SEISMIC WAVEFORM DATA ANALYSIS OF SEISMIC NETWORK STATIONS OF ISLAMABAD, PESHAWAR AND LAHORE, PAKISTAN

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A thesis submitted to Bahria University, Islamabad in partial fulfillment of the requirement for the degree of B.S in Geophysics

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ABSTRACT

Pakistan is one of the most seismically dynamic nations on the planet. It is surrounded by several active fault zones due to which earthquakes are a frequent activity in Pakistan. Pakistan Meteorological Department's Seismology Division is responsible for keeping a record of these events. The primary goal of this research project is to trace these events and separate them from the noise. After that separation, different calculations will be applied to check the quality of seismic data obtained from three different stations of Islamabad, Lahore, and Peshawar.

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CHAPTER 1
INTRODUCTION

1.1.1 Introduction

1.1.2 Earthquake seismology

The study of earthquakes and the seismic waves that move through and around the earth is known as seismology. A seismologist is a researcher who concentrates on these occasions. The most effective method for studying the earth's interior is earthquake seismology. At the point when a seismic occasion like a quake (normal) or a blast (counterfeit) happens, a piece of the energy delivered is as flexible waves that are sent through the earth. Waves are then distinguished, recognized, and recorded by seismograms that action and upgrade the reaction of ground shaking.

1.1.3 Seismic waves

The physical science behind a seismic tremor is the breaking or development along a shortcoming zone that delivers a monstrous measure of energy as various waves that move along and through the outer layer of the earth. The waves that move through the outer layer of the earth are called body waves and they have a high speed and low sufficiency. Body waves are of two types, Primary and Secondary. Primary waves or P-waves are compressional waves and are the main appearances on a seismogram while Secondary or S-waves are shear/tensional waves that have more noteworthy sufficiency than P-waves yet can't go through liquids. Surface waves are named as the most disastrous kind of waves as they show high abundancy, however their speed is low when contrasted with the body waves. Surface waves are additionally partitioned into two sorts, Love and Rayleigh waves. Loves waves show a side-to-side movement while Rayleigh waves display a moving movement that can cause huge obliteration upon influence (Bolt, 1985).

1.1.4 Pakistan Meteorological Department

Pakistan Meteorological Division (PMD) is both, logical and administration office.

Its capabilities are under Bureau Secretary (Aviation Division). PMD is a legislative stage that gives Meteorological and Seismological information and administrations all through Pakistan for various exercises and tasks that require significant information.

PMD is appointed with the task to record these seismic events, analyze them, and store them. Earthquakes are the most frequently occurring events on earth and PMD has the sole responsibility of recording them and storing them. It is their task to conduct research and issue warnings if a major earthquake is about to occur or a tsunami is underway.

The provided data was searched thoroughly and some of the noticeable events were separated. These events were both, seismic and tele seismic, occurring around some of the most active tectonic zones around Pakistan. Three earthquakes were traced back to the Hindukush region, one was in Baluchistan, and three were on Main Boundary Thrust while one event was traced back to the Murray Ridge, Arabian Sea. These events were recorded on Islamabad, Peshawar, and Lahore Seismic Stations but there was a slight difference in the quality of the data recorded at these stations. The purpose of our study was to examine the quality of all the data three Pakistan Seismic Network Stations. The following figure was generated on a Generic Mapping Tool (courtesy, PMD).

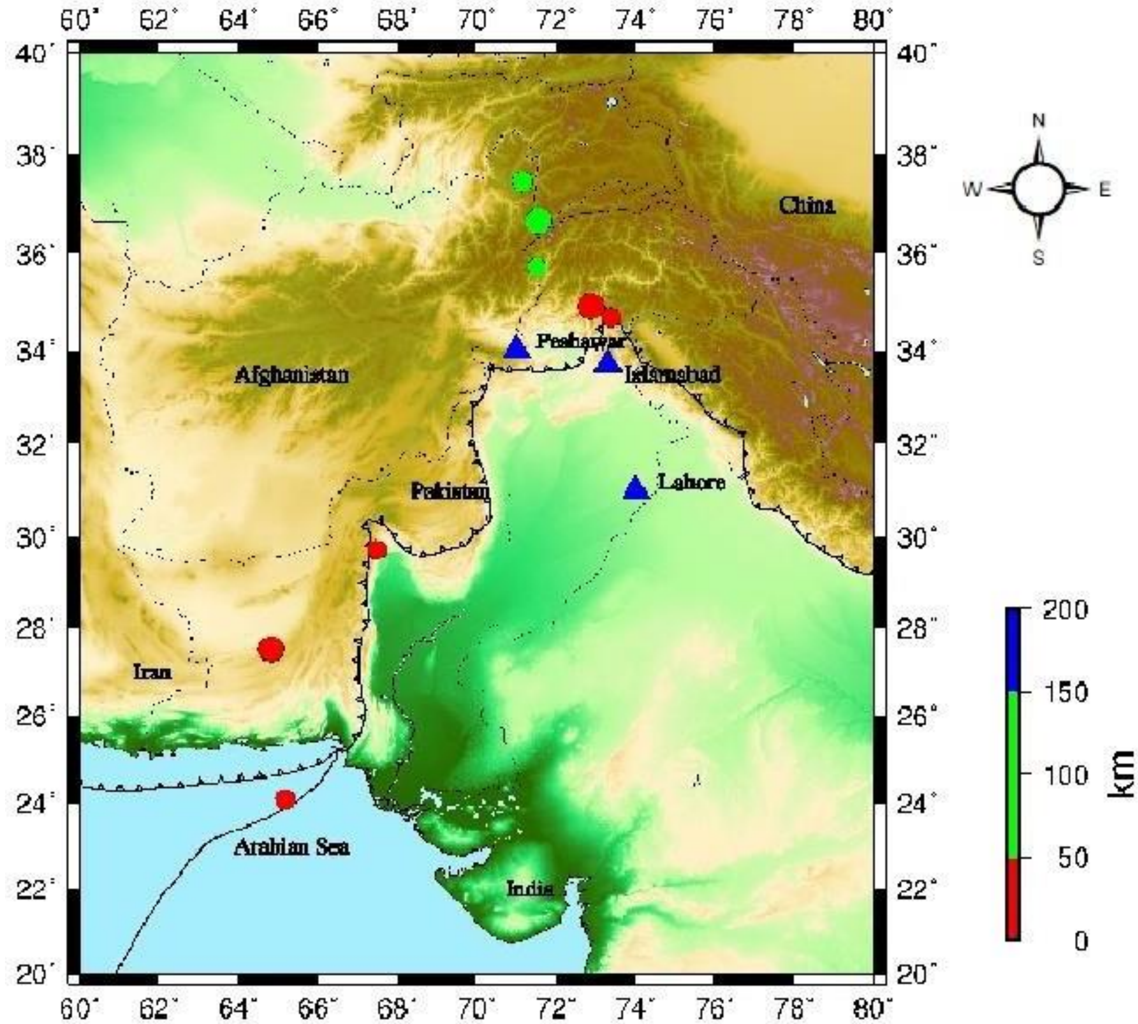


Figure.1.1. Location of three PMD Seismic Network Stations, Islamabad, Lahore and Peshawar and Earthquake epicenters used for this study. (Generic mapping tool)

1.2 Objectives

The main objectives of our research study are.

1. To separate events from noise.
2. To calculate the distance between the station and the source.
3. To calculate the ray parameter or slowness.
4. Performing H/V analysis using Geopsy.

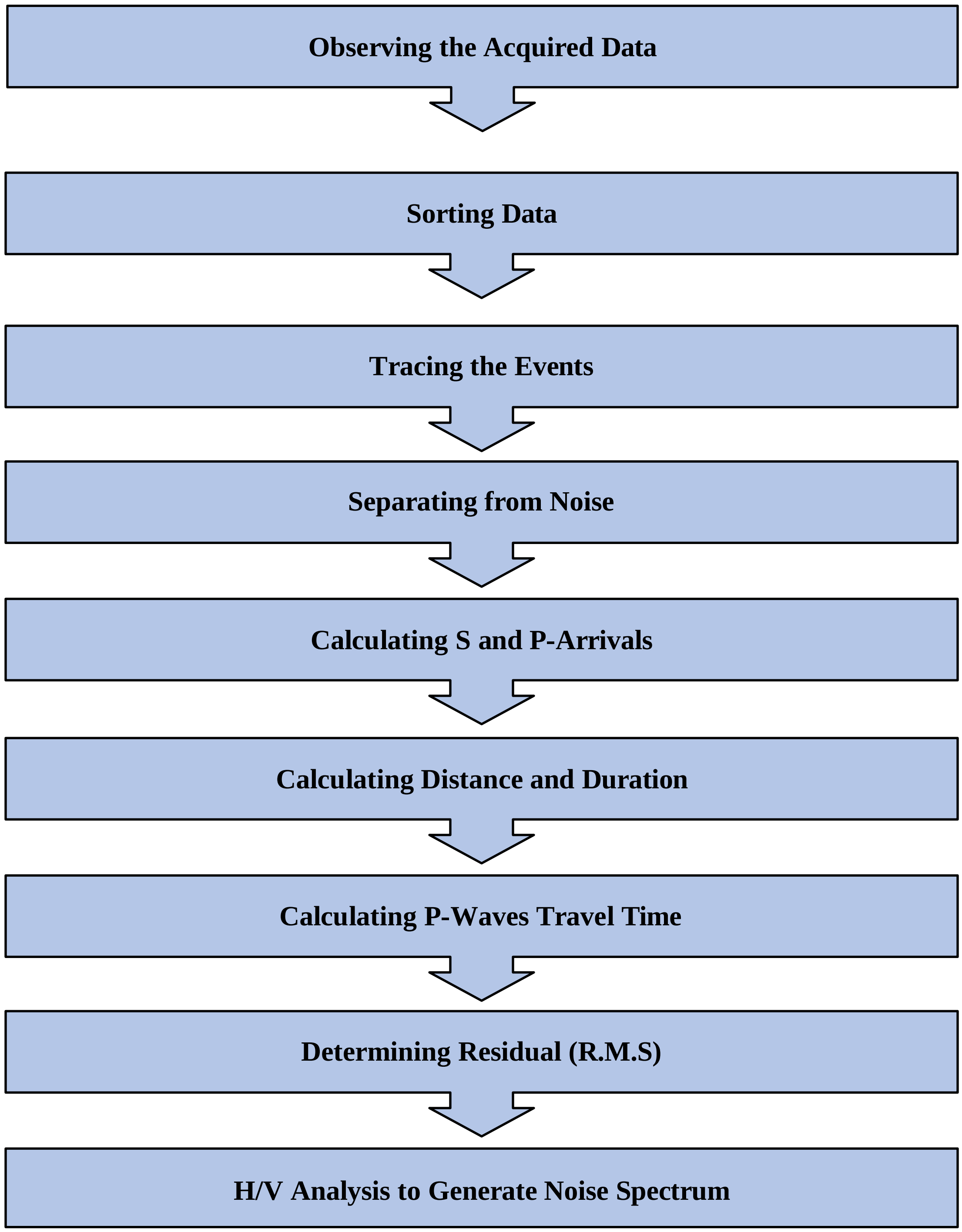
5. To analyze the earthquakes with identification of travel time phases with residuals (R.M.S) to check the quality of stations waveform data.

1.3 Available data

Provision of Main Data was done by Pakistan Meteorological Department. This information contained seismograms of all the events and noise, recorded at Lahore, Islamabad and Peshawar stations that occurred from 4^{th} April 2017 till 26^{th} July 2017. The provided events were in three axes North- South (n), East-West (e) and Vertical axis (z).

It is not necessary that the ground shake only in one direction. The three axes always provide a clear picture of the events. As the seismic waves travel in different trends, their motion forms a peculiarity and this peculiarity helps in identifying S from P waves, for instance, in an event, if the P-wave is traveling in a North-South trend and S- wave is shaking the ground in East-West direction then the waves will exhibit a strong motion on the n-axis and e-axis, respectively (Capon and Members, IEEE, 1969). Therefore, all three axes are taken into consideration before analyzing the seismogram for accuracy and precision in further interpretation.

1.4 Methodology adopted.



CHAPTER 2
GENERAL GEOLOGY OF STUDY AREA

2.1. General geology of Islamabad

The prevailing component controlling the topography of the Islamabad region is the union of the Indian and Eurasian structural plates and the impact between the plates that started around a long time back. This cycle delivered complex construction and stratigraphy in the Islamabad region. The Islamabad region can be partitioned into three primary zones, moving commonly east-upper east, that reflect pressure and movement Oriented S. 20° E (Naeem and Bhatti, 1985).

1. The Margalla Hills in the northern region consist of a geological formation ranging from Jurassic to Eocene, comprising limestone and shale that exhibit intricate folding and thrusting along the Hazara fault zone. The uplifting of these mountains has created a significant topographic barrier over the past 1 million years (Naeem and Bhatti, 1985).
2. South of these mountains, there is a piedmont slope slanting towards the south, known as the piedmont crease belt. This area is primarily characterized by compressed folds in the sandstone and shale formations of the Rawalpindi Group (Naeem and Bhatti, 1985).
3. In the southernmost part of the region, the Soan River predominantly follows the course of the Soan syncline axis. (Naeem and Bhatti, 1985).

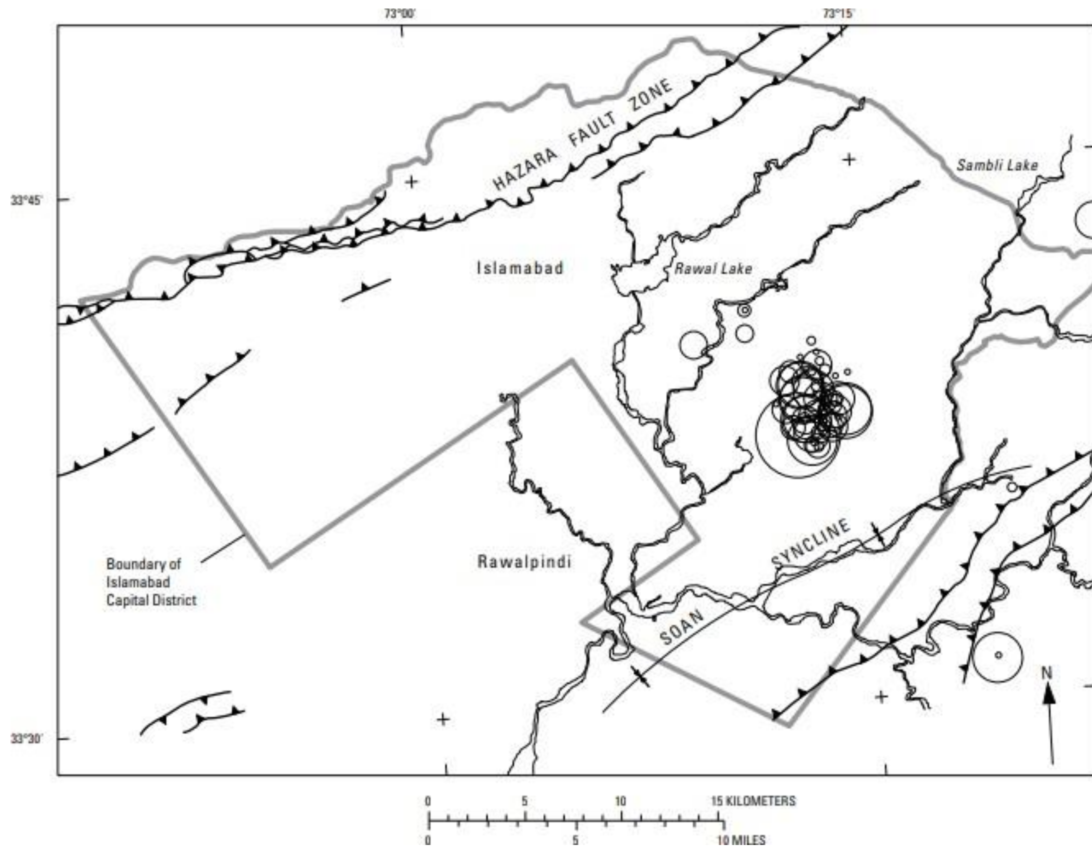


Figure 2.1. Geological map of Islamabad (Adhami et al., 1980)

2.1.1. Seismic risk

In the recent geologic past, faulting, folding, and earthquakes have occurred in the tectonically active zone that includes the Islamabad region. The entire area is filled with structurally deformed quaternary deposits. An earthquake believed to have had Mercalli force IX destroyed the Buddhist cloisters at Taxila, which is located 25 km to the west-northwest of Islamabad, in the year 25 A.D. More recently, damage exhibiting Changed Mercalli Intensity VII at the focal site was produced by a Richter magnitude 5.8 earthquake that occurred on February 14, 1977, focused 7 km northeast of Rawalpindi (Adhamietal.,1980).

2.2. General geology of Peshawar

Peshawar station lies in the core of Peshawar basin. The geography and structural setting nearby Peshawar basin are extremely perplexing. The Peshawar basin lies 150 km north of the dynamic front of Himalayan deformation at the Salt Range and 50 km south of the MMT, the suture between the Indian plate and the Kohistan Island arc terrain. Between the Panjal-Khairabad fault and the MMT, the Peshawar basin covers about 5500 km2. The largest part of the basin is covered by Plio-Pleistocene basin fill with a Precambrian to Mesozoic sequence underlying it (Kazmi and Jan 1997). Between 2.8 and 0.6 Ma, the lacustrine and fluvial deposits of the Peshawar basin fill continued to be deposited. The boundaries of the basin are not well defined. Generally, the southern part has meta-Sediments while the northern part contains fracture related plutonic-volcanic rocks (Hussain and Yeat, 1989).

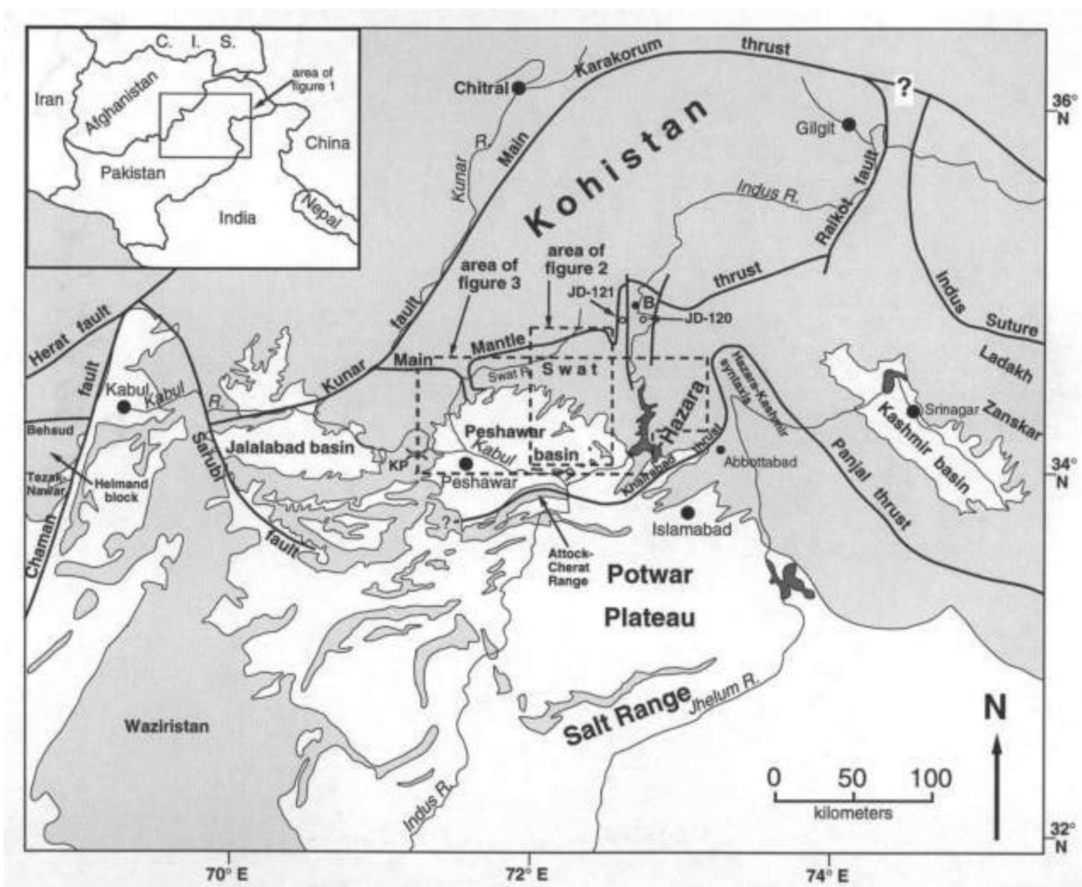


Figure 2.2. Map of Peshawar basin and vicinity (Survey of Pakistan, 1989).

2.2.1. Seismic risk

Peshawar in the western Himalayas experiences high seismicity rates. Main Boundary Thrust (MBT) system along which the overwhelming Kashmir earthquake happened in 2005 is situated in the encompassing the Peshawar along with some other active regional fault systems, Include Main Mantle Thrust (MMT) and Main Karakorum Thrust ((MKT). These faults, whenever reactivated can go about as an expected Source of seismic risk for the locale including Peshawar (Lisa and Khawaja, 2002).

2.3. General geology of Lahore

The topography of Lahore is extremely basic as Lahore lies on the Punjab platform. It lies on the alluvial plain called Bari Doab. The area that lies between rivers is known as doab. Bari Doab is a part of the Indo-Gangatic alluvial plain formed by the Indus Stream and its tributaries. It is bounded by the Ravi and Chenab rivers in the northwest and west and by Sutlej Stream in the southeast. Doab's northeastern boundaries are close to the Himalayan Range’s foothills (Naseem and Ghulam ,2011).

2.3.1. Seismic risk

The Punjab plain, where the project site is located, has low to moderate seismic activity. The project area has previously experienced intense shaking because of Himalayan earthquakes. The Main Boundary Thrust (MBT), the primary active fault of the Himalayas, is located approximately 180 km northeast of Lahore along the Himalayan front. Over the previous century, this fault has recorded earthquakes with magnitudes greater than 8. The subterranean fissures in the basement rocks, which are hidden by dense alluvial deposits, are linked to the epicenters of low to moderate magnitude earthquakes that have been seen in the Punjab plain (Shah et al., 2008).

CHAPTER 3
ANALYSIS

3.1 Introduction

Seismogram interpretation is the heart of earthquake analysis. To trace the event and calculate its parameters that include, S and P arrivals, distance, duration, depth, travel time of the waves, slowness and calculate the residual time that causes the delay.

After acquiring these parameters, several processes are applied to generate noise spectra. These processes involve many spectral analyses like H/V analysis, F-K Analysis.

Calculation of these parameters will be explained step-by-step following the methodology that was explained earlier in chapter 1.

3.2 Methodology

3.2.1 Observation of acquired data.

The provided data was in the form of. GCF format. This data was recorded live from 4th April 2017 till 26th July 2017. This data contained events as well as noise. The first step is to identify the events and noise. For that, scream 4.5 is used which supports the GCF format. The data is present in three separate folders, each containing seismograms relating to the three axes, North-South, East-West and Vertical. As mentioned in Chapter 1, the earth doesn't shake in a single direction, but its motion is a combination of these three separate axes. Sometimes the intensity of ground shaking is stronger in one direction. Therefore, the three seismograms of the same event are sorted and opened as a single file for better observation.

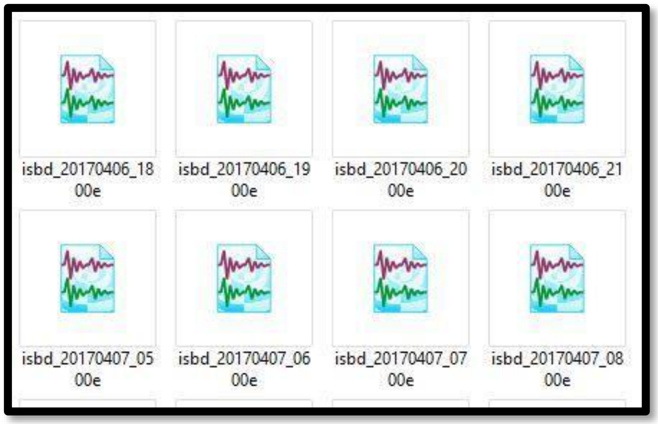


Figure 3.1. Raw Seismograms in East-West axis.

3.2.2 Sorting of data

The data that is initially present in three separate folders with respect to their axes, is then sorted according to their date and time. This sorting of data provides us with a clear picture of an event and makes the earthquakes easy to identify.

Figure 3.2. Data in three separate folders w.r.t. their axis.

The time and dates of each seismogram is plotted as it is being recorded. These seismograms have a time window of one hour. Therefore, a huge amount of data from April 2017 to July 2017 was compiled, sorted, and thoroughly checked.

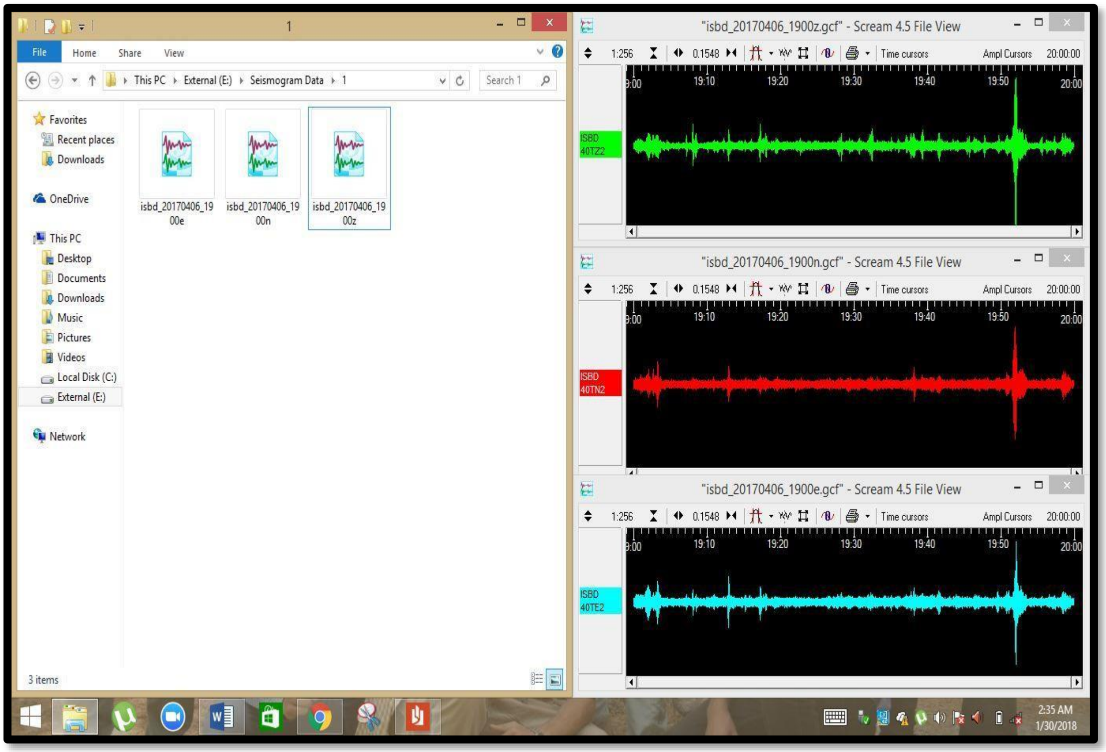


Figure 3.3. Data in separate file windows.

Seismograms are then picked according to their date and time. They are then combined with all three axes of the same date and time by selecting all three GCF files (right-click>View with Scream). After that, they are viewed in Scream in a single window instead of three separate ones. This compilation, though easy, does create an ease of accessing all three files at the same time as shown in fig. 15.

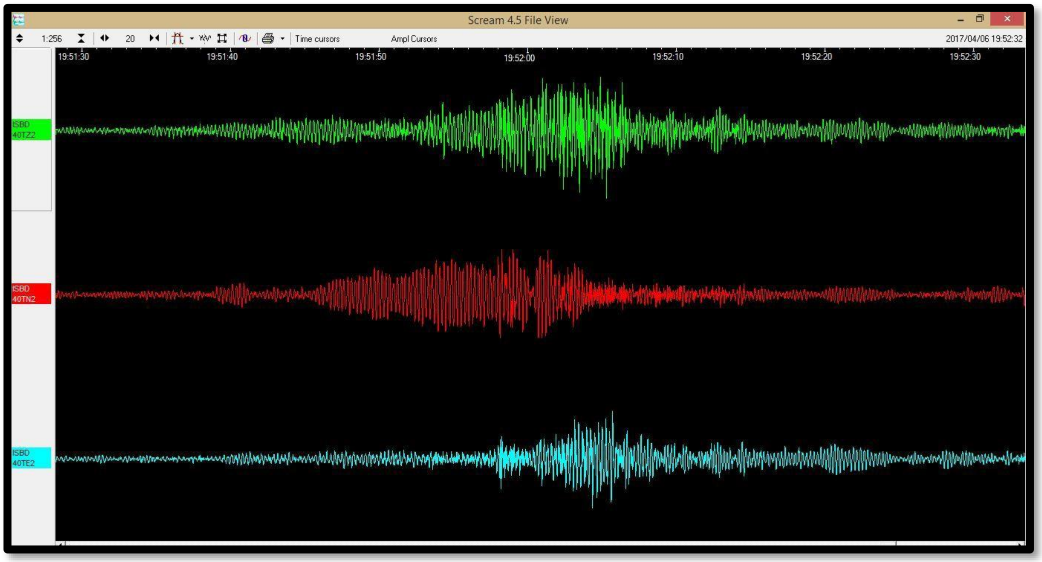


Figure 3.4. Three axes files viewed in the same window.

Instead of selecting all three files, the three files can also be saved as a single file so that all three axes could be accessed by a single click. To do so, first the files are opened as mentioned before, and then the required part is cropped out of the seismogram by dragging the cursor while keeping the "shift" key pressed.

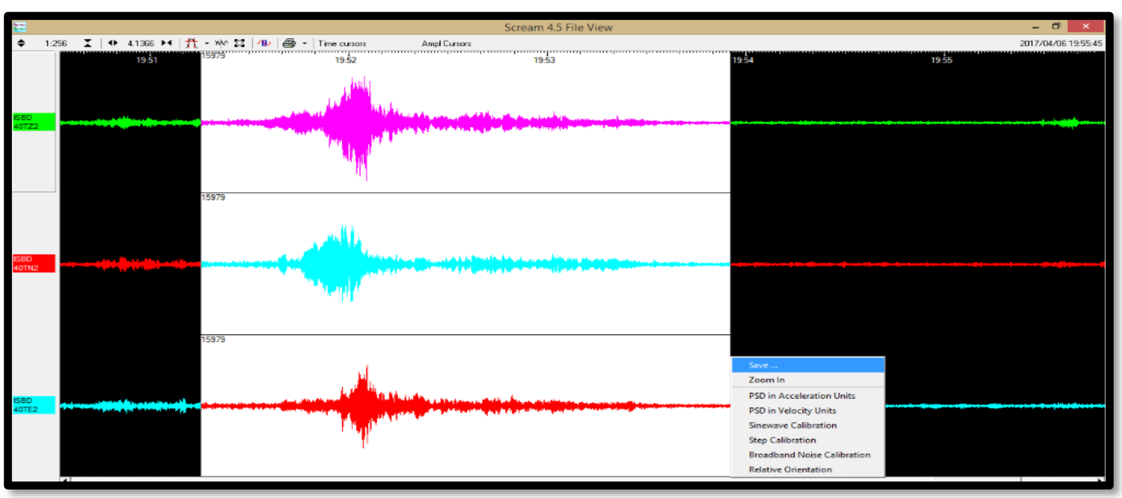


Figure 3.5. Cropping out the desired part and saving it as a single file for ease of access.

3.2.3 Tracing the event

Tracing an event is tough but crucial. Seismograms, a mix of signals and background noise, help us understand what happened. In this context, the signal is an earthquake. P-waves and S-waves create a special pattern, the only way to tell them apart from noise. Noise, like wind or traffic, can make the seismograph vibrate. During an earthquake, the fastest waves, P-waves, are usually recorded first. They're the initial, bigger wiggles. S-waves come next, usually larger than P-waves. If a seismogram shows no S-waves, it means the earthquake was on the opposite side of the Earth since S-waves can't go through the liquid layer. Surface waves (Love and Rayleigh), often bigger, show up later due to their lower frequency. They reach the seismograph just after S-waves because they travel a bit slower. In shallow earthquakes, the strongest waves on the seismograph are usually surface waves.

Eight events were traced using the above-mentioned technique and these events were of and around the vicinity of Pakistan.

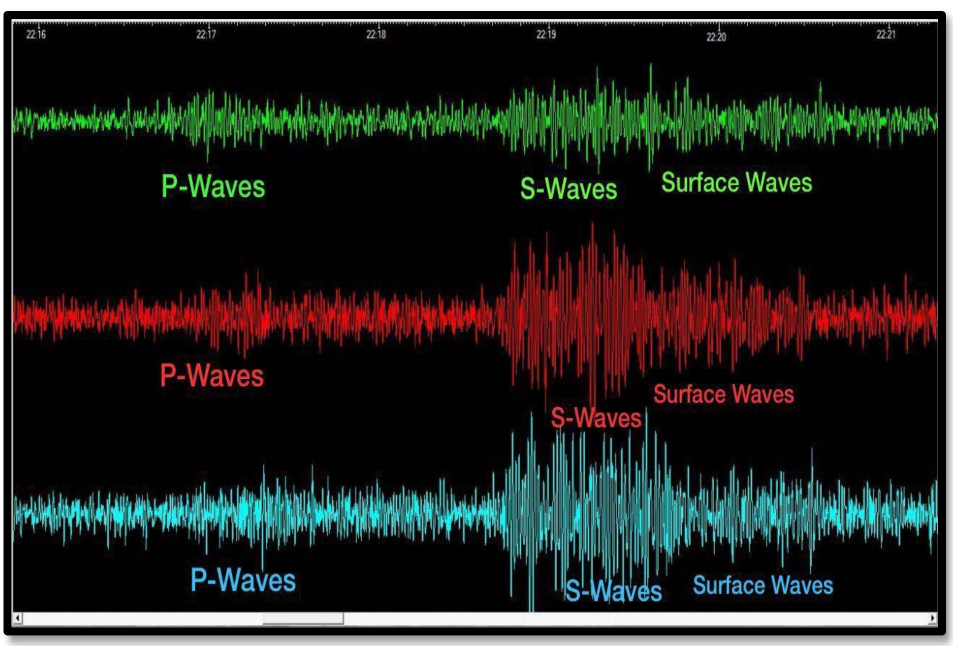


Figure 3.6. Tracing an event based on wave pattern.

3.2.4 Separation from noise

The refinement of the signal is done in this step and to do so, the band pass filter is applied. Scream 4.5 offers a wide range of filters but the filter used in this research is the band-pass filter. The filter is configured with a low-pass frequency set at 1.0 hertz and a high-pass frequency set at 0.1 hertz. After the application of the filter the waveform data appears to be reduced. This reduction in the amplitude can be magnified using the arrow keys (Left for spreading the waves, right for compressing the waves, up for amplifying the amplitude and down to reduce the amplitude). It is hard to separate an event from the noise without applying the band-pass filter because the entire seismogram seems to be distorted and the event is divulged in the noise while unnecessary disfiguring of waves is present.

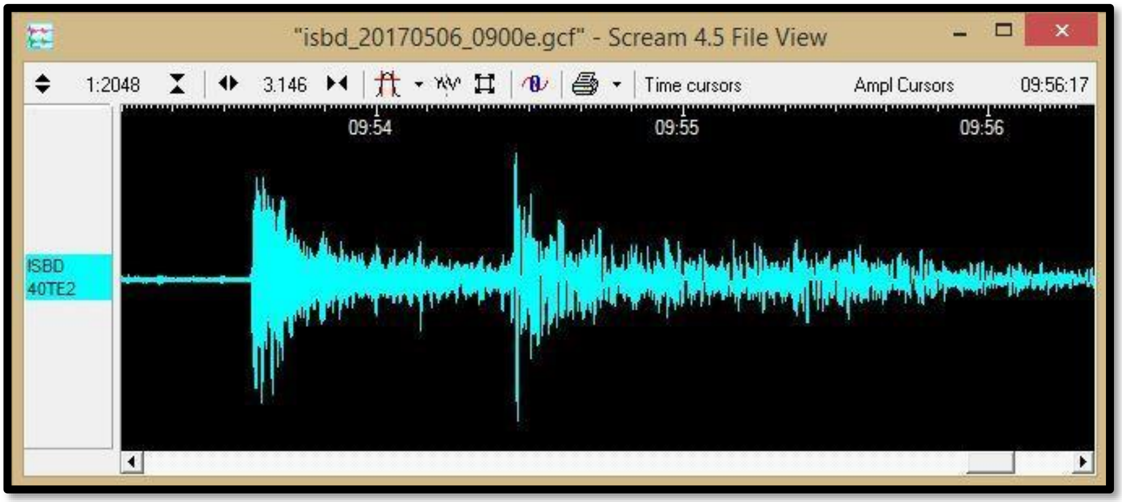


Figure 3.7.A non-filtered event.

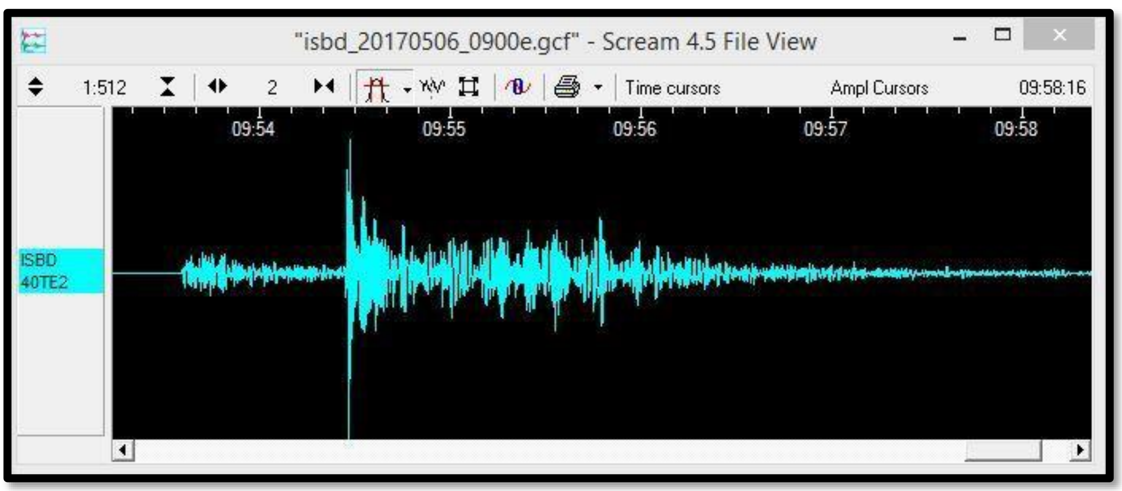


Figure 3.8.A filtered event.

3.2.5 Calculating P and S arrivals

Calculation of P and S arrival is the first and foremost step in attaining the parameters of a seismic event. P and S arrivals indicate the time at which the earthquake was generated and the distance the seismic waves have traveled from the point of source to the seismic station. To calculate the P and S arrivals, scream software is used.

The P-arrivals are termed as the first arrivals on a seismogram, followed by the S-arrivals. Therefore, P-arrivals are easy to identify as they exhibit the first noticeable undulation of greater amplitude than their predecessor. These first breaks indicate the time at which the P-wave reached the seismic recorder.

View the event in Scream 4.5 in all three axes. Place the cursor on the first noticeable break, left click and drag it until the next noticeable change that would be the S-Arrivals. The time window will indicate the S-P time (18.839 seconds in fig. 20). S-P time is necessary for predicting the epicenter because the greater the S-P, the farther will be the source of the event and greater will be the distance between the station and the source.

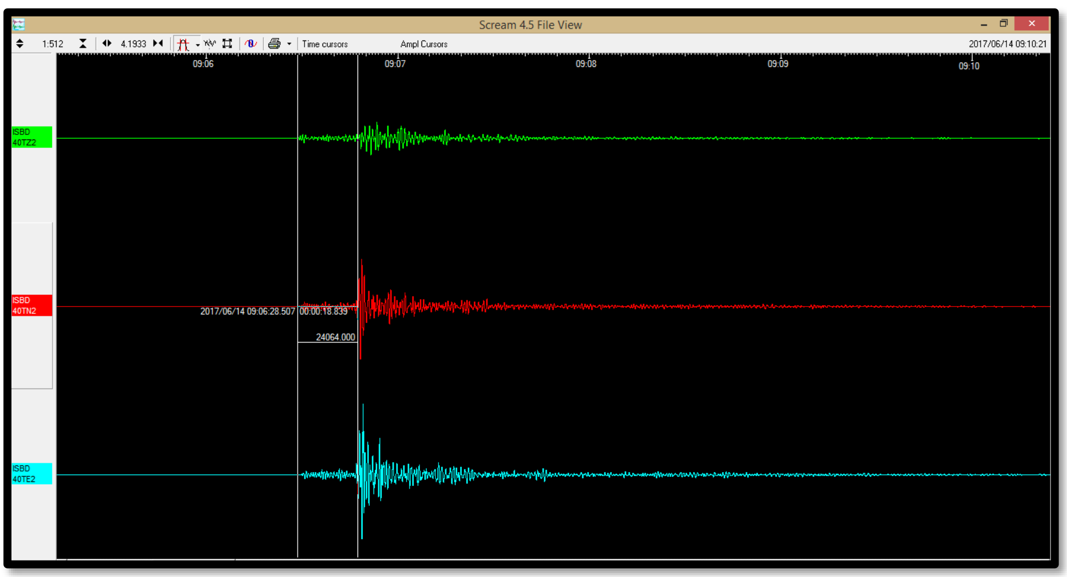


Figure 3.9 P and S arrivals and S-P window.

3.2.6 Calculating the duration and distance of the event

The second step in the seismogram interpretation is calculating the duration of the event and the distance between the source and station. Scream 4.5 is used again for the calculation of the duration of an event. Similar methodology is applied in this step as well, the time window is generated but instead of isolating the P-waves, the entire event is marked. This entire plotting of the time window on the event will give the duration of the earthquake (4 minutes 21.250 seconds in this example) (Figure. 21)

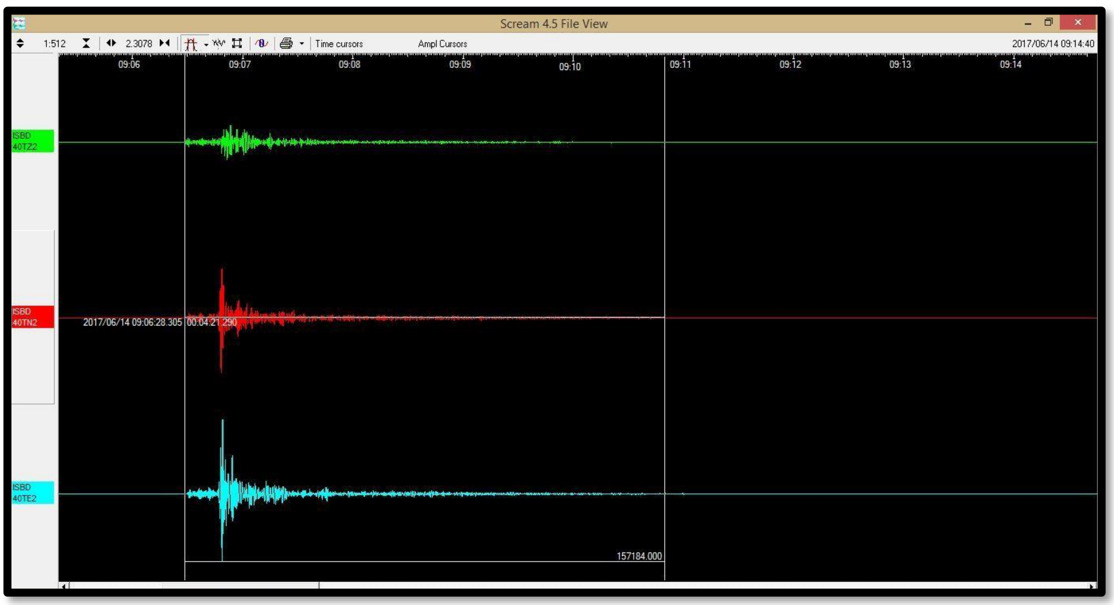


Figure 3.10. Duration of the event plotted by the time window.

For the distance calculation, the coordinates of the station and the coordinates of the source of the event are subtracted. This subtraction will give us the path of displacement from source point to the seismic station.

3.2.7 Calculating observed and theoretical P-Wave travel time

P-waves are the first to reach the seismograph and they carry the most useful information. These waves can pass through solids as well as liquids but apart from that, They are also quite important in seismological studies. P-waves travel time is dependent upon the depth of the source of generation. For a specific depth, The P-waves' observed travel time is recorded.

For the P-waves' hypothetical travel time, a standard iasp91 velocity model is given where velocities of P-waves are plotted against a specific depth of source. From there, the velocity of P-waves is noted and as the source-station distance is known, the travel time of P-waves can be calculated. Note that this travel time is different from the observed travel-time.

3.2.8 Calculating residual (R.M.S.) and ray parameter

The primary goal of this study is to evaluate each seismic station's data quality. The residual values that are left behind after deducting the P-waves' theoretical and observed travel periods are used to assess the quality of the data. The recorded data is of low quality if there is a larger discrepancy between the observed and theoretical journey times. On the other hand, the data quality will improve with a lower residual.

Ray Parameter or the "Slowness" of the wave is the reciprocal of its apparent velocity. The geometric characteristic of a seismic ray that doesn't change along its course is called the ray parameter. All that is needed to determine the ray parameter is to add the residual (r.m.s) to the measured P-wave travel time.

3.2.9 H/V Analysis to generate noise spectrum.

The horizontal-to-vertical spectral ratio, or H/V, is a quick and easy method for obtaining site parameters of technical importance. It measures the ambient noise wave field on the surface of the ground using a single, three-component sensor. (Hirono, Mayuko, & Kohji, 2004), (Donat, Fortunat, and Domenico (2004). Several modeling techniques are used to simulate the H/V curve, and these techniques may have an impact on the retrieved soil profile. A three-component sensor that is positioned on the ground's surface and records the seismic noise wave field is used to collect the data. Geopsy is used to calculate the Fourier spectra of the recorded seismic noise for each of the three components.

Geopsy is a graphical user interface for organizing, viewing, and processing geophysical signals. Geopsy is a database used to gather all information about recorded signals. GCF files are not supported by Geopsy, therefore they should be converted in SAC format. For that, gcf2sac converter is used. There are two ways in which the files can be converted, either select the desired events (in GCF) and drag and drop them on the gcf2sac conversion file (figure 23) or convert the entire GCF data in SAC by a single command. To do so.

a) DOS is opened.
b) GCF data folder is accessed by the command, “cd <folder name>”
c) To check for the entire GCF file in the folder, “DIR” command is used.
d) To select the .GCF files, “dirf *.gcf” command is used.
e) For the conversion of GCF data into SAC, “gursei” command is used.

The signals are then converted into SAC format that is easily supported by Geopsy.

Figure 3.11.GCF files converted in SAC using gcf2sac convertor.

These SAC files are then accessed by using Geopsy database. These files are then loaded in the processing window.

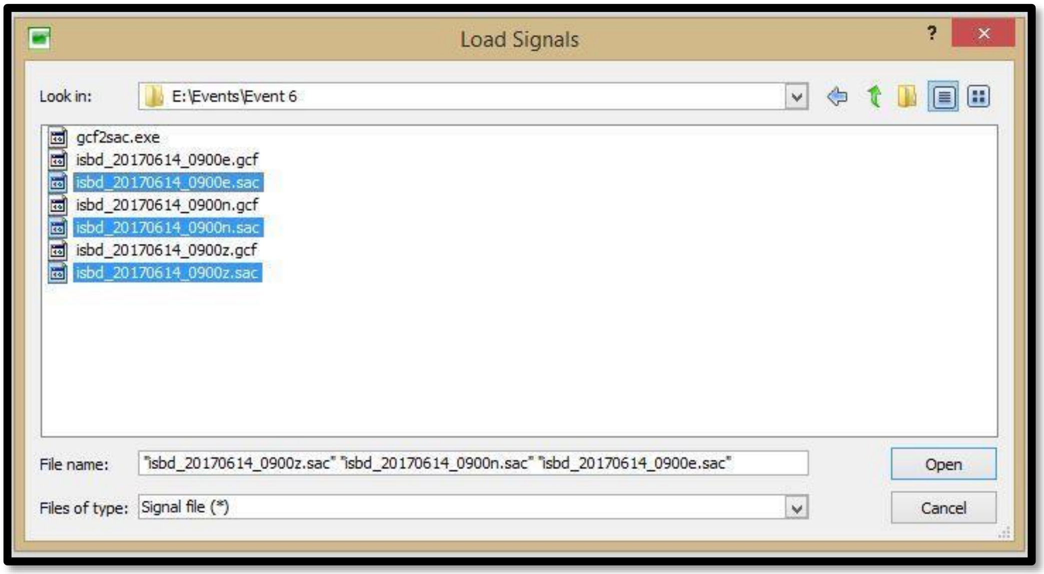


Figure 3.12. Loading of signals in Geopsy.

After the signals are loaded in Geopsy, the SAC files are selected and with the right click of the mouse the H/V analysis is selected.

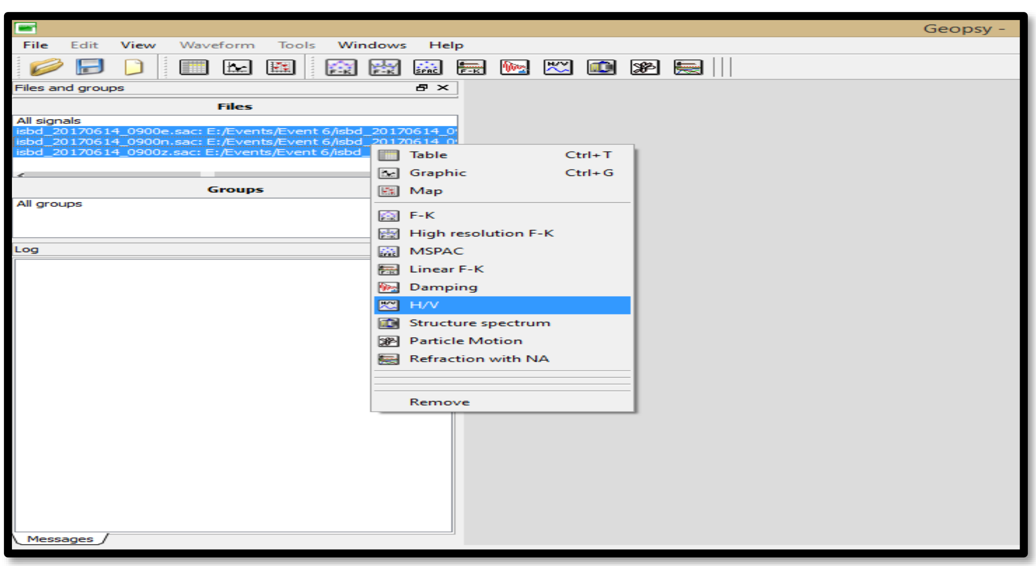


Figure 3.13. Selection of H/V.

First, the signals are shown in the form of waves and a parameter-processing window is opened. Filters can be added or removed as per requirement.

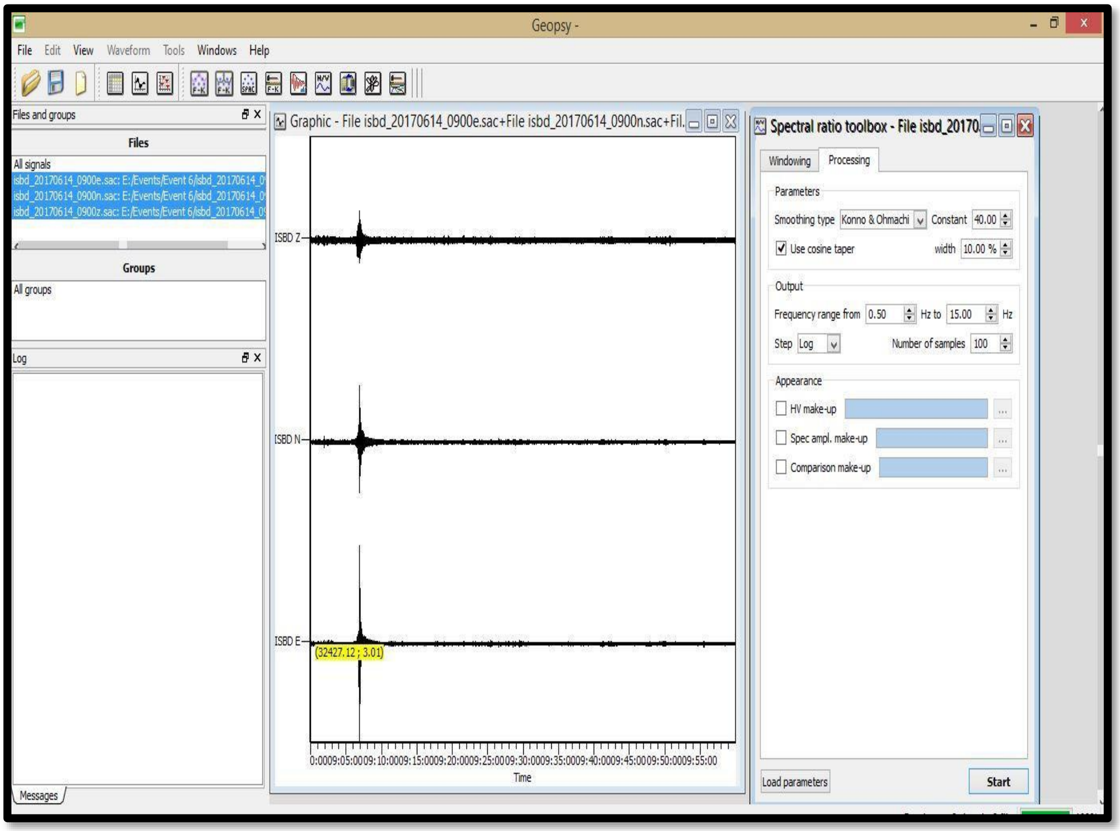


Figure 3.14. Waveform view in Geopsy.

After clicking “start” in the bottom right corner, the spectrum is then generated. The spectrum is a combination of a solid black line (the main signal), dotted lines (possible standard deviation), and colored lines.

CHAPTER 4
EVENTS INTERPRETATION

4.1 Interpreted events.

The same events that were recorded in Islamabad, Lahore and Peshawar seismic stations had to be chosen and they depicted some residual (r.m.s). These events were then sorted according to their respective seismic stations and the data that was calculated in interpretation was then complied. These events are displayed individually with respect to their respective seismic recording stations.

Sr. No.	**Date**	**Time (UTC)**	**Lat. (N)**	**Long. (E)**	**Depth (Km)**	**Magnitude**	**Region**
1	2017-07-08	10:12:33	34.680	73.380	40	4.8	Pakistan
2	2017-05-06	09:52:29	36.670	71.550	198	5.2	Hindukush, Afghanistan
3	2017-04-22	19:37:36	29.700	67.480	15	4.4	Pakistan
4	2017-07-20	14:04:43	36.460	71.150	187	4.0	Hindukush, Afghanistan
5	2017-06-14	09:06:09	34.900	72.870	54	4.6	Pakistan
6	2017-05-16	18:13:32	36.720	71.500	175	4.2	Hindukush, Afghanistan

Sr.no.	**Date**	**Time UTC**	**Lat. (N)**	**Long. (E)**	**Depth (Km)**	**Magnitude**	**Region**
7	2017-07-09	11:35:28	27.500	64.830	49	4.7	Southwest Pakistan
8	2017-07-08	22:13:53	24.080	65.170	10	4.1	Off-coast Pakistan

4.2 Calculated parameters for Islamabad station

These same events were recorded at the Lahore seismic station and the parameters were calculated using the same methodology. Below is the list of all events in a single table.

Sr. No.	**P-Arrival**	**S-Arrival**	**S – P**	**P-wave travel time(obs.)**	**P-wave travel time(th.)**	**Ray Parameter**	**Residual (R.M.S)**
1	10:12:51	10:13:07	16 s	18 s	13.53 s	22.47 s	4.47 s
2	09:53:35	09:54:27	52 s	66 s	42.87 s	89.13 s	23.13 s
3	19:39:17	19:40:32	75 s	101 s	84.49 s	115.51 s	14.51 s
4	14:05:57	14:06:16	19 s	74 s	43.09 s	106.99	31.99 s
5	09:06:28	09:06:45	17 s	19 s	16.39 s	21.60 s	2.60 s

Sr. No.	**P-Arrival**	**S-Arrival**	**S – P**	**P-wave travel time(obs.)**	**P-wave travel time(th.)**	**Ray Parameter**	**Residual (R.M.S)**
6	18:14:26	18:14:56	30 s	54 s	44.38 s	63.62 s	9.62 s
7	11:37:45	11:39:17	92 s	137 s	134.86 s	139.14 s	2.14 s
8	22:17:19	22:18:44	86 s	216 s	194.25	237.75	21.75

4.3 Calculated Parameters for Lahore Station

These same events were recorded at the Lahore seismic station and the parameters were calculated using the same methodology. Below is the list of all events in a single table.

Sr. No.	**P-Arrival**	**S-Arrival**	**S – P**	**P-wave travel time(obs.)**	**P-wave travel time(th.)**	**Ray Parameter**	**Residual (R.M.S)**
1	10:13:01	10:13:23	22 s	28 s	43.84	43	15
2	09:53:48	09:54:59	71 s	79 s	74.258	83.742	4.742
3	19:39:31	19:40:51	80 s	155 s	84.873	145.127	30.127
4	14:06:09	14:06:47	38 s	86 s	74.81	101.19	15.19
5	09:06:58	09:07:19	21 s	49s	48.395	59.605	10.605
6	18:14:41	18:15:20	39 s	69s	76.244	76.244	7.244
7	11:38:02	11:39:54	112 s	154 s	126.77	181.23	27.239
8	22:17:51	22:19:24	93 s	238s	179.85	296.15	58.151

4.4 Calculated parameters for Peshawar station

Sr. No.	P-Arrival	S-Arrival	S - P	P-wave travel time(obs.)	Ray Parameter	Residual (R.M.S)	P-wave travel time(th.)
1	10:13:07	10:13:27	20 s	34 s	45.49 s	11.49	22.51 s
2	09:53:38	09:54:35	57 s	69 s	102.497 s	27.50	35.503 s
3	19:39:49	19:40:57	76 s	133 s	191.68 s	38.68	74.32 s
4	14:06:55	14:07:16	21 s	132 s	130.471 s	36.47	33.529 s
5	09:07:00	09:07:23	23 s	51 s	82.903 s	19.93	19.097 s
6	18:14:51	18:15:23	32 s	80 s	123.267 s	13.27	36.733 s
7	11:38:46	11:40:30	104 s	217 s	289.347 s	29.35	120.653 s
8	22:18:03	22:19:24	86 s	250 s	313.524 s	43.53	186.47 s

4.5 Generation of H/V spectrum of the events recorded at Islamabad seismic station.

This instrument measures the spectral ratios of horizontal to vertical (H/V) vibrations from any kind of vibration signal, including earthquake and ambient vibrations. H/V analysis is performed on the events that were traced from the available data of Islamabad station. These events contained noise as well as the traces of the event.

To distinguish noise from signal.

we perform H/V analysis that will generate noise spectrum. Following H/V analyses were performed on Geopsy software.

4.5.1 Event 1 H/V spectrum

H/V analysis of the first event was performed. Figure (54) displays each elements' H/V spectrum.

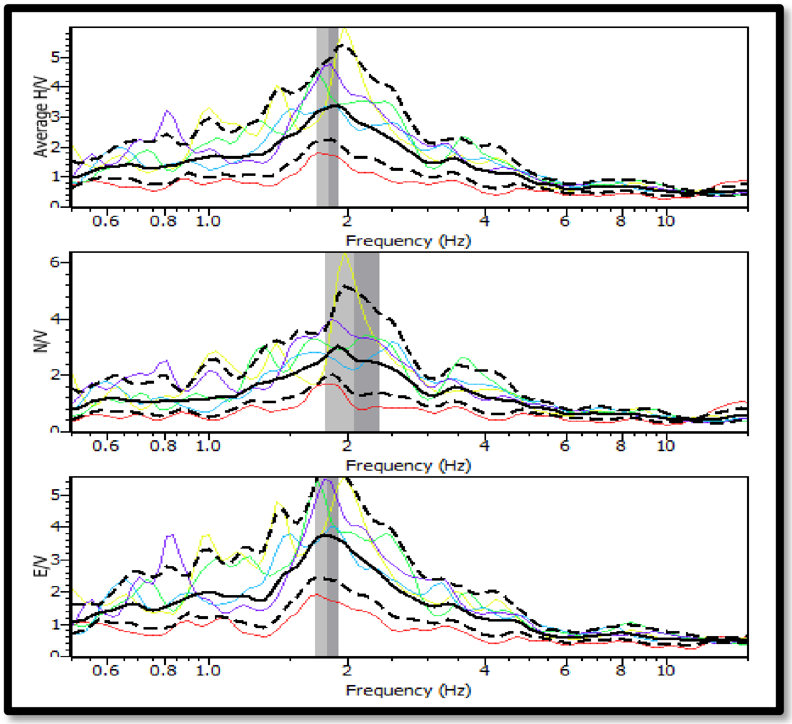


Figure 4.1. Event 1 H/V spectrum for seismic station.

The H/V mathematically averaged overall colored individual H/V curves are shown by the black bar. The two lines with dashes on this graph represent the peak frequency and average deviation. The frequency value is on the edge of the vibrant and dark greys. The surrounding noise is depicted by the colored lines. In this case, the H/V maximum frequency's minimum average Deviation is fo = 1.855, while its highest average deviation is fo = 1.947. Ao=3.55 is the value of the H/V Max. average amplitude

4.5.2 Event 2 H/V spectrum

H/V analysis of the second event was performed. Figure (55) Displays the H/V Spectrum of all the elements.

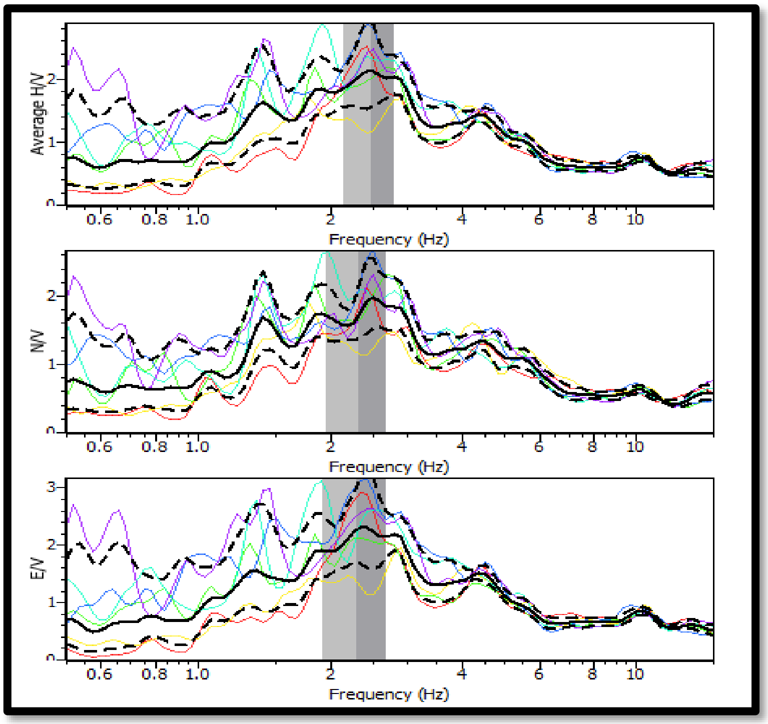


Figure 4.2. Event 2 H/V spectrum for seismic station.

H/V mathematically averaged overall colored individual H/V curves are shown by the black bar. The two lines with dashes on this graph represent the peak frequency and average deviation. The frequency value is on the edge of the vibrant and dark greys. The surrounding noise is depicted by the colored lines. In this case, the H/V maximum frequency's minimum average Deviation is fo = 1.610, while its highest average deviation is fo = 1.613, Ao=3.11 is the value of the H/V average peaked amplitude.

4.5.2 Event 3 H/V spectrum

H/V analysis of the third event was performed. Figure (56) shows the H/V spectrum of all the components.

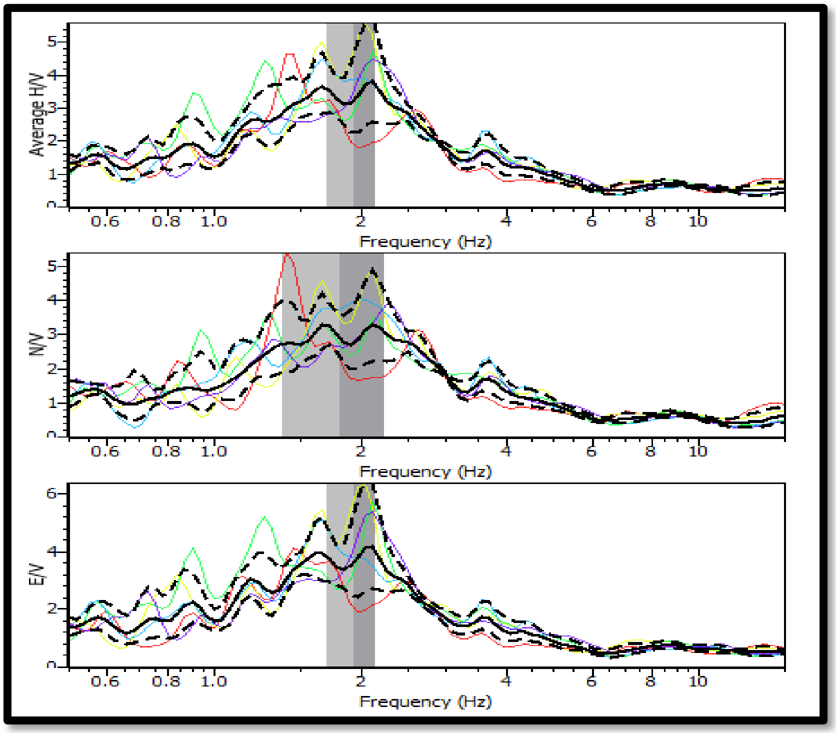


Figure 4.3. Event 3 H/V spectrum for seismic station.

H/V mathematically averaged overall colored individual H/V curves are shown by the black bar. The two lines with dashes on this graph represent the peak frequency and average deviation. The frequency value is on the edge of the vibrant and dark greys. The surrounding noise is depicted by the colored lines. In this case, the H/V maximum frequency's minimum average Deviation is fo = 2.473, while its highest average deviation is fo = 2.274, Ao=2.77 is the value of the H/V average peaked amplitude.

4.5.3 Event 4 H/V spectrum

H/V analysis of the fourth event was performed. Figure (57) shows the H/V spectrum of all the components.

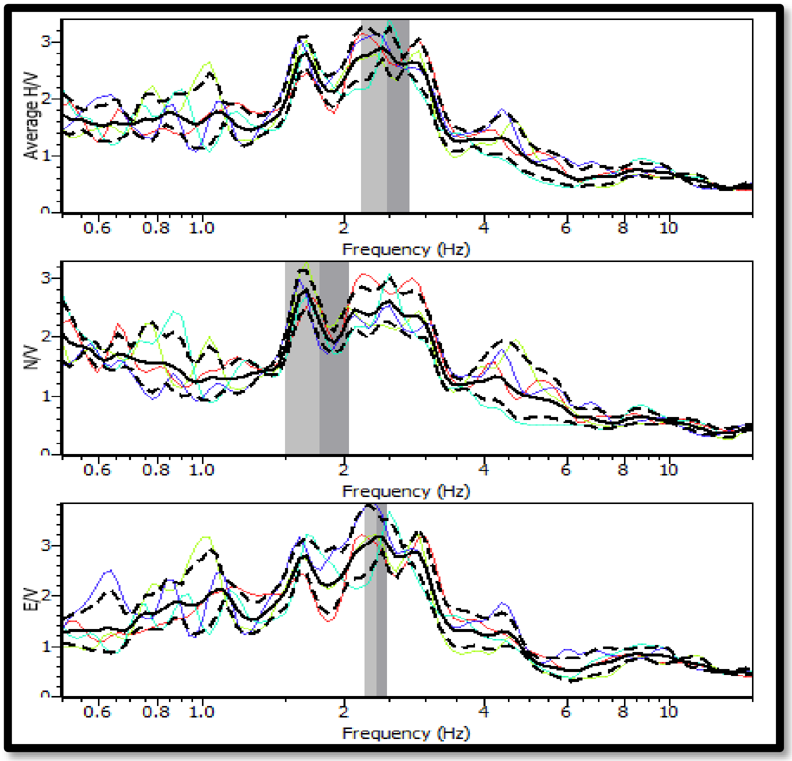


Figure 4.4. Event 4 H/V spectrum for seismic station.

H/V mathematically averaged overall colored individual H/V curves are shown by the black bar. The two lines with dashes on this graph represent the peak frequency and average deviation. The frequency value is on the edge of the vibrant and dark greys. The surrounding noise is depicted by the colored lines. In this case, the H/V maximum frequency's minimum average Deviation is fo = 2.398, while its highest average deviation is fo = 2.404, Ao=2.92 is the value of the H/V average peaked amplitude.

4.5.4 Event 5 H/V spectrum

H/V analysis of the fifth event was performed. Figure (58) shows the H/V spectrum of all the components.

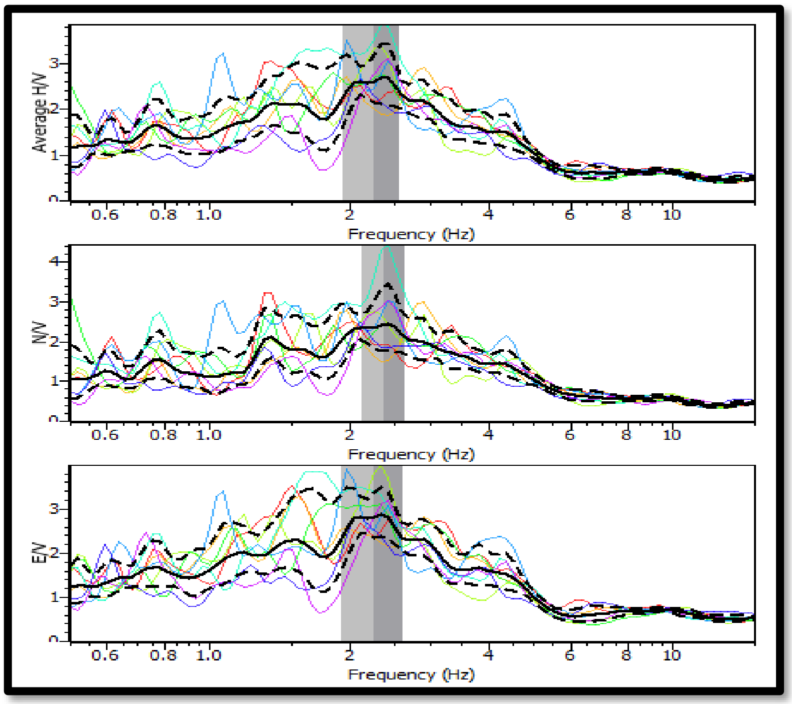


Figure 4.5. Event 5 H/V spectrum for seismic station.

H/V mathematically averaged overall colored individual H/V curves are shown by the black bar. The two lines with dashes on this graph represent the peak frequency and average deviation. The frequency value is on the edge of the vibrant and dark greys. The surrounding noise is depicted by the colored lines. In this case, the H/V maximum frequency's minimum average Deviation is fo = 1.905, while its highest average deviation is fo = 1728, Ao=3.47 is the value of the H/V average peaked amplitude.

4.5.5 Event 6 H/V spectrum

H/V analysis of the sixth event was performed. Figure (59) shows the H/V spectrum of all the components.

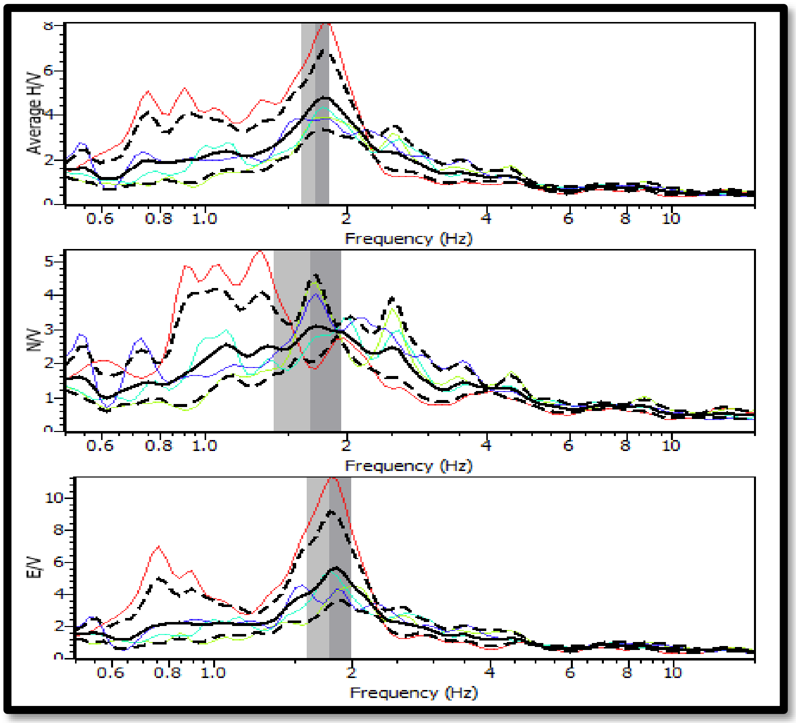


Figure 4.6. Event 6 H/V spectrum for seismic station.

H/V mathematically averaged overall colored individual H/V curves are shown by the black bar. The two lines with dashes on this graph represent the peak frequency and average deviation. The frequency value is on the edge of the vibrant and dark greys. The surrounding noise is depicted by the colored lines. In this case, the H/V maximum frequency's minimum average Deviation is fo = 2.284, while its highest average deviation is fo = 2.387, Ao=2.287 is the value of the H/V average peaked amplitude.

4.5.6 Event 7 H/V spectrum

H/V analysis of the seventh event was performed. Figure (60) shows the H/V spectrum of all the components.

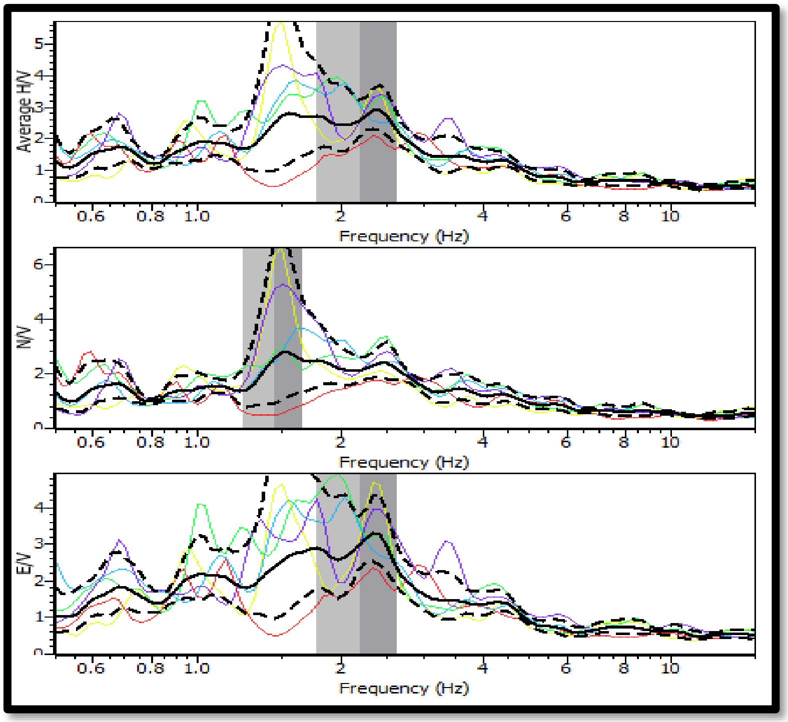


Figure 4.7. Event 7 H/V spectrum for seismic station.

H/V mathematically averaged overall colored individual H/V curves are shown by the black bar. The two lines with dashes on this graph represent the peak frequency and average deviation. The frequency value is on the edge of the vibrant and dark greys. The surrounding noise is depicted by the colored lines. In this case, the H/V maximum frequency's minimum average Deviation is fo = 2.632, while its highest average deviation is fo = 2.147, Ao=2.59 is the value of the H/V average peaked amplitude.

4.5.7 Event 8 H/V spectrum

H/V analysis of the seventh event was performed. Figure (61) shows the H/V spectrum of all the components.

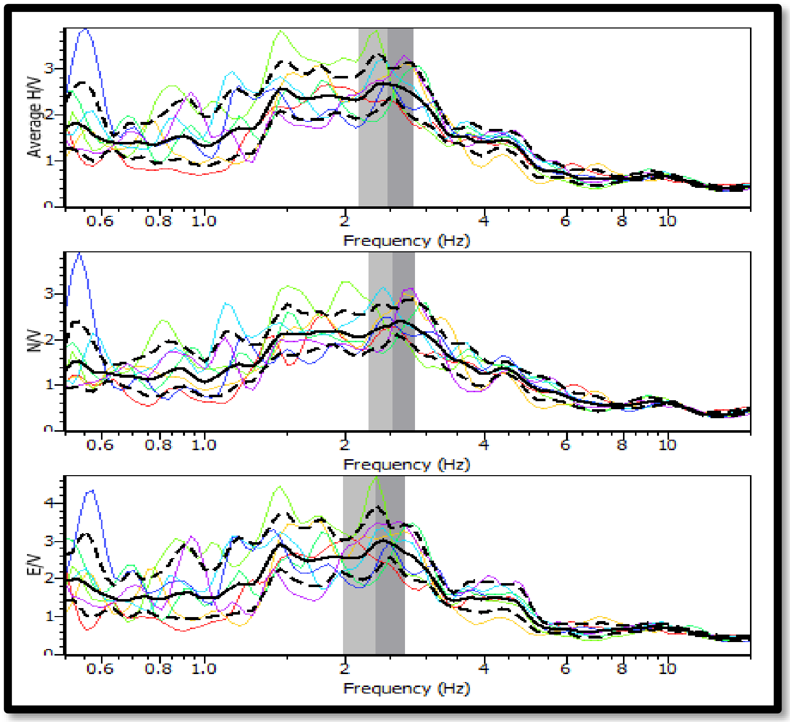


Figure 4.8. Event 8 H/V spectrum for seismic station.

H/V mathematically averaged overall colored individual H/V curves are shown by the black bar. The two lines with dashes on this graph represent the peak frequency and average deviation. The frequency value is on the edge of the vibrant and dark greys. The surrounding noise is depicted by the colored lines. In this case, the H/V maximum frequency's minimum average Deviation is fo = 2.441, while its highest average deviation is fo = 2.473, Ao=2.86 is the value of the H/V average peaked amplitude.

4.6 Results

The residual error is computed by contrasting the actual travel time of P-waves with their expected theoretical travel time. This error basically shows the time delay and slowness in the P-wave arrival. This time delay indicates the hindrance that comes across the path of P-waves. Residual errors from all three stations were calculated and sorted out. These residuals were calculated, and the total error generated from all three seismic stations of Islamabad, Lahore and Peshawar was compared.

Sr. No.	Islamabad (R.M.S.)	Lahore (R.M.S)	Peshawar (R.M.S)
1.	4.47	15.00	11.49
2.	23.13	4.74	27.50
3.	14.51	30.13	38.68
4.	32.10	15.19	36.47
5.	2.61	10.61	19.93
6.	9.62	7.24	13.27
7.	2.14	27.24	29.35
8.	21.75	58.15	43.53
Total	110.33	168.3	220.22

CONCLUSIONS

1. Earthquake events that were traced from the provided data were dominant in two regions, the Hindukush region of Afghanistan and the Main Boundary Thrust in Pakistan.
2. The residual error calculated for all three stations portrayed variations. The total R.M.S. from Islamabad, Lahore and Peshawar seismic stations differed from each other. This difference shows that the data quality in these stations is not same.
3. Residual is a direct function of noise. Peshawar station exhibited the greatest R.M.S. values which mean that data from Peshawar station was not dependable.

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