 years

Since the PGA on average spectra for Nepal is maximum for soft soil site condition with value 0.56g. In this study, PGA of 0.56g is adopted for design purpose If we use response reduction factor R=5 for special moment resisting frame as in IS 1893:2002, Then, the design spectra is obtained in terms of basic seismic coefficient (C) as in Figure 4.7. These spectra have higher ordinates than that in NBC 105. Figure 8 is for contours of zone factor Z.

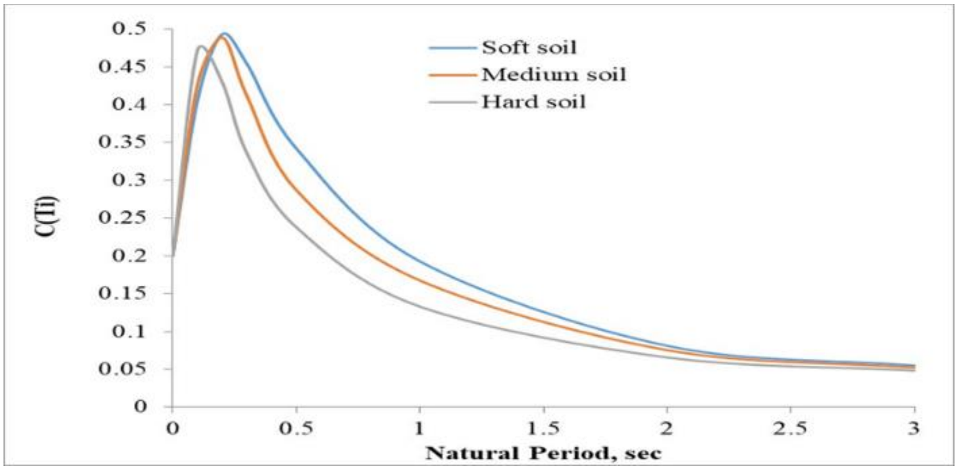

Figure 7: Design spectra for Nepal

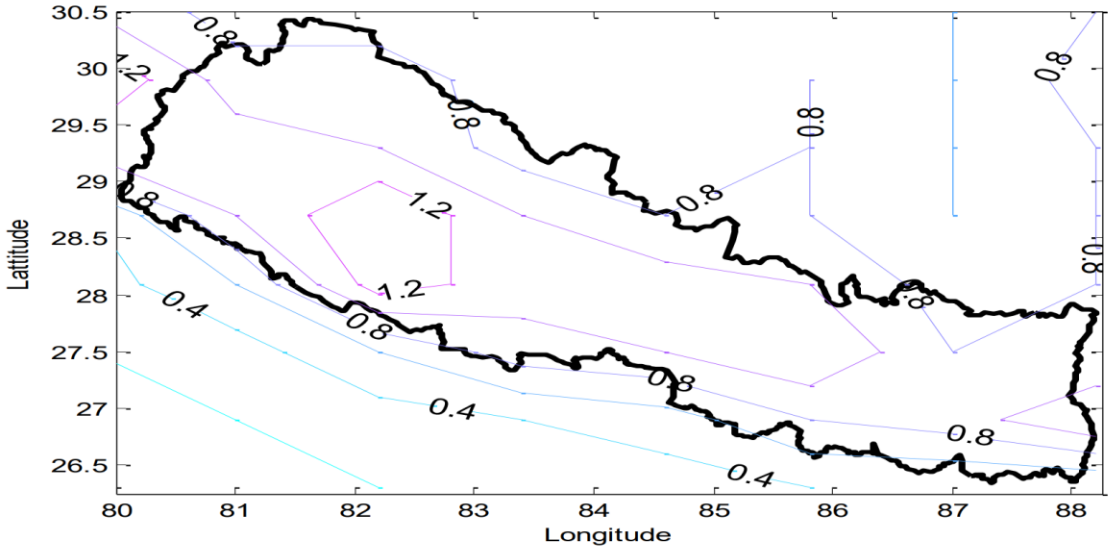

Figure 8: Contour for zone factor, Z

5. Conclusion

Through the magnitude frequency relationship, Gutenberg Richter's 'a' and 'b' values for Nepal is found nearly equal to 5 and 1 respectively. The average PGA for Nepal in hard, medium and soft soil for 10% probability of exceedence in 50 years are 0.35g, 0.46g and 0.56g. The peak value of normalized spectra (Sa/g) is found as 2.5.

References

[1] Ambraseys ,N.N., Douglas, J. & Smith, P.M. (2004). Estimation of strong ground motion from shallow crustal earthquakes. *Geophysics. J. Int.*, *159*, 165-206.

[2] Beca Worley International. (1993). *Seismic Hazard Mapping and Risk Assessment for Nepal.* New Zealand.

[3] Das S., Gupta, I.D., and Gupta, V.K., 2006. A probabilistic seismic hazard analysis of northeast India.*Earthquake spectra, 22(1), pp. 1-27*

[4] Gardner J.K. & Knopoff L. (1974). Sequence of earthquake in southern California with aftershock removal. *Bulletin of the seismological society of America*, *16*(5).

[5] Gutenberg, B. & Richter, C.F. (1944). Frequency of Earthquakes in California. *Bulletin of Seismological Society of America*, *34*(4), 1985-1988.

[6] Kanno, T., Narita, A., Morikawa, N.,Fujiwara, H. and Fukushima, Y. (2006). ANnew Attenuation Relation for Strong Ground Motion in Japan based on Recorded Data. *Bulletin of Seismological Society of America*, *96*(3), 879-897.

[7] Maskey, P.N., and Datta, T.K., 2004. Risk consistent response spectrum and hazard curve for a typical location of Kathmandu valley,. *13th world conference on earthquake engineering, Vancouver, B.C., Canada, Aug.1-6*, p. 3124.

[8] Maskey, P.N., and Mishra, H.K., 2005. Selection of Attenuation Laws for Estimation of Seismic Input in Nepal. *Journal of the Institute of Engineering, 5(1), pp. 75-85.*

[9] Pandey,M.R. , Chitrakar,G.R. , Kafle, B.,Sapkota , S.N. , Rajaure, S. and Gautam,U.P., 2002. Seismic Hazard Map of Nepal, Kathmandu, Nepal: s.n.

[10] Parajuli, H.R., Kiyono, J.,Taniguchi, H. and Maskey, P.N, 2008. Probabilistic Seismic Hazard Assessment for Nepal.

[11] NBC 105. (2060). *Seismic Design of Buildings in Nepal.* Kathmandu.

[12] Rana B. S. J. R. (1935). *Nepal's Great Earthquake 1934 (in Nepali).* Sahayogi Press, Tripureshwor, Kathmandu.

[13] Scordilis, E. (2006). Empirical global relations converting Ms and mb to moment magnitude. *J. Seismol.,10*, 225-236.

[14] Stepp, J. (1992). Analysis of completeness of the earthquake sample in the Pudet Sound area and its effect on statistical estimates of earthquake hazard. *Proceedings of the first microzonation conference*, (pp. 897-909). Seattle, WA.

[15] Youngs, R.R., Chiou S.J., Silva, W.J. and Humphrey, J.R. (1997). Strong ground motion attenuattion relationships for subduction zone earthquakes. *Seismological Research Letters, 68*(1), 59-73.

[16] Zhao, J. X., Zhang, J., Asano, A., Ohno, Y., Oouchi, Takahashi, T., Ogawa, H., Irikura, K., Thino, H. K., Somerville, P. G., Fukushima, Y., and Fukushima, Y. (2006). *Bulletion of Seismological Society of America, 96*(3), 898-913.