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Development of seismic hazard map for shigo kas hydropower project area considering local site effects

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Abstract: This research work aimed for development of seismic hazard map for Shigo Kas hydropower project area based on extensive geophysical and geotechnical investigations. Seismic refraction survey was conducted on the lines at the important structures for the delineation of the subsurface lithology and other geophysical parameters. A comprehensive seismic layout plan consisting of fourteen lines (2.52 Kilometers) was formulated. The geophysical data was processed by computer aided software IXRefrax of Interpex Limited of USA to calculate the exact average velocities of the layers and depth of each layer under NSL. Four hundred meter rotary diamond drilling has been executed to confirm the seismic refraction survey results. The strata properties were used for site response analysis by DEEPSOIL software using ground motion data of Chi-Chi 1999 (TCU 078 EW) earthquake record form PEER data base. The maximum magnitude potential for the identified faults is calculated by Wells and Coppersmith, 1994 relationship. The study indicates that Main Mantle Thrust located 1.5 Km away from intake site with potential of 7.8 magnitude is the most seismogenic source. The shallow crystal earthquake model of Campbell Bozorgnia et al., 2008 has been used. NEES Integrated Seismic Risk Assessment Framework (NISRAF) developed by Sheng-Lin and Professor Elnashai at University of Illinois at Urbana-Champaign, USA has been used for deterministic seismic hazard map in form of contours. The PGA values at intake and power house are 0.50 g and 0.40 g.

Keywords: *Hazard Map; Seismic Refraction Survey; Main Mantle Thrust; Deepsoil; Nisraf*

I. Introduction:

The prediction of earthquake is not possible so far but there are some tools for prediction of earthquake ground motion, which is called seismic hazard analysis. Seismic hazard analysis is basically an estimate of strong ground motion parameters that are Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV) and Peak Ground Displacement (PGD). Seismic hazard analysis is very essential for seismic resistant design of structures and for safety assessment of already constructed structures.

Dams stores enormous volume of water, its failure results in disastrous phenomenon due to flooding. In the past designer used pseudo static analysis with seismic coefficient of 0.1 for incorporation in the design of hydropower projects. This is totally a false approach as several dames in Iran designed with this method failed in earthquakes. The arguments of seismic coefficient of 0.1 are totally obsolete and not safe even in the countries of low seismicity (Martin Wieland 2011). The main reason for invalidation is no existing relationship between seismic coefficient and Peak Ground Acceleration. Furthermore the dynamic characteristic and damping properties of dam cannot be justified by pseudo static analysis because of its simplicity. This concept was rejected after 1971 San Fernando earthquake as the dynamic response and associated damage were not assessed by the pseudo static analysis (ICOLD 2010).

The study area is located in seismically active region of the world (Durreni et al., 2005). The Himalayan region has the potential to produce an earthquake of magnitude 8 in future (W.F. Chin and Charles Scawthorn, 2003). In this study a detail geophysical and geotechnical investigations of the study area has been carried out which is used for the seismic hazard assessment of the project area considering local site effects.

II. Geology of the study area:

The project is located between 34.40 – 35.20 latitude and 71.40 – 72.20 longitude. Stratigraphic sequence of the study area consists of granitic gneiss (Chakdara Granite Gneisses). It is granite with siliceous schist layers on the peripheries. These rocks are medium to coarse grained with association of Schistose Gneisses and Quartz mica Schist phyllitic gneiss. Phyllite and quartzite intercalations have been observed in the study area at higher elevations. Regional geology has been shown in Figure 1.

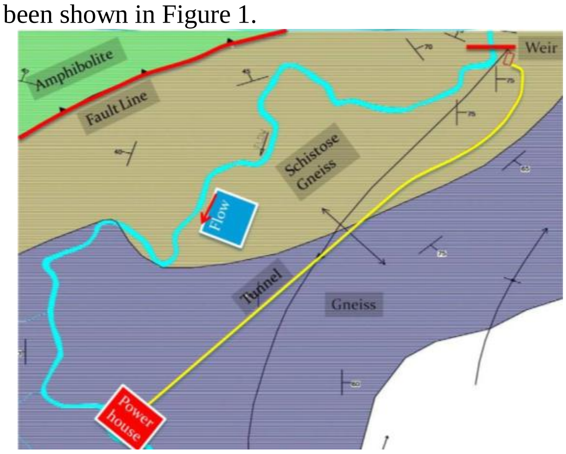

Figure 1: Regional geology of Shigo Kas HPP area

Major rock group of the project area are Granitic gneiss and widely spread along weir, intake area, sand trap, intake of tunnel, along the tunnel and power house areas. In most of the reaches along tunnel, rock of the area is well exposed and widely distributed under thin to thick cover of Secree/Colluviums and terrace deposits.

III. Tectonic Settings of Surrounding Region:

The earth crust is made of 15 crystal faults. These plates move relative to one another and results in the formation of mountains, faults and other geological formations. Pakistan is situated at the boundaries of Eurasian plate and Indian Plate, The Indian plate is moving toward Eurasian plate at a rate of 4-5 cm/year, and is being subducted under the Eurasian plate. The Hindu Kush, Himalayan and Karakoram mountains are formed due to collisions of these two plates. The Upper plate has been broken into faults and thrusts, which results in the formation of Main Mantle Thrust (MMT), Main Karakorm Thrust (MKT) and Main Boundary Thrust (MBT). The Subduction of Indian plate under the Eurasian plate is shown in Figure 2 whereas the tectonic settings of the surrounding region are shown in Figure 3.

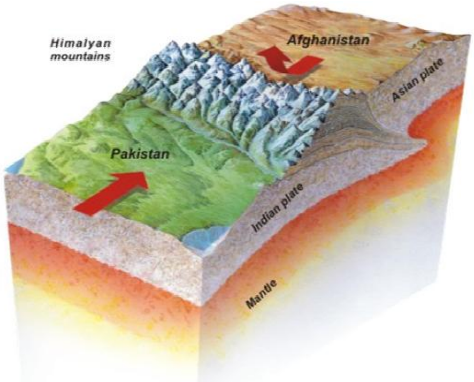

Figure 2: The Indian Plate is being subducted under Eurasian Plate and results in the formation of Himalayan, Hindo Kush and Karakorum mountains (Durrani et.al 2005)

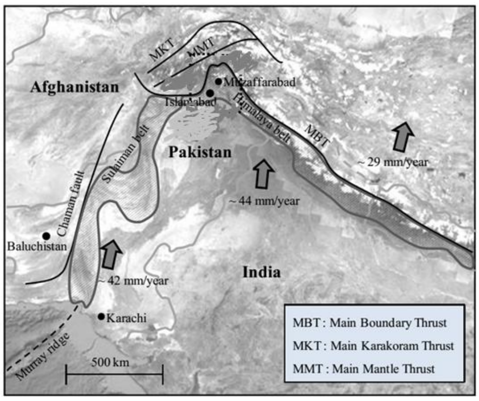

Figure 3: Tectonic plates movement in the surrounding of the project location in (Larson et al.1999 and Bilham 2004)

The study area is located in the seismically active region of the world (Durrani et al., 2005). All the faults in the surrounding of study area has been identified among all these faults MMT is so close to the study region (1.5 km away from intake) and hence most seismogenic and critical. The maximum magnitude for this fault was identified by Wells and Coppersmith 1994 relationship. The resultant magnitude was 7.8 considering half of the rupture length (ICOLD 1989).

IV. Seismic Refraction Survey & Rotary drilling:

The seismic refraction methods are well suited for soil dynamics, site investigation and earthquake engineering purposes. The elastic wave properties of layered profile of soil are determined by this method. Seismic wave velocity, layer thickness and other properties of soil can be easily determined. Seismic refraction survey was conducted on the lines at the important structures for the delineation of the subsurface lithology and other geophysical parameters. A comprehensive seismic layout plan consisting of fourteen lines was formulated. The total length of these lines is about 2520 meter (2.52 Kilometers).

The energy source utilized for generating a seismic impulse at this site was 12 kg Hammer. Three to Five shots were made for each seismic spread in order to make the signals Refract properly from the basement rock. The seismic refraction data for each spread has been processed and evaluated for positioning & elevation of each geophone. The arrival times are subsequently interpreted for all five shots i.e. beyond end forward & reverse Shoots, forward and reverse shots and center shots. The geophysical data was processed by computer aided software IXRefrax of Interpex Limited of USA to calculate the exact average velocities of the layers and depth of each layer under NSL. The velocity analysis of the seismic data shows that the two top layers slightly differ in velocity at weir and power house sites but velocity of bed rock varies significantly as it encounters. The study reveals that at intake location two lithological layers have been interpreted. Only thin layer of weathered bedrock or compact overburden has been interpreted. P-wave velocity range 1000 – 2275 m/sec constitutes the first layer composed of compact overburden / weathered bedrock along seismic lines at intake. The thickness of the surface layer along all lines is mostly shallow. The second interpreted layer is sound bedrock having velocity range 2600 – 3700 m/sec.

Three lithological layers have been interpreted at powerhouse location. P-wave velocity range 612 – 912 m/sec constitutes the first layer composed of loose overburden (Silty, Sandy clay / gravel & boulders).The second interpreted layer is compact overburden / weathered bedrock having velocity range

1200 – 2222 m/sec. The third interpreted layer is sound bedrock having velocity range 2165 – 3475 m/sec. The corresponding P wave velocities have been converted to S wave velocities by well known formula developed by Carroll (1969). The proposed relationship is valid for rock site having compressional wave velocities upto 6000 m/s. The Carroll (1969) formula has been given in equation 1.

$$VS = 0.756090\ Vp^{0.81846} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

The velocity can be expressed in Km/sec and the density range for the rock is 1.6 to 2.7 g/cm. The finalized seismic velocities of different refractors were categorized into three zones, as defined in the Table 1. The Figure 4 and Figure 5 show the geophysical and geotechnical layout plan at intake and powerhouse locations. The boreholes/drill hole was done by rotary diamond drilling on the lines of seismic refraction survey. Total 400 m drilling has been done at 10 locations.

In-situ testing in the boreholes was carried out on regular intervals. The waxed core samples from the rock strata were preserved as per requirement of the study and have been evaluated for percentage extraction, coefficient of rock quality (RQD) and natural density of rock and soil samples.

Based on above mentioned experimental tests overall project area has been divided into 2 lithology layers, the upper most having average depth of 2 to 3 meters and composed of medium to course gravels of igneous and metamorphic origin, milky white, greenish and grayish in colour. The second lithology layer was sound bed rock found beneath the top overburden layer and Quartz, mica and Schistose Gneiss are major components found.

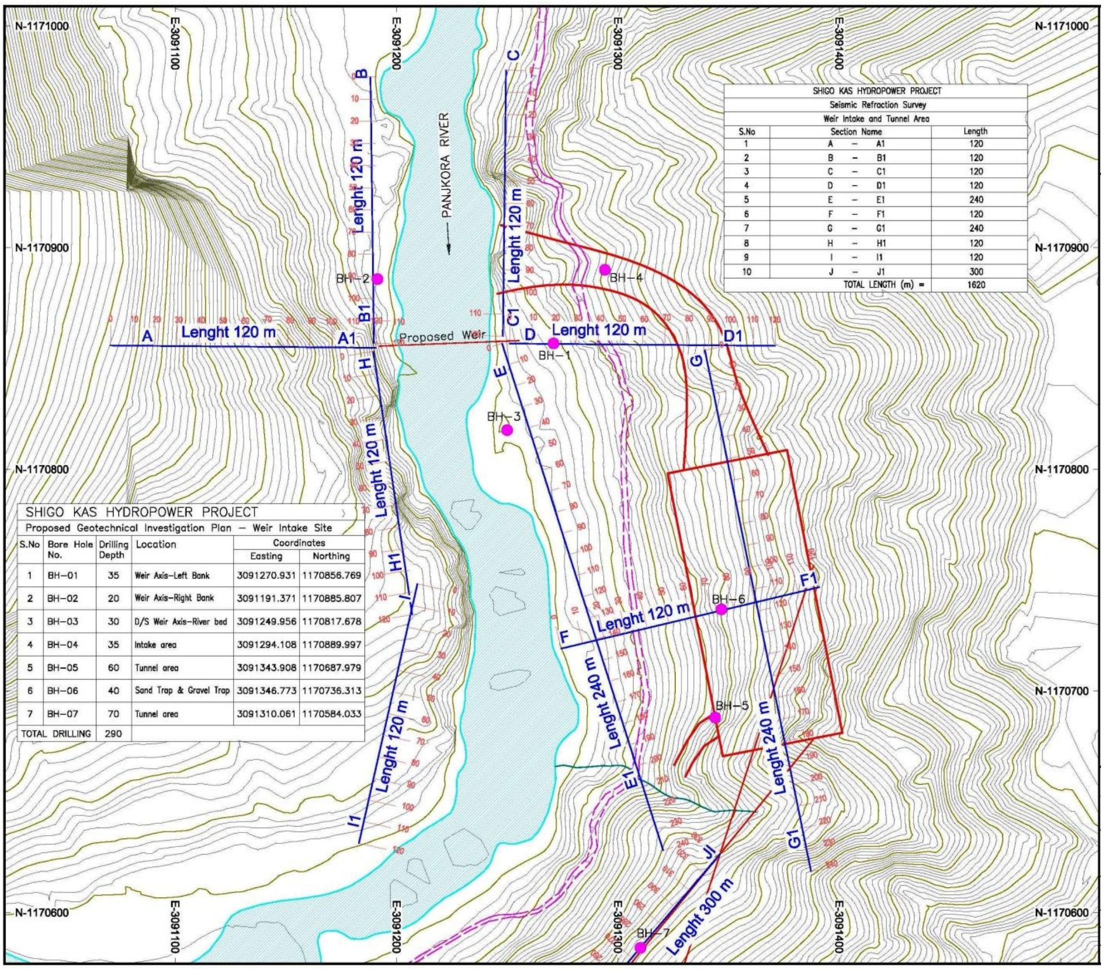

Figure 4: Seismic layout plan at intake of Shigo Kas HPP

TABLE I. Ranges of Seismic Wave Velocities Representing Seismic Zones & interpreted Subsurface Lithology

Structure	**Zone Numbe**	***Range of Seismic* Velocities (Vp)**	***Range of Seismic* Velocities (Vs)**	**Interpreted Subsurface Lithology**
Weir Site	1	1000 - 2275 m/sec	756 - 1482 m/sec	Compact Overburden / Weathered Bedrock
	2	2600 - 3700 m/sec	1653 - 2206 m/sec	Sound Bedrock
Power House Site	1	612 - 912 m/sec	506 - 701 m/sec	Overburden: (Silty sandy Clay Mixed with gravel & Boulders)
	2	1200 - 2222 m/sec	878 - 1453 m/sec	Compact Overburden / Weathered Bedrock
	3	2165 - 3475 m/sec	1423 - 2096 m/sec	Sound Bedrock

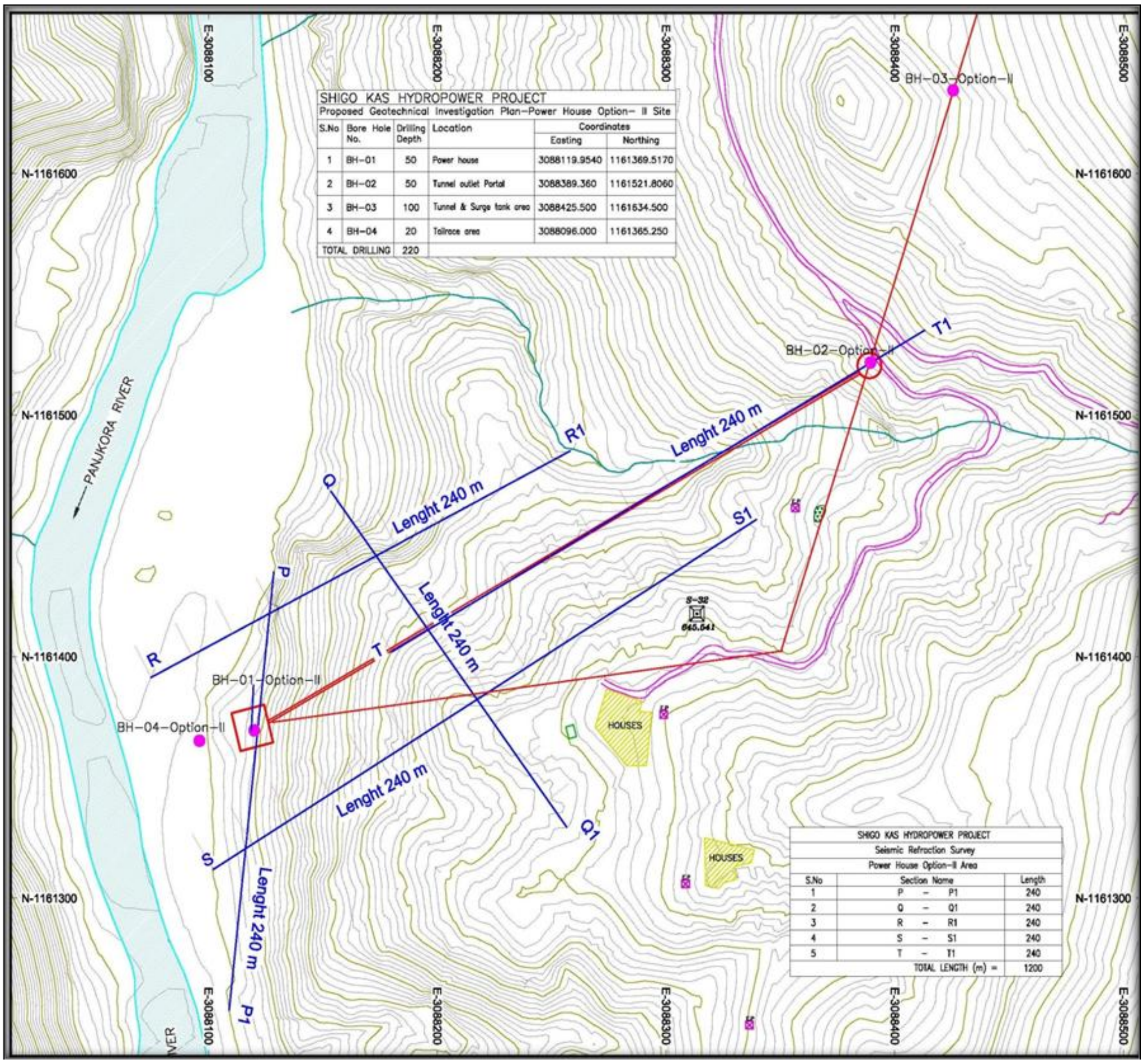

Figure 5: Seismic layout plan at power house of Shigo Kas HPP

V. Site response analysis:

Site response analysis evaluates the effect of ground motion at the overlaying soil layers above bed rock. In this study for Site Specific Response Analysis DEEPSOIL Version 5.1 software (Hashash 2008) has been used. 1-D equivalent linear approach has been utilized. Since soil behave non linear behavior but to know its characteristic is complicated process. Therefore the linear approach of ground response analysis has been modified to achieve more accurate results of site response analysis (Kramer-1996).

Seismic refraction survey has been performed at different locations of the project site and shear wave velocity and other characteristic of the soil profile were obtained. The results were then confirmed by drilling at those sites. The soil profile, shear wave velocity and Modulus and damping ratio curves of Schnabel et al., 1972 for gravel and rock were then entered in DEEPSOIL.

Strong motion data record for Pakistan is not available therefore Chi-Chi 1999 (TCU 078 EW) earthquake record form PEER data base has been selected based on the guidelines of Kim and Elnashai 2009. The acceleration time history of Chi-Chi (TCU 078) has been shown in Figure 6. Due to effect of rocky strata the overall amplification was not so considerable and therefore ignored.

VI. Hazard Map Development:

NEES Integrated Seismic Risk Assessment Framework (NISRAF) has been used for development of Hazard Map. The software is used for multiple purposes like seismic hazard analysis, hazard map development and risk assessment of structures. In this study it has been used for hazard map development. For hazard map development, NISRAF require the site response analysis file by DEEPSOIL, Study region coordinates, the scenario event parameters and the attenuation equation.

Site response analysis for the intake and power house locations have been performed by DEEPSOIL and the resultant file were exported to NISRAF. MMT is considered out to the scenario event which is 1.5 km away from intake location and having a magnitude potential of 7.8. Cotton et al., 2005 guidelines has been used for suitable attenuation model selection for the study region. Pakistan has not yet prepared any attenuation model due to lack of ground motion data. Campbell Bozorgnia et al., 2008 next generation attenuation equation have been selected which has been made from PEER data base. Based on above geophysical and geotechnical investigations site class B boundary condition NEHRP a classification system has been used. The shear wave velocity $V_{s,30}$ has been used is 1200 m/s.

The other parameters for CB08 has been $Z_{2.5}$ and Z_{tor} which represents the depth where shear wave velocity reaches upto 2.5 km/sec and depth and Z_{tor} is the depth up to the top The nearest point of the projection of MMT was used as epicenter which is (34.780^o N, 71.920^{o}E). The analysis was successfully performed and the hazard map has been generated which has been shown in Figure 7. The PGA value at intake and powerhouse location is 0.50 g and at powerhouse 0.40 g.

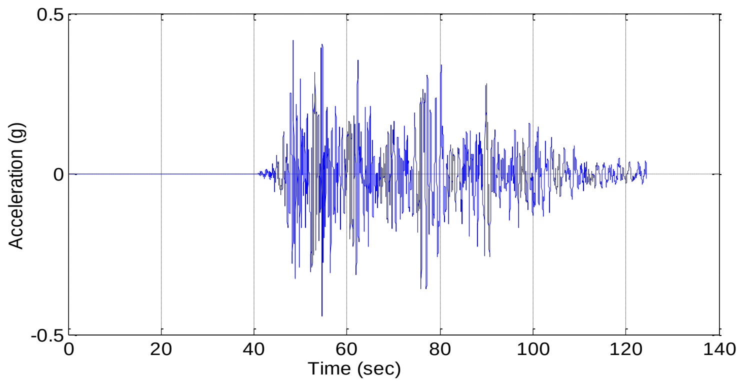

Figure 6: The acceleration time history of Chi-Chi earthquake measured at TCU 078 station (PEER Data Base)

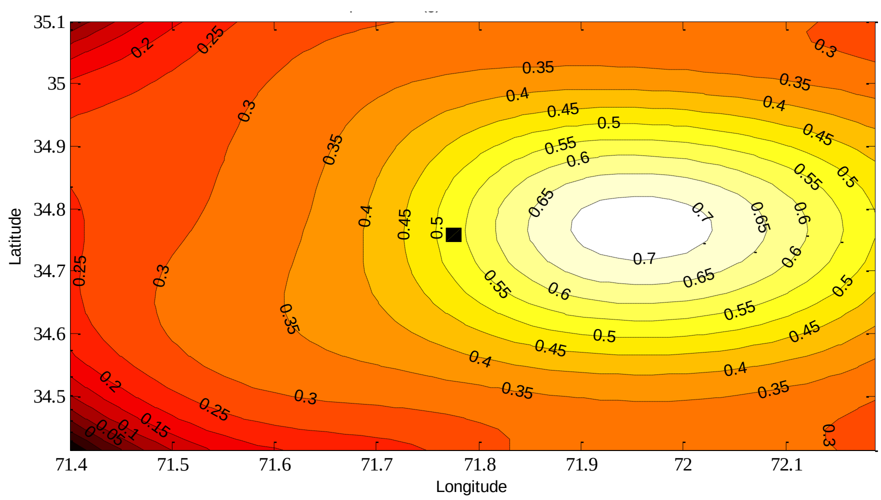

Figure 7: Hazard map for Shigo Kas HPP in terms of ground acceleration (g).

VII. Conclusion:

The proposed area of Shigo Kas HPP is characterized by high seismic activity. The scenario hazard map has been prepared by NISRAF software. The nearest point on the projection of Main Mantle Thrust has been used as epicenter with maximum magnitude potential of 7.8. The local site effects have been incorporated by analyzing the geotechnical and geophysical properties of 10 boreholes and 2.5 Km seismic refraction survey. The PGA values obtained at intake and powerhouse locations of Shigo Kas HPP are 0.50 g and 0.40 g. The overall surrounding area has been represented by contour map of 0.05 g contour interval. It was found that the amplification obtained was considerably low due to absence of soft soil.

VIII. References:

[1] Bilham, R [2005], "The Kashmir Earthquake". Web report: http://cires.colorado.edu/~bilham/kashmir%202005.htm

[2] Bonilla, M.G., Mark, R.K and Lienkaemper, J.J.[1984] "statistical relations among earthquake magnitude, surface rupture length and surface fault displacement", Bull. Seism.Soc.Am 74, 2379-2411.

[3] Boore, D.M., Atkinson, G.M. [2008] "Ground Motion Prediction Equations for the Average Horizontal Component of PGA, PGA and 5% Damped PSA at Spectral Periods between 0.01s and 10.0s" Earthquake spectra, Vol 24, No. 1, pages 99-138.

[4] Boore, D.M [2010]," Ground Motion Prediction Equations (GMPEs) from a Global dataset: the PEER NGA equations.

[5] Building Code of Pakistan (Seismic Provisions –2007), Government of Islamic Republic of Pakistan Ministry of Housing and Works, Islamabad, 2007.

[6] Campbell, K. W. and Bozorgnia, Y. (2008). "NGA ground motion model for the geometric mean horizontal component of PGA, PGV, PGD and 5% damped linear elastic response spectra for periods ranging from 0.01 to 10 s." Earthquake spectra 24(1): 139-171.

[7] Campbell, K. W. and Bozorgnia, Y. (2008). "NGA ground motion model for the geometric mean horizontal component of PGA, PGV, PGD and 5% damped linear elastic response spectra for periods rangin from 0.01 to 10 s." Earthquake spectra 24(1): 139-171.

[8] Hashash, Y.M.A. 2002-2008 "1-D non-linear and equivalent linear wave propagati on analysis program for geotechnical seismic site response analysis of soil deposits" University of Illinois at Urbana Champaign USA.

[9] ICOLD [1989], "International Commission on Large Dams, Guidelines for selecting seismic parameters for large dams, Paris".

[10] Lin, S.-L. 2010. An Integrated Earthquake Impact Assessment System, Ph.D. dissertation, Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, IL.

[11] Nowroozi, A.A [1985] "Empirical relation between magnitude and fault parameters for earthquakes in Iran",Bull Seism.Soc.Am 75,1327-1338.

[12] Scordilis, E.M., [2006], "Empirical global relations converting Ms and Mb to moment magnitude" Journal of Seismology Volume 10, pp 225-236.

[13] Slemmons, D.B., Bodin, P. and Zhang, X. [1989]" determination of earthquake size form surface faulting events,' Proc. Inter. Seminar on Seismic Zoning China.

[14] "Seismic Hazard Analysis and Zonation of Azad Kashmir and Northern Areas of Pakistan", by Pakistan Metrological Department and NORSAR Norway, August 2006.

[15] "Seismic Hazard Analysis for the cities of Islamabad and Rawalpindi", by Pakistan Metrological Department and NORSAR Norway, February 2006.

[16] PhD dissertation by Shahzada .2011. "Seismic risk assessment of buildings in Pakistan (Case study Abbottabad city)" University of Engineering and Technology Peshawar, Pakistan.

[17] T.G Sitharam and P. Anbazhagan [2006] "Seismic Hazard Analysis for the Bangalore region", Natural Hazards 2007, 40: 261.