Proceedings of International Structural Engineering and Construction, 10(1), 2023
Innovative Theory and Practices in Structural Engineering and Construction
Edited by Karatas, A., Iranmanesh, A., Gurgun, A., Yazdani, S., and Singh, A.

ISSN: 2644-108X
www.doi.org/10.14455/ISEC.2023.10(1).RAD-08

ANALYSIS OF FREQUENCY CONTENT AND STATISTICAL RELATIONSHIP AMONG EARTHQUAKE PARAMETERS OF SEISMIC DATA

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The frequency content of the strong-motion seismic data collected from seismic stations by the Bangladesh Meteorological Department (BMD) using GL-S60/120 broadband seismometers of earthquakes in and around Bangladesh is examined. In addition, the statistical relationships among various earthquake parameters, such as the peak ground velocity (PGV), magnitude, epicentral distance, and time of arrival of p- and s-waves of the collected data, are analyzed. Approximate seismic wave velocities are also obtained. The Fourier and wavelet analysis results reveal delicate differences in the frequency content of the p- and s-waves occurring during earthquakes. These results are compared to those generated from the STEAD dataset, which contains seismic waveforms collected in the U.S., France, and Greece regions. Regression analysis on the BMD data derives relationships among the aforementioned parameters. Collected data from some stations show perfect linear relationships among PGV and the travel time of seismic waves with magnitude and epicentral distance, whereas, in other stations, such relationships are not significant. Plausible explanations for these disparities are provided along with similar regression analysis using the STEAD data. The findings are useful for earthquake early-warning systems, geology research, seismic risk zone delineation, and seismic hazard forecasts.

Keywords: Fourier analysis, PGV, Regression, Seismic waveforms, Wave velocity, Wavelet analysis.

1 INTRODUCTION

Bangladesh is situated near the seismically active Himalayan frontal thrust in the North and Indo-Myanmar Ranges in the east (Figure 1). According to the USGS earthquake catalogue, this region has experienced more than 400 earthquakes with a magnitude greater than 5 Mw between 1900–2021. Historically, Bangladesh has experienced several significant earthquakes. In the south-east, the 1762 (Mw > 8) Arakan Earthquake caused liquefaction, landslides, tsunami waves near Chittagong region (Mondal *et al.* 2018). The 1897 Assam Earthquake (Mw > 8) originated from the Dauki fault located along the northern border, caused the collapse of several bridges and houses in Shillong located 50 km from Bangladesh border (Bilham 2008). The 2015 Nepal Earthquake had reported cases of structural damage all over the country (Hossain *et al.* 2016). If a similar catastrophic earthquake were to occur in the future, how disastrous could it be? Given the potential consequences, this paper aims to better understand the relationships among earthquake parameters in Bangladesh by analyzing 18 earthquake waveforms recorded by the Bangladesh Meteorological Department between 2020–2022 (Table 1).

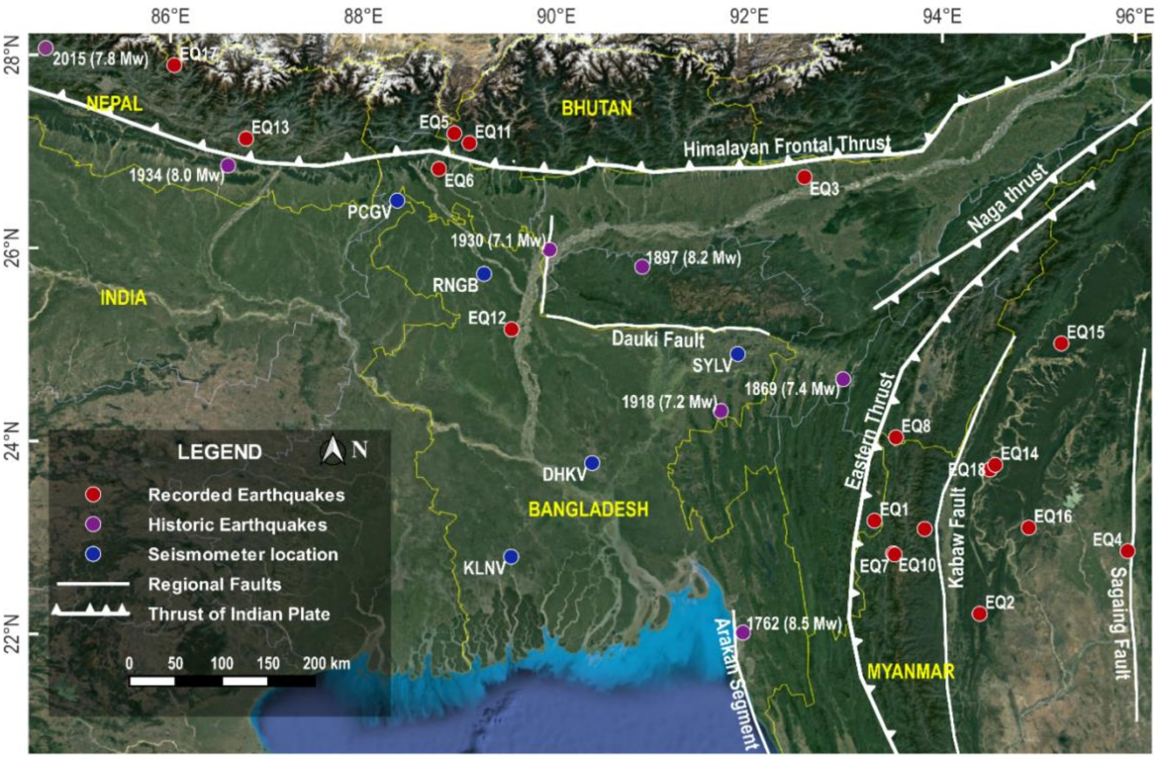

Figure 1. Map showing seismometer stations and epicenter of recorded earthquakes. Fault and thrust lines are reconstructed following Bürgi *et al.* (2021).

Table 1. List of earthquake waveforms collected from Bangladesh Meteorological Department (BMD).

EQ No.	Date	Time	Mw		EQ No.	Date	Time	Mw
EQ1	2020-07-05	11:56:35	4.8		EQ10	2022-05-21	3:14:07	4.5
EQ2	2020-12-08	5:14:35	5.1		EQ11	2022-07-01	21:23:45	4.2
EQ3	2021-02-17	12:24:47	4.6		EQ12	2022-07-30	20:00:00	4.0
EQ4	2021-02-25	2:34:27	4.9		EQ13	2022-07-31	2:28:10	5.1
EQ5	2021-04-05	15:19:58	5.2		EQ14	2022-08-24	21:48:11	5.0
EQ6	2021-04-06	1:36:56	3.9		EQ15	2022-08-26	4:52:25	4.6
EQ7	2021-11-25	23:45:42	6.2		EQ16	2022-09-29	22:22:37	5.6
EQ8	2022-01-18	2:22:16	4.5		EQ17	2022-10-19	9:22:40	4.9
EQ9	2022-01-21	10:12:32	5.4		EQ18	2022-10-29	5:38:21	4.4

2 RELEVANT WORKS

Analysis of seismic waveforms can be used to develop relationships among various earthquake parameters. For earthquake early-warning systems (EEWS), Satriano *et al.* (2011) explained the relations between earthquake magnitude and the p-wave amplitude to enhance earthquake magnitude predictions in Japan. To predict peak ground acceleration for Bangladesh and northeastern India for future earthquakes, Tabassum and Ansary (2020) developed an attenuation equation by analyzing peak ground accelerations from the waveforms recorded northeast of India by the Indian Meteorological Department. For seismic design, Islam *et al.* (2011) scaled earthquake waveforms recorded in Bangladesh to determine time-varying forces for dynamic analysis. Furthermore, for predicting the s-wave arrival, travel time curves of p and s-waves can also be constructed by analyzing the seismometer recordings of multiple stations, similar to the works of Si *et al.* (2017). Waveform datasets are available for these types of analysis, such as STEAD (STanford EArthquake Dataset), which includes 450,000 earthquakes with about 1,050,000 three-component seismograms (Mousavi *et al.* 2019).

3 PRELIMINARIES

Moment Magnitude (Mw), according to the USGS earthquake catalogue, is used to measure the size of an earthquake, which relates to the energy released during an earthquake. It is based on the seismic moment, Mo, which is a function of rigidity along the fault, fault area, and dislocation (Hanks and Kanamori 1979).

When seismic waves pass through the soil matrix, soil particles vibrate, which is detected by the seismometer. Waveforms are the plots of these vibrations on the ground. This vibration can be measured in UD, NS, and EW directions. For our analysis, we have used UD waveforms. The maximum acceleration detected during the vibration of the soil matrix is the peak ground acceleration (PGA), and the maximum detected velocity is peak ground velocity (PGV). The waveforms consist of different types of seismic waves. P-waves (primary wave) are detected first in the waveforms, which are compressional waves that travel faster, followed by s-waves (secondary wave), which are shear waves. Surface waves, which cause major damage during earthquakes, are generated when s-waves reach the earth's surface. Surface waves have a longer period and a higher amplitude than p- and s-waves.

The Bangladesh Meteorological Department uses GL-S60/120 velocity seismometers to collect wavefronts. Five active seismometers, denoted as PCGV, RNGB, SYLV, DHKV, and KLNV, are installed in the Panchagarh, Rangpur, Sylhet, Dhaka, and Khulna districts of Bangladesh, respectively.

4 STATISTICAL RESULTS AND ANALYSIS

This section presents some statistical analysis that establishes key relationships between the earthquake parameters, such as the peak ground velocity, magnitude, epicentral distance, and time of arrival of p- and s-waves of the collected data. To corroborate the results of our analysis, we juxtapose them with identical analysis on the STEAD dataset.

Since magnitudes are in a logarithmic scale, we replace them with the energy released during earthquakes. As Figure 2 demonstrates, there exists a linear relationship between the square root of energy and PGV, whereas there is an inverse relationship between the epicentral distance and PGV. While in some seismic stations (DHKV), these relationships are unambiguous, in others (PCGV), they are not so evident at first glance, as shown in Figure 3. This is due to excessive noise in the collected data, especially in cases where the recording stations are too far from the epicenter.

Next, linear regression is performed to derive the interdependence of the travel time of seismic waves with the epicentral distance. Figure 4 reveals a perfect linear relationship between these parameters. The inverse slopes of these plots yield the approximate s-wave velocity as 4.31 km/s and 4.22 km/s for the BMD and STEAD data, respectively. Due to the presence of high noise, there are some significant outliers in the BMD data are seen.

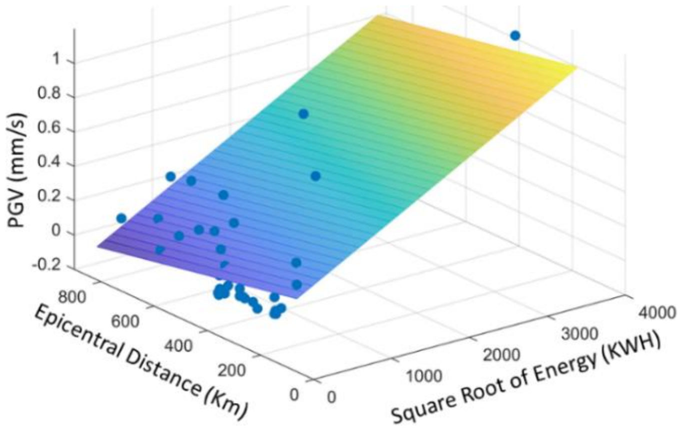

Figure 2. Plot of PGV with epicentral distance and energy released during earthquake.

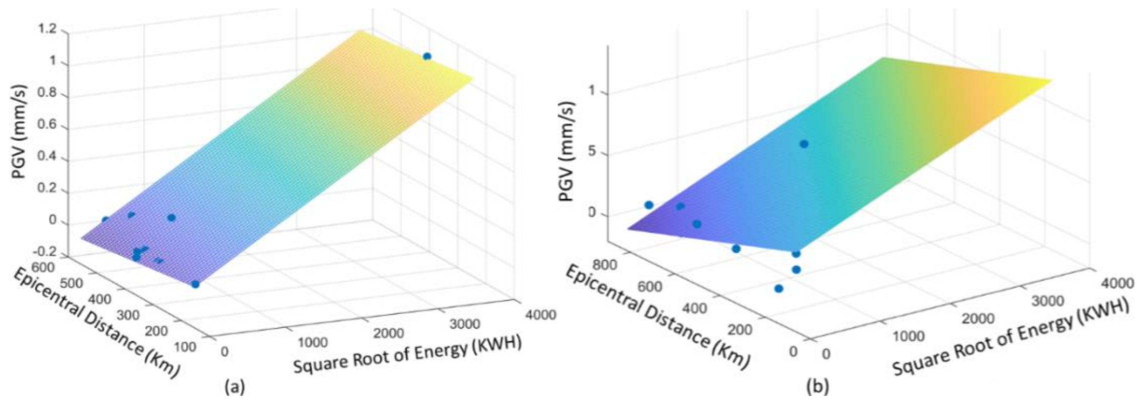

Figure 3. Plot of PGV: (a) For Seismic Station DHKV (b) For Seismic Station PCGV.

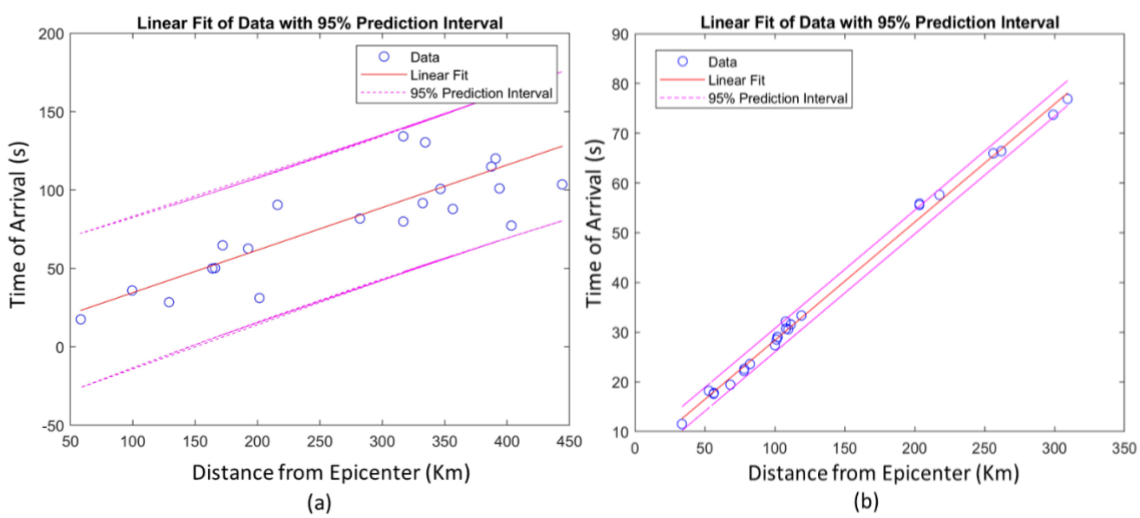

Figure 4. Plot of travel time of s-waves: (a) BMD data (b) STEAD data.

Similar regression methods are also performed on p-wave travel time, which results in a precise linear relationship like the one shown in Figure 4. The p-wave velocities are 6.13 km/s and 6.02 km/s for the BMD and STEAD data, respectively. The difference in these p- and s-wave velocities is of vital importance in providing earthquake early warnings.

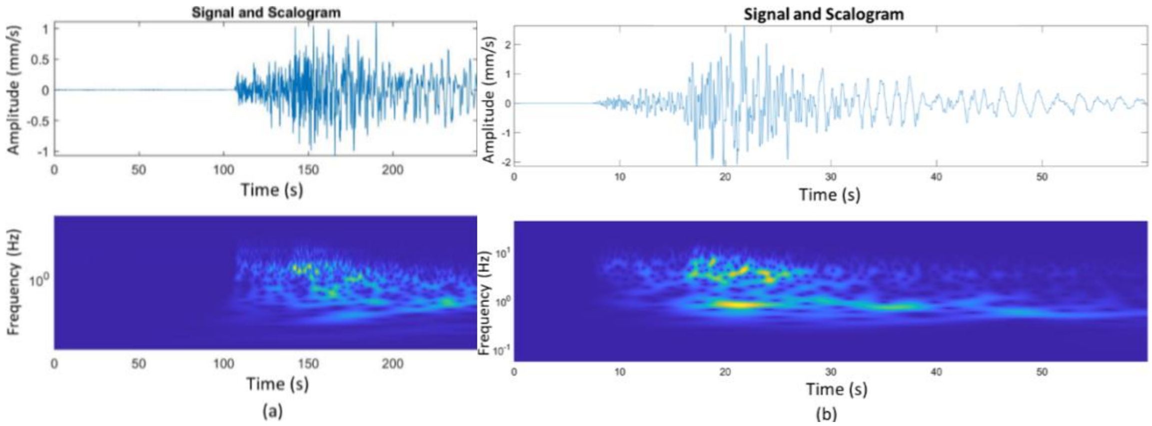

Figure 5. Wavelet analysis of seismic waves: (a) BMD data (b) STEAD data.

Furthermore, Fourier and Wavelet transformations are performed to investigate the frequency content of the seismic waves. Fourier transforms are used to represent signals in the frequency domain and are useful for analyzing repeating patterns and separating frequency components. Wavelet transforms, on the other hand, represent signals in a time-frequency domain and are well-suited for analyzing signals with sudden changes or transients. Figures 5 and 6 bring to light some intriguing peculiarities. It is evident from Figure 5 that as the seismic waves travel through a point, gradually, more and more frequencies in the lower band are observed. Figure 6 validates this observation; it is found that p-waves have a relatively higher frequency content than s-waves. The higher the frequency, the faster the wave travels, a certainty. High-frequency waves also experience higher attenuation. This explains why p-waves travel faster and suffer more attenuation than s-waves.

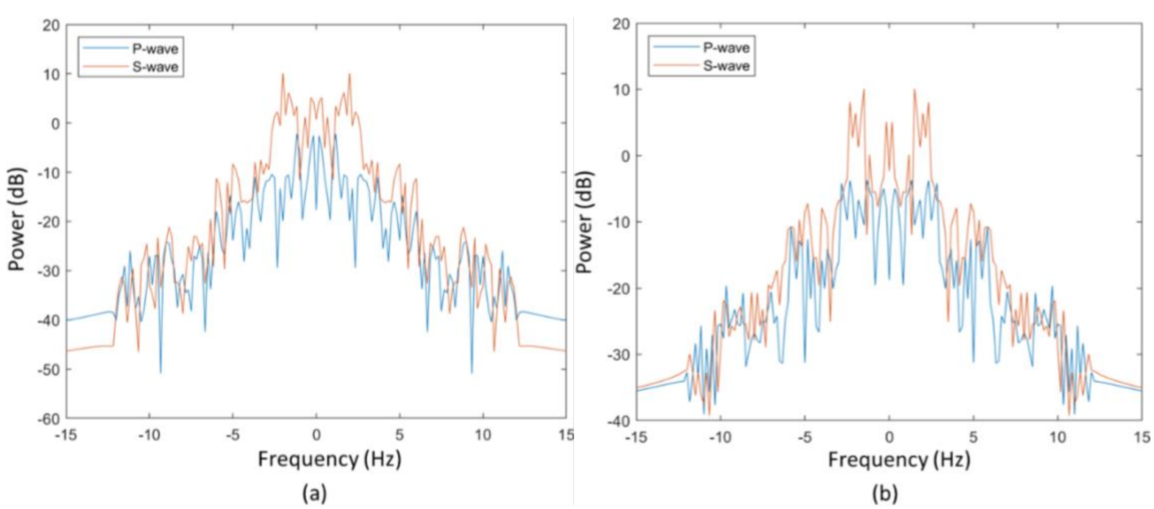

Figure 6. Average frequency spectrum: (a) BMD data (b) STEAD data.

5 CONCLUSION

In this work, a comprehensive statistical analysis was carried out to derive some thought-provoking interdependence among earthquake parameters. The relationship between PGV, epicentral distance, and magnitude was closely examined. It was found that the square root of energy and PGV are linear, while epicentral distance and PGV are inverse. Linear regression revealed that the travel time of seismic waves is directly proportional to the epicentral distance. Fourier and Wavelet analysis alluded to the higher frequency contents of p-waves compared to s-waves. These findings shall aid researchers in applications such as earthquake early-warning systems, seismic risk zone delineation, seismic hazard forecasts and geological research.

Acknowledgement

Authors would like to acknowledge the contribution of Bangladesh Meteorological Department for providing earthquake waveforms.

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