SITE SPECIFIC PROBABILISTIC SEISMIC HAZARD ANALYSIS OF MANSEHRA URBAN AREA

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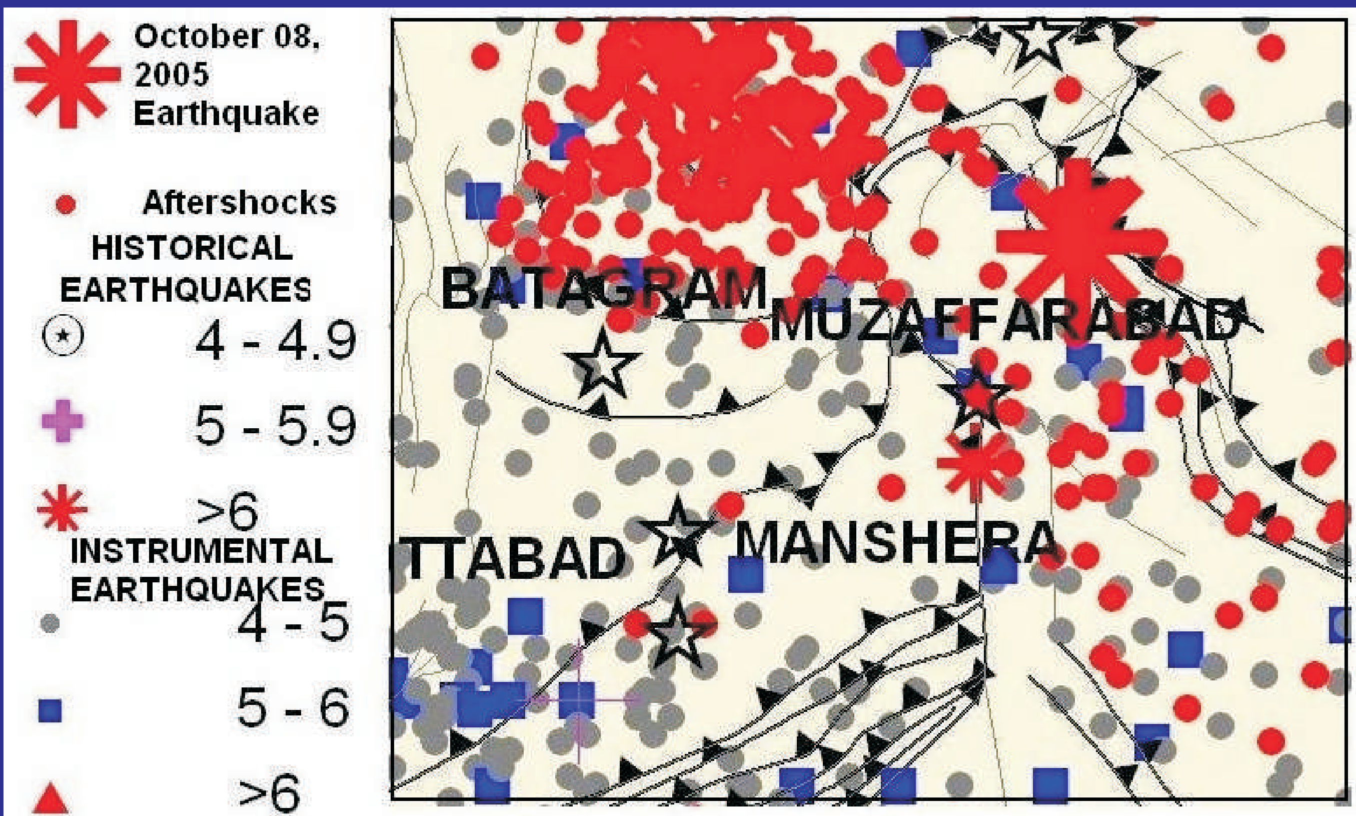

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ABSTRACT

The scope of the work presented herein is to conduct the site specific probabilistic seismic hazard analysis (PSHA) of Mansehra urban area in order to quantify the total annual rate of exceedance (ARE) of different ground motion levels to obtain the total hazard curve. Hazard curve is used to compute the uniform hazard spectra (UHS) for acceleration and displacement for 475 year of return period. This return period corresponds to 10% probability of exceedance in 50 years considering the ground motion occurrences as a Poisson process. Additionally, Deaggregation is performed for 475 year return period at the site to find out the most contributing scenarios to the total hazard.

Current state of the practice methodology is used for the hazard analysis. The most updated Empirical Ground Motion Prediction Models (EGMPM) developed for active shallow crust regions are used for the site. Site dependent EGMPM is used to calculate the spectral accelerations on rock or stiff soil and on soil. The study site has hard rock, represented by soil type B of NEHRP site classification, and alluvial soil of gravel with sand and clay which is represented by type C soil for the present study.

PSHA is carried out for considering a background source and three fault sources. The seismicity is considered within, roughly, 100 km of the site in each direction. The background source covers an area of about (200kmx150km) around the site of interest. This area takes seismic contribution from three seismotectonic zones out of the four zones defined in the previous study for NW Himalayan. Each of the three zones is assigned credibility based on its relative covered area for considered background source. The fault sources are the simplified representation of Main Boundry Thrust (MBT) on the south, Main Mantal Thrust (MMT) on the north, and Main Frontal Thrust (MFT) on the south-east of the site. Each Fault source is assumed with a characteristic earthquake of 7.5 once every 400 years. Finally, total hazard curve is obtained for the combined effect of background and 1/3rd of each fault source. Hazard curve is then used to calculate UHS for acceleration and displacement at a return period of 475 years.

LIST OF SYMBOLS

ARE	annual rate of exceedance
c	amplitude of ground motion
EGMPM	empirical ground motion prediction model
f	probability density function
g	acceleration due to gravity
l	location of seismic sources
m, M	earthquake moment
M_W	moment magnitude
MBT	main boundary thrust
MFT	main frontal thrust
MMT	main mantal thrust
NEHRP	national earthquake hazard reduction program
NW	north-west
P[.]	probability of event defined as [.]
PDF	probability density function
PGA	peak ground acceleration
PSHA	probabilistic seismic hazard analysis
R, r	source to site distance
RA	rupture area of the fault
S	representing source properties e-g Moment Magnitude (M_W)
SA	spectra acceleration
SD	spectral displacement
T	time period of a structure
TE	truncated exponential
TN	truncated normal
UHS	uniform hazard spectrum
w	rupture width of the fault
x	location of earthquake along the fault
y	location of earthquake down the surface
β	parameter of the exponential moment distribution
ε	logarithmic ground motion deviation
γ(c)	annual frequency of exceedance for amplitude (c)
υ	rate of occurrence of an earthquake

1 INTRODUCTION

The impact of an earthquake manifests in the form of socio-economic losses of exposed society. Future losses of exposed society are estimated through the risk analysis study in earthquake engineering discipline. Risk is the convolution of seismic hazard, exposure, vulnerability of the exposure, and damage-loss conversion factor (specific Cost). Seismic hazard defines the future earthquakes potential in term of annual frequency of ground motion. Vulnerability is the capacity measure of the exposure, where exposure represents the building inventory in a locality. Damage-loss conversion includes the effect of repair cost of the building stock after an earthquake. Risk analysis results in locations with high and low seismic risk potential. These informations are used to form the Microzonation map of the area. Microzonation map can be used to identify high seismic risk locations, which can be used further to mitigate the future seismic risk through different controlling measures. Also, the map can provide guidance on the emergency response and rescue operation following an earthquake.

Seismic hazard depicts a natural phenomenon and cannot be altered. But the accurate prediction of future seismic hazard in an area is of prime importance as the overall seismic risk and loss estimation is dependent on the accuracy of all inputs. If the seismic hazard results are not correct and do not represent the actual future earthquake potential in the area, the final risk assessment will be misleading. Hence an accurate prediction of seismic hazard is important.

The annual frequency of different level of ground motions is obtained using EGMPM through the probabilistic approach, which takes into account the possibility of all future earthquakes to be equally likely everywhere on a seismic source with variability in ground motion estimation. The deterministic approach considers only one or few scenarios without any information of its contribution to the total future hazard. Deterministic approach is useful for macrozonation study of an earthquake to compare the predicted and observed earthquake damages in the area. The present study looks at the seismic hazard for future risk estimation and microzonation of the area under consideration. Thus further discussions in the report will be based on probabilistic seismic hazard analysis (PSHA) only.

Most of the PSHA usually conducts the study for the rock outcrop motion and do not consider the effects of sediment directly. These studies calculate the UHS for rock site and then use a constant factor to amplify the rock spectra at all period values. The soil has a definite range of natural periods of vibration. This property makes the soil to behave like a filter, amplifying ground motion amplitude at certain period values and deamplifying at other period values. In some cases only the peak ground acceleration (PGA) for rock outcrop is reported in PSHA study. A standard spectral shape is then considered and anchored to the computed PGA at zero period. This is the methodology adopted in many building codes e-g Eurocode 8. This approach results with spectral accelerations which do not necessarily have the same return period and ARE (McGuire 1977, Ambraseys et al 1996).

To overcome this inconsistency, the present study obtain the UHS for rock and soil condition using the site shear velocity dependent EGMPM. Since, the EGMPMs are developed based on the actual observed data from different earthquakes worldwide; their results are believed to be logically more accurate than those obtained using previous approaches.

2 METHODOLOGY

The basic methodology of PSHA for a specific site is based on the pioneering work of Allin Cornell (1968). Although many features (variability in ground motion for a given magnitude and distance) have been incorporated into his model of PSHA but the basic approach remains the same. The idea of his approach is to consider all the possible scenarios; assigning them equal credibility, for estimating seismic hazard at a site. PSHA calculate how often a suite of ground motion level is exceeded at a site in terms of its annual frequency.

The general methodology outlined by McGuire R. K. (2004) is adopted for PSHA in this report. The various steps involved to conduct PSHA are depicted in figure 1 and explained as follow.

Step A: it shows the distribution of earthquakes on a seismic source (fault or areal source/background source). It is assumed that the future earthquakes have likely to occur every where on a seismic source independent on each other.

Step B: it represents the distribution of seismic source properties (M_W); the frequency of magnitude over the source. It defines the magnitude recurrence law of a fault or an areal source/background source.

Step C: step A and step B usually consider all the possible magnitude and distance over a seismic source. Empirical ground motion model is used to calculate the expected ground motion level. The probability function; P[C>c/S,l], is then calculated for each scenario.

Step D: the annual frequency of the ground motion levels are calculated from the model as given below.

$$\gamma_j[C > c] = \upsilon_j \iint P_j[C > c / S, l].P[S, l]dSdl \quad (1)$$

$$\gamma_j[C > c] = \upsilon_j \iint P_j[C > c / S, l].P[l / S].P[S]dSdl \quad (2)$$

In the above model

$_j$ = annual frequency with which c is exceeded by an earthquake at source j

$_j$ = rate of occurrence of an earthquake of interest at source j. The inverse of return period.

S = representing source properties e-g Moment Magnitude (M_W)

l = location of seismic sources

P[l/S] = PDF of location distribution for seismic sources

P[S] = PDF of source properties (M_W); size distribution

P[C>c/S,l] = the probability with which c is exceeded for a given source property and location of seismic source

2.1 PSHA; Current State of the Practice

This section summarizes the PSHA methodology of Abrahamson N. (2000), which is based on the current state of the practice of seismic hazard evaluation and used as a standard methodology for conducting PSHA in most of the case studies in United States, Europe, and rest of the world. Most of the available commercial softwares incorporate this methodology for conducting PSHA.

The annual frequency of exceedance involves several probability distributions for each seismic source: the frequency of occurrence of earthquakes of various magnitudes, the rupture dimension and location of the earthquakes, the attenuation of the ground motion from the earthquake rupture to the site, and the variability in ground motion estimation from the EGMPMs. Annual frequency is formulated for the areal source/background source; which is considered as point source earthquakes, as follow.

$$\gamma_j[C > c] = \upsilon_j \int \int \int P[C > c/m,r,\varepsilon] f_{m_j}(m) f_{r_j}(r) f_\varepsilon(\varepsilon) \quad (3)$$

Where

$f_{m_j}(m), f_{r_j}(r), f_\varepsilon(\varepsilon)$ = PDF of magnitude, PDF of epicentral distance, and PDF of epsilon values at source j.

Equation (3) differs from equation (1) & (2); it considers the variability in the estimation of ground motion as well. Equation (3) when applied for the fault source, it has to take in to consideration the variability or randomness of the earthquake location over the fault plane.

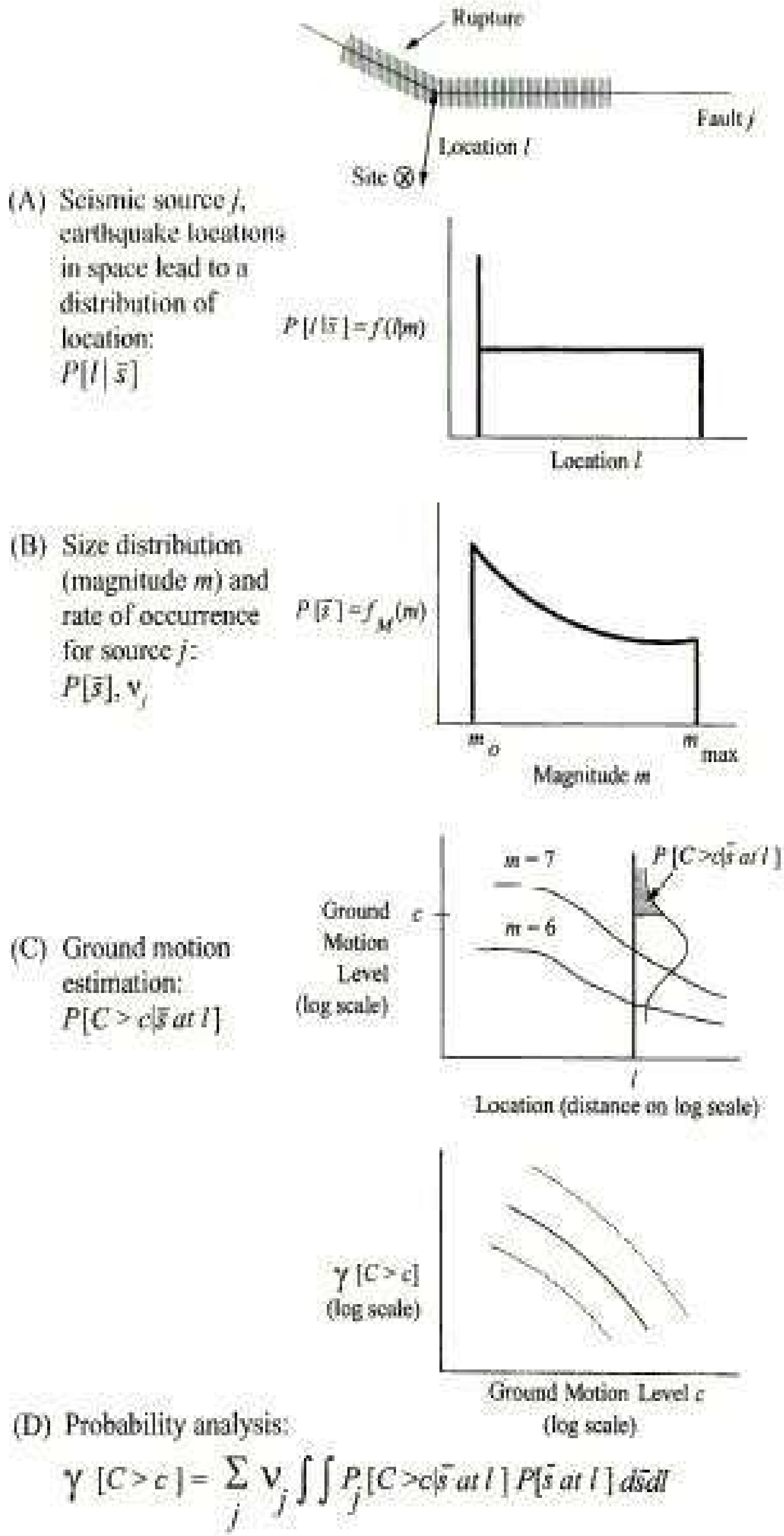

Figure 1. Steps in performing PSHA, McGuire R. K. (2004)

The next step is to include PDF for rupture area, rupture width, and PDF for hypocenter location along the fault and down the surface. The formulation is given in equation (4). For multiple seismic sources the total annual frequency will be the sum of annual frequency from all the sources (faults and areal sources).

$$\gamma_j[C > c] = \upsilon_j \int_W \int_{RA} \int_{Ex} \int_{Ey} \int_m \int_\varepsilon P[C > c / m, r(x, y, w, RA), \varepsilon] f_{m_j}(m) f_{m_j}(m, W) f_{m_j}(m, RA)$$

$$f_{Ex_j}(x) f_{Ey_j}(y) f_\varepsilon(\varepsilon) dWdRAdxdyd\ md\varepsilon \qquad (4)$$

$$\gamma[C > c] = \sum_{i=j}^{N_{sources}} \gamma_j[C > c] \qquad (5)$$

Most of the seismic hazard analysis studies consider the earthquake as a Poisson process; it means that there is no memory of the past earthquakes and hence the earthquakes are assumed to be independent on each other. The accurate model is the one of renewal model which considers the effects of previous earthquakes. The present study calculates the annual frequency, ARE, of a different level of ground motions at different period ranging from zero to 5.0 sec. From this information a seismic hazard curve can be plotted, as shown in figure 1 step D. From the Hazard curve the ground motion level is directly obtained for a given return period (inverse of annual frequency).

3 SEISMIC SOURCE AND SITE CHARACTERIZATION

3.1 SEISMIC SOURCE CHARACTERIZATION

3.1.1 Seismic Sources

3.1.1.1 Background Source

The first step in conducting PSHA is to know where the future seismicity is expected. In general, areal/background sources and fault sources are used to carry out seismic hazard analysis at a site. Areal sources are the areas with in which the future seismicity is assumed to be uniformly distributed in time and space. Historical seismicity alone describes the geometry and location of areal sources. For example Monalisa et al (2007) used historical data and areal sources to conduct PSHA at different sites in NW Himalaya Pakistan. The historical seismicity and four seismic areal sources used in that study are shown in figure 2.

For the present study the PSHA is conducted for a background source as shown in figure (4) (black outlined square). On each side from the site the distance is roughly 100km; which is considerable for the hazard analysis required for short period structures. In case of tall structures on soil and bridges, longer distance should be assumed to take into account far field seismicity due to large distant earthquakes. The hazard analysis in the present study is not required for these types of structures and so, the long distance seismicity is not considered in PSHA.

3.1.1.2 Fault sources

Fault sources are zones for which the tectonic features causing earthquakes have been identified. These are individual faults or regions of multiple and complex faults, as shown in figure 3. The geologic informations of these faults are used to estimate the earthquake activity rate and so the recurrence law for future earthquakes at faults.

The area under consideration has a very complex structure of faults and cannot be easily represented in PSHA for its actual form. The present study considers three faults; simplified representation of MBT, MFT, and MMT, as shown in figure (4). Other faults are not considered because their contribution has been considered in the background source. The actual representation is not even necessary, because the simplification will not affect the hazard analysis to a great extent.

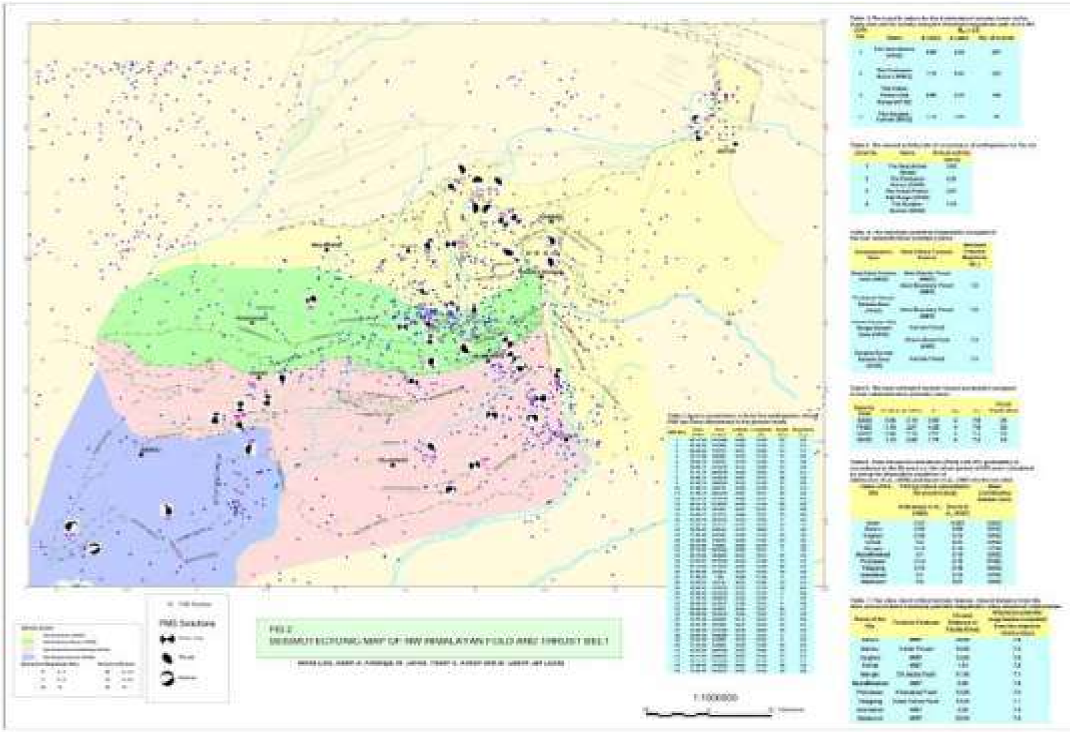

Figure 2: Seismicity map of NW Himalaya, Mona Lisa et al 2007

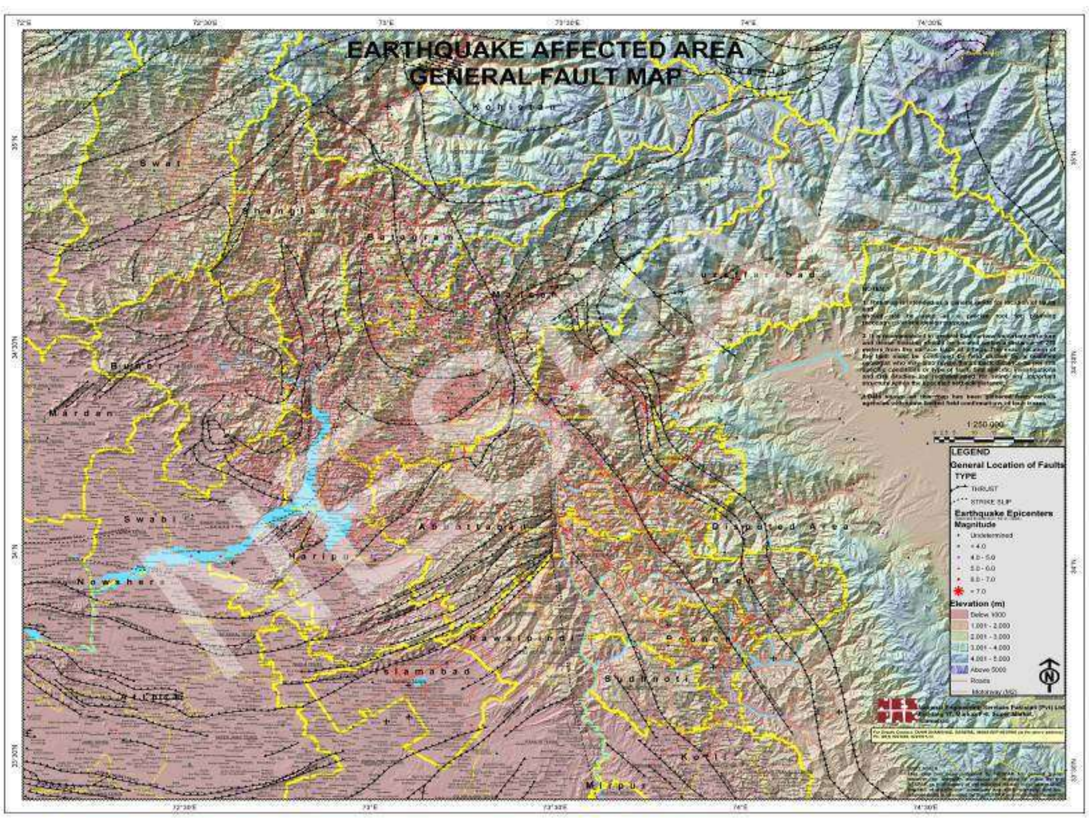

Figure 3: Faults distribution in NW Himalaya, Source NESPAK

3.1.2 Magnitude Distribution

The second step in PSHA, as depicted in figure 1, is to assign moment distribution to each of the seismic sources. This fact takes into account the annual seismicity distribution over a source or relative frequency of magnitudes over a seismic source.

3.1.2.1 Background Source

Most of the hazard analysis studies use exponential distribution of earthquakes to represent the relative frequency (Probability density function, PDF) of different magnitudes for areal sources and background sources. This is due to the fact that the historical seismicity is exponentially distributed for seismic sources (e-g Richter 1958). The PDF is truncated at a particular magnitude in the upper and lower bounds (e-g Gutenberg and Richter, 1944).

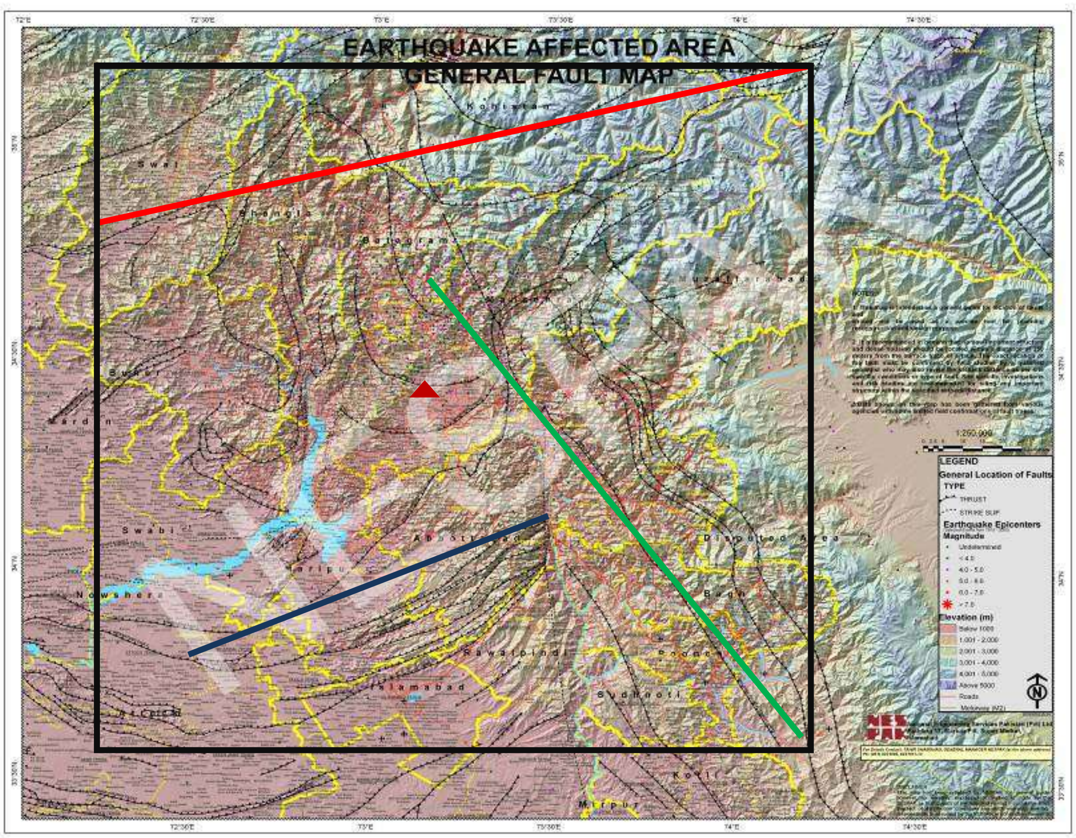

Figure 4: Background and Fault sources considered for PSHA

The truncation is usually performed in order to exclude the lower magnitude value; which is not of engineering interest, and higher magnitude that is maximum magnitude observed in the past or it could be based on geologic informations i-e slip rate and rupture area. The PDF of exponential distribution is formulated in equation (6). The small letters represent variable while the capital letters represent a particular value. The PDF is depicted in figure (5) for =2.53, M_{min} = 4.0 and M_{max}=6.5. For the present study, each of three seismotectonic zones contributing to the hazard were assigned TE PDF with M_W = 4.0 to M_W = 6.5.

$$f_m^{TE}(m) = \frac{\beta e^{(-\beta(m-M_{min}))}}{1-e^{(-\beta(M_{max}-M_{min})}} \quad (6)$$

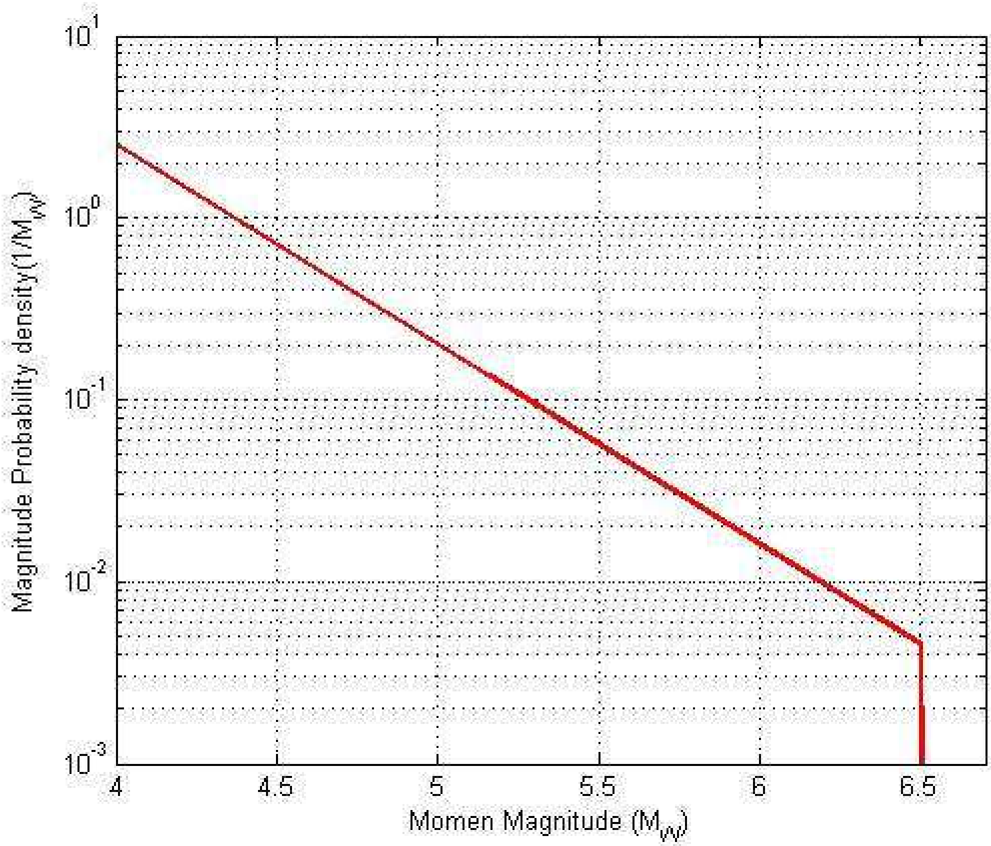

Figure 5: PDF of Truncated Exponential distribution

3.1.2.2 Fault Sources

Some faults exhibit seismicity, which is not represented correctly by simply extrapolating the exponential distribution of that area (for example the San Andreas Fault (McGuire 2004) and Faults in Himalayan). Every 400 to 500 years there is a big earthquake in the Himalayan with magnitude ranging from 7.5 to 8.0 (Bilham, 2004). If the exponential model is used in this case, it will underestimate the hazard at the site for long return period. Alternative option is to use the characteristic model; a model which considers that a particular fault generates only characteristic magnitude earthquake i-e having single characteristic value with certain standard variation. The PDF for this model is given in equation (7) and shown in figure (6).

$$f_m^{TN}(m) = \frac{1}{0.977}\frac{1}{\sigma_m\sqrt{2\pi}}e^{\frac{(m-M_{char})}{2\sigma_m^2}} \qquad (7)$$

Equation (7) is given for truncated normal (TN) distribution with standard deviation () of 2 about the mean/Characteristic magnitude (M_{char}). The PDF is depicted for M_{char} = 7.5 with standard deviation of = 0.5. TN distribution model is used in the present study for fault sources.

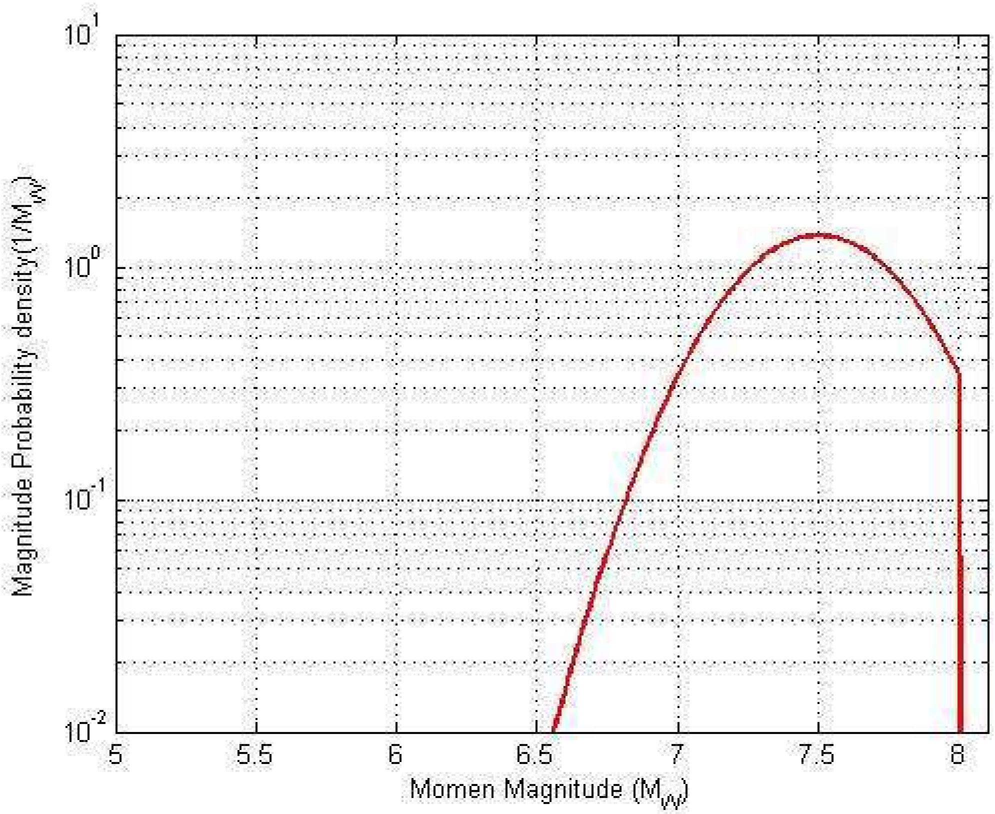

Figure 6: PDF of Truncated Normal distribution

3.1.3 Magnitude recurrence law and Activity Rate

3.1.3.1 Recurrence law

The PSHA model, given in equation (3) and (4), requires the activity rate of the threshold moment besides many PDF; Magnitude, Rupture length, Rupture width, location of hypocenter, and Ground motion variation. This section describes how activity rate is calculated for the present study.

The previous study (Monlisa et al , 2007) in the area, established four seismotectonic zones; Peshawar-Hazara Seismic Zone (PHSZ), Swat-Astor Seismic Zones (SASZ), Kohat-Potwar Salt Range Seismic Zones (KPSR), and Surghar-Kurram Seismic Zone (SKSZ). The four zones described above are shown in figure (2). Their study deri ved recurrence laws, from the analysis of 813 events, from 1904 to 2002, obtained from local and international sources, for each of the four seismic zones, as given in equation (8) for SASZ, (9) for PHSZ, (10) for KPSZ, and (11) SKSZ.

$$N(m) = 10^{(4.54-0.99m)} \qquad (8)$$

$$N(m) = 10^{(4.54-0.99m)} \qquad (9)$$

$$N(m) = 10^{(4.54-0.99m)} \qquad (10)$$

$$N(m) = 10^{(4.54-0.99m)} \qquad (11)$$

N(m) is the mean annual rate/mean activity rate of a given magnitude (m); which represent the number of earthquakes per year equal to or greater than m. The background source considered in the present study, takes contribution from the 1^{st} three seismic zones and so, only the 1^{st} three seismic zones are considered in the study. Fault sources do not use the above recurrence relations because faults seismicity is based on characteristic earthquake in the area.

3.1.3.2 Activity Rate

There are two common approaches used for the calculation of activity rate; historical seismicity data and geologic (geodetic) informations. If historically data is available the most traditional approach is the least-square; to fit the Truncated exponential (Gutenberg-Richter) distribution to the data and compute the value of activity rate. The best method will be to calculate the activity rate using the likelihood procedure; the number of observed earthquakes of a particular magnitude (equal and greater) for a given interval of time. For example, the number of earthquakes of M_W 4.0 in the past T years. The ac tivity rate can be calculated by equation (12).

$$\nu[m \geq] = \frac{N}{T_S} \qquad (12)$$

where N is the total observed earthquakes (equal and greater) in the area and T_S is the time window considered. The previous study (Monalisa et al, 2007) reported activity rate based on likelihood procedure but the results were very sensitive to the time window selected. Unlike, In the present report, the activity rate of background source is obtained for each seismic zone using the recurrence laws given in equations (8) to (11).

The activity rate for fault soucces is calculated by the energy balance method (Abrahamson, 2000); the long term energy built up at a fault is equal to the energy release in a characteristic magnitude earthquake. For the present study a recurrence interval of characteristic magnitude (M_{char} = 7.5) is taken as 400 years. The recurrence interval of M_{char} is used by CRISIS2007v5.5 (Ordaz et al2007) to compute the hazard for fault sources.

3.2 SITE CHARACTERIZATION

Site specific EGMPM characterize soil based on its average shear wave velocity at a depth of 30m. The present models donot take into account the geometric properties; depth to bedrock, cross-section, 2D- or 3D-valley.

3.2.1 Rock Site

For the present study the rock site is assigned with, assumed, type D soil of NEHRP soil classification. The shear velocity for the rock is taken as 960 m/sec; which is based on the recommendation of Boore et al (2008).

3.2.2 Soil Site

Tehsil Municipal Administration (TMA) at Mansehra classified, qualitatively, the sediment fill of Mansehra as alluvial soil of Gravel with sand and clay; overlying the bedrock at 30 m depth. The classification is based on the resistivity tests conducted at the site for tube wells and ground water study. The report of the test is not a general publication and can be obtained only directly from TMA Mansehra. For the present study, the soil site is considered as type D soil of NEHRP soil classification and the shear velocity assigned is taken as 250 m/sec.

4 GROUND MOTION MODEL

4.1 Selection Criteria

A vital component of a seismic hazard analysis is the EGMPM developed for that area. As, clear from the PSHA model of equation (3) and (4); where it calculate a suit of ground motions for different combination of magnitude and distance with considered variation (known as Aleatory variability). Since the EGMPM are dependent on minimum parameters; magnitude, distance, and site classification, the ground motion calculated at the site always has epistemic uncertainty; which is usually reduced by the process called logic tree. In logic tree many EGMPMs are selected from the available list of models and are adjusted to get the parametric compatibility (Cotton et al, 2006). The uncertainties get even more severe when the target site uses the host model developed for another region. In the present study, although logical and important, the process of logic tree is not performed.

Since the target site does not have its own EGMPM, the criteria described in Cotton et al (2006) is used to select a host model for PSHA of the target site. The adjusted model can be obtained through the procedure described in figure (7). For more detail, the reader is referred to Cotton et al (2007).

It is suggested by Cotton et al (2007) to perform pre-selection process for screening the available list of models for final adjustment. The rejection criteria are described below.

1. The model is from completely an irrelevant tectonic regime.
2. The model is not published in an international peer-reviewed journal.
3. The documentation of model and its underlying dataset is insufficient.
4. The model has been superseded by more recent publications.
5. The frequency range of the model is not appropriate for engineering application.
6. The model has an inappropriate functional form.
7. The regression method or regression coefficients are judged to be inappropriate.

For site specific PSHA, the authors of the present study believe to add one more point, given below, to the pre-selection criteria of Cotton et al (2007).

1. The model is not site shear velocity dependent.

Because the model defining the site as generic rock, shallow soil and/or deep soil (e-g Abrahamson et al 1997) cannot be believed as site specific EGMPM.

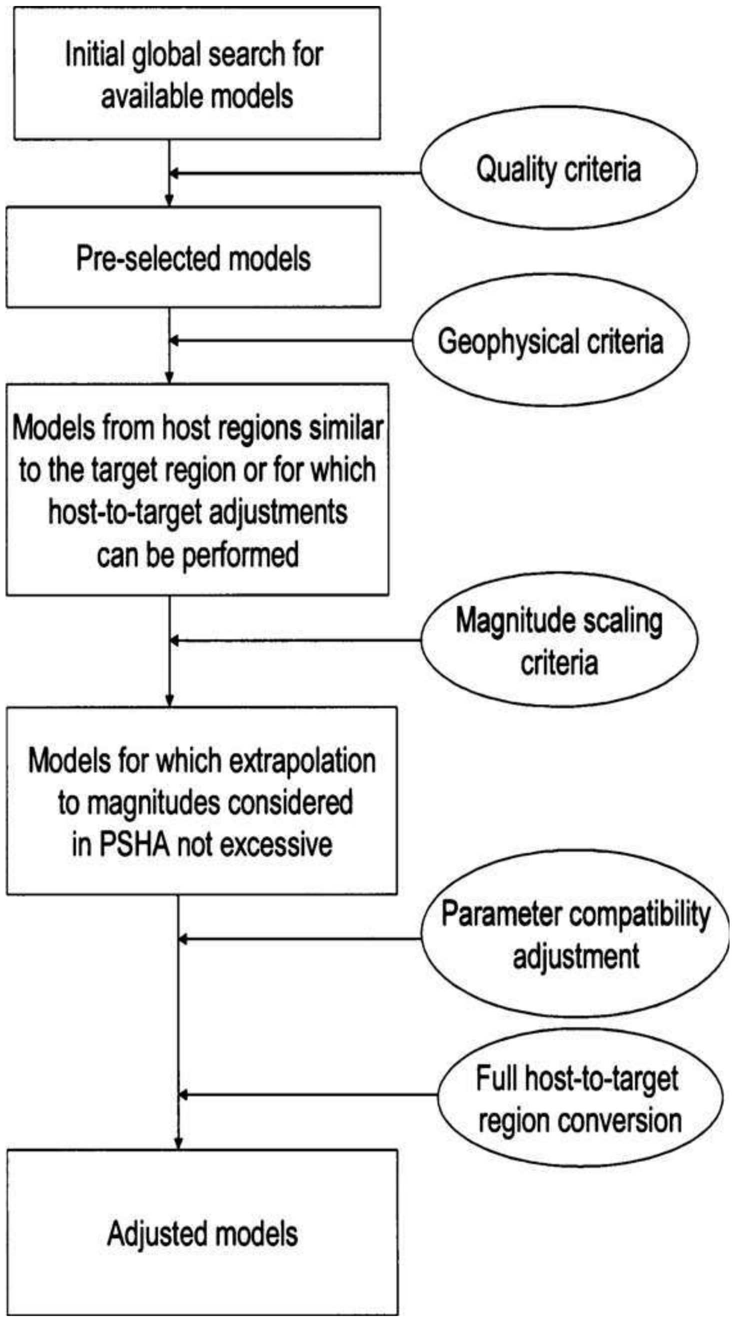

Figure 7: EGMPM selection criteria, Cotton et al, 2007

4.2 EGMPM of Current Study

4.2.1 Boore and Atkinson (2008), BA08

Following the pre-selection criteria of Cotton et al (2007), the EGMPM of Boore et al (2008) is selected for the ground motion estimation of the present site. Hereafter called as BA08. The model calculate the average horizontal PGA and 5% damped spectral acceleration; for the range of period (T) from T = 0.01sec to T = 10.0 sec. The model has been developed for a large data set compiled by PEER NGA (Pacific Earthquake Engineering Research Center's Next Generation Attenuation) for shallow crust and active tectonic regime. The General analytical representation of the model is given in equation (13).

$$\ln Y = F_M(M) + F_D(R_{JB}, M) + F_S(V_{S30}, R_{JB}, M) + \varepsilon\sigma_T \qquad (13)$$

In this equation, F_M, F_D, and F_S represent the magnitude scaling, distance function, and site amplification, respectively. M is the moment magnitude, R_{JB} is the Joyner-Boore distance; the closest distance to the surface projection of the fault. R_{JB} is closed to the epicentral distance for M<6. V_{S30} is the average shear velocity at a depth of 30m of a site (recommended from 180 m/sec to 1300 m/sec) and is the functional number of for lower and/or higher value of lnY than the mean value. For more explanation of the terms and functions used in equation (13), the reader is referred to Boore et al (2008).

The most appealing point of the model is the velocity function, although empirical (formulated by choi and stewart (2005), which consider both the linear and nonlinear response of the soil over all the range of period. Using Equation (13), the attenuation of Median PGA for M_W = 7.6 with distance is shown for rock site and soil site. The rock is considered as type B soil, and the soil is considered as type D soil according to the NEHRP soil classification. The velocity for each type of class is assigned according to the suggestions of Boore et al (2008). The results are shown in figure (8). The attenuation of PGA clearly shows high amplitude for soil site than rock site. The amplification is minor at closer distances but very high at intermediate distances (30 to 100 km); which are of engineering interest.

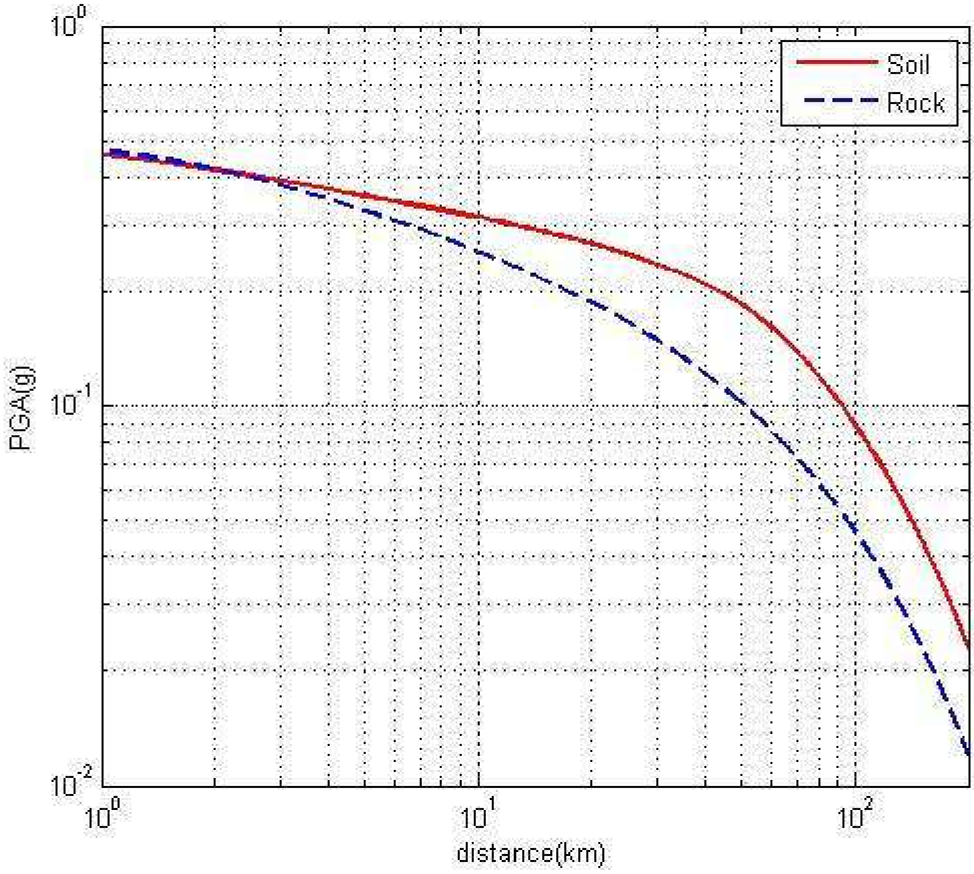

Figure 8: PGA Attenuation with distance using BA08

4.3 Ground Motion Uncertainties

All the EGMPMs developed has aleatory variability and epistemic uncertainty even for the region it has been developed. The present model selected for PSHA has standard deviation of 0.56 to 0.7 above the median value at different period. Also, the present model do not consider the effects of rupture directivity which is an important characteristic of an earthquake; amplifying motion in the direction of propagation with high frequency (low period) and prolonging the duration of ground motion, with relatively low frequency (high period), opposite to the propagation direction.

As stated before that the present methodology is to perform a logic tree procedure to reduce the uncertainties in the ground motion prediction. Although logical and usually practiced, the present study does not perform this procedure for the sake of simplicity.

5 PROBABILISTIC SEISMIC HAZARD ANALYSIS

5.1 Seismic Hazard Curve

After defining seismic sources, their properties, and ground motion model, the seismic hazard of the site is performed using the program of CRISIS2007 v5.5, developed by Ordaz et al. Provided all the seismic sources properties and site information, the program perform very fast integration in a short time. The program is not described here in detail, only the results are presented, the reader is referred to the documentations of CRISIS2007 v5.5 for further explanation.

For the considered seismic sources and their properties, as mentioned before, the seismic hazard curves for rock site and soil site were obtained at different period values, as shown in figure (9) and figure (10) respectively. The plot depicts the annual rate of exceedance (ARE) of different ground motion level. The reciprocal of ARE is the return period of that ground motion. The plot is read for looking at a particular ground motion for certain return period or ARE.

The plot clearly shows that ARE is higher for lower ground motion level and lower for higher ground motion values. The correct way is to say that when return period increase or ARE decreases the ground motion level increases at a site. Both of the plots show that ARE is higher at T=0.20 sec. Also, ARE is more for soil than rock for a given ground motion level. The effect of soil is higher at longer periods.

5.2 Uniform Hazard Spectrum

5.2.1 Acceleration, UHS

In general, UHS is the representation of SA values at different periods which have a common ARE or return period. It shows demand (inertial) on structures. The present study considered 475 year of return period or ARE = 0.0021, which corresponds to 10% probability of exceedance in 50 years using the Poisson distribution model for the earthquakes occurrences. As stated before that, Poisson model does not have time memory of previous event and treats the each earthquake as an independent event. Since it is a traditional approach in PSHA, it is also used in the present study. Also, pointed out by McGuire (2004) that it is the ARE or return period which is important for hazard analysis not the probability of exceedance in a given year. The Acceleration UHS for soil and rock are obtained by reading the SA values for different periods at a common ARE (0.0021) value, as shown in figure (11) and figure (12) respectively and compared in figure (13).

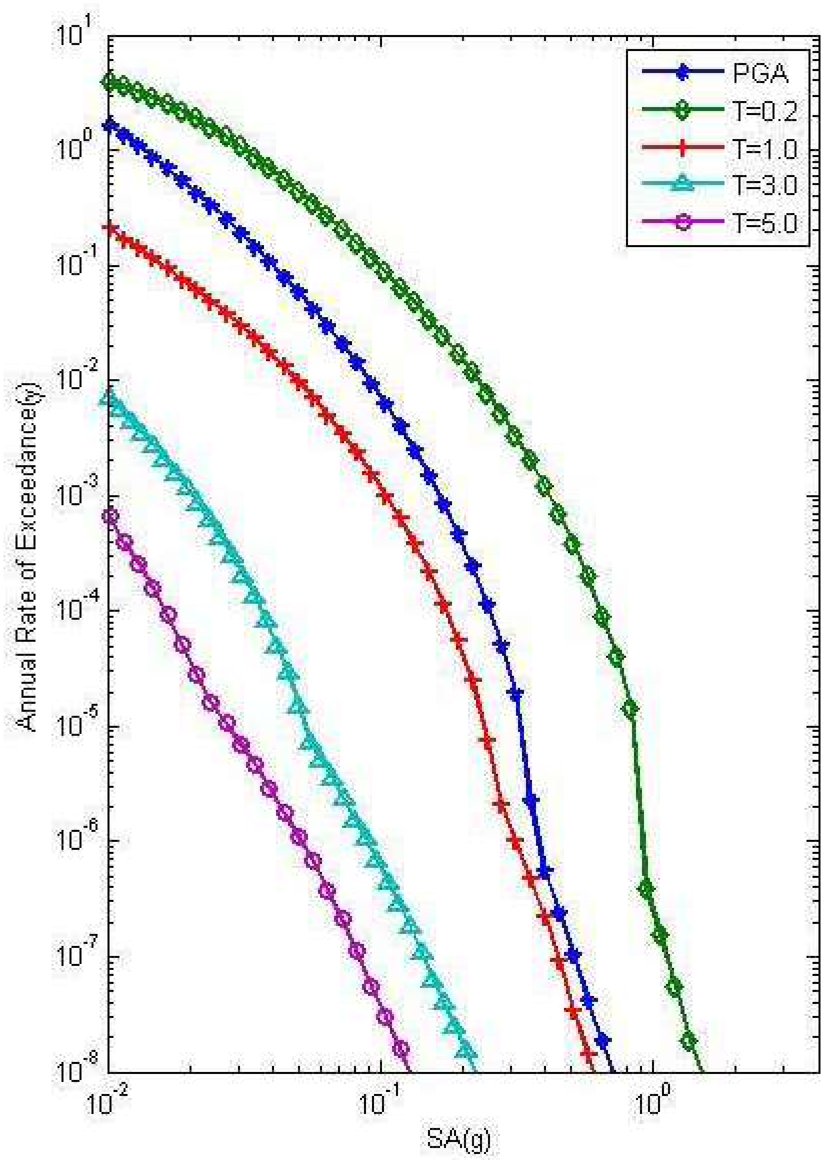

Figure 9: Seismic Hazard Curves for Rock site

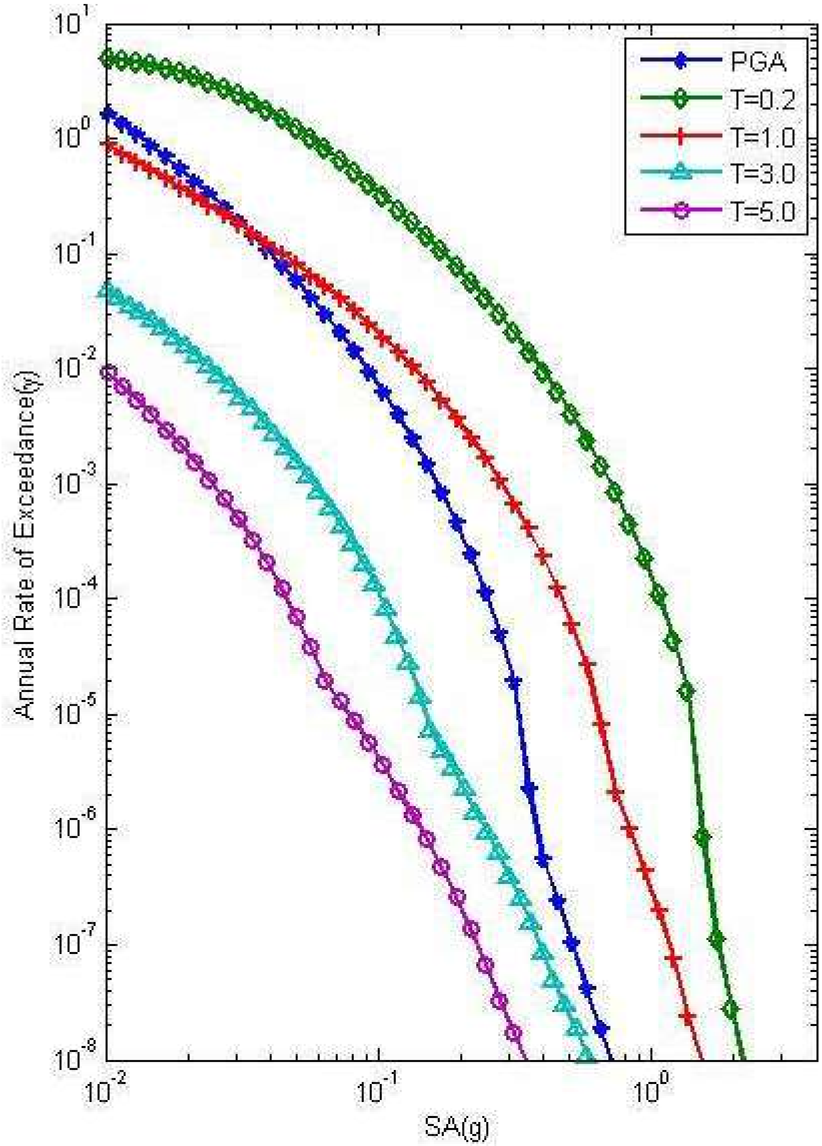

Figure 10: Seismic Hazard Curves for Soil Site

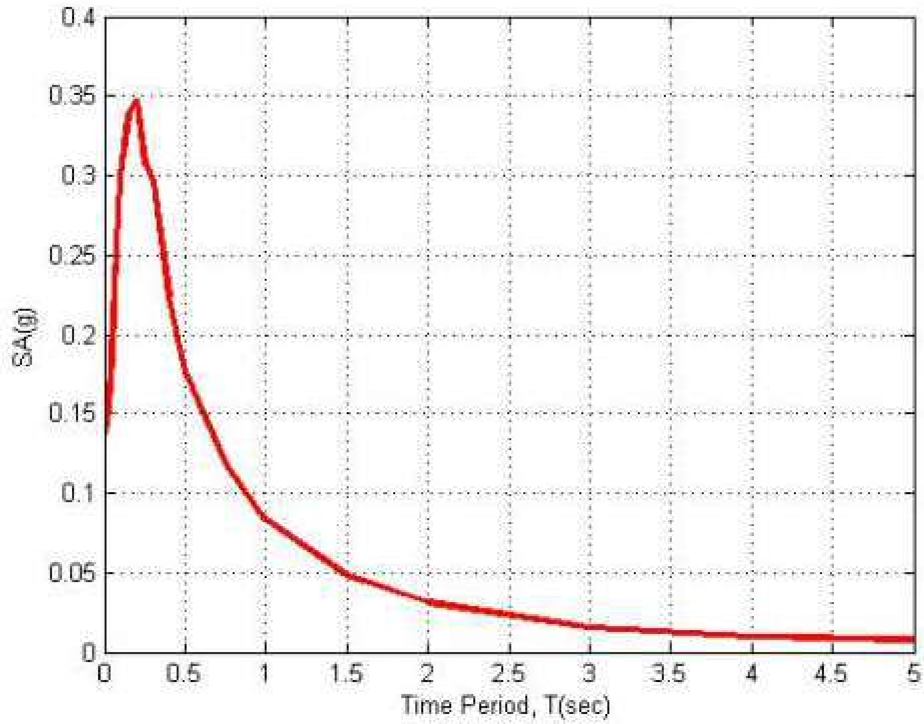

Figure 11: UHS for Rock site

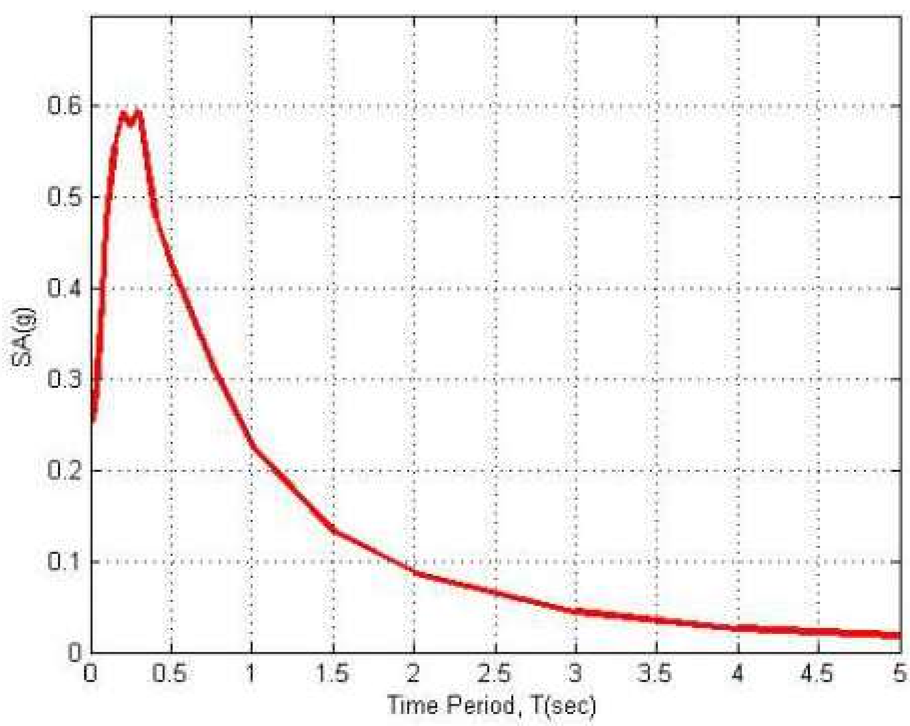

Figure 12: UHS for Soil site

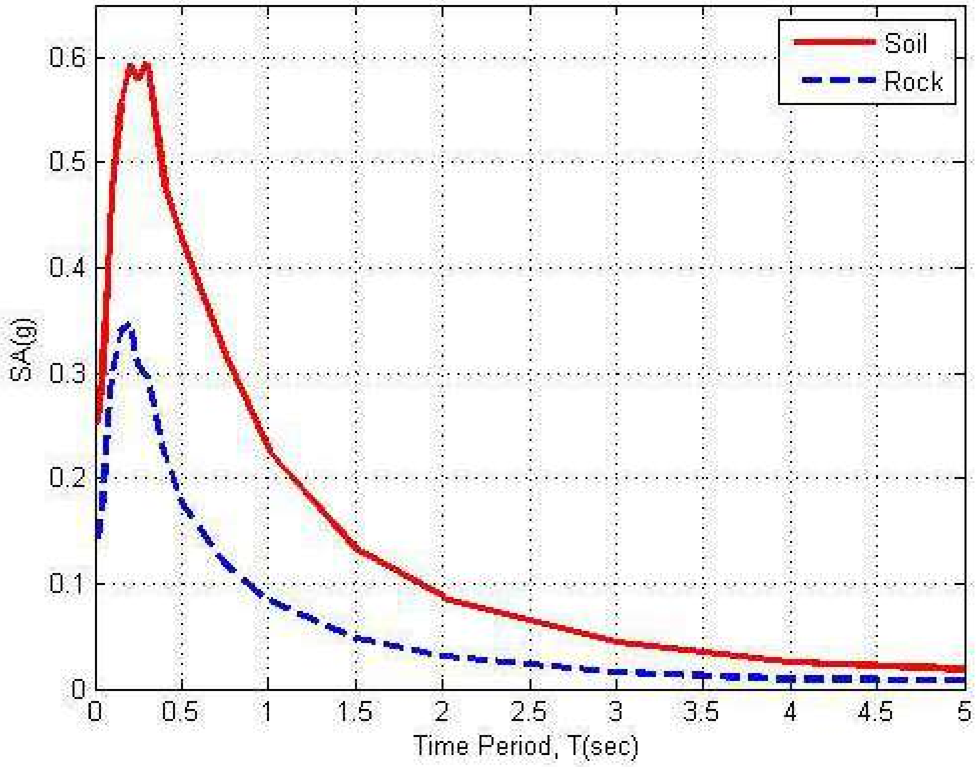

Figure 13: Rock and Soil UHS normalized to PGA = 0.14g of the Rock

The PGA estimated for rock site is 0.14g, while for soil site a value of 0.25g is measured. The PGA on rock is amplified by a factor of 1.8. the amplification is increased by a factor of 2.8 for longer period values. The PGA value on rock site shows a good agreement with the value (0.13g) reported by previous study (Monalisa et al2007) for a site (Muzaffarabad) close to the site of the present study.

5.2.2 Displacement, UHS

UHS are also presented in the form of spectral displacement; which shows displacement demand on different structures. The displacement UHS are obtained from acceleration UHS by using the Pseudo relation between acceleration and displacement; given in equation (14).

$$S_D(T) = \frac{(2\pi)^2}{T^2}.S_A(T) \qquad (14)$$

In this equation $S_D(T)$ is the spectra displacement, and $S_A(T)$ is the spectra acceleration at a period value T. The displacement spectra though obtained are shown in figure (14), for rock site and soil site. The effect of soil on ground motion is clearly shown to be significant in medium and long period range; which is of engineering interest. At very low period values the effect of soil is negligible.

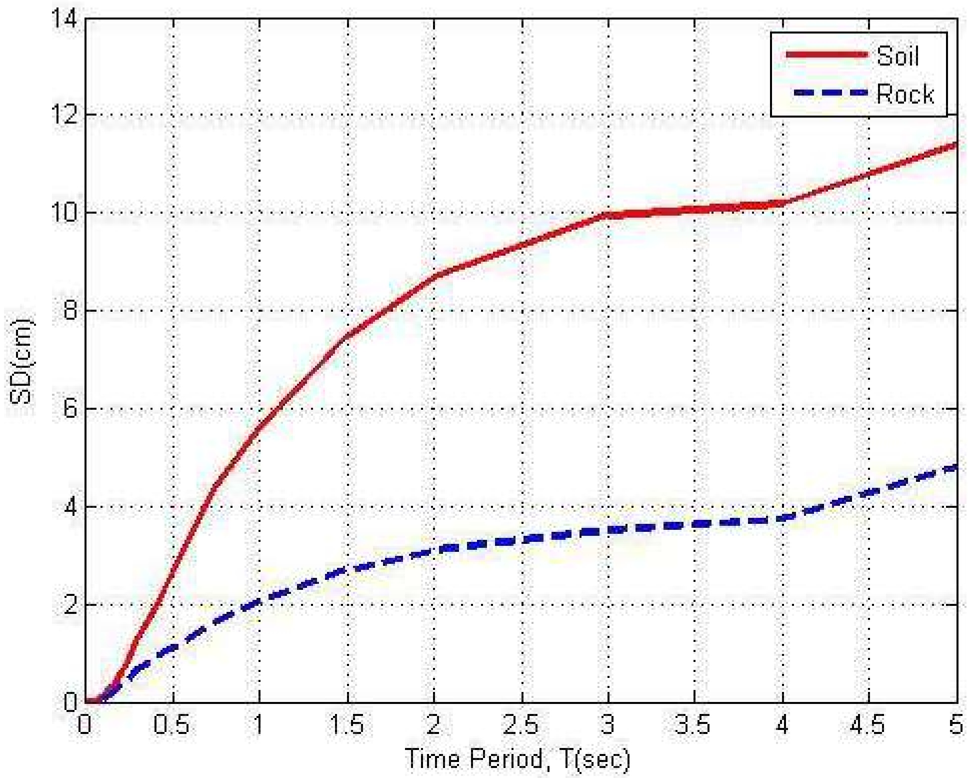

Figure 14: Displacement Spectra for soil and rock site.

5.3 Deaggregation

The final step in any PSHA study is to perform the deaggregation process. It is the decomposition of total hazard of a site into many single scenarios, inorder to know which scenario contribute the most to the hazard for that site. The total hazard gives the combined effect of all magnitudes and distances on the probability of exceeding a given ground motion level for different seismic sources and so, it is difficult to know which source, magnitude, and distance contribute the most to the hazard. The controlling scenario is also important for the time history analysis of the structures.

The deaggregation is performed for the PGA on rock and soil site ata return period of 475 years, as shown in figure (15) and figure (16). On the right side of each deaggregation window, the considered seismic sources (back ground and Fault) and the location of the site is shown with respect to its co-ordinates on the globe.

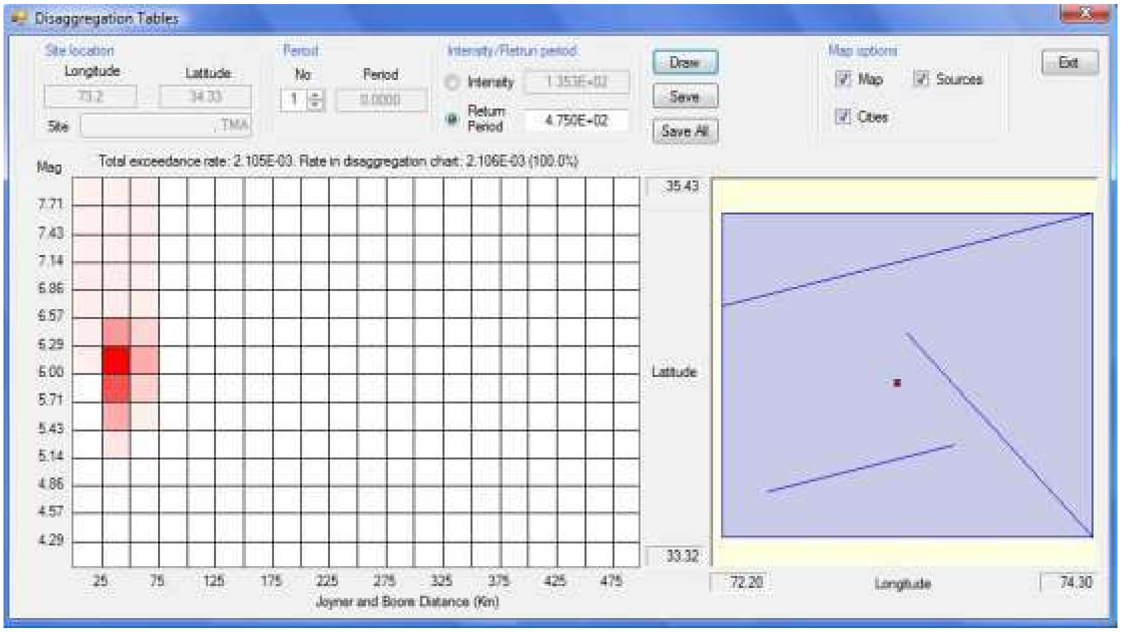

Figure 15: Deaggregation for Rock site

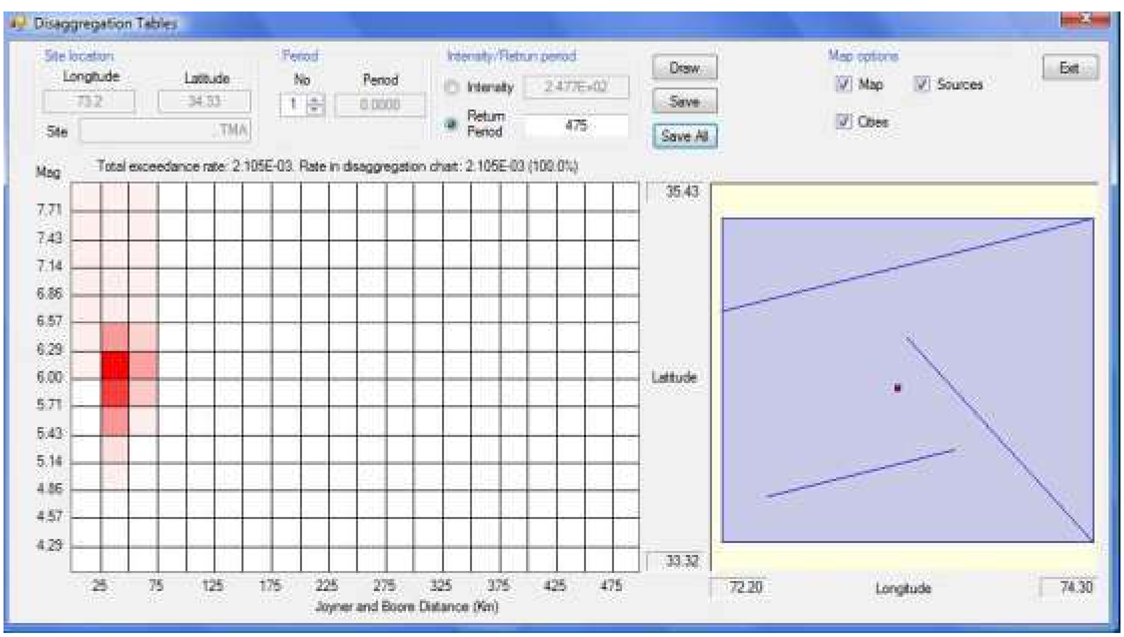

Figure 16: Deaggregation for Soil site

The relative contribution of each scenario is represented by the colour concentration. In both the cases the deaggregation results show that a given earthquake with moment magnitude of 6.0 to 6.30 with a distance between 25 and 50 km governs the total hazard at a site. It means that this scenario contribute the most to the hazard at the site.

This information can be used to look for the earthquake data (accelerogram) having M_W = 6.0, distance less than 50 km, and having PGA values close to 0.14g and 0.25g for rock and soil site respectively. Acceleration Time histories (Accelerogram) having the above mentioned characteristics can be used to perform the time history analysis (elastic and/or inelastic) of the structures for design or assessment.

6 CONCLUSION AND FUTURE DEVELOPMENT

6.1 Conclusion

Most of the PSHA usually conducts the study for the rock outcrop motion and do not consider the effects of sediment directly. These studies calculate the UHS for rock site and then use a constant factor to amplify the rock spectra at all period values. In some cases only the peak ground acceleration (PGA) for rock outcrop is reported in PSHA study. A standard spectral shape is then considered and anchored to the computed PGA at zero period value. This approach results in spectral accelerations which do not necessarily have the same return period or ARE.

Contrary, in the present study, Site specific probabilistic seismic hazard analysis (PSHA) of Mansehra urban area is conducted to compute the uniform hazard spectra (UHS) for acceleration and displacement for 475 year of return period. The acceleration UHS for rock site has a PGA of 0.14g and a maximum spectral acceleration of 0.35g at a period of 0.20 sec. For soil site, PGA of 0.25g and spectral acceleration of about 0.60g at a period of 0.20 sec is obtained. The soil amplifies the PGA of rock site by a factor of 1.8.

Deaggregation is performed for 475 year return period at the site to find out the most contributing scenarios (magnitude, and distance) to the total hazard; this information is used for the design and time history analysis of the structure.

The study used the current state of the practice methodology and the most up-to-date site specific EGMPM; developed for shallow active crust, for the hazard analysis. The study site has Hard rock and alluvial soil condition. The rock site is represented by soil type B, while soil site is represented by soil type D of NEHRP site classification. The values of shear velocity; V_{S30}=960 m/sec for rock and V_{S30}=250 m/sec for soil, were assigned based on the recommendation of BA08.

PSHA is conducted for considering a background source and three simplified fault sources representation. The seismicity is considered within, roughly, 100 km of the site in each direction; which is of engineering interest. Far field seismicity is ignored due to its minor effects at low period of the spectra. The background source used TE distribution model with M_W = 4.0 to 6.5, while the fault sources were assigned with TN model with a characteristic earthquake magnitude of M_W = 7.5 having standard deviation of 0.5. Finally, the results are presented in the form of Total Hazard curve, UHS for acceleration and displacement, and Deaggregation for controlling scenario.

6.2 Future Development

PSHA is a mature field and is used throughout the world for seismic hazard definition at a site for seismic design and assessment purposes. PSHA takes into consideration all the possible future expected scenarios and calculate the characteristic ground motion for a site. The final results of PSHA are highly dependent on the different input (Seismic sources, their characteristics, site characteristics, and EGMPM) to the PSHA model.

The present study considered seismic sources in a very general and simplified form, due to the reasons of high complexity in modelling all the seismic sources in NW Himalayan. Based on previous study experience and recommendation, the range of magnitude is considered arbitrary for each seismic source. In future, even more accurate modelling can be performed to represent all the seismic sources and their characteristics.

The present study classified the site condition as type B soil for Rock and type D soil for sediment based on professional judgement. Although not given in the report, the final results are highly dependent on the site shear velocity. This fact warns to know the actual site condition through site experiments.

The study site does not have an EGMPM of its own. The present study used the model of BA08 which is developed for shallow active crustal earthquakes, using the most intensive and up-to-date seismicity data. Although not so important, the development of an EGMPM for the target site will improve the results.

Most of the uncertainty associated with the computed PSHA can be reduced through the process of logic tree. Logic tree is not performed in the present study and the future work should consider it also.

Looking at all the simplifications and assumptions made for the study, the final results should be used with cautions.

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NDMA Vision Statement

"To achieve, sustainable, economic, social and environmental development in Pakistan through reducing risks and vulnerabilities, particularly those of poor and marginalized groups, and by effectively responding to and recovering from all types of disaster events.

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