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Strong motion observation at Middle Marsyangdi Hydroelectric Project dam, Lamjung, western Nepal

***S. Rajaure[1], T. R. Paudel[2], and G. K. Bhattarai[3]**

[1]*Department of Mines and Geology, Kathmandu, Nepal*
[2]*Nepal Electricity Authority, Kathmandu, Nepal*
[3]*Khwopa Engineering College, Purbanchal University, Bhaktapur, Nepal*
*(*Email: srajaure@yahoo.com)*

ABSTRACT

Middle Marsyangdi Hydroelectric Project (MMHEP) of the Nepal Electricity Authority (NEA) has installed a network of four strong motion seismometers (accelerometers) at its dam site. The network has recorded two earthquakes of local magnitudes (ML) 4.0 and 4.3 on 13th of April in 2009. These earthquakes occurred at less than 20 km hypocentral distance from the dam site. Analysis and interpretation of the ML 4.3 earthquake only are presented in this paper because the other earthquakes are closely spaced and the spectral characteristics are similar.

The maximum acceleration (28 gal, 1 gal = 9.8 cm/sec^2) is recorded by the north-south component of accelerometer installed at the crest of rock-fill dam (Acc-1) and the smallest acceleration is recorded by north-south component of Acc-4 installed on the hard rock. Spectral amplification of up to 18 is observed, at 3.33 Hz, on the N-S component of accelerometer (Acc-2), which is installed at the concrete dam-crest. Similarly, the maximum amplification of peak acceleration of about 8 is observed on N-S component of Acc-1.

The variations observed in seismic parameters, recorded at different parts of the dam, reflect the response of the different parts of the structure to the input seismic motion.

Keywords: Peak acceleration, hypocentral distance, Fourier spectra, response spectra, spectral amplification

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INTRODUCTION

Middle Marsyangdi Hydroelectric Project (MMHEP) has been constructed in Lamjung District of Nepal. The project is situated at 28.189°N and 84.419°E and its elevation is 620 m above the mean sea level. It is a run-of-the-river type project with a 5 hour peaking capacity and its installed capacity is 71 MW. The crest length of the dam is 84 meter, its height is 55 meter (74 m in the central section) and width is about 45 meter (Fig. 1). The dam consists partly of concrete at the canyon and partly of rock-fill type at left bank of the Marsyangdi River. There is strong quartzite bedrock in the right bank of the river and glacial mudflow is in the left bank. The natural frequency of the concrete dam is calculated to be about 5 Hz.

MMHEP has installed four accelerometers at its dam site (Table 1, Fig. 1). They were installed in November, 2008 just after the impounding of the reservoir of the project commenced. The accelerometers are connected to a network and the data is centrally recorded at the control building. The instruments are (CMG-5TD) digital accelerometers, which record seismic acceleration in three axes: north-south (N-S), east-west (E-W) and vertical (Z).

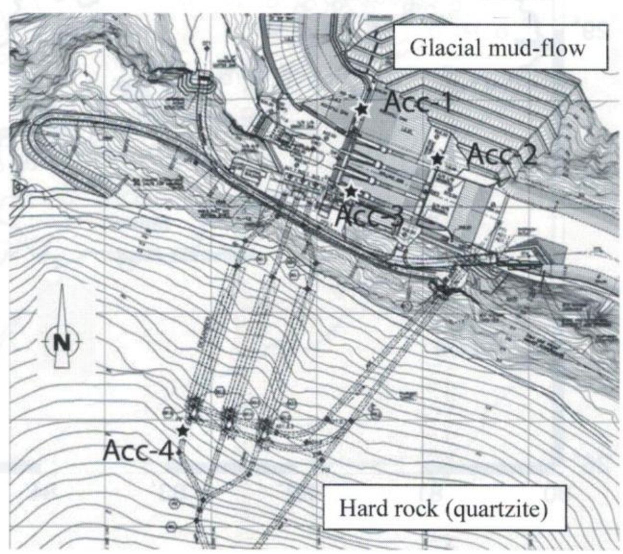

Fig. 1: Location map of the dam site. The black stars are locations of the accelerometers.

Table 1: Location of accelerometers installed at the dam site

Accelero meter	Location	Band width	Dynamic Range	Location
Acc-1	28.189°N 84.419°E	DC to 100 Hz	Up to 4 g	Rock-fill dam crest
Acc-2				Spillway gate control-3 (crest level)
Acc-3				Bed load flush (20 m below crest)
Acc-4				Desander-3 (Rock site)

When the analyzed earthquakes occurred, the accelerometers were operating on continuous recording mode and the sampling rate was 100.

The main objective of seismic monitoring of structures (high-rise buildings, dams, power plants, bridges, etc.) is to study response of the structures that lead to improved understanding of the dynamic behavior and potential damage to structures under seismic loading. The installation of seismic networks to record strong earthquakes and the results which are obtained from them has become an essential need in the field of earthquake engineering. Monitoring and analysis of strong earthquakes have considerable contribution to the overall activities in seismic risk reduction of existing urban area and to minimize the damage to structures under the effect of destructive earthquakes. The use of the results is very important, both for the theoretical and fundamental investigations in the field of earthquake engineering and for application and practical investigations in the earthquake engineering.

The analyzed earthquake is not a big one but it can give us vital information that is usually sought from large earthquakes. In the absence of large earthquakes; smaller events also can be used to investigate the strong motion parameters and amplification of seismic motion at different locations of structures.

The main objectives of this study are: (i) process and analyze time series data for strong motion parameters and spectral parameters of the magnitude 4.3 earthquake, (ii) estimate possible amplification at the crest of rock-fill dam

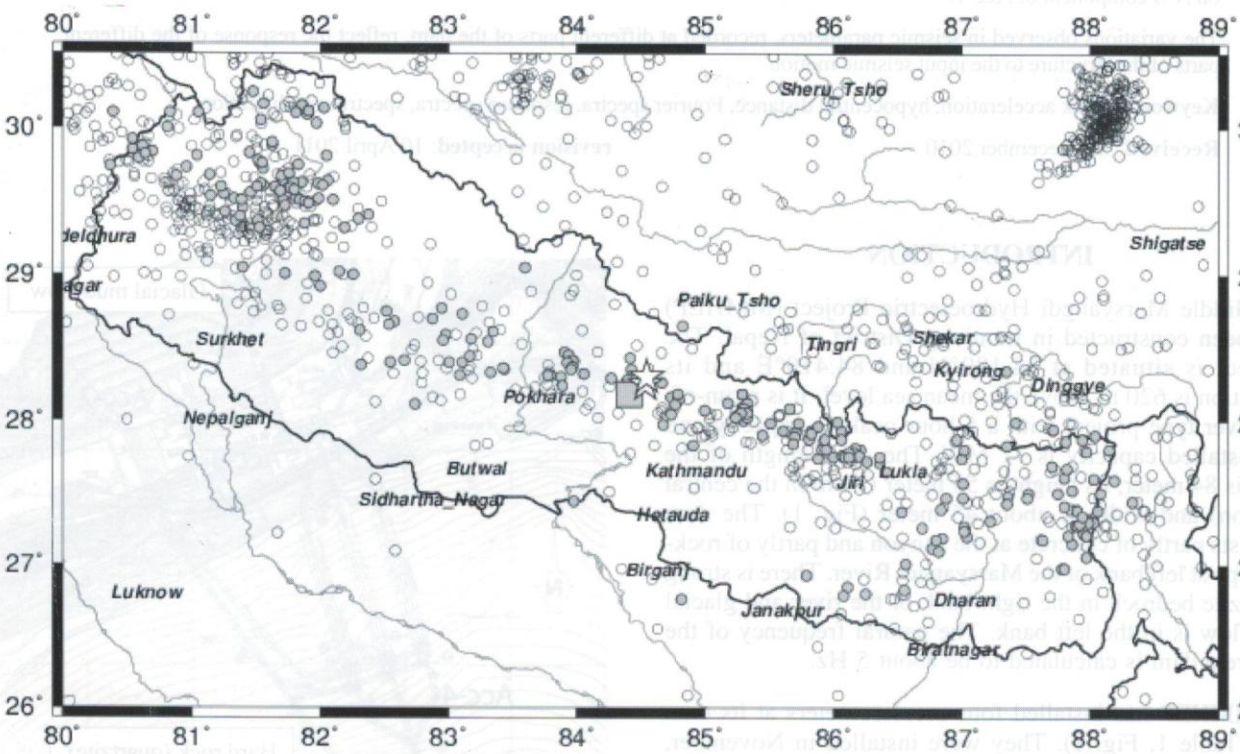

Fig. 2: Seismicity distribution in and around Nepal. Two earthquakes, which occurred on 13 April, 2009 are represented by stars. The grey square represents the dam site. Black circles are locations of local earthquakes (ML ³ 4.0) recorded by National Seismological Centre (NSC) of Department of Mines and Geology (DMG) (1994-2011). Open circles are locations of earthquakes collected from the catalog of International Seismological Centre (ISC), UK (1964-2008).

Table 2: Some earthquakes (parameter source: www.sesmonepal.gov.np) which occurred near the project site after the installation of the accelerometer network.

Date	Latitude (N)	Longitude (E)	Magnitude (ML)	Distance from Damsite (km)	Remarks
2009/03/12	28.43°	84.42°	4.1	26.77769	
2009/04/13	28.3°	84.55°	4	17.89701	Event-1
2009/04/13	28.25°	84.54°	4.3	13.76349	Event-2
2010/05/13	28.3°	84.51°	4.2	15.27318	
2009/12/15	28.28°	84.4°	4.1	10.28449	
2010/09/01	28.23°	84.37°	4	6.654688	

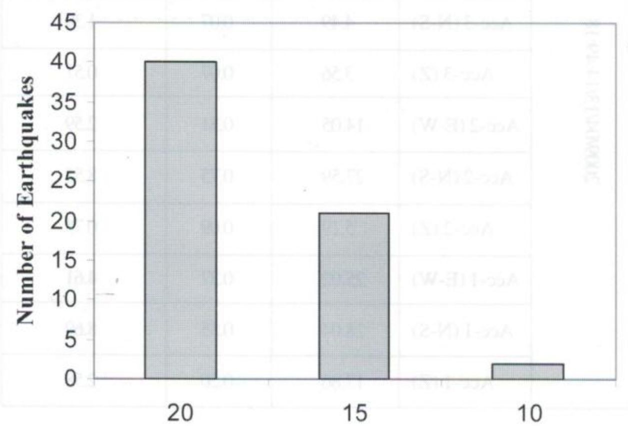

Fig. 3: Number of local earthquakes recorded by accelerometers from 1st April, 2009 to 16th April 2009. This figure shows the number of earthquakes vs. their hypocentral distance from the dam site.

and concrete dam with reference to a base observation, and (iii) interpret the strong motion parameters, spectral parameters and amplification observed at the dam site.

SEISMICITY OF THE PROJECT SITE

The MMHEP dam site is situated close to the seismicity belt in Nepal that runs almost all along the Nepal Himalaya at the front of the Higher Himalaya (Fig. 2). The earthquakes in the belt are characterized by shallow depth (depth <20 km) (Pandey et al. 1995 and 1999). Pandey et al. (2002) predicted peak ground acceleration (PGA) of 0.35 g (1 g = 9.81 m/sec^2) for hard rock, which has 10% chance of exceedance in 50 years, at the project site using probabilistic approach of seismic hazard assessment.

On 13th of April 2009 two earthquakes of Local Magnitude (ML) of 4.0 (hereafter called 'Event-1') and 4.3 (hereafter called 'Event-2'), respectively occurred at less than 20 km hypocentral distance from the dam site (Table 2). In addition to the earthquakes listed in Table 2, the network has recorded many small earthquakes (Fig. 3); however, hypocentral parameters of these earthquakes are not available because the network of MMHEP is not capable to localize earthquakes due to its small aperture. To estimate the approximate location of the smaller events, an alternative approach has been used. The approximate location (in terms of distance (km) from the recording station) has been estimated using the difference in arrival times of Secondary and Primary waves (S-P) and seismic velocity model (Rajaure 2002, Table 3). The result suggests that most of the small earthquakes occurred at less than 20 km hypocentral distance from the dam site (Fig. 3) and we believe that they occurred in the source region of Event-1 and Event-2 that falls at the same distance range from the intake (Table 2).

Table 3: Seismic velocity model (Rajaure 2002). This model was derived from the simultaneous inversion of travel time data for hypocenter and velocity structure.

Layer No.	Thickness	Depth to top (km)	Vp (km/sec)	Vs (km/sec)
1	23	0	5.53	3.18
2	32	23	6.29	3.62
3	Infinity	55	8.13	4.66

Data and software used

Seismic acceleration data was collected from the accelerometer network of MMHEP, which was recorded from 1st of April to 16th of April, 2009. The available data consists of half-an-hour long waveform data on Guralp Compressed Format (GCF) that was available for sixteen days. 'Scream' software from Guralp Systems Ltd. was used to identify and select signals of required length from the continuous signal of half an hour length. Then, ART2.0 software was used to process and determine different types of seismic motion parameters. Generic Mapping Tool

(GMT) from www.soest.hawaii.edu/gmt and MS Excel program were used to produce graphics. Some small programs were written in FORTRAN77 to produce data for figure production.

Strong motion parameters

On 13th of April, 2009, two earthquakes (ML 4.0 and ML 4.3) occurred at less than 20 km hypocentral distance, in the north-east direction, from the dam site. The network of accelerometers at the dam site of MMHEP has recorded these earthquakes very well. The first earthquake (Event-1) occurred at 14:48:15 UTC (Universal Time Coordinate) and the second earthquake (Event-2) occurred at about 14:49:18 UTC. Both these earthquakes were felt by people at the project site during night time.

Results from the analysis of Event-2 (ML 4.3) only are presented in this paper. The largest acceleration (28 gal) is recorded by the N-S component of accelerometer installed at the crest of the rock-fill dam (Acc-1) and the smallest acceleration (3.22 gal) is recorded by N-S component of accelerometer installed on hard rock (Acc-4). The seismic motion parameters of this earthquake recorded by four accelerometers are given in Table 4. Time histories of the records are presented in Figs. 4 and 5. Except for accelerometer Acc-4, all other accelerometers have recorded peak accelerations on their N-S component. The accelerometer Acc-4 has recorded peak acceleration on its vertical component.

Table 4: Seismic motion parameters of the magnitude 4.3 earthquake. The peak acceleration and the maximum ratio of peak acceleration relative to the Acc-4 are observed on the N-S component of Acc-1.

Date and origin time	Sensor and component	Peak Acceleration cm/sec 2 (gal)	Peak Velocity (cm/sec)	Ratio of peak acceleration relative to hard rock (Acc-4) site
2009/04/13/14:49:18	Acc-4 (E-W)	5.42	0.09	1
	Acc-4 (N-S)	3.22	0.01	
	Acc-4 (Z)	6.90	0.06	
	Acc-3 (E-W)	4.51	0.08	0.83
	Acc-3 (N-S)	4.49	0.07	1.39
	Acc-3 (Z)	3.56	0.07	0.51
	Acc-2 (E-W)	14.05	0.31	2.59
	Acc-2 (N-S)	27.59	0.75	8.55
	Acc-2 (Z)	5.19	0.09	0.75
	Acc-1 (E-W)	25.02	0.37	4.61
	Acc-1 (N-S)	28.04	0.55	8.69
	Acc-1 (Z)	17.86	0.20	2.58

FOURIER SPECTRA

Fourier amplitude spectra depict the distribution of amplitudes at different frequencies contained in the seismic motion. Figs. from 6 to 9 represent the Fourier amplitude spectra of the ground motion recorded by four accelerometers. In general, the Fourier amplitude is observed large on N-S components of accelerometers installed at different parts of the dam (Figs. 6, 7 and 8) except for Acc-4 (Fig. 9). The largest Fourier amplitude (19 cm/sec) is recorded by Acc-2 (Fig. 7) on its N-S component. In the case of Acc-4 (Fig. 9), the maximum amplitude (0.7 cm/sec) is observed on the vertical (Z) component.

Elastic response spectra

Elastic response spectra are useful tool to evaluate the dynamic behavior of existing structures and they are equally useful in the design of new structures. The elastic response spectra are calculated at 5 % damping, commonly used in engineering practice in Nepal. Both acceleration spectra and velocity spectra are calculated for four accelerometers on their two horizontal components (Figs. 10, 11, 12 and 13). The shapes as well as spectral parameters of the spectra of Acc-3 and Acc-4 are quite similar and small because both the sites are quiet in comparison to the sites of Acc-1 and Acc-2. Ignoring the natural frequency and magnitude of amplitude of peak responses, the shapes of velocity and acceleration spectra are similar on the N-S components for Acc-1 and Acc-2.

The calculation of spectral ratios from weak motion records is one of the most frequently applied techniques for the estimation of site response (Borcherdt and Gibbs 1976). Borcherdt and Glassmoyer (1992) found a correlation in site amplification between the weak motion records of the 1989 Loma Prieta aftershocks and the observed damage from the main shock in the Marina district of San Francisco.

In this study, an attempt has been made to calculate spectral amplification experienced by Acc-1 and Acc-2, which are installed on the crest of rock-fill dam and concrete dam respectively, with respect to a reference site (Acc-3) installed at 20 m below the crest. The observed spectral amplifications are presented in Figs 14, 15 and 16. The maximum spectral amplification of about 18 is observed at 3.33 Hz on N-S component of Acc-2 relative to N-S component of Acc-3 (Fig. 16). Similarly the least amplification is observed on the vertical component of Acc-2 (Fig. 14). The E-W component of Acc-1 has recorded an intermediate amplification (13.8) at about 4 Hz (Fig. 15).

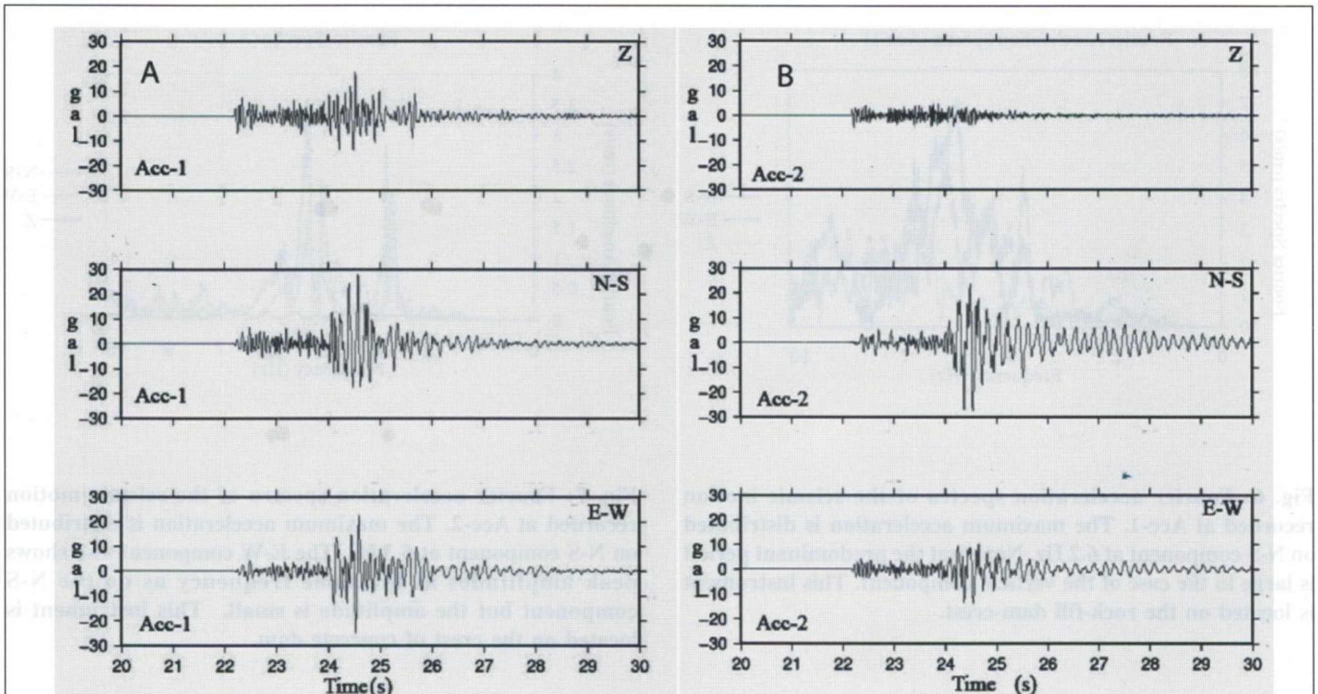

Fig. 4: Accelerograms (A and B) of the earthquake recorded by accelerometers Acc-1 and Acc-2. The amplitudes of waves are larger in these two records in comparison to those of Acc-3 and Acc-4 presented in Fig. 5. The upper-panel signals belong to vertical (Z) component, the middle panel belongs to N-S component and the lower one belongs to E-W component.

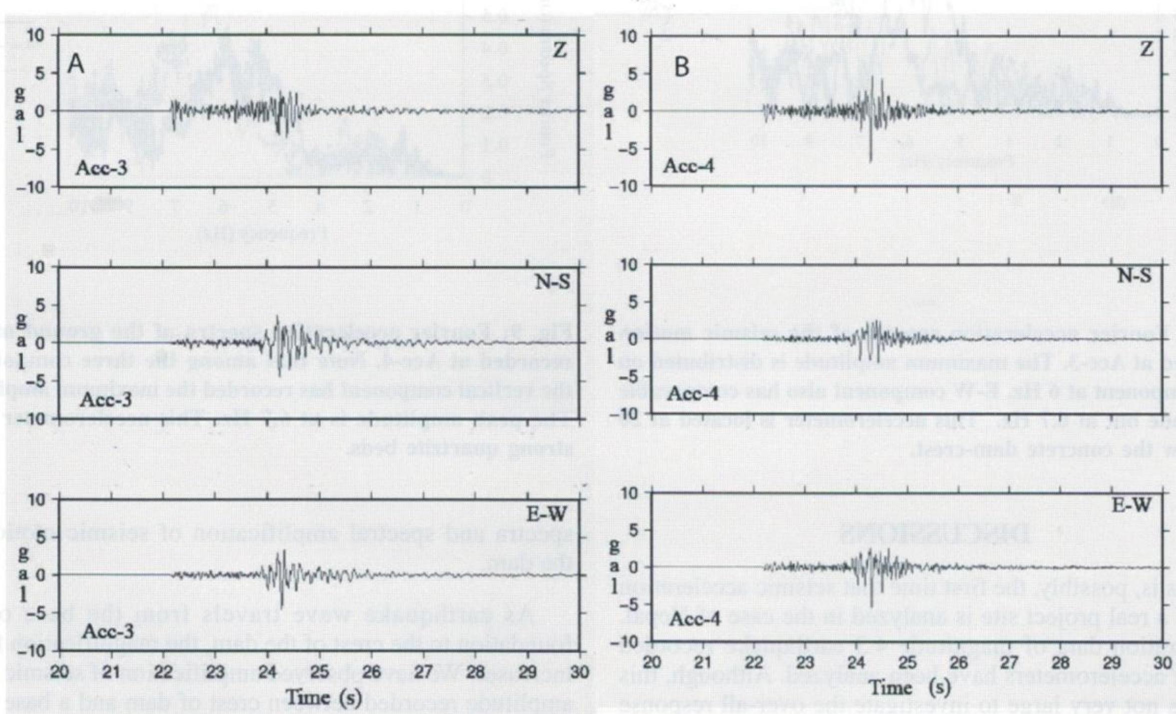

Fig. 5: Accelerograms (A and B) of the earthquake recorded by accelerometers Acc-3 and Acc-4. The amplitudes of seismic waves are smaller because they are located at relatively quiet sites. The top-panel signals belong to vertical component, the middle panel belongs to the N-S components and the lower panel belongs to the E-W components.

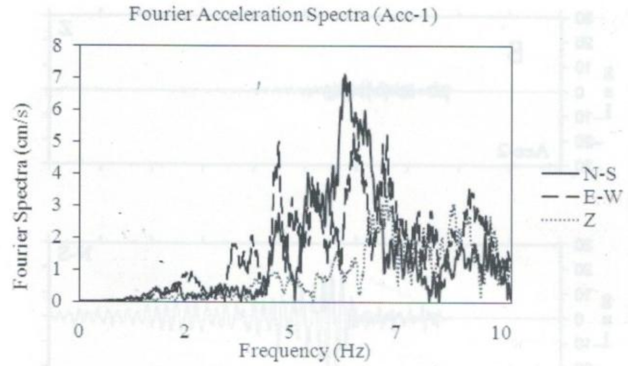

Fig. 6: Fourier acceleration spectra of the seismic motion recorded at Acc-1. The maximum acceleration is distributed on N-S component at 6.2 Hz. Note that the predominant period is large in the case of the vertical component. This instrument is located on the rock-fill dam-crest.

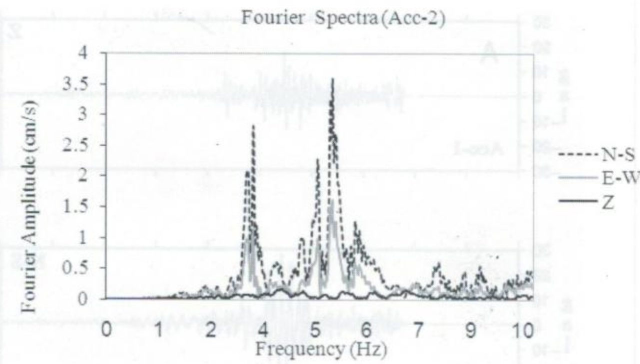

Fig. 7: Fourier acceleration spectra of the seismic motion recorded at Acc-2. The maximum acceleration is distributed on N-S component at 5.3 Hz. The E-W component also shows peak amplitudes at the same frequency as do the N-S component but the amplitude is small. This instrument is located on the crest of concrete dam.

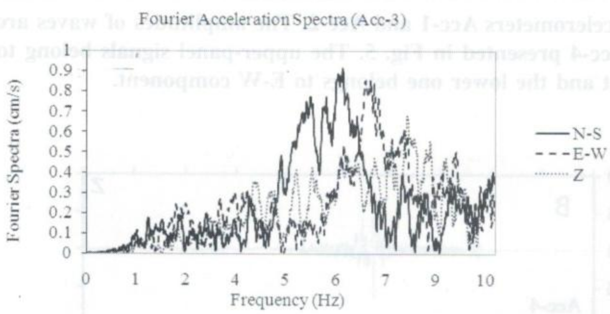

Fig. 8: Fourier acceleration spectra of the seismic motion recorded at Acc-3. The maximum amplitude is distributed on N-S component at 6 Hz. E-W component also has comparable amplitude but at 6.7 Hz. This accelerometer is located at 20 m below the concrete dam-crest.

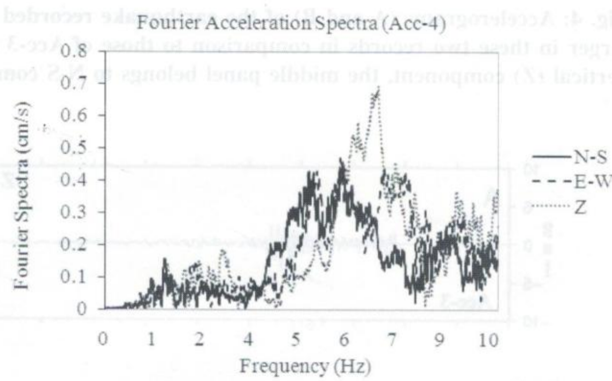

Fig. 9: Fourier acceleration spectra of the ground motion recorded at Acc-4. Note that among the three components, the vertical component has recorded the maximum amplitude. The peak amplitude is at 6.7 Hz. This accelerometer is on strong quartzite beds.

DISCUSSIONS

This is, possibly, the first time that seismic acceleration data of a real project site is analyzed in the case of Nepal. Acceleration data of magnitude 4.3 earthquake recorded by four accelerometers have been analyzed. Although, this event is not very large to investigate the over-all response of the structure to the dynamic loading, the results of this research can contribute in seismic vulnerabity assessment of this hydropower intake site (dam, tunnel, and gates, etc). This analysis focuses on calculation and interpretation of peak accelerations, Fourier spectra, elastic response spectra and spectral amplification of seismic motion on the dam.

As earthquake wave travels from the base of the foundation to the crest of the dam, the magnification factor increases. We have observed amplification of seismic wave amplitude recorded between crest of dam and a base at 20 m below in the dam. Similarly, amplification of seismic wave is observed by accelerometers installed at the crest of dam (Acc-1 and Acc-2) and relative to the accelerometer installed on a rock site (Acc-4). The analysis shows that the N-S components of the records have recorded large

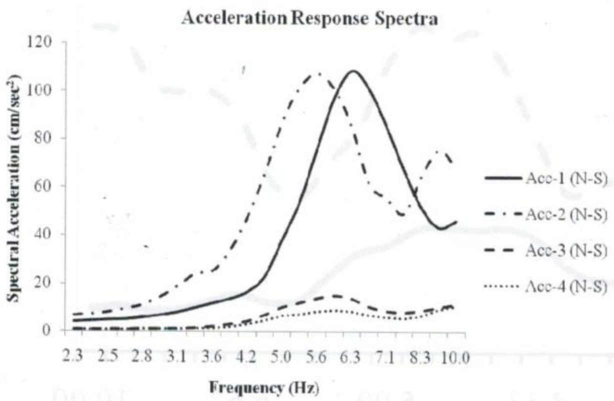

Fig. 10: Elastic (accleration) response spectra of N-S components of four accelerometers. The response spectra are calculated at 5 % damping. The peak amplitudes on Acc-1 and Acc-2 are similar in magnitude. However, the peaks are distributed at different frequencies.

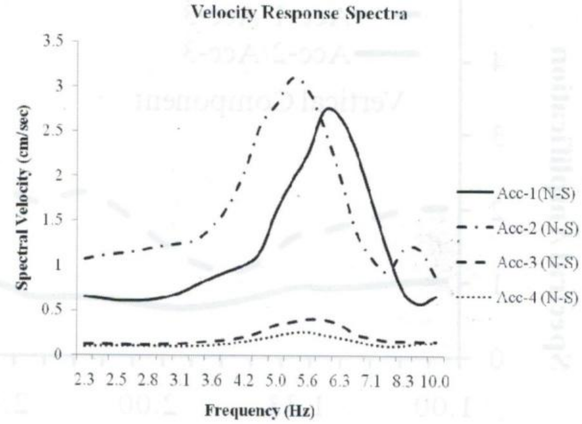

Fig. 11: Elastic (velocity) response spectra of N-S components of four accelerometers. The response spectra are calculated at 5 % damping. The shapes of the spectra are similar on Acc-1 and Acc-2. However, the peaks are distributed at different frequencies.

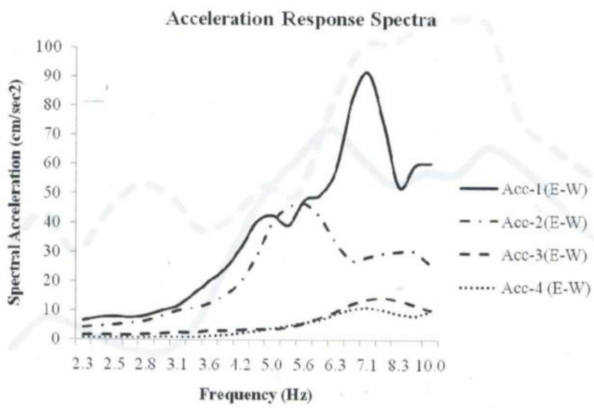

Fig. 12: Elastic (acceleration) response spectra of E-W components of four accelerometers. The response spectra are calculated at 5 % damping

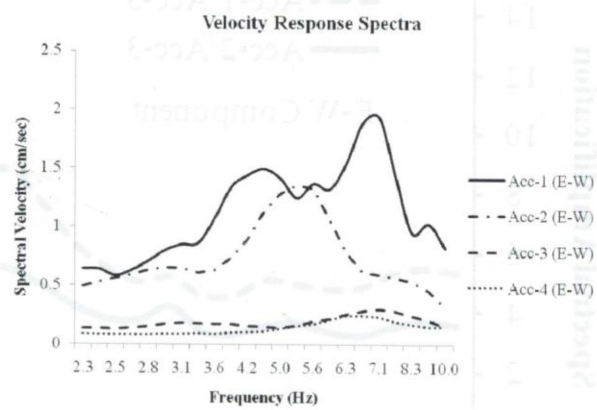

Fig. 13: Elastic (velocity) response spectra of E-W components of four accelerometers. The response spectra are calculated at 5 % damping.

amplitudes compared to E-W and vertical components in the case of Acc-1, Acc-2 and Acc-3, respectively. However, in the case of Acc-4 (Fig. 5 B), which is installed on hard rock, the vertical component has recorded the largest amplitude in comparison to its two horizontal records. Similar feature is observed in the Fourier spectra also (Figs. 6, 7, 8 and 9); which is possible when seismic wave approaches the site vertically.

The large Fourier amplitudes and peak accelerations recorded by Acc-1 and Acc-2 exhibit the response of the structure to the seismic ground motion because structures of different natural periods respond differently to the common seismic input motion. The natural frequency of the concrete dam is manually calculated to be about 5 Hz. using IS code 1983: 1984. The predominant frequency (5.5 to 6 Hz) of the seismic ground motion on N-S and E-W components (Fig. 9) and the natural frequency of the dam (5 Hz) have narrow difference. This narrow difference in the frequencies may result in strong shaking of the dam due to resonance.

The crest of rock-fill dam (Acc-1) was shaken strongly in the N-S direction in comparison to others. The amplification ratio of peak acceleration is about 8 in comparison to the N-S component on hard rock (Acc-4). Maximum spectral accelerations (100 gal) recorded on N-S components of Acc-1 and Acc-2 (Figs. 10 and 11) are in

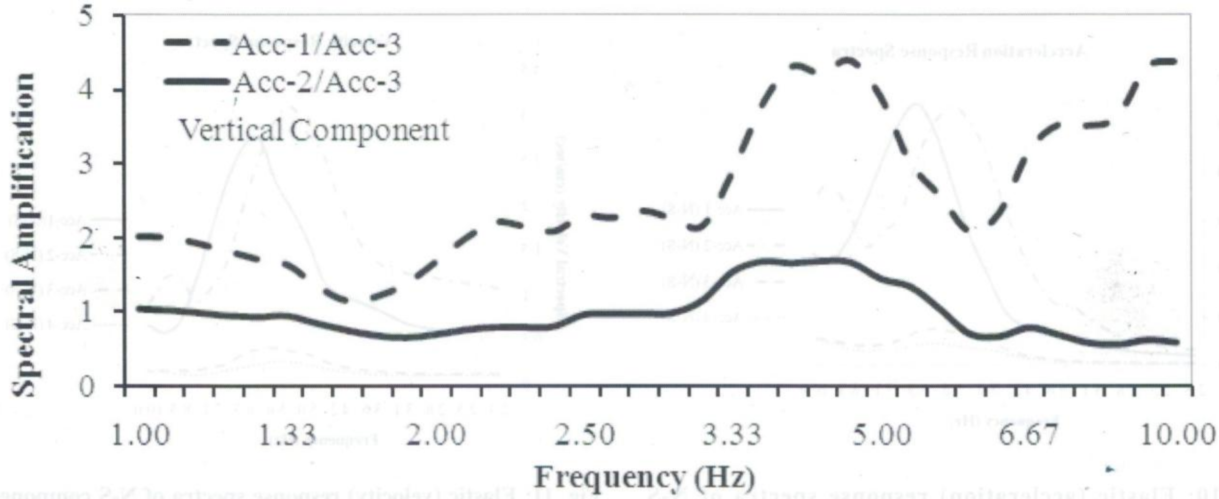

Fig. 14: Spectral amplification of seismic motion recorded on the vertical component of Acc-1 and Acc-2 with respect to Acc-3 that lies 20 m below the dam crest. The maximum amplification is observed on Acc-1.

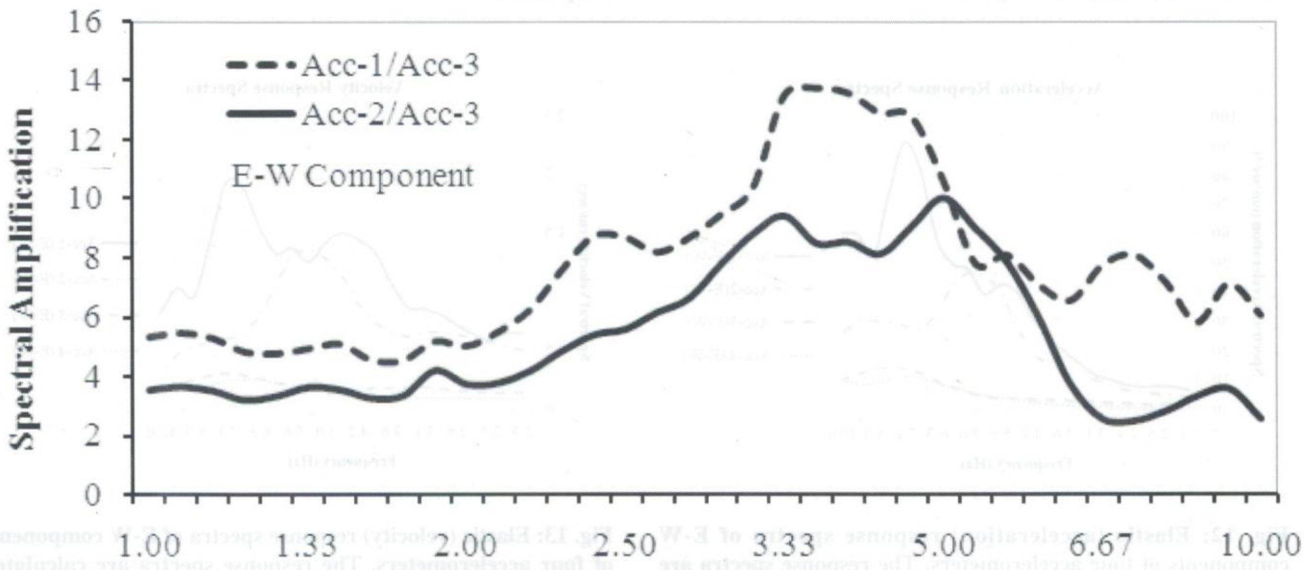

Fig. 15: Spectral amplification of seismic motion recorded on the E-W component of Acc-1 and Acc-2 with respect to Acc-3. The maximum amplification is observed on Acc-1.

good agreement with the peak accelerations (Fig. 4) and Fourier spectra (Figs. 6 and 7) observed on the N-S components of the accelerometers. However, variation in the spectral parameter (in terms of predominant period and amplitude) of motion is observed (between Acc-1 and Acc-2) in the E-W direction as shown in Figs.12 and 13. The crest of rock fill dam (Acc-1) has maximum spectral acceleration of 96 gal as high as twice of the value recorded at Acc-2 (on the concrete dam). Both these responses were observed on the E-W components. This difference depicts the difference of response of the rock-fill dam and concrete dam along the E-W direction.

CONCLUSIONS

The dam site is situated close to the seismicity belt that runs at the foot of the Higher Himalaya. Epicenter distribution (M>4) from ISC and NSC (Fig. 2) reveals that the site has experienced frequent M >4.0 earthquakes in the past and, therefore, should be common in the coming days also.

Spectral acceleration, peak acceleration and Fourier spectra of the acceleration depict that the crest of dam vibrates strongly in comparison to the base of the dam and hard rock site. The maximum shaking is observed on the

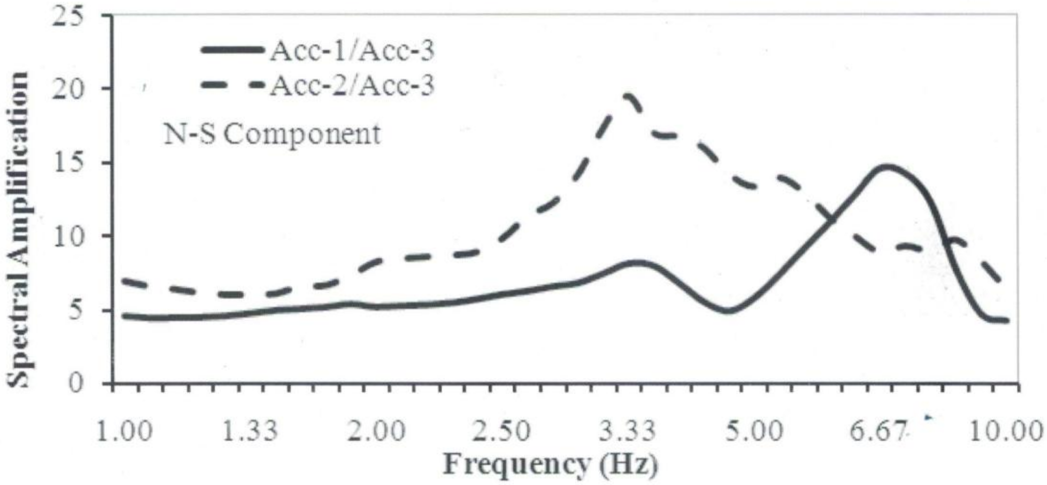

Fig. 16: Spectral amplification of seismic motion recorded on the N-S component of Acc-1 and Acc-2 with respect to Acc-3. The maximum amplification is observed on the Acc-2.

N-S component of Acc-1 and Acc-2. In comparison to the hard rock site, the crest of the rock-fill dam shows 8 times magnification of shaking in terms of peak acceleration (Table 4). Maximum spectral amplification as high as 18 is observed at 3.33 Hz on the N-S component of Acc-2 on concrete dam crest (Fig. 16). The maximum accelerations are observed, in general, on the N-S component of Acc-1, Acc-2 and Acc-3 (Figs. 4, 5, 6, 7 and 8). In contrast, Acc-4 has recorded its maximum acceleration on its vertical component (Fig. 9). The parameters of seismic motion recorded at different parts of the dam are different and reflect the response of different components of the structure to the seismic input motion. The narrow difference in the predominant frequency of the seismic ground motion (5.5 to 6 Hz, Fig. 7) and natural frequency of the dam (5 Hz) implicates the possibility of strong shaking on the crest of the dam on account of possible resonance.

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