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Seismic Hazardand Spectral Acceleration For Hydro Power Project in Gilgit Baltistan Pakistan

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Abstract: Peak ground acceleration is the maximum ground shaking intensity parameter in geophysics. To prevent the big loss of infrastructure, dam site or multistorey buildings as well as power project due to any seismic hazard, it is essential to mitigate the damages. Seismic hazard analysis for peak ground acceleration was carried out for hydropower project in Gilgit Baltistan to mitigate the effect of seismic hazard. Seismicity and tectonic map was drawn for distribution of seismic events.Study region was divided into seven source zones to rectify the seismic risk reduction assessmement of the region. Regression analysis for freqeuncy magnitude was also carried out using seismicity catalogue. Three distinct ground motion equations were used to predict the value of g with their return period. The actitvity rate analysis of seismic source zones was also done drawn to determine the source contribution. Maximum credible earhquake, operational based earthquake and maximum design earthquake were detremined. According to the ICOLD and seismic risk reduction policy, the values of peak ground acceleration for Phandar hydro power project was 0.59g for maximum credible earthquake, for design basis earthquake g value was 0.311g for and 0.231g foroperational basis earthquake with 475 years of return period at 50% probability of exceedence. Spectral acceleration for 0.1s, 0.2s, 0.5s, 1s and 2s was also computed for horizontal and vertical components. The values of spectral accleeration varied from 0.19g to 1.250g for maximum credible earthquake, 0.019g to 0.700g for design based earthquake and 0.050g to 0.480g for operational based earthquake. The results reveal that the maximum credible earthquake is to ensure safety level and for reliability level, operational based and design based earthquakes can be utilized.

Keywords: Peak ground acceleration, annual rate of exceedence, rate of activity, design operational and credible earthquakes**,** response spectra.

Introduction

During last two decades Pakistan facing terrible earthquake and rate of seismicity has increased due to global warming and earth inside temperature (Usman and Zafar, 2010). Many large earthquake have occured in the Pakistan region over the last 100 years having magnitude 7. Three disastrous earthquakes with magnitude more than 7.0 included Quetta earthquake in 1935, Makran coast earthquake 1945 and Kashmir-Hazara earthquake in 2005. Ground shaking is the significant threat to the human lives which requires earthquake resistant structures to prevent and mitigate the loss (Khalid et al., 2016 ; Khurram et al, 2021). The parameters of maximum ground motion such as strike, dip and rake angle as well as tectonics and geology, and rock formation factors arethe mian features for construction of dam, hydro power plant or any other large sturtcure. Earthqauke and structural engineering are the main branches, which pah dominant role in the study of earthquake resistant design structures (Khurram and Khalid, 2021 ; Sarfraz et al., 2018).Pakistan has three large dams and many hydro power plants, which are very useful to overcome the shortage of water and electricity in Pakistan. Phandar lake project of hydro power provides the electricity for local area. The Phandar power proejct lies at 36° 10' 05.8" N and 72° 57' 50.84" E about 165 km northwest of Gilgit on Ghizar river in Gilgit-Baltistan area. The proposed project aims to provid the power of 80 MW to local areas of Gilgit and adjoining valleys to mitigate the prevailing high cost of supply, and to meet the local demand of the area (WAPDA Report, 2012). Peak ground acceleration is an imprtant tool to compute the value of maximum ground shaking at site that is associated with uncertainty in time and space(Rehman et al., 2012 ; Rafi et al., 2011).There are two methods to attain the g value for any site analysis, first is deterministic seismic hazard analysis (DSHA) and 2nd is probabilistic seismic hazard analysis (PSHA) (Khalid et al., 2002). PSHA is the well known method for hazard assessment among all other approaches, firstly described by Cornell(1968). Seismic hazard analysis (SHA) utilized the earthquake science and statistics directly, and provides a signifcant value of peak ground acceleration (PGA) that can be readily used for earthquake resistant design structure. Therefore, careful seismic hazard analysis involves the quantitative and qualitative estimation of ground shaking for hydropower projects proposed in seismically active region. Phandar hydor power project has important role in the progress of Pakistan. So it is necessary before construction to find out maximum ground shaking value in the term of PGA.

The earthquake soucre parameters such as strong ground motion, risk map and seismic hazard analysis have a key role to assess the significance of the PGA (Bilham et al., 2001; Bilham, 2006). Historical and instrumental seismicity catalogues are important to explain the behavior of PGA (Kumar et al., 2006; Khurram and Khalid, 2021; Khan et al., 2021).

The objective of this study is to find the value of g according to the guidelines gien by ICOLD specifications for hydro power project. The famouse Basha dam is also located in the Gilgit Baltistan region Khurram et al. (2021) has obtained the value of peak ground acceleration of Dia Mir Basha dam determinitically and probabilistically. Norsar Report (2017) has been prepared for seismic zonation and seismic hazard assessment of Azad Kashmir in collaboration with Pakistan Meterological department (PMD) and Norway. They have drawn the hazard curves of different region of Pakistan at different return period, correlatrion between their focal depth, magnitude according to the freqeuncy magnitude relation. Waseem et al. (2018) also explained the seismic hazard assessment of northern Pakistan, and also obtained the g value with response spectral acceleration.

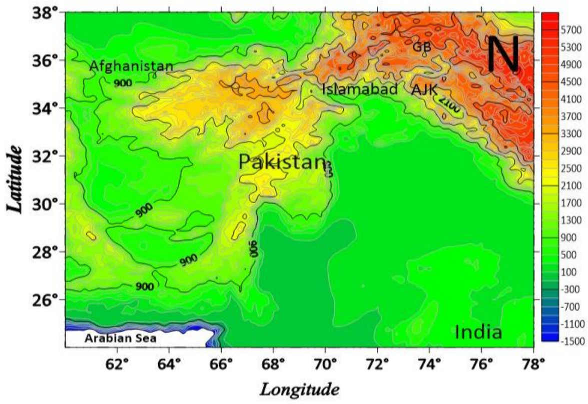

Fig. 1 Pakistan altitude map showing the geographic location (plus sign) of Phandar hydro power project.

Regional Tectonic Framework

Phandar hyrdo power project lies in northern Pakistan which is sitauted in the centre of Kohistan Island Aarc (KIA). Main Mantle Thrust (MMT) and Main Korakorum thrust (MKT) are two main tectonic features including Nanga Parbat Haramosh syntaxial bend are included in this region. The incrseasing rate of seismicity have been recorded for three decades along the MBT and other associated thrusts. Seeber et al. (1980) described that great earthquakes have occured along Himalayan Arc. Based on the above, MBT considered as an active thrust having more seismic potential which is sufficient enough to generate large earthquakes (Seeber and Armbuster, 1979).

Regional geodynamic framework of the Phandar Hydropower Project (PHP)area is characterized by collision of Eurasian and Indian continental plates.This collisionbegan in late Eocene to early Oligocene, and still continues. It has resulted in the formation of Himalayan Range(Condie, 1989). Tirich Mir fault along eastern Hinudkush region has been formed during early Cretaceous period Karakoram terrain (Zanchi et al., 2000; Hildebrand et al., 2001), and intra-oceanic Kohistan arc formed over a subduction (Khan et al., 1997). A sandwich had been made in the Kohistan is an intra-oceanic island arc between MMT to the south and the MKT in the north. Gravity data modeling indicates that the MMT and MKT dip northward at 35° to 50° and the thickness of Kohistan Isalnd arc varied from 8 to 10 km (Malinconico, 1989). Instrumental data of storng groundmotion and gravity modelling reccomended that this arc is underlain by the Indian crustal plate (Seeber and Armbuster, 1979;Fineti et al., 1979). This region comprises the mountain ranges of Nanga Parbat, Hazara, Southern Kohistan, Swat, Margalla, Kalachitta, Kohat, Potwar and Salt Range (Quittmeyer et al., (1979).

Pivnik & Wells, 1993 described that the subduction of Indian plate beneath the Eurasian plate has generated many tectonic features such as Main Karakoram Thrust (MKT), Main Mantle Thrust (MMT), Main Boundary Thrust (MBT), Main Central Thrust (MCT) and Salt Range Thrust (SRT) (Fig. 2).

Structurally MMT is characterized by a number of northwest dipping high angle thrusts, which converge together in the east and terminate at Raikot Fault (Kazmi and Jan, 1997). Many other shear stresses associated with MMT and near Bunji and Chilas together to join Raikot fault.The main historical large earthquake 'Patan earthquake' December 28, 1974 with Mw 6.2 was associated with MMT.Seismicity and geological setting ofPanjal fault nearby MMT has active regional tectonic feature capable of generating large earthquakes (Ghzanfar and Chaudry, 1996).

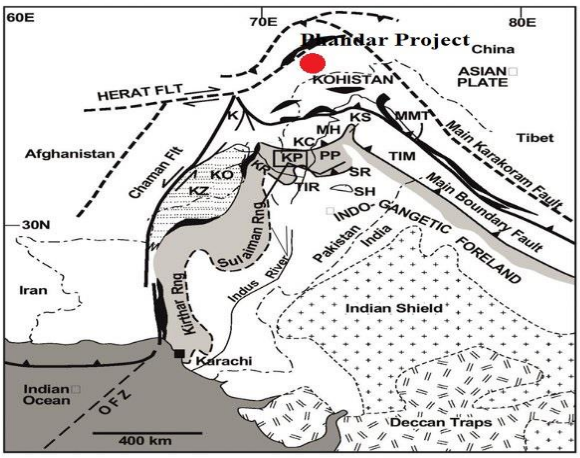

Fig. 2 Tectonicframework of northern Pakistan (modified after Pivnik, and Wells., 1999).

Materials and Methods

Probilistic seismic hazard analysis (PSHA) is used to determine the peak ground acceleration, specifically for dam site assessment, hydro project. This procedures can also be used to identify the uncertinities during hazard assessment. The PSHA method based on four basic steps that can be easily approcahed. The first step, identification and characterisation of earthquake sources, same as in deterministic hazard assessment (DSHA).2nd step is, toassign the seismicity to each zone, probability distributions was carriedout such that earthquakes are not occurhomogenously within all source zone. The seismicity or temporal distribution of earthquake recurrence must be characterised. 3rd one is recurrence relation for accumulative numbers of earthquakeusing freqeucny magnitude relation famous as Gutenberg Richter Law (1956a) and their rate of productivity '*a*' and slope of region '*b*' value mentioned in Eq. (1).

$$\text{Log N (m)} = a - b^*M_w \qquad 1$$

Where N = cumulative numbers of earthquake per year ,Mw = moment magnitude, The earthquake catalogue was utilized as instrumental seismicity for the period from 1960 to 2020 was used to determine freqeucny magnitude relation parameters. All the seismic events having M_w< 3.5 were not considered for site analysis. The last one is ground motion attenuation equation (GMPEq) proposed by different researchers (Douglas, 2011; 2021). The earthquake catalogue consists the epicentral location, earthquake size, and ground motion parameter prediction which were combined to obtain the probability estimation for specific time period.There are some uncertainties mentioned below which make the probabilistic analysis more reliable according to site parameters namely attenuation law and reccurence relation.

For the PSHA, EZFRISK computer based program was used to identify the values of PGA for site analysis in the term of hazard curve after utilizing the three different new generation attenuation (NGA) ground motion prediction equations (GMPEqs), Three ground motion Prediction equations namely,Cambell and Bozorginia 2008 (NGA) and Boore-Joyner-Fumal1997 and Idriss 2008 (NGA) for PGA. These equation based on rock formations parameters and rock quality factor. First, we divide the study region into 7 seimic source zones and prepared a significant earthquake catalogue specific for the study region. These zones are based on seismictectonic features. A working radius of about 200 km around the site was choosed as per the ionstruction and reccoemndation of the dam or hydro powe project construction given in ICOLD (2007) guidlines.. The following zones were charaterised in the form of polygon bounded by their region. For Phandar Hydropower Project, the global position of hydro power project at N: 36° 10' 05. 87", E: 72° 57' 50.84" is taken as reference site. Seven zones have been made for PGA assessment presented given below:

Zone - 1

(70.61, 38.13) (73, 38.13) (73, 36.70) (70.61, 36.70)

Zone - 2

(73, 38.13) (75.39, 38.13) (75.39, 36.70) (73, 36.70)

Zone - 3

(70.61, 36.70) (73.13, 36.70) (73.13, 35.30) (70.61, 35.30)

Zone - 4

(73.13, 36.70) (75.39, 36.70) (75.39, 35.85) (75, 36.04) (73.13, 36.04)

Zone - 5

(73.13, 36.04) (75, 36.04) (75.39, 35.85) (75.39, 34.40) (73.45, 34.87) (73.13, 34.85)

Zone - 6

(70.61, 35.30) (73.13, 35.30) (73.13, 34.27) (70.61, 34.27)

Zone - 7

(73.13, 34.85) (73.45, 34.87) (75.39, 34.40) (75.39, 34.27) (73.13, 34.27)

Results and Discussion

Prepared a composite earthquake catalogue included stduy region which contained epicentral locations, depth, magnitude, time and source.The spatial division of this region divided into seven source zones on the basis of seismicity distribution and their tectonic activity in study region (Fig. 3). Zone 1 and zone 3 lie in the intense seismic activity, whereas zone 2 and zone 4 are less around the project location. Phandar hydro project lies in zone 3 which is tectonically active having higher seismicity rate. Zone 5, zone 6 and zone 7 are less active as compared to zone 3. Their seismic activity is almost similar. This project lies in earthquake prone region (Fig. 2). Main Mantle thrust and Main Karakorum thrust passess beneath this project. Therefore, due to these two thrust zones, project is at high risk on Ghizer river in Gilgit Baltistan. This zones vise speration of the whole is the easy way to identitfy the study region vulnerability with respect to earthquake.

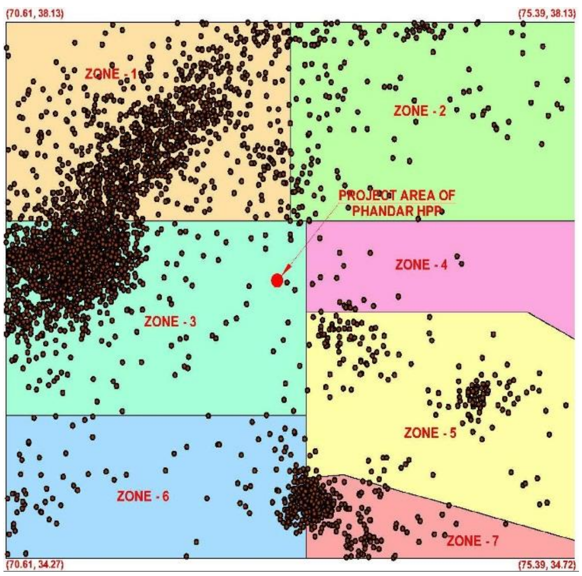

Fig. 3 Seismicity distribution over the seven seismic source zones.

The seismicity distritbution map with respect to moment magitude can be seen in Fig. 4 using ZMAP program proposed by Weimer, (2000) ; (2001) which spatially distributed earthquake catalogue. The seismicity catalogue was prepred from the period 1963-2020, Many faults and folds occured in this region. This seismicity map differientiate the seismic events with different colour variations. It ca be observed from the map that very rare events are of highe rmagnitude above the 8 magnitude. Very few events in the bottom of the region are magnitude 7. Saturation of seismic events was observed between two magnitude classess of 5 to 5.9, and 4 to 4.90 respectively.

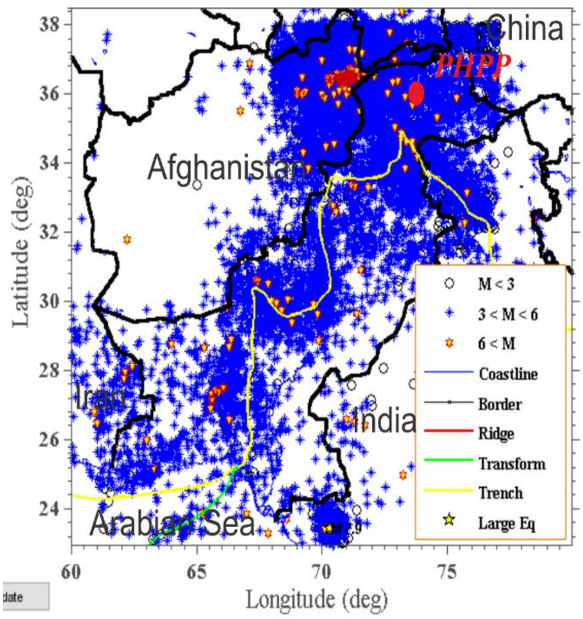

Fig. 4 Spatial distribution of the seismic events from1963– 2020 using moment magnitude.

Regression analysis was carried to obtained the value of frequency magnitude relation. For this purpose Gutenberg-Richter law (1944) was used to formulate the regression coefficient in the form of a and b values. determine the source parameters for all seven seismotectonic zones in the project area which lies in zone 3. The regression analysis plots between magnitudes and commulative number of events / year are shown in Figure 5 in which frequency magnitude relation can be seen for each zone seperatly. Their values of rate of productivity '*a*' and slope level '*b*' of are also displayed in Table 1.Beta value mentioned in table 1 can be taken as b*ln10 for EZFRISK software to easily interpret this input data. Specific zone 3 has more than one thousand seismic events with minimum magnitude 4.4 to maximum magnitude of 7.8. Zone 1 has high seismicity with high intenisty level. The Maximum potential earthquake was obtained from famouse empirical relation described by Wells and Coppersmith (1994) in Table 2. These source parameters are essential part to calculate the g value using ground motion attenuation models in EZFRISK, A computer based program to evaluate the g value.

Table 1 Seismic source zones with their source characteristics.

Zones /	EQs Min. Magnitude	Magnitude (Mw) Min	Activity Rate (a)	b Value	β Value	Magnitude (Mw) Max
Zone 1	2365	4.5	7.814	1.419	3.267	7.0
Zone 2	543	4.6	6.114	1.207	2.779	6.8
Zone 3	1344	4.4	6.340	1.092	3.296	7.8
Zone 4	817	4.3	3.296	0.81	1.890	7.8
Zone 5	412	4.6	5.571	1.067	2.457	8.0
Zone 6	285	4.6	6.464	1.272	2.929	8.0
Zone 7	86	4.6	6.790	1.272	2.929	8.0

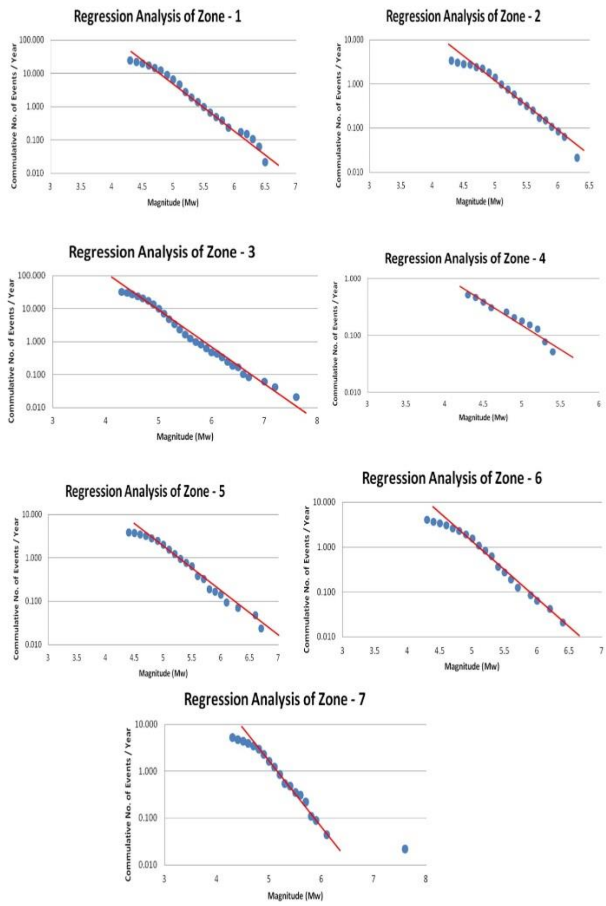

Fig 5. Regression analysis for frequency magnitude relation for seven source zones.

Seismic hazard curve is the g value curve for obtaining the value of maximum ground shaking intensity. This study also inolves the spectral acceleration for Phandar hydropower project. Spectral accleration for MCE, DBE and OBE was obtained for different time span in the term of spectral time period. Seven zones were drawn to elaborate the seismic significance of the project. For the selected spectral time period are 0.1s, 0.2s, 0.5s, 1s and 2s (Table 2) with their spectral acceleration computed for horizontal and vertical components. The values of spectral accleeration varied from 0.19g to 1.250g for maximum credible earthquake, 0.019g to 0.700g for design based earthquake and 0.050g to 0.480g for operational based earthquake. The Figures 6a, 6b, 6c showing the MCE, DBE and OBE spectral accleration values for

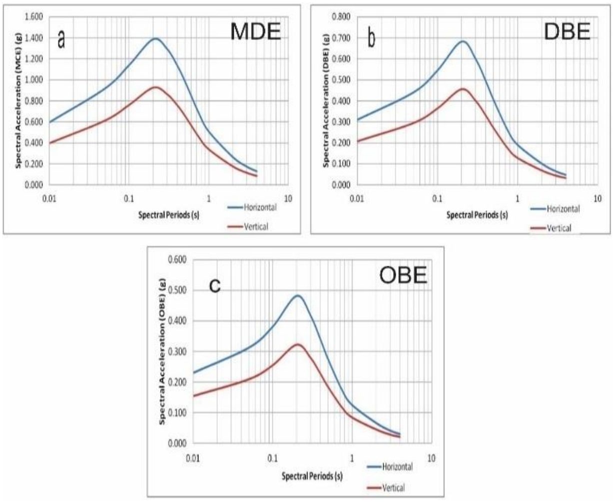

Fig. 6 a). Response spectra acceleration for horizontal and vertical components of MCE, Probability of Exceedance 1 / 10,000 Years, b). For DBE, Probability of Exceedance 1 / 475 Years, c). For OBE, Probability of Exceedance 1 / 145 Years at 5% damping.

Table 2. Horizontal and vertical components of spectral accleration for MDE, DBE and OBE.

MCE Horizontal / Vertical Comp.	**Spectral Accleration (g)**	1.150 / 0.780	1.250 / 0.850	1 / 0.65	0.500 / 0.300	0.300 / 0.190
	Spectral Period (Second)	0.1	0.2	0.5	1	2
DBE Horizontal / Vertical Comp.	**Spectral Accleration**	0.550 / 0.350	0.700 / 0.450	0.400 / 0.270	0.200 / 0.175	0.150 / 0.019
	Spectral Period	0.1	0.2	0.5	1	2
OBE Horizontal / Vertical Comp.	**Spectral Accleration**	0.390 / 0.250	0.480 / 0.325	0.280 / 0.190	0.125 / 0.098	0.05/ 0.09
	Spectral Period	0.1	0.2	0.5	1	2

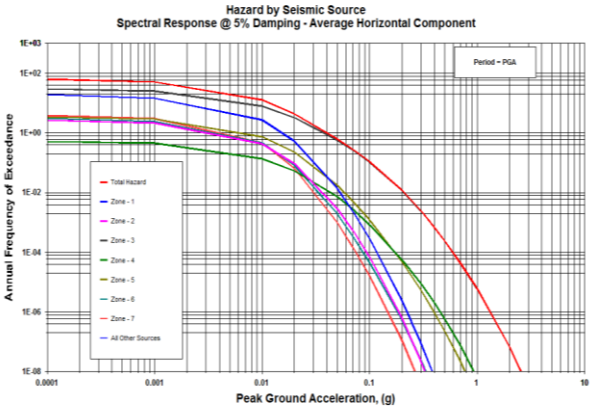

Fig 7. PGA by spectral response at 5 % damping source zones contribution.

The results of the PSHA computations were compiled in the form of (total hazard and individual hazard at the site) for seismic zones with PGA at period 0.01s are shown in Fig. 6. Total hazards are measured for peak ground acceleration (0.01s) and In the hazard curve three distinct ground motion attenuation eqiations were used to findout the values of PGAs. Annual frequency of exceedence or return priod with respect to their g values. The resulting value for the Horizontal Peak Ground Acceleration (PGA) at the Phandar Hydropower Project site is 0.595g for MCE, for DBE and OBE, values of 0.311g and 0.231g The mean hazard curve was taken among all curves of three GMPEqs. Individual zone desripton for the participation of each curve with respect to site analysis can be seen in Fig. 8. The main contribution is zone 3 and zone 1 in and aournd the power project. These two source zones have much impact on the value of maximum ground acceleration.

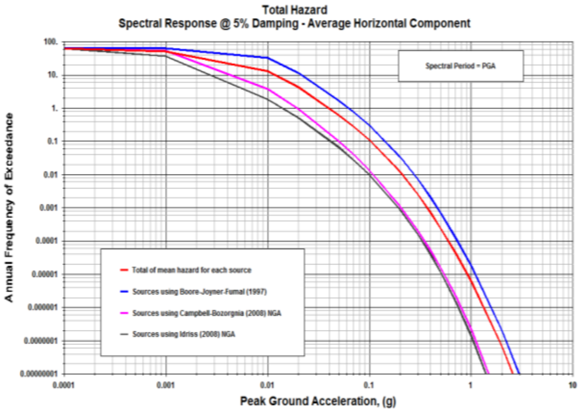

Fig. 8 PSHA for PGA for Period of 0.01 sat 5% damping.

Conclusion

According to the ICOLD and seismic risk reduction policy, it was concluded that the values of peak ground acceleration for Phandar hydro power project was 0.59g for maximum credible earthquake, for design basis earthquake, g value was 0.311g whereas, the determined value 0.231g for operational basis earthquake with 475 years of return period at 50% probability of exceedence. Spectral acceleration for 0.1s, 0.2s, 0.5s, 1s and 2s was also computed for horizontal and vertical components. The values of spectral accleeration varied from 0.19g to 1.250g for maximum credible earthquake, 0.019g to 0.700g for design based earthquake and 0.050g to 0.480g for operational based earthquake.All these values can utilized by the structural engineer to construct the earthquake resistant design structure at certain level of ground shaking without any damage.

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