Seismic Hazard Estimate of Kathmandu

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ABSTRACT

Convergence of Indian and Tibetan plates has formed many faults and has occurred many earthquakes in the interface region of two plates where Kathmandu lies. Available earthquake data are examined and found insufficient to justify the current slip rate of the moving plates. In contrast with previous estimate based on uniform distribution of assumed earthquake data over the big area, probabilistic seismic hazard assessment of Kathmandu with a different approach employing constant rate of occurrences of bigger events that obtained from available earthquakes data, 50% intra-plate slip rate and separate density of earthquakes for each small region is done and result is compared with previous estimate.

INTRODUCTION

Kathmandu, the capital city of Nepal, lies in the Himalayan range which was produced by the continental collision of Indian plate with Eurasian plate in early tertiary period (Molnar, 1984) forming faults in the region. Out of them, three fault systems, Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Himalayan Frontal Thrust (HFT), pass east to west throughout the length of Nepal within its narrow width and have resulted many earthquakes in the past in excess of moment magnitude M8 (Molnar, 1984, Ambraseys and Douglas, 2004) showing the needs of hazard estimate for risk mitigation. Some efforts (BECA, 1993) have been already made to estimate seismic hazards in the region. It has divided whole area into three sub zones depending on earthquake density obtained from available and assumed earthquakes, however, details have not been provided on what basis earthquakes data were considered. Seismic hazard has been estimated considering both historical data and assigned characteristic earthquakes after subdividing it into 21 small zones with assigned different maximum magnitude. But none of areas has maximum magnitude greater than M8, whereas three earthquakes in excess of M8 have already occurred and one of which is also included in their catalogue. Thus a different approach employing constant rate of occurrences of bigger events that obtained from available earthquakes data, 50% intra-plate slip rate and separate density of earthquakes for each small region is presented here.

ATTENUATION OF GROUND MOTION

No earthquake attenuation relations have been developed so far for the Himalayan region specially. Because of unavailability of sufficient data, here, instead of developing the attenuation equation for the region, an attenuation law (Atkinson and Boore, 2003) developed for sub-duction zone is selected for the study and the functional form is given by equation 1.

$$\log Y = c_1 + c_2 M + c_3 h + c_4 R - g \log R + c_5 slS_C + c_6 slS_D + c_7 slS_E \quad (1)$$

$$R = \sqrt{D_{fault}^2 + \Delta^2} \quad (2)$$

$$\Delta = 0.00724 * 10^{0.507M} \quad (3)$$

$$g = 10^{(1.2-0.18M)} \text{ for interface events} \quad (4a)$$

$$g = 10^{(0.301-0.01M)} \text{ for in-slab events} \quad (4b)$$

Where, Y is peak horizontal acceleration (gal), M is moment magnitude, h is focal depth (km) and D_{fault} closest distance to fault surface (km), Δ is near surface saturation factor which accounts for fault geometry, c_1-c_7 are coefficients and sl is factor for amplification corresponds to soil type. Thrust mechanisms are assumed to represent in-slab events if the events occur at depths greater than 50 km. It is impossible to predict at what depth in the fault, the next earthquakes will occur. So, the magnitude dependent value delta (Δ) is assumed as depth in the analysis.

MAGNITUDE FREQUENCY RELATIONSHIP

All the historical earthquakes data with in 300 km radius includes events since 1100 to 2006, are collected. The earthquake

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catalogue was formed merging the data from U.S. Geological Survey, National earthquake Information Centre (NEIC), BECA, 1993, Ambraseys and Douglas (2004) and Lave et.al (2005). The earthquakes data have been reported in different magnitudes and in intensity scales. To make uniformity, all data were converted to moment magnitude (Hank and Kanamori, 1979) using various relationships (McGuire, 2004) and scaling relationship for Himalayan region (Ambraseys and Douglas, 2004). The total 197 earthquake events with magnitude greater than M4.0 are grouped as shown in table 1. Earthquake data are not uniformly distributed, only few records are available in early periods and numbers of records have been increasing towards end. In order to do completeness analysis (Stepp, 1972) of data, events have been grouped into small interval of time and each magnitude ranges have been judged separately. If k_1, k_2, k_3, …k_n, are the number of quakes per unit time interval, then unbiased estimate of the mean rate of earthquakes per unit time interval of the sample exceeding each magnitude is given by equation 5.

$$rate_M = \frac{1}{n}\sum_{i=1}^{n} k_i \tag{5}$$

Table.1 Earthquake data

Year		Earthquakes greater than				
Start	End	M4	M5	M6	M7	M8
1100	1956	31	27	17	9	3
1957	1961	2	2			
1962	1966	13	6	1		
1967	1971	15	4	1		
1972	1976	16	3			
1977	1981	12				
1982	1986	14				
1987	1991	32	3	1		
1992	1996	21	2	1		
1997	2001	25	2			
2002	2006	16				
Total events		**197**	**49**	**21**	**9**	**3**

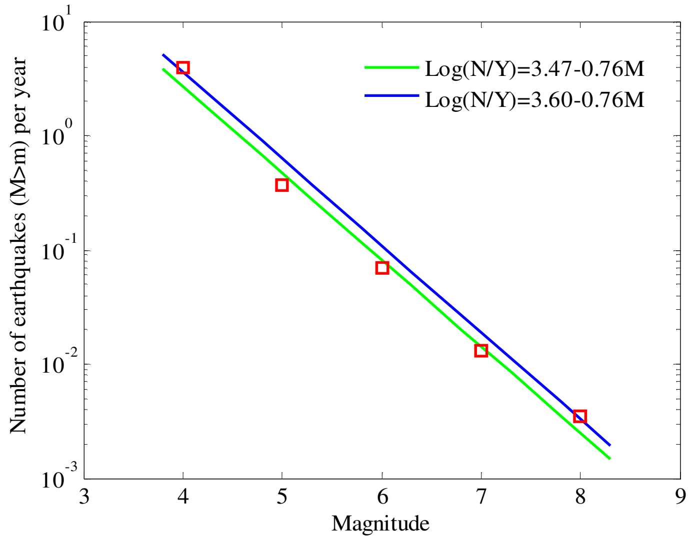

Fig. 1. Magnitude-frequency relationship

The rates of earthquakes exceeding each magnitude using equation 5 are calculated and plotted in semi log scale which yields magnitude frequency relationship (figure 1, lower line). Though historical earthquakes occurred in Nepal has been documented since 1100AD, earthquakes data have gone missing (Bilham and ambrasseys, 2005, Jouanne et al., 2004) and available data are not sufficient to justify the current slip rate 19mm/year (Jouanne et.al, 2004). Thus coefficient of magnitude frequency relationship is estimated using equations 6-9 (Mcguire, 2004 and Hank and Kanamori, 1979).

$$\dot{s} = \frac{\nu_{M_{\min}} k\beta \exp[\beta(M_{\min} + 16.05/1.5)]}{\mu A_f(\gamma-\beta)}\left(M_{0_{\max}}^{1-\beta/\gamma} - M_{0_{\min}}^{1-\beta/\gamma}\right) \tag{6}$$

$$k = \left[1 - e^{-\beta(M_{\max} - M_{\min})}\right]^{-1} \tag{7}$$

$$\nu_{M_{\min}} = 10^{(a - bM_{\min})} \tag{8}$$

$$\log_{10} M_0 = 1.5M + 16.05 \tag{9}$$

Where $\gamma = 3.454$ and $\beta = 2.303b$, $\dot{s}$ is slip rate, A_f fault area and $M_{0_{\max}}$ and $M_{0_{\min}}$ are maximum and minimum moments corresponding to maximum and minimum magnitudes. Considering the lower threshold magnitude M5 and maximum magnitude M8.8 (Lave et al, 2005), fault area 600kmX80km (Bilham, 2004), b value (figure 1, slope of lower line) and shear modulus, μ=3.3E11dyne/cm^2, the slip rate is 50% of total slip (1.9cm/year) yields a value (coefficient of magnitude frequency relation) to 3.60, which is close to the rate of occurrence of event greater than M8 and complete M4 (figure 1, upper line) and the magnitude frequency relation can be represented by equation 10.

$$Log(N/Y) = 3.60 - 0.76M \tag{10}$$

PROBABILISTIC SEISMIC HAZARD ASSESSMENT (PSHA)

Seismic hazard curve can be obtained for individual source zones and combined to get total hazard at particular site. N_s be the numbers of sources in the region, total average exceedence rate (Kramer, 1996) for the region is given by equation 11.

$$\nu_{y^*} = \sum_{i=1}^{N_s} \sum_{j=1}^{N_r} \sum_{k=1}^{N_m} \nu_{i_{M\min}} \rho_i P[Y > y^* \mid m, r] P[M = m] P[R = r] \Delta m \Delta r \tag{11}$$

$$\rho_i = \frac{\lambda(m,x)_i}{\sum_{i=1}^{N_s} \lambda(m,x)_i} \tag{12}$$

Where, $P[Y > y^* \mid m, r]$ is conditional probability that chosen acceleration exceeded for a given magnitude (M) and distance (R), and $P[M = m]$ and $P[R = r]$ are probabilities of occurring particular magnitude and distance respectively. Here, M and m are used as random variable and specific value for magnitude. Total area of 600kmX600km around Kathmandu (27.7N, 85.2E) is taken and divided into 120X120 cells. Distances between centre of cells and site are calculated. Only the cells within 300km radius are considered in the study. Magnitude is divided into 0.5M and distance into 5km intervals. N_m and N_r are the total numbers of magnitudes and distances bins. Earthquake densities (ρ_i) for each cell are considered using kernel estimation methods (Woo, 1996). The mean activity rate $\lambda(m,x)$ satisfying $r \le h(m_j)$, at a cell x is taken as a kernel estimation sum considering the contribution of N events inversely weighted by its effective return period which can be obtained from equations 13-15.

$$\lambda(m,x)_i = \sum_{j=1}^{N} \frac{K(m_j, r_j)}{T(r_j)} \tag{13}$$

$$K(m,r)_j = \left[\frac{D}{2\pi h(m_j)}\right] \left\{\frac{h(m_j)}{r_j}\right\}^{2-D} \tag{14}$$

$$h(m_j) = H \exp(C m_j) \tag{15}$$

Where, $K(m,x)$ is kernel function, $T(r)$ is return period of the event located at distance from r, $h(m)$ is kernel band width scaling parameter shorter for smaller magnitude and vice vice-versa, which may be regarded as fault length, D is fractal dimension, is taken as 1.7 , H and C are constants equals to 1.45 and 0.64.

PROBABILISTIC SPECTRA

Mean rate of exceedences of peak ground accelerations and spectral accelerations at various periods of vibration are obtained using equation 11. Assuming earthquake occurrences obey Poisson's process, accelerations corresponding to return periods 100 , 475 and 1000 years are determined at peak ground acceleration and at various natural periods and plotted against BECA, 1993 as shown figure 2.

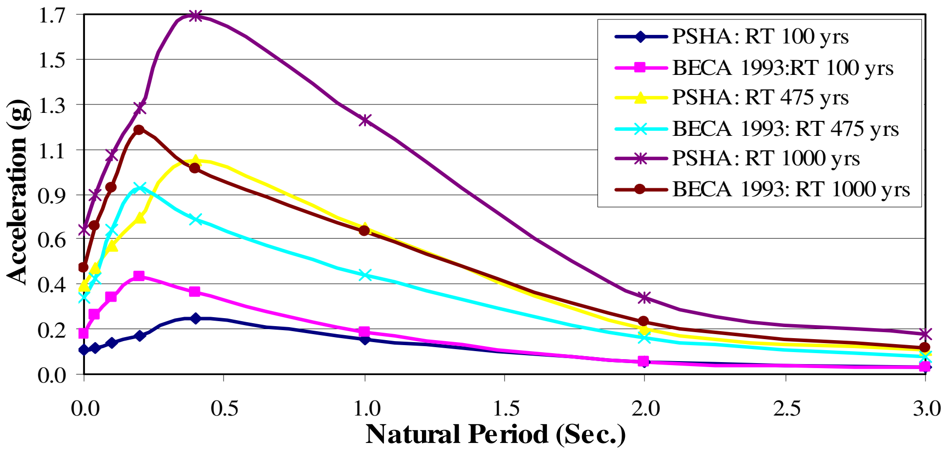

Figure 2. Comparison with of probabilistic response spectra (5% damping) for soft soil

CONCLUSION

From figure 2, hazard estimates by BECA, 1993 which is also used in code provision is over estimated for frequent events and highly underestimated for moderate to less frequent events. Depending so far observed information, the previous hazard estimate based on assumed earthquake data is very low and should be revised.

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