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Research Paper

Probabilistic Seismic Hazard Analysis on Dam Site for Specific Hydraulic Structure

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ABSTRACT

In this research, the probabilistic seismic hazard analysis has been carried out at Upper Seti hydropower, located at Damauli, Tanahu District; western part of Nepal. The earthquake magnitudes and epicenter list; earthquake catalog were collected from various sources and then the declustering of earthquake data was performed. The seismic source zone around the site within 300 km radius has been taken reference for seismic source model. Similarly, relationship between magnitude and frequency of earthquake has been developed to obtain Guttenberg-Richter ‘a’ and ‘b’ parameters. Adopting suitable attenuation relationship and obtaining different probability densities and the seismic hazard curve has been developed for the dam site area where hydraulic structure is to be located. Finally, various levels of Peak Horizontal Acceleration (PHA) are obtained for various return periods using hazard curve at the dam site.

1. Introduction

Nepal has been experiencing many natural disasters; major can be listed as landslides, floods, earthquakes, GLOF (Glacial Lake Outburst Flood) etc. More specifically relating on natural hazards and disasters, Nepal is located between the boundary of the Indian and the Tibetan tectonic plates thus resulting as seismically active zone. Earthquakes are most unpredictable natural and destructive natural hazard. Public infrastructures and national economics are also at remarkable risk due to earthquakes. It will be quite unrealistic to prevent earthquake occurrence however, the effect can be minimized by scientific and probabilistic understanding of its causes, nature, frequency content, magnitude and area of influence. It is also not possible to predict where and when the next earthquake will occur and what will be its magnitude, its intensity and effect of resulting earthquakes. So, the hazard associated with earthquake cannot be easily evaluated.

Seismic hazard analysis is carried out for the design of new structures or for the seismic safety assessment of important existing mega-structures like dams, nuclear power plants, high-rise buildings, bridges of long spans and so on. Seismic hazard analysis refers to the estimation of a measure of the strong earthquake ground motion expected to occur at the concerned site.

The main purpose of this study is to prepare the seismic hazard curve at a dam-site which represents mean annual rate of exceedance with respect to different levels of ground motion parameters in terms of Peak Horizontal Acceleration (PHA). Then, for various levels of probabilities, their return periods and time periods the quantification of PHA at the dam site can be estimated using hazard curve. The obtained PHA value can be further used for seismic performance and design of hydraulic structures located at the dam site. This study

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Note: Discussion on this paper is open until September 2020 comprised with dam site selection, estimation of ground motion parameters, hazard curve and different level of ground motion parameter with probability of exceedance at the dam site of Upper Seti Hydropower Project.

2. Literature Review

Due to insufficient seismic measurement instruments and paleo-seismic data, Nepal still under the development phase or stage in seismic hazard analysis research.

Gutenberg and Richter (1944), defined the relationship of the annual rate of exceedance of earthquake that exceeded different magnitudes during that time period for Southern California earthquakes. Probabilistic Seismic Hazard Analysis became popular after Cornell (1968) from his study ‘Engineering Seismic Risk Analysis’. Schwartz and Copper Smith (1984) describes recurrence law to represent the behavior of single source. Youngs and Copper Smith (1985) developed a generalized magnitude-frequency density function that combined an exponential magnitude distribution at lower magnitudes with a distribution in the vicinity of the characteristic earthquake.

Review on PSHA in case of Nepal

Pandey et al. (2002) prepared seismic hazard map of Nepal for Department of Mines and Geology under National Geological Center.

Thapa and Wang (2013) performed PSHA for Nepal and estimated PGA for bedrock level by taking account 23 seismic zones for 63%, 10% and 2% probability of exceedance in 50 years.

Stevens et al. (2018) have performed probabilistic seismic hazard analysis (PSHA) for Nepal allowing better characterization of geometry of the Main Himalayan Thrust (MHT) and enabled comparison of recorded motions with predicted ground motions and developed a region-specific ground motion prediction equations for future seismic hazard analysis in Nepal.

Review on PSHA at dam-site

Shrestha (2009) has conducted seismic hazard analysis and vulnerability assessment of the existing dam site of Kulekhani, Nepal. The Author has determined PGA of dam site using Young et al. (1997) attenuation relationship and analyzed the stability of dam.

Wagle (2010) conducted earthquake response of concrete gravity dams in which the author has performed PSHA for Arun-III hydropower dam site in Nepal and determined the design earthquakes for the seismic analysis and evaluation of concrete gravity dam.

Timalsina (2017) in his master thesis focused on seismic study of Sunkoshi-3 hydropower project by carrying PSHA at dam site to determine the ground motion parameters and found Design Basis Earthquake (DBE) value as 0.54g which was higher as compared to 0.36g recommended by National Building Code of Nepal (1994) and also suggest revision of seismic hazard analysis for Nepal. The author further performed finite element modeling of dam to determine response of dam to seismic force.

For this study, above mentioned literatures were used for comparisons of results or methodology or for the equations during seismic hazard analysis at the dam site.

3. Research Methodology

3.1 Selection of Dam Site

For this study, the proposed dam site located at Damauli district for the Upper Seti Hydropower project was selected. The Project site is located in the upper part of the Seti River, a tributary of the Trishuli River flowing in the central part of Nepal. The Seti River originates at the Annapurna (7,555 m height above sea level) of the Himalaya Mountains and flows north to south. The installed capacity of this hydropower project is 127 MW and the concrete gravity dam is 140m high.

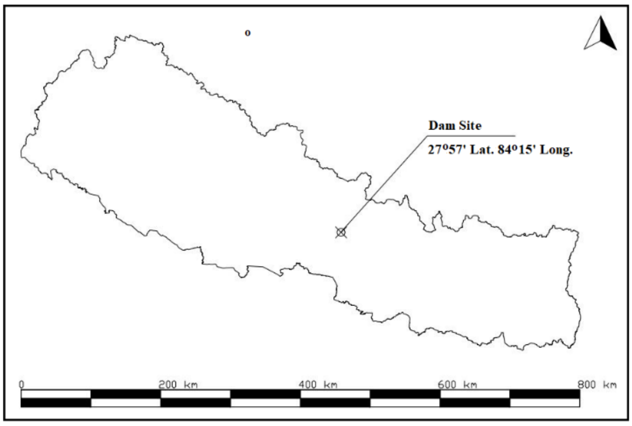

Fig. 1. Dam Site Location on map of Nepal

3.2 Earthquake Data Collection and Processing

Initially, the past earthquake data with its epicenter location, magnitudes and date of occurrence from 1255 to 2018 AD was collected from National Seismological Center (NSC) and United States Geological Survey (USGS). The obtained earthquake data consist of various magnitude scales such as local magnitude (M_L), surface wave magnitude (M_s), body wave magnitude (M_b), moment magnitude (M_w) and also intensity scale (I_o). The following relationships are used to convert them into moment magnitude:

Conversion from I_o to M_L (Gutenberg and Richter, 1956):

$$M_L = 0.67I_o + 1.0 \quad [1]$$

Conversion from M_L to M_s (Wang, 2010):

$$M_s = 0.98M_L + 0.03 \quad [2]$$

Conversion from Mb to M_s (Liu, 2007):

$$M_s = 1.07M_b - 0.63 \quad [3]$$

Conversion from M_s to seismic moment (M_o) (Ambraseys and Douglas, 2004):

$$\log M_o = 16.03 + 1.5\ M_s \ \ (\text{for } M_s > 5.94) \quad [4]$$

$$\log M_o = 19.38 + 0.93\, M_s \text{ (for } M_s < 5.94) \quad [5]$$

3.3 Earthquake Declustering

The converted moment magnitudes consist of various main shocks and aftershocks. Only major or main events are sufficient for the PSHA while the aftershocks do not follow Poisson distribution, so the aftershocks are ignored for further processing. The method of removal of aftershocks is known as declustering. Gardner and Knopoff (1974) have provided the window algorithm for removal of aftershocks as specified in Table 1.

Table 1. Window Algorithm for Aftershocks removal

Magnitude, M_w	Distance, L (km)	Time, T (days)
2.5	19.5	6
3.0	22.5	11.5
3.5	26.0	22
4.0	30.0	42
4.5	35.0	83
5.0	40.0	155
5.5	47.0	290
6.0	54.0	510
6.5	61.0	790
7.0	70.0	915
7.5	81.0	960
8.0	94.0	985

3.4 Seismicity Parameters

Guttenberg-Richter, ‘a’ and ‘b’ parameters are used for the development of seismic hazard curve at the dam site. The Equation [6] is used for this purpose.

$$\log\lambda_m = a - bm \quad [6]$$

where;

λ_m = average number of earthquakes per annum with magnitude greater than or equal to m

a = Guttenberg-Richter parameter (taking tenth power of ‘a’ i.e. 10^a, represents mean yearly no. of earthquake

b = describes the relative likelihood of large and small earthquakes.

3.5 Attenuation relationship

For this study, though there are availability of various attenuation relation in world till date, no specific attenuation relationships has not been developed yet for Nepal. To choose appropriate attenuation relationship the soil at site, seismic environment and tectonic feature of the site should be considered. So, the most appropriate attenuation relationship that match tectonic environment i.e. subduction boundary being Youngs et al (1977) has been adopted. Youngs et al. (1977) has provided attenuation relation for both rock and soft soil cases.
The attenuation relationships for rock site is:

$$\ln(y)=0.2418+1.414M+C_1+C_2(10-M)^3+ C_3\ln(r_{rup}+1.7818e^{0.554M)}+0.00607H+0.3846Z_t \quad [7]$$

where,

y = PHA or SA in g
M = moment magnitude
r_{rup} = closest distance to rupture (km)
H = focal depth (km)
Z_t = source type, 0 for interface, 1 for intraslab
s=standard deviation = C_4+C_5M

Values of coefficients for equation [7] is obtained using Table 2.

Table 2: Values of coefficients for equation [7]

Periods (s)	C_1	C_2	C_3	C_4	C_5
0 (PGA)	0.000	0.0000	-2.552	1.45	-0.1
0.075	1.275	0.0000	-2.707	1.45	-0.1
0.100	1.188	-0.0011	-2.655	1.45	-0.1
0.200	0.722	-0.0027	-2.528	1.45	-0.1
0.300	0.246	-0.0036	-2.454	1.45	-0.1
0.400	-0.115	-0.0043	-2.401	1.45	-0.1
0.500	-0.400	-0.0048	-2.36	1.45	-0.1
0.750	-1.149	-0.0057	-2.286	1.45	-0.1
1.000	-1.736	-0.0064	-2.234	1.45	-0.1
1.500	-2.634	-0.0073	-2.160	1.50	-0.1
2.000	-3.328	-0.008	-2.107	1.55	-0.1
3.000	-4.511	-0.0089	-2.033	1.65	-0.1

3.6 Probabilistic Seismic Hazard Analysis

3.6.1 Probability Distribution for source-to-site distance

If earthquakes are likely to occur anywhere within 300km around the dam site, the probability of an epicenter being located at a distance of less than r is equal to radial distance of circle divided by the area of the circle of radius 300 km,

$$F_R(r) = P(R<r)=r^2/300^2 \quad [8]$$

Probability density function (PDF) is:

$$PDF = f_R(r) = \frac{d(F_R(r))}{dr} \quad [9]$$

3.6.2 Probability Distribution of Magnitude

For probability distribution of magnitude, for the magnitude between minimum magnitude (m_{min} = 4.5) and maximum magnitude (m_{max} = 8.1) is divided into equal intervals of length, Δm = 0.05. For each magnitude interval (m and Δm) probability density function and probability of magnitude that lies between m and Δm is;

$$P[M=m] = f_M(m) x\Delta m = f_m(0.5[m+(m+\Delta m)]) x\Delta m \quad [10]$$

3.6.3 Seismic Hazard Curve for site

PSHA finally gives seismic hazard curve at a specific site, repsenting annual exceedance of different values of selected ground motion parameter (say, y*). The calculation for developing hazard curve is given by:

$$P[\,Y > y^*\,] = \int\int P[\,Y > y^*\,]\, f_M(m)\, f_R(r)\, dm\, dr \qquad [11]$$

The hazard curve may be also represented in terms of probability of exceedance, P, in period of t years using Poisson's model as;

$$P = 1 - e^{-\lambda PHA * t} \qquad [12]$$

And return period (T_R) is determined by:

$$T_R = -t / (\ln(1-P)) \qquad [13]$$

4. Result and Discussion

4.1 Earthquake Data Processing and Declustering

For consistency of work, all different magnitude scales and intensity scales were converted to one single moment magnitude for the study using above mentioned equations (equation [1], [2], [3], [4] and [5]). Fig 2. Shows the plot of all available raw data available in earthquake data.

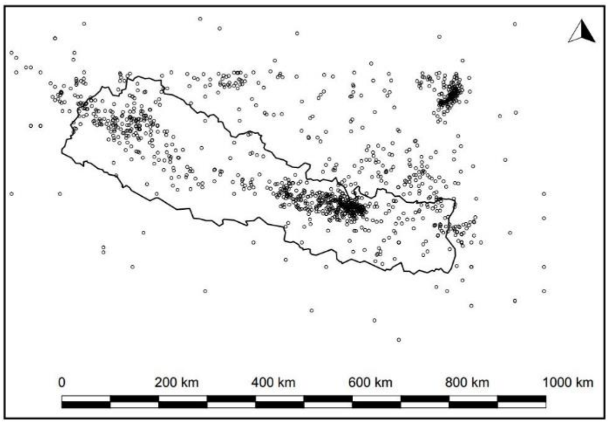

Fig. 2. Earthquake epicenter map for Nepal (raw data before declustering)

Initially the raw data catalog consists of total 1175 number of data. Then, after the declustering the data reduced to 809 number. Fig. 3 shows the plot of earthquake data after declustering and Fig. 4 shows earthquake epicenter within 300km radius around the dam site.

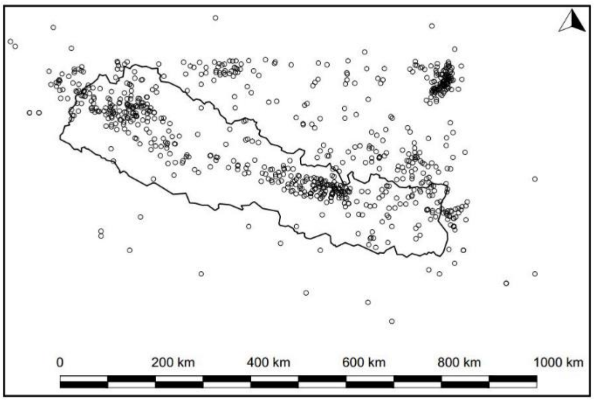

Fig. 3. Earthquake epicenter map for Nepal (after declustered)

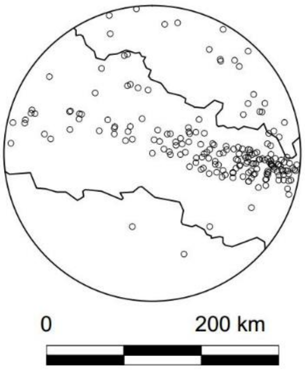

Fig. 4. Earthquake epicenters within 300km (source model)

4.2 Seismicity Parameters

Gutenberg-Richter 'a' and 'b' parameters are the main parameters required for probabilistic seismic hazard analysis. For determination of the seismicity parameters using least square regression analysis, the catalog must be complete for all the magnitudes. After performing completeness analysis, using Kijo and Smit (2012) the results were found as '3.48 and 0.83 for 'a' and 'b' parameters resp.

4.3 Probability Distribution for source-to-site distance

The probability distribution for source to site distance is plotted and shown in Figure 5. It was found that the probability of an epicenter being located at a distance less than 'r' varies linearly.

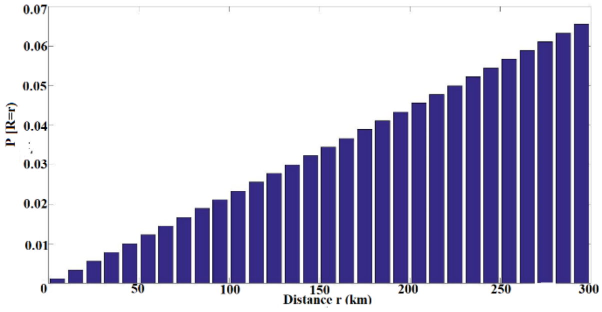

Fig. 5. Source to site distance distribution

4.4 Probability Distribution of Magnitude

The probability distribution for the magnitude at the dam site is plotted as shown in Figure 6. It was found that probability of occurrence of smaller magnitude earthquakes found to be higher than those of larger magnitudes.

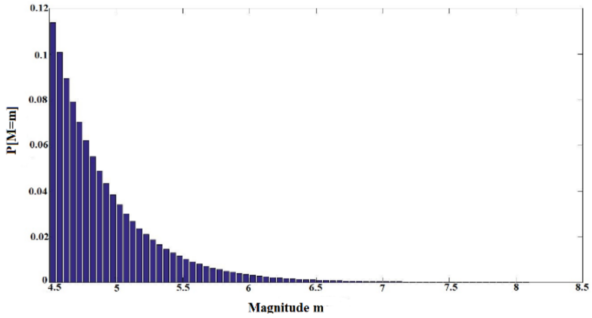

Fig. 6. Magnitude distribution for source

4.5 Seismic Hazard Curve for site

The Figure 7 shows the seismic hazard curve for the dam site which is the plot between mean annual rate of exceedance and the PHA values. Here, final seismic hazard curve was obtained using equations 9, 10 and 11 and combined using MATLAB program coding.

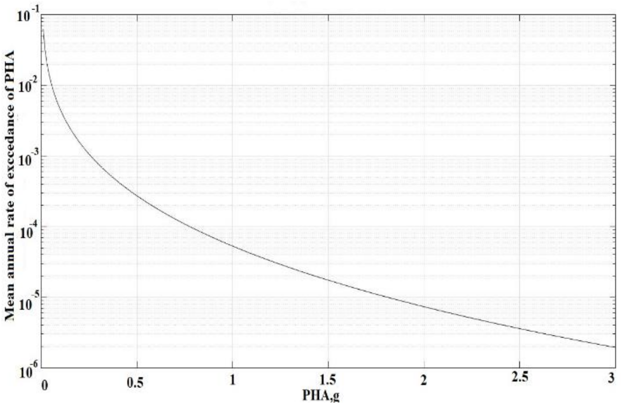

Fig. 7. Seismic Hazard Curve for the dam site

Using the equations 12 and 13 and seismic hazard curve as shown in Figure 7, the PHA value for return period 145 years was 0.25g at the dam site. The range of PHA value for return period 475 years by Pandey et al (2002) was 0.25 – 0.3g, Thapa and Wang (2013) was 0.425– 0.475g and Stevens et al. (2018) was 0.25 – 0.5g at the dam site. Here, values of PHA found to be within range with Pandey et al. (2002) and Stevens et al. (2018) and PHA value was quite lesser as per Thapa and Wang (2013).

5. Conclusions

A dam site at Upper Seti hydropower was selected for this study. All the past earthquakes were collected from past history to till date and were converted into moment magnitudes for consistency of work. Eventually, other possible source zones were chosen within 300 km radial direction from site of concentration after declustering of earthquake data. Then, the probability distribution for source to site distance and probability density for magnitude were obtained. Using Young et al. (1997) attenuation relationship, the probability density for site to source and magnitude, the final seismic hazard curve was developed for the dam site. Using the hazard curve and the return periods of 475; the PHA value was found to be 0.25g. That obtained PHA value were compared with the recent studies and literatures for seismic hazard analysis for Nepal. Thus, obtained PHA value will be very useful for evaluation of seismic performance, design and analysis of any hydraulic structures that are located at the dam site.

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Symbols and abbreviations

DBE	Design Basis Earthquake
HPP	Hydro-Power Project
NEA	Nepal Electricity Authority
NSC	National Seismological Center
PGA	Peak Ground Acceleration
PSHA	Probabilistic Seismic Hazard Analysis
SHA	Seismic Hazard Analysis
M_L	Local magnitude
M_s	Surface Wave Magnitude
M_b	Body Wave Magnitude
M_w	Moment Magnitude
I_o	Intensity Scale