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Deterministic Seismic hazard Assessment of Karora Hydro Power Plant

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Abstract — *Northern Pakistan is well known for its active fault system and seismicity. Thus to prior to any investment in developing certain facility a through seismic analysis is unavoidable to justify the investment. The chosen location for Karrora Hydro Power is District Shangla in the north of Pakistan, and thus a "Seismic Hazard Analysis" was inevitable for this facility.*

To evaluate the seismicity of the site data about characteristics of seismic faults was gathered from Provincial Disaster Management Authority Punjab (PDMA). Source to site distance was calculated by delineating the geographical location of the faults and Weir using QGIS. Similarly, for site characterization borehole data from seven boreholes, drilled at the target site, was used. The average values of shear wave velocity are above 800 m/sec at all the locations.

Different attenuation relationships were adopted to calculate the Peak Ground Motion (PGA) at the target site, with the equation of Akkar & Bommer (2013) providing more realistic results for the Active Shallow Crustal Region (ACR). Among various PGA values corresponding to different active faults Main Mantal Thrust (MMT) has a maximum PGA of 0.35g. Akkar & Bommer (2013) is used to compute Response Spectrum for all the active faults and MMT. "Time History Scaling" was performed, using wavelet method, for the target spectrum of MMT.

A. INTORDUCTION

Geographically Pakistan lies in the south Asian region between 23° and 37° north latitude and 60° and 76° east longitude and stretches over 1600 KMs from southwest to northeast. Pakistan has an estimated hydel potential of more than 40,000 MW, most of which lies in the province of Khyber Pakhtunkhwa. It is unfortunate that major portion of this hydel potential is still not utilized which needs to be harness. At the moment, the total installed hydel capacity in the Pakistan is about 10127 MW, out of which 5790 MW is in the province of Khyber Pakhtunkhwa, 2386 MW in Azad Jammu & Kashmir (AJK), 1802 MW in Punjab and 151 MW in the province of Gilgit Baltistan. Similarly, various hydropower projects of total approximate capacity of 8518 MW are currently under construction in the country.

Energy is critical for the progress of the countries not only for social development and human welfare but also as a reagent for overall development. Energy in the form of electricity provides the basic infrastructural input to the national economic growth. The per capita electric consumption is considered as an index of a nation's progress and development. Pakistan's per capita electric consumption is 471 KWh as compared to the average per capita consumption of the world 3127 KWh *(retrieved from https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC)* which is on the much lower side that needs to be rapidly improved.

Chronic shortage of electric power has been faced by Pakistan in the recent years. The gap between demand and supply from the national electric power stations is increasing day by day and reaches a maximum of 7500 MW in the months of June to September. The power generation authorities are striving hard to narrow the gap, by installing thermal power stations with steam and gas turbines as well as combined cycle units. These power generation stations are not only expensive but also not convenient to rely upon, due to continually increasing cost of fuel and exhausting resources. Water is the primary source, cheap and abundantly available source of energy in Pakistan. The shortage of energy can be minimized by exploring small and medium hydel projects in the country and especially in the Khyber Pakhtunkhwa Province.

The proposed Karora HPP is a run of river scheme on Khan Khwar approximately 300 m upstream of village Kuz Kana in Shangla District. The project is nearly 25 km from Besham which is about 225 km from Islamabad. The proposed weir site is located at latitude 34º 55' 21" North and longitude 72º 45' 25" East while the powerhouse is located 5.2 km downstream of the proposed weir site near Ranial village. Karora HPP is accessible through fairly good condition Besham–Mingora road upto Karora village and fair condition single metaled road from Karora village to Kuz Kana village near the weir site. The power generation capacity of the Karora HPP is 11.8 MW.

Earthquakes are generally caused by the release of accumulated stresses in the earth's crust. These stresses build up due to crustal deformation resulting from the movement of continental plates and are released along faults causing rupture of the crust. Therefore, the occurrence of earthquakes is not merely a random phenomenon but is governed mainly by elastic and tectonic processes. Location map of Project site with respect to Seismic Hazard is shown in Figure-1.

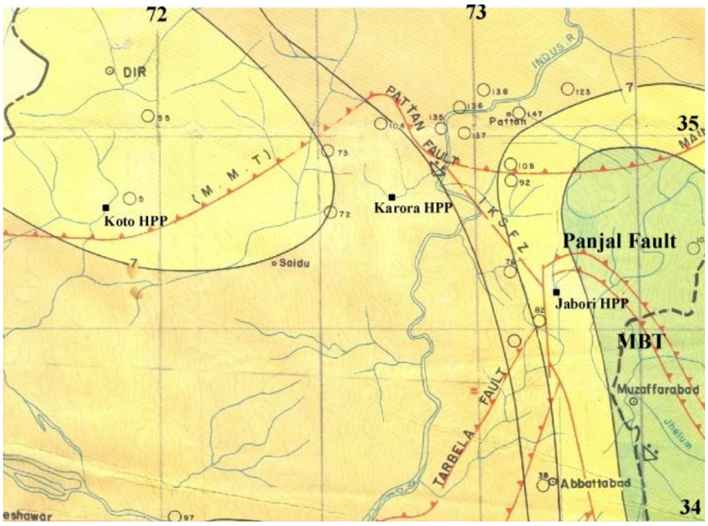

Figure-1 Location Map of Karora HPP Site, Khyber Pakhtunkhwa

According to Basin Architecture Map shown in Figure-2 and Tectonic Map of Pakistan and Northern Areas shown in Figure-3, the site is located in a highly seismically active area affected by the continuing northward drifting of the Indian plate and its subduction below the southern flank of Eurasian plate. The collision of the two plates began about 50 million years ago and the full contact between them was completed about 40 million years ago. Yet the Indian plate keeps on slowly drifting northward. As the Indian plate subducts below the Eurasian plate, its top surface layers get "peeled off" and folded back. This has resulted in the production of a crustal accretion wedge, the Himalayan Range, and this deformation is continuing at the rate of about 2-4 cm per year. The accreted wedge is made up of continental crust and is separated by a general plane of decollement or separation along weak strata. The geology in this corner of the Indian plate is very complex and a biaxial state of stresses in the crust has created sharp bends and closed arches of faults called syntaxes.

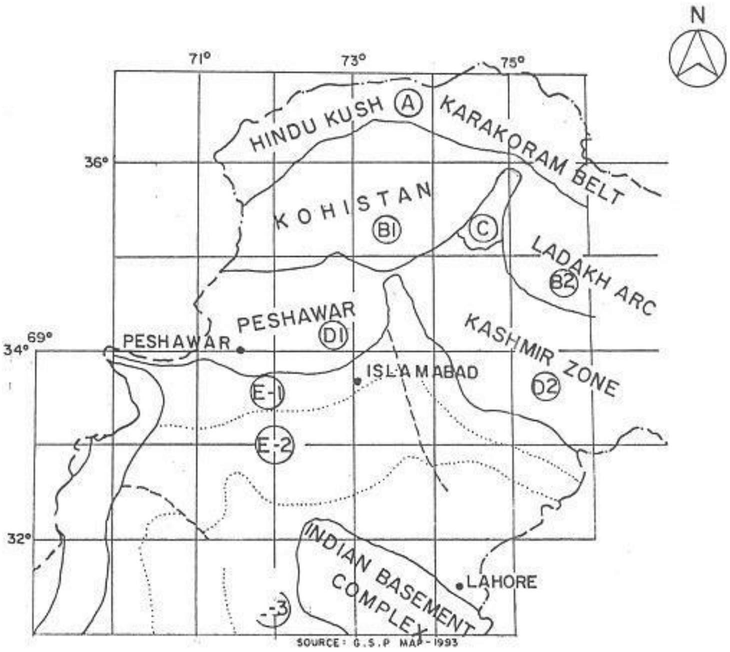

Figure-2 Basin Architecture of Pakistan

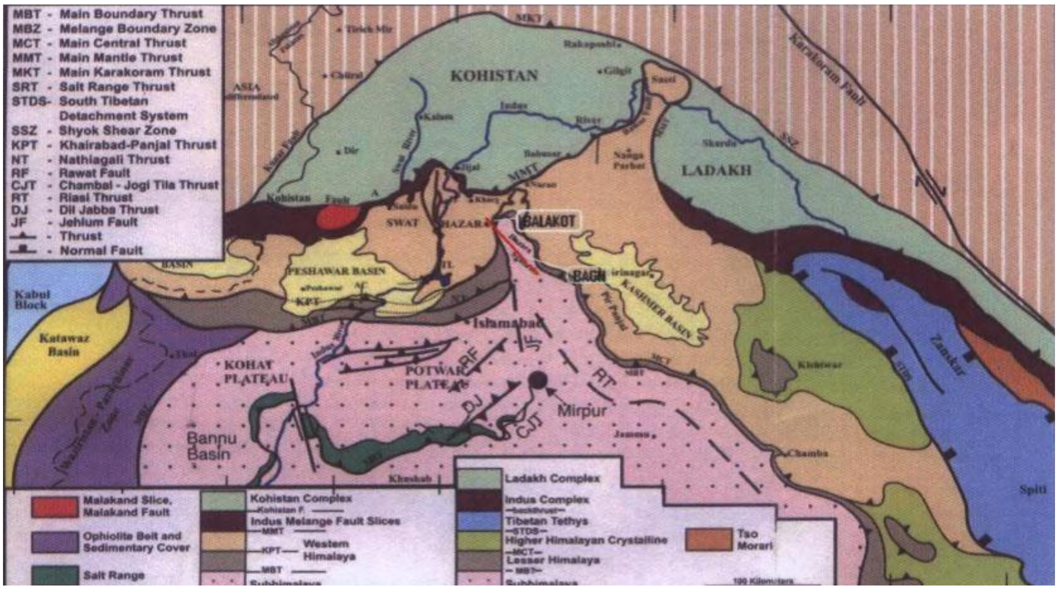

Figure-3 Tectonic Map of Northern Pakistan

The geotectonic of the whole region is therefore related to the collision of the Indian tectonic plate with the Eurasian Plate and subsequent formation process of the Himalayan ranges. This intercontinental collision has resulted in intense deformation with complex folding involving strike-slip and thrust faulting and crustal thickening, expressed as a series of thrust faults accompanied by a continental subduction process. This tectonic process is the origin of the seismicity along the Himalayas and in particular where Northern Pakistan and Kashmir are located. The major regional faults, related to the intercontinental collision, include Main Karakorum Fault (MKF), Main Mantle Thrust (MMT), Punjal Thrust (PT), Main Boundary Thrust (MBT), Main Frontal Thrust (MFT) and Salt Range Thrust. The Karora hydropower plant site is, however, located in the sub Himalayas close to the Kashmir Thrust, considered to be an extension of Main Frontal Thrust (MFT) / Himalayan Frontal Thrust (HFT), which is active and a source of a large number of destructive earthquakes.

The above discussion indicates that the project site is located in an area where crustal deformation is an active process due to presence of some major active faults in the region, and it is, therefore, imperative to carry out seismic hazard evaluation for safe design of the various project structures and equipment.

B. INPUT DATA

To compute Peak Ground Acceleration at a particular site, by using Deterministic Seismic Hazard Analysis, it is an unavoidable prerequisite to have information about the significant Earthquake Sources, information about source to site distance and data about the target site condition. The Source Information is necessary in a sense that a Source more likely to cause severe shaking at the site should be identified, similarly, the source to site distance have effect on Earthquake Waves in form of attenuation. The site characteristics are of particular importance for soft soil, as soft soil amplifies the Earthquake Waves and might make the condition worse through local resonance.

C. SEISMIC SOURCES

To identify the significant seismic sources, it was essential to have an idea of the physical location of the Karrora Hydro Power with respect to its surrounding. This purpose could be best met by plotting the location the Weir on Global Map using Geographical Information System (GIS). The coordinates of the Weir were obtained using GPS and the same were input to GIS to plot the location of the Weir.

After delineating the weir's location, the areas in the near vicinity of the target site could be easily identified. The data about seismic sources of Pakistan is quite sparse, however, the faults data, in form of GIS shape file was obtained from PDMA Punjab, which reports the active faults and separation zones (blind) in the Northern Regions of Pakistan. This shape file was uploaded to our GIS file and two buffers (50 Km and 100 Km) were drawn to mark the locations of the faults near by the Target Site. The faults in those buffers were clipped and their details drawn from rest of the data for the purpose of further analysis.

To get a rough idea about the activeness of these faults Earthquake data obtained from ISC catalogue (from 1905 to 2018) was plotted on top of the faults to identify the faults with more epicenters. It clearly shows events parallel to non for the predicted and expected blind zones. As the data of PDMA Punjab is quite rudimentary, however, still it is the most detailed source present at hand.

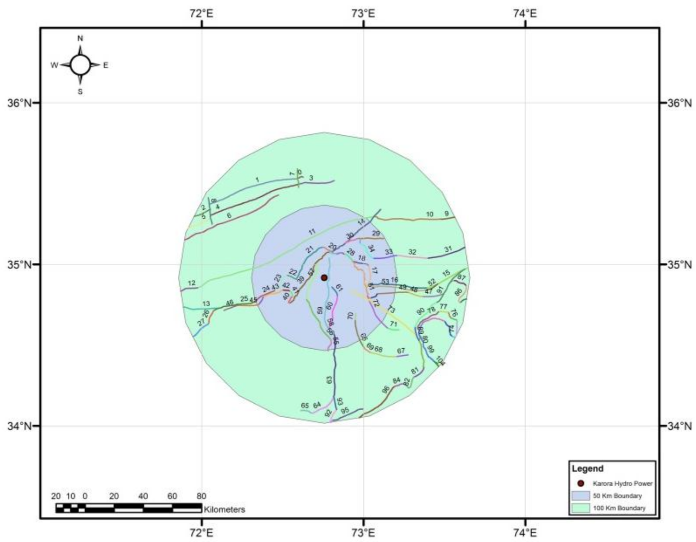

Figure-4 Earthquake producing sources around Karora

D. Source to Site Distance

As mentioned previously, source to site distance "D" is one of the major inputs for computing PGA, and thus the source to site distance of the selected faults was calculated using a measuring tool on QGIS. Efforts were made to obtain the optimum shortest distance between the particular fault and the weir location. Although the Hydro Power consists of different structures located at different locations in the vicinity of the weir, but still the all the distances were calculated from faults to weir location. The difference between the final results is insignificant if distances to each of the structures are calculated separately.

Site characteristics:

To obtain Idea about the Earmarks of site Seven Boreholes were made throughout the Hydro Power site. The Site is mostly rocky with a few meters of clayey overburden layers. However, the depth of soft layer is so insignificant that the shear wave velocity is still above 800 m/s thus exempting the need for site response analysis. Moreover, due to shallow rock outcrops the foundations for different structures are to be laid directly at the rocks.

Analysis:

To compute the PGA values at the target site a proper attenuation relationship should be adopted. The attenuation relationships recommended by (STEWART ET AL) for active shallow crustal regions (ACR) were used. The inputs in form Fault's Magnitude, Epicentral Distance and Shear Wave Velocity were used. The Fault Magnitude was calculated from the fault's length. Besides PGA values, the response spectra corresponding to each fault was obtained. This response spectrum was further used to obtain the "Matched Earthquake Time History" for our case.

Magnitude:

Different models are available to anticipate the magnitude of a fault. Two such models are that of Wells & Coppersmith and Toecher's Formula. Both models were used to anticipate the Magnitudes of the selected faults based on the rupture length, however, the well & copper smith model being more advanced and compatible with the empirical results was used in the final calculations. The calculation from Toecher's formula was used mere for comparison.

With regards to rupture length, if the rupture length of a fault is not known then half the length of the fault should be used for calculating magnitude in case of Hydro Power (ICOLD Specification). The rule of selecting 50% of the total fault's length as a rupture length is flexible subjected to the total length of the fault, say, for faults with very short length can rupture fully easily as opposed to faults with longer total lengths.

S. No.	Fault Name	Length (M)	Distance (M)	Wells & Smith	Toechr
1	Banna Fault	74.72	39	6.75	7.23
2	Baraul Fault	18.30	86	6.10	6.62
3	Batal Fault	28.93	91	6.31	6.82
4	Chakesar Fault	50.66	3	6.57	7.06
5	Chawa Fault	22.44	29	6.19	6.71
6	Darband Fault	72.37	46	6.73	7.22
7	Dir Thrust	93.46	65	6.85	7.33
8	Gandhar Fault	49.11	94.5	6.55	7.05
9	Kaghan Fault	59.59	71	6.64	7.13
10	Kalam Thrust	98.02	71	6.87	7.35
11	Kamain-Patas Fault	90.78	35	6.84	7.31
12	Kamila Shear Zone	243.45	28	7.29	7.74
13	Kandar Fault	30.86	10	6.34	6.85
14	Kishora Fault	105.50	9	6.91	7.38
15	MBT	134.49	80	7.02	7.48
16	MMT	258.16	38	7.32	7.77
17	Nandihar Fault	31.71	34	6.35	6.86
18	Pakhli Fault	51.31	36	6.57	7.07
19	Panjal Fault	98.76	75	6.88	7.35
20	Puran Fault	66.25	9	6.69	7.18
21	Shahai Fault	79.00	65	6.77	7.25
22	Shekdar Fault	41.38	36	6.47	6.97
23	Shergarh Sar Fault	45.35	44	6.52	7.01

Table 1: All values are in Km. D is source to site Distance, while Length represents Length of the Fault.

Peak Ground Acceleration:

STEWART ET AL recommended three equations for Active Shallow Crustal Region one of them is that of AKKAR & BOOMAR ET AL2010, however, an updated version of this model is AKKAR & BOOMAR 2013 which was used instead of 2010 to compute the PGA values at the site along with the response spectrums for different faults. The equation takes inputs in form of Magnitude, Source to Site Distance, Shear Wave Velocity and Fault's Mechanisms. Different empirical coefficients of the equation are available for using three different kinds of Source to Site Distances i.e. Epicentral Distance, Rjb and Hypocentral distance. We used Epicentral Distances calculated from GIS and the data of Fault's Mechanisms as provided by the PDMA Punjab. The Maximum reliable PGA value obtained was 0.35g for Main Mantle Thrust (MMT).

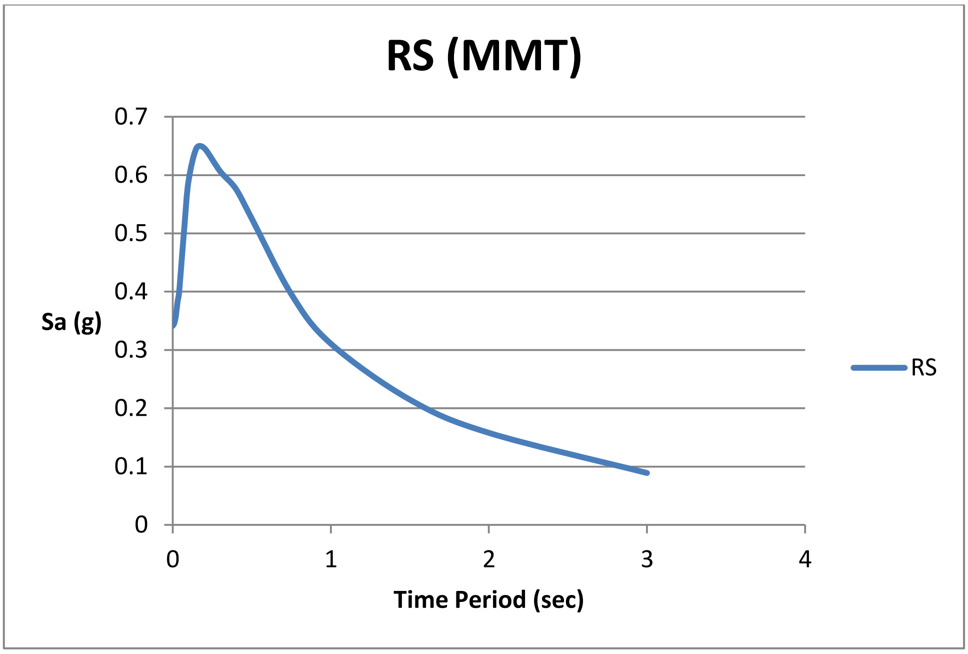

Figure 4: Response Spectrum for MMT

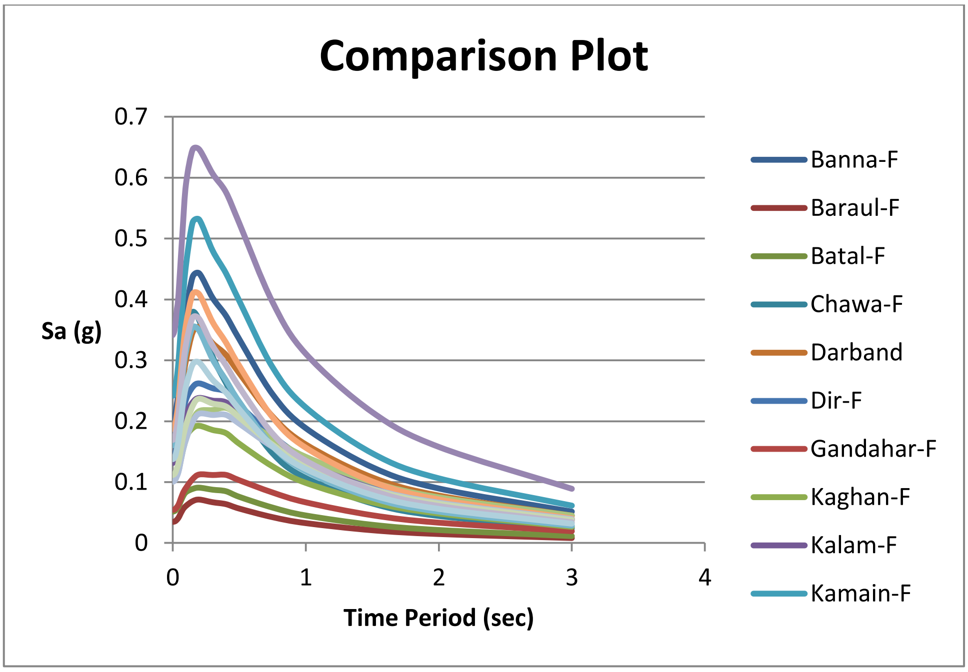

Figure 5: Comparison of RS for different Faults

Time History Scaling:

To obtain a time history that would produce same Response Spectrum as our target spectrum Wavelet Matching Process was adopted using" Seismo Match" and Time Histories obtained from Peer NGA data base of San Fernando 1971 (RSN80). While obtaining these Time Histories the prevailing condition of the study area were kept in mind. Using double scaling with a final scale factor of 1.1 the Time History that would produce the Response Spectrum same, at least in the range of periods on interest, as that of the Target Response Spectrum was obtained. In the first run scaling was done from 0.05sec to 2sec, while in second run the range was expanded in lower bound to 0.02sec.

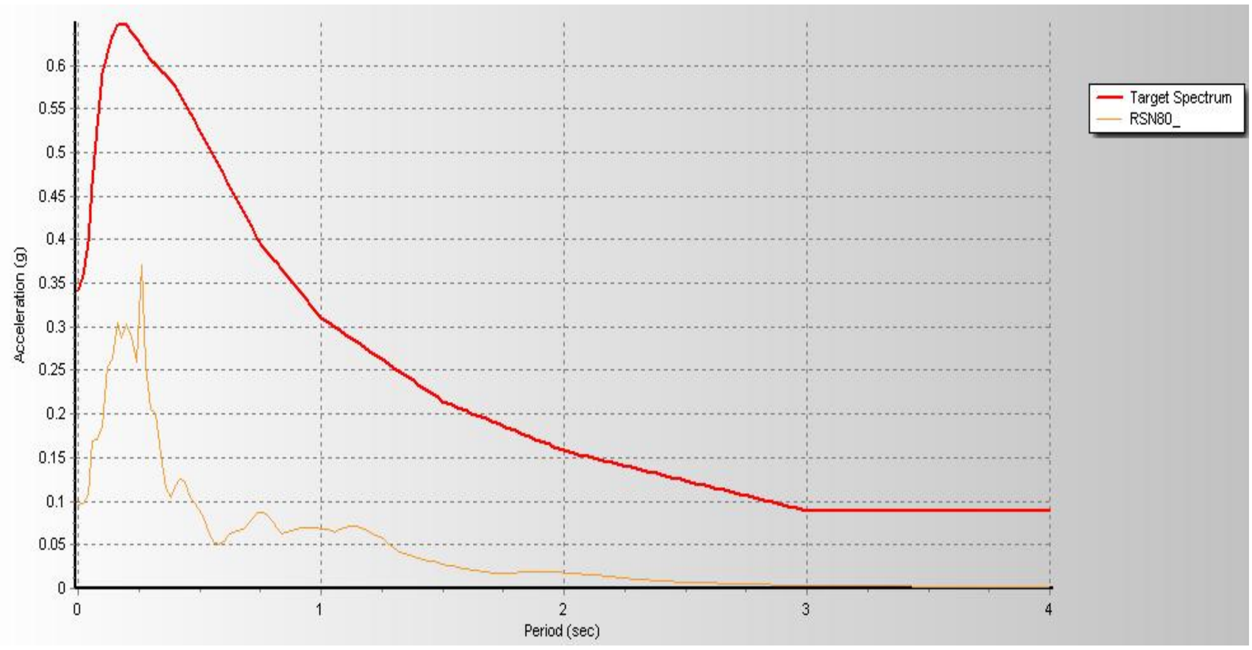

Figure 6: Unmatched Spectrums

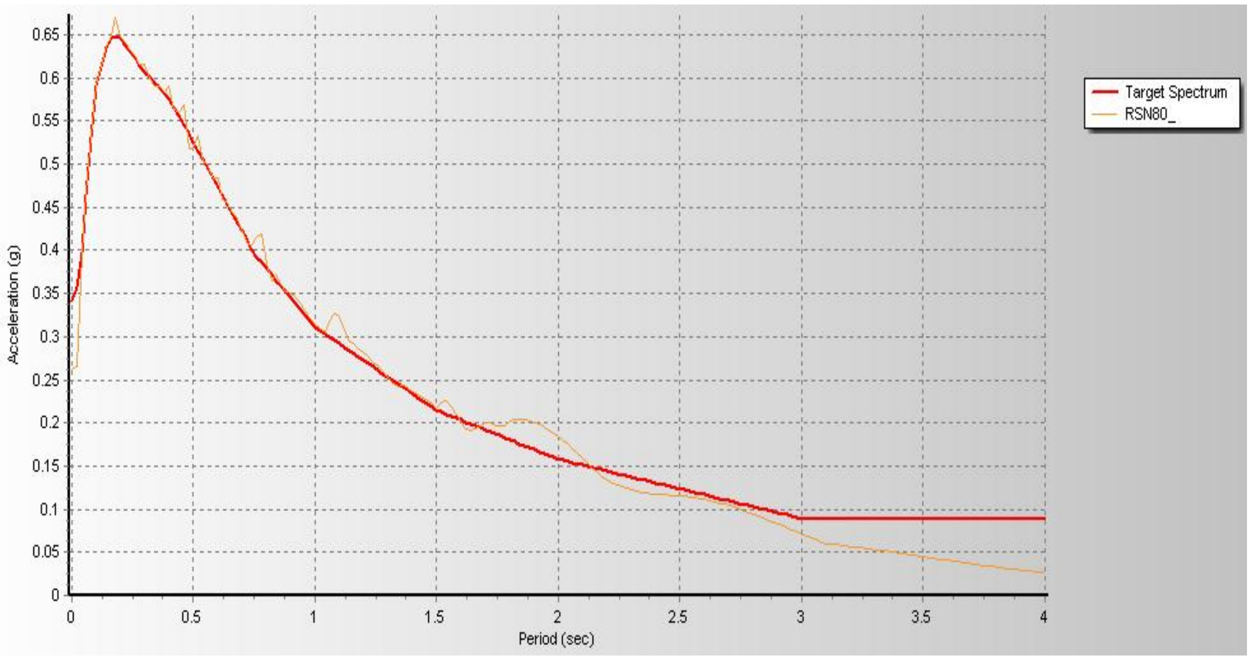

Figure 7: Matched Spectrums

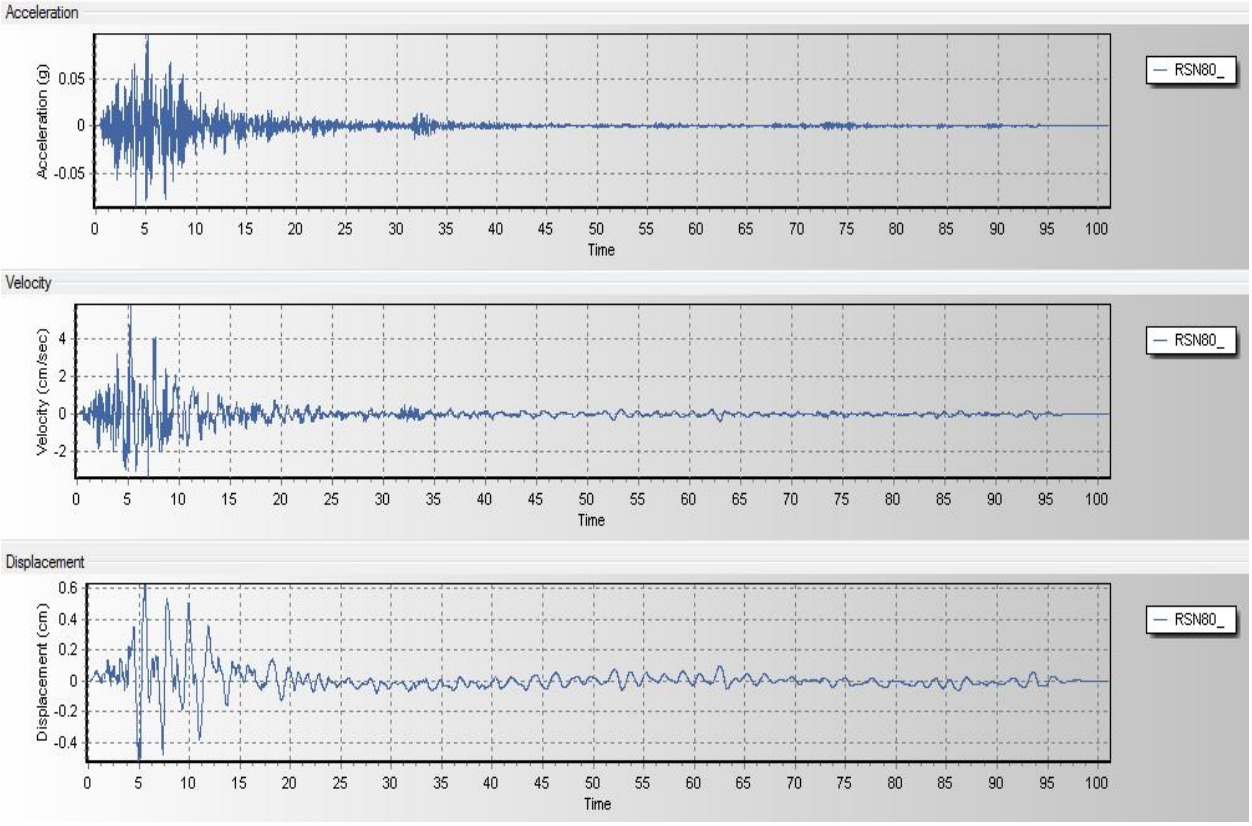

Figure 8: Original Time Histories

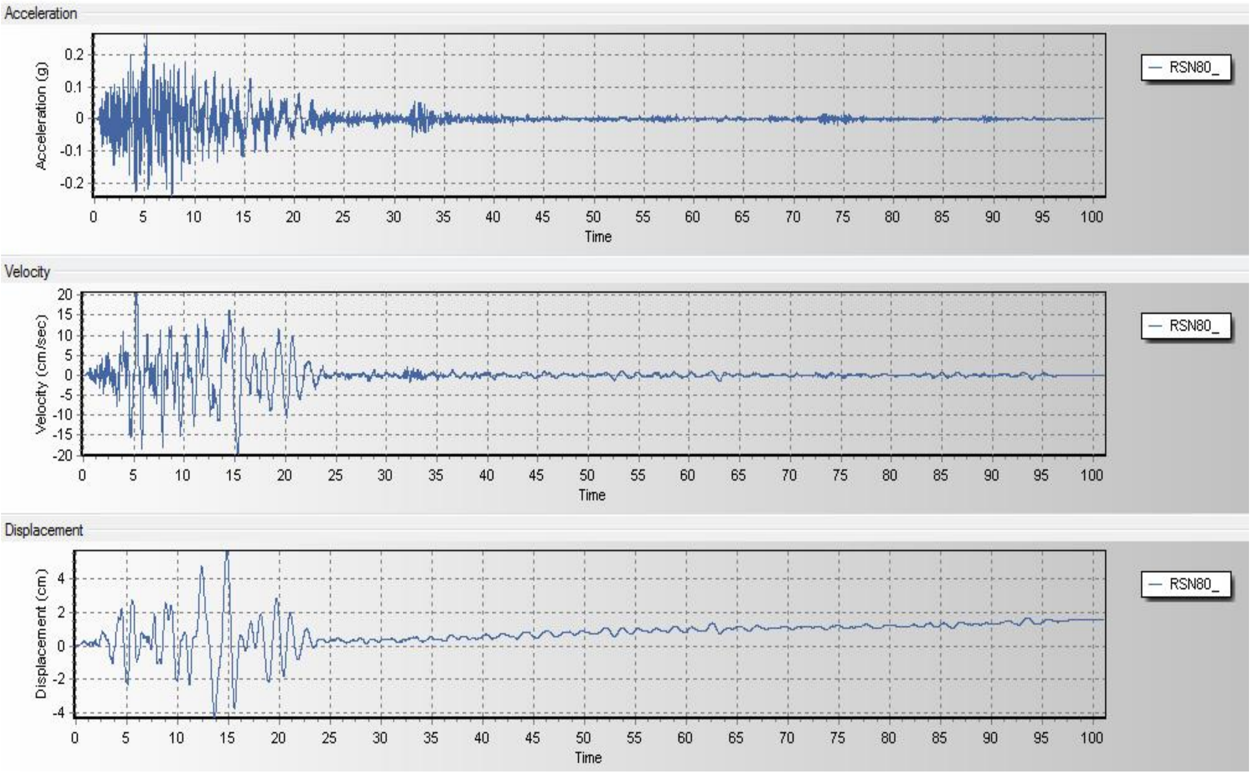

Figure 9: Modified Time Histories

Conclusions:

- The Karora HPP site lies in a seismically active zone which might experience seismic hazard of significantly high magnitude.
- On the basis of felt intensity data and the instrumental record of macro and micro seismicity, the faults of Main Boundary Thrust (MBT), Kashmir Thrust (KT), Main Mantle Thrust (MMT) and Indus Kohistan Seismic Zone (IKSZ), are considered to be active in the Project area.
- Deterministic Seismic Hazard Analysis was performed to obtain the hazard value of 0.35g corresponding to MMT. Attenuation relationship developed by Akkar & Bommer (2013) was using for calculation of PGA and Response spectrum as recommended by Stewart et al 2013.
- Response Spectrum corresponding to MMT was selected as a target spectrum and Time History Scaling was performed through SeismoMatch by using Wavelet Method.
- With Deterministic Seismic Hazard Analysis (DSHA), value of 0.39g for Maximum Credible Earthquake (MCE) has been calculated. The available 635 seismic events around this site indicate OBE values of the order of 0.35g for Karora HPP.
- The values calculated in the previous paras are considered adequate for structures of the relatively small Hydropower Projects (7.5 MW) involving diversion weirs and small structures.
- Faults Data obtained from PDMA Punjab have depicted both blind separation zones and active faults. One of such Faults in a very close vicinity to the target site is Chakesar Fault a mere of 3 KM distance from site.

Faults Data obtained from PDMA Punjab have depicted both blind separation zones and active faults. One of such Faults in a very close vicinity to the target site is Chakesar Fault. Following recommendations should be adopted keeping in view the proximity of some of the Faults.

- True nature of the near field faults, say, Puran Fault and Chakesar Fault should be studied through proper field observations.
- Near-Field attenuation relationships should be used to calculate the hazard posed by the near field faults.

After gaining some insight in to the realistic nature of near field seismic source the PGA value corresponding to MMT might be recommended for final design or discarded subjected to a more critical situation posed by the closer faults.

References:

1. World Bank, 2014, https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC
2. Government of Pakistan (2013) Economic Survey of Pakistan 2012-2013, Ministry of Finance, Pakistan
3. A Sullivan, M & Windley, Brian & Saunders, Andy & R Haynes, J & C Rex, D. (1993). A palaeogeographic reconstruction of the Dir Group: evidence for magmatic arc migration within Kohistan, N. Pakistan. Geological Society, London, Special Publications. 74. 10.1144/GSL.SP.1993.074.01.11.
4. Armbruster, J., Seeber, L., Jacob, K., 1978. The northern termination of the Himalayan front: active tectonics from micro-earthquakes. Journal of Geophysical Research 83, 269–282.
5. Foster, M., Fell, R. and Spannagle, M. (2000) The Statistics of Embankment Dam Failures and Accidents. Canadian Geotechnical Journal, 37, 1000-1024
6. DAMS AND EARTHQUAKES, Jonathan HINKS, 2015, SECED 2015 Conference: Earthquake Risk and Engineering towards a Resilient World, 9-10 July 2015, Cambridge UK.
7. Eunice Olson, University of Notre Dame, http://www.geol.ucsb.edu/faculty/ sylvester/Teton_Dam/Teton%20Dam.htm
8. "The Failure of Teton Dam" US Bureau of Reclamation, 2011
9. Failure of the Fujinuma Dam during the 2011 Tohoku Earthquake, Daniel Pradel F. ASCE, Joseph Wartman M. ASCE, and Binod Tiwari M. ASCE, Geo-Congress 2013.
10. ChiefHira - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/ w/index.php?curid=15300715
11. Youd, T. L.; Olsen, H. W. 1971, Damage to constructed works associated with soil movements and foundation failures, in The San Fernando, California Earthquake, of February 9, 1971: US Geological Survey professional paper 733, P. 126-132.
12. Robert E. Wallace, USGS - [1], Public Domain, https://commons.wikimedia.org/ w/index.php?curid=20761243

13. Kazmi, A. H., 1979, Active fault systems in Pakistan; In: Farah, A.and K.A. DeJong (eds.), Geodynamics of Pakistan. Geol. Surv.Pakistan. Quetta, p.285-294.

14. "Horizontal Movements Related to Subsidence" by Kenneth L. Lee, C. K. Shen, Serial Information: Journal of the Soil Mechanics and Foundations Division, 1969, Vol. 95, Issue 1, Pg. 139-166

15. ICOLD (1989). "Selecting Seismic Parameters for Large Dams", ICOLD Bulletin 72, International Commission on Large Dams, Paris

16. Pierre Dèzes 1999, "Tectonic and metamorphic Evolution of the Central Himalayan Domain in Southeast Zanskar (Kashmir, India)

17. http://www.technologyreview.pk/12-years-october-earthquake-pakistan-prepared-handle-another-big-one/

18. Kramer et. al. 1996. Seismic, geotechnical and earthquake engineering site characterization

19. The Kangra Earthquake of 4th April 1905. Memoirs of the Geological Survey of India. 38. Calcutta. 1910

20. Lavé, J., D. Yule, S. Sapkota, K. Basant, C. Madden, M. Attal, and R. Pandey (2005), Evidence for a great medieval earthquake (approximate to 1100 AD) in the central Himalayas, Nepal, Science, 307, 1302–1305

21. National Engineering Services of Pakistan, 2007. Building code of Pakistan seismic hazard evaluation studies, Ministry of Housing and Works, Government of Pakistan.

22. Bard et al., 1979. J.P. Bard, H. Maluski, P. Matte, F. Proust, "The Kohistan sequence: Crust and mantle of an obducted island arc"

23. Panjamani, Anbazhagan & Vinod, J S & Thallak, Sitharam. (2009). Probabilistic seismic hazard analysis for Bangalore. Natural Hazards. 48. 145-166. 10.1007/s11069-008-9253-3.

24. John Douglas 2018, Ground motion prediction equations 1964 to 2018, https://www.strath.ac.uk/staff/douglasjohndr/

25. Mona Lisa, Azam A. Khawaja and M. Qasim Jan, 2007. Seismic Hazard Assessment of the NW Himalayan fold and thrust belt, Pakistan, using Probabilistic approach. Journal of Earthquake Engineering 11, 257 - 301.

26. Stewart, Jonathan & Douglas, John & Javanbarg, Mohammad & Bozorgnia, Yousef & A. Abrahamson, Norman & M. Boore, David & Campbell, Kenneth & Delavaud, Elise & Erdik, Mustafa & Stafford, Peter. (2013). Selection of Ground Motion Prediction Equations for the Global Earthquake Model. Earthquake Spectra. 31. 141208072728004. 10.1193/013013EQS017M.

27. Mathew P. Williams. The Geology of The Besham area, North Pakistan: Deformation and Imbrication in the Footwall of the Main Mantle Thrust. www.nceg.uop.edu.pk/GeologicalBulletin/Vol-22-1989/Vol-22-1989-Paper6.pdf

28. Don Tocher; (1958) Earthquake energy and ground breakage. Bulletin of the Seismological Society of America; 48 (2): 147–153. Doi

29. D. L. Wells & K. J. Coppersmith. (1994). New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement. Bulletin of the Seismological Society of America. 84. 974-1002.

30. Cotton, F., Scherbaum, F., Bommer, J.J., Bungum, H., 2006. Criteria for selecting and adjusting ground-motion models for specific target regions: Application to central Europe and rock sites. Journal of Seismology, 10(2), 137–156

31. Boore, D.M., and Atkinson, G.M. (2008). Ground-Motion Prediction Equations for the Average Horizontal Component of PGA, PGV, and 5%-Damped PSA at Spectral Periods between 0.01s and 10.0s. Earthquake Spectra 24:1, 99-138.

32. K.W. Campbell and Y. Bozorgnia, (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, Volume 24, No. 1, pages 139–171, February 2008;

33. K. W. Campbell. Near-source attenuation of strong ground motion for moderate to large earthquakes: An update and suggested application to the Wasatch fault zone of north-central Utah. In proceedings of conference XXVI: A Workshop on Evaluation of Regional and Urban Earthquake Hazards and Risk in Utah, pages 483–499. US Geological Survey, 1984. Open-File Report 84-763.

34. W. B. Joyner and D. M. Boore. Measurement, characterization, and prediction of strong ground motion. In Proceedings of Earthquake Engineering & Soil Dynamics II, pages 43–102. Geotechnical Division, ASCE, Jun 1988.

35. S. Akkar, M. A. Sand kkaya, and J. J. Bommer. Empirical ground-motion models for point- and extended-source crustal earthquake scenarios in Europe and the Middle East. Bulletin of Earthquake Engineering, 12(1):359–387, 2014b. doi: 10.1007/s10518-_013-_9461-_4.

36. S. Akkar, M. A. Sand kkaya, and J. J. Bommer. Erratum to: Empirical ground-motion models for point- and extended-source crustal earthquake scenarios in Europe and the Middle East. Bulletin of Earthquake Engineering, 12(1):389–390, 2014c. doi: 10.1007/s10518-_013-_9508-_6.

37. S. Akkar and J. J. Bommer. Empirical equations for the prediction of PGA, PGV and spectral accelerations in Europe, the Mediterranean region and the Middle East. Seismological Research Letters, 81(2):195–206, Mar/Apr 2010.

38. S. Akkar and Z. Çağnan. A local ground-motion predictive model for Turkey and its comparison with other regional and global ground-motion models. Bulletin of the Seismological Society of America, 100(6):2978–2995, Dec 2010.

39. Bilham, R., Ambraseys, N., 2005. Apparent Himalayan slip deficit from the summation of seismic moments for Himalayan earthquakes. Current Science 88, 1658-1663.

40. Boore, D. M., Atkinson, G. M., 2008. Ground-motion prediction equations for the average horizontal component of PGA, PGV, and 5%-damped PSA at spectral periods between 0.01 s and 10.0 s. Earthquake Spectra 24(1), 99-138

41. 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 10s. Earthquake Spectra 24(1), 139 - 171.

42. Building Code of Pakistan (Seismic Provisions) 2007, Government of Islamic Republic of Pakistan Ministry of Housing and Works, Islamabad.

43. Building Seismic Safety Council, 2001. NEHRP recommended provisions for seismic regulations for new buildings and other structures. In: 2000 Ed., Part 1: Provisions, Prepared by the Building Seismic Safety Council for the Federal Emergency Management Agency (Report FEMA 368), Washington, DC

44. Campbell, K. W., Bozorgnia, Y., 2007. Campbell-Bozorgnia NGA ground motion relations for the geometric mean horizontal component of peak and spectral ground motion parameters, Pacific Earthquake Engineerign Research Center.

45. Campbell, K. W., 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.

46. Daniel, P., Joseph, W., Binod, T., 2012. Failure of Fujinuma Dam during the 2011 Tohoku Earthquake. 9th International Conference on Urban Earthquake Engineering/ 4th Asia Conference on Earthquake Engineering, Tokyo Institute of Technology, Tokyo, Japan.

47. Durrani, A., Elnashai, A., Hashash, M.A., Arif, M., 2005. The Kashmir Earthquake of October 8, 2005. A quick look report. Urbana, Mid-America Earthquake Center, University of Illinois at Urbana-Champaign, 51 p.

48. Gutenberg, B., Richter, C. F., 1954. Seismicity of the earth and associated phenomena. Second edition, Princeton University Press, Princeton.

49. 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.

50. Heaton, T.H., Tajima, F., Mori, A.W., 1986. Estimating ground motions using recorded accelerograms. Surveys in Geophysics 8, 25-83

51. Pakistan Meteorological Department (PMD) and Norsar, Norway, 2007. Seismic hazard analysis and zonation for Pakistan, Azad Jammu and Kashmir, final repot PMD Pakistan.

52. Sarhad Hydal Development Orginazation (SHYDO), Government of NWFP, Feasibility Studies of Three Hydro Power Plants 2010.

53. Pakistan Meteorological Department (PMD) and Norsar, Norway, 2007. Seismic hazard analysis for the cities of Islamabad and Rawalpindi.

