# ESTIMATION OF SOURCE CHARACTERISTICS OF HIMALAYAN EARTHQUAKE

**A DISSERTATION**

***Submitted in partial fulfilment of the***

***requirements for the award of the degree***

***of***

**INTEGRATED MASTER OF TECHNOLOGY**

**in**

**GEOPHYSICAL TECHNOLOGY**


**By**

**VIKAS**



**DEPARTMENT OF EARTH SCIENCES**

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

**ROORKEE – 247667 (INDIA)**


**MAY, 2016**

# CERTIFICATE

I hereby solemnly declare that the work presented in the dissertation thesis entitled **“Estimation of source characteristics of Himalayan earthquake"** submitted by me in partial fulfillment of requirements for award of the degree Integrated Master of Technology in Geophysical Technology to the Department of Earth Sciences , Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out during the period of June 2015 to May 2016 under the supervision of **Prof. S. Mukhopadhyay**, Department of Earth Sciences, Indian Institute of Technology, Roorkee.

The matter embodied in this dissertation thesis has not been submitted by me for the award of any other degree of IIT, Roorkee or any other institution.

Date:
Place: Roorkee

VIKAS
Integrated M.Tech.
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# CANDIDATE'S DECLARATION

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This is to certify that the statement made by the candidate is correct to the best of our knowledge.

Date:

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I am short of words to thank my parents, who always stood by my side and supported me despite great difficulties. My parents are my strong pillars and I owe every bit of my work to their dedication, hard work, care & support. I pay my respect to my grandparents, who have played a very important role in my days of upbringing. Their encouragement has always motivated me to pursue my higher studies. My family is my source of inspiration and I owe everything to them.

Besides this, I thank all colleagues who have knowingly and unknowingly helped me in the successful completion of this project.

# ABSTRACT

The scope of this work involved the estimation and analysis of source characteristics for the Himalayan earthquakes. The data is collected from the seismic network , Wadia Institute of Himalayan Geology. The data includes a total of 369 events recorded at 123 seismic stations in the month of April in 2015. The data consisted of earthquake that occurred in Nepal on 24$^{th}$ April, 2015. The source characteristics estimated are Local Magnitude, Moment Magnitude, Source Radius, Corner Frequency, Seismic Moment and the Stress Drop. S phase spectra of the events have been modelled according to a 3 point model. P-phase, S-phase, coda wave and amplitudes were picked initially to determine the source characteristics. Maintaining the residual travel time as low as possible determines the higher accuracy of result. The result that is obtained after locating events and determining source characteristics showed that the result followed the standard observations as the Local Magnitude vary with Moment Magnitude. Corner Frequency and the Stress Drop also vary with the magnitudes which confirms to the established result. Some events however were too scattered to determine a decent value of the source parameters.

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# Chapter 1: Introduction

## 1.1 Overview

To analyse an earthquake we have to study the mechanism according to which the stored stress releases. With the help of that mechanism we can physically explain the earthquake source in terms of some characteristics known as source characteristics. In order to calculate the source characteristics we make use of some standard seismic software like SEISAN. When we calculate and interpret these basic parameters of earthquake occurred in a particular region then we can also predict the physical and seismic attributes of an earthquake that might be occur in future.

In this report, we estimated the source characteristics of Nepal earthquake that occurred on 25 April, 2015. The data was taken from the Wadia Institute of Himalayan Geology network. Firstly phases like P-phase, S-phase and coda wave were picked in order to estimate the source characteristics. Then we pick different magnitudes manually on the waveforms. These magnitudes include local magnitude, coda magnitude, body wave magnitude and surface wave magnitude. Then we do spectral analysis from where we get stress drop, moment magnitude and corner frequency. In this way we estimate various source parameters.

## 1.2 Objective of Dissertation

The main concern of this project has been on the estimation of the source characteristics viz. Stress drop ($\Delta\sigma$), Seismic Moment (Mo), Source Radius (R), Corner frequency ($f_0$), Moment magnitude (Mw). All these parameters are determined by using the data that which was recorded at different stations viz. Keeping in mind the objective mentioned above the waveform data of Nepal earthquake have been analysed.

## 1.3 Methods Followed

Following steps have been followed to determine the source characteristics of earthquake occurred in the Himalayan region

- Picking of the S, P and coda phase for all the events in the database.
- Picking of amplitudes at every station.

- Spectral analysis to determine moment magnitude, corner frequency and stress drop.
- Interpreting the results.

## 1.4 Plan of Thesis

Chapter 1 contains an overview of the work done is given which include the objective of dissertation and methods to be followed to meet the objective.

Chapter 2 contains details about the region of interest including its tectonic history and a brief geology is given.

Chapter 3 contains the theoretical concepts and methodology; various source parameters are defined one by one in this chapter.

Chapter 4 contains details about the data collected, software used and the working steps to process the data in software to determine the required characteristics.

# Chapter 2: Area of Study

## 2.1 Geology

The Himalayas are formed due to the orogenic process. Himalaya is formed due to a consequence of continuous collision of two massive tectonic plates – Eurasin and Indian.  The huge forces of colliding tectonic plates resulted in high mountains of Himalaya which we see today.

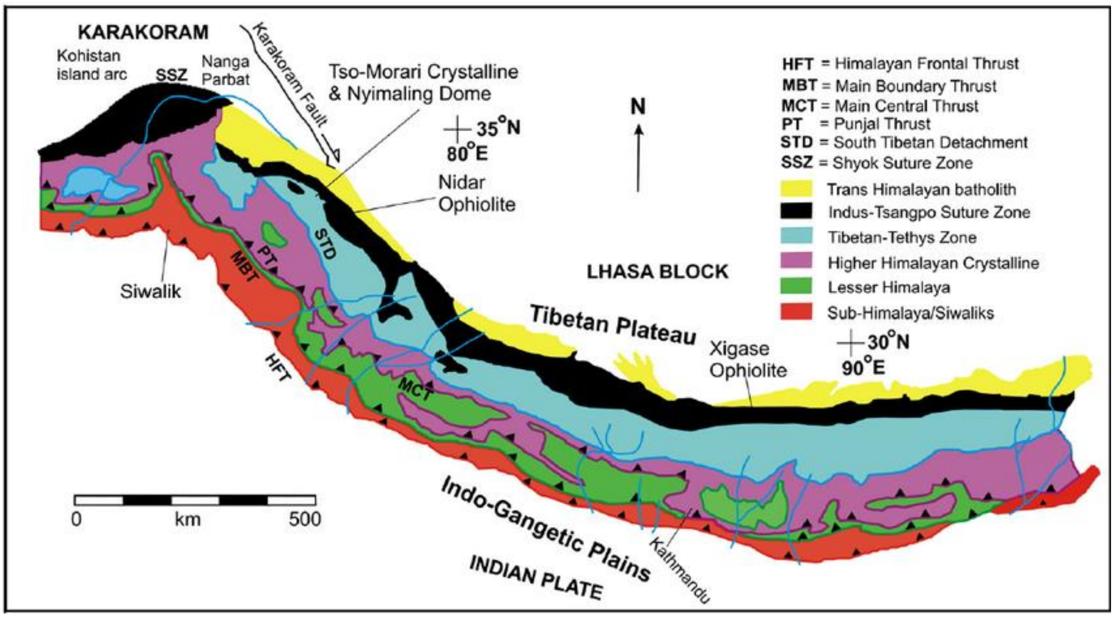



Figure 26: General geology and tectonics of the Himalayan arc

Himalaya is also sculpted by continuous weathering process as well as erosion. Within Himalayas, one of the most significant portions is Tibet region. This region is source of freshwater for a fifth of human population and contributes to a fourth of Earth's sedimentation budget.

The Himalyan-Tibet belt has few characteristic features. Tectonically, it has highest uplift rate (~1cm per year near Nanga Parbat), highest mountain (Mount Everest, 8848m), and the major contributor to glacial process after the Polar region

Himalayan seismicity is much in evidence. It is revealed by historical record that earthquakes of devastating nature have been a common and regular feature in the entire Himalayas

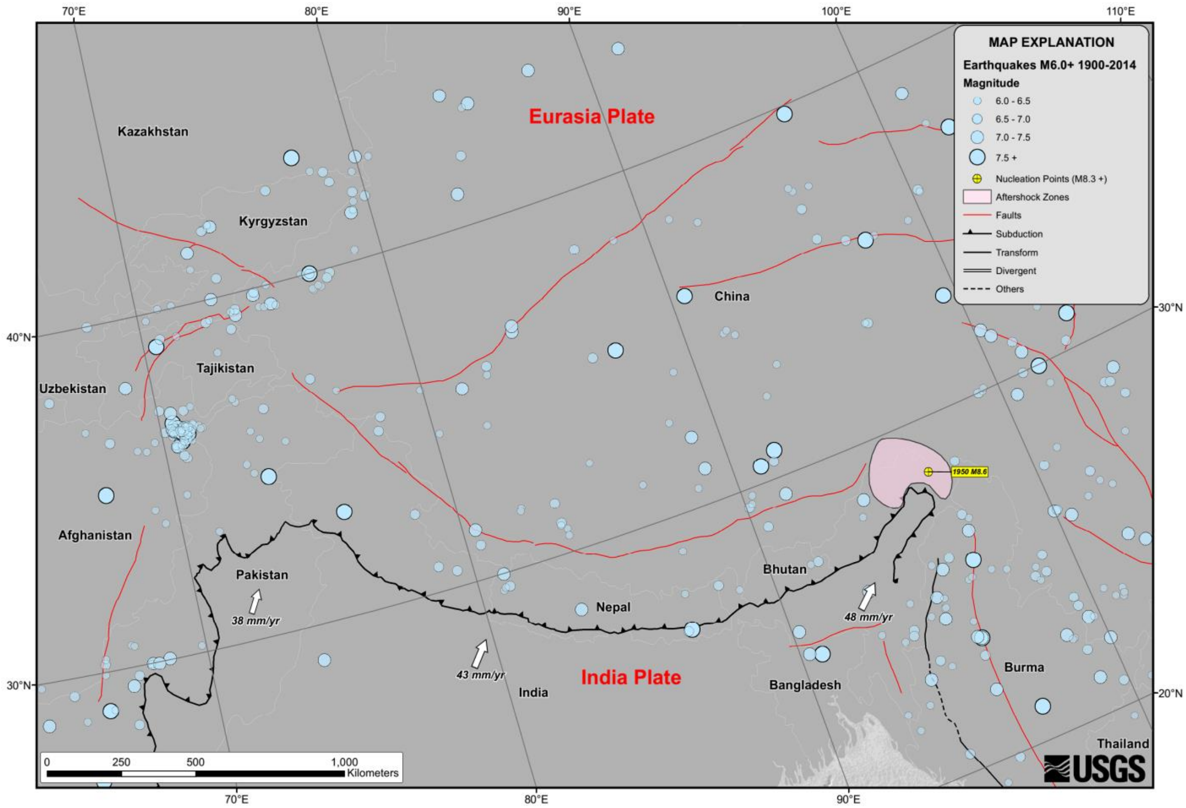



**Figure 27: M6+ Himalayan region earthquakes**

Nepal is situated at a central position in Himalayan range and is south of the colliding Indian and Eurasian plates. Nepal is divided in 5 tectonic zones. They are:

1. Terai Plain

2. Sivalik range (Sub-Himalayas)

3. Mahabharat range (Lesser-Himalayas)

4. Higher Himalayas

5. Tibetan Tethys (Inner-Himalayas)

They are identified through the visible and clear geology, morphology and tectonic feature.

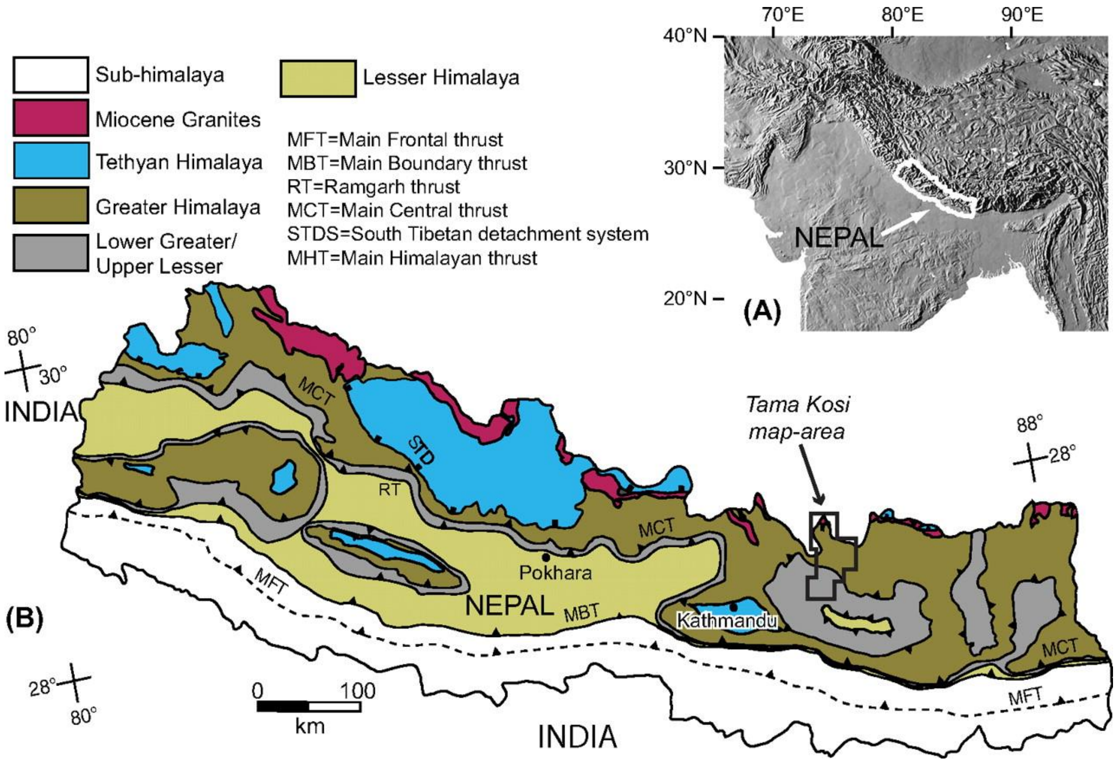



**Figure 28: Generalized geologic map of Nepal illustrating the major tectonostratigraphic units**

Nepal due to a high convergence rate which is 45 mm or 18 inch per year is an ideal location for tectonic activities. Kathmandu earthquake (April 2014) was due to a slip of plates along the Main frontal thrust. Kathmandu has sedimentary origin and lies in a basin as thick as 600m of sedimentation.

Studies on Main Frontal Thrust suggest that an earthquake occurs after period of 750 (accuracy 140 years) to 870 (accuracy 350 years) years in Nepal. The Nepal earthquake in 2015 was delayed by 700-years. The delay has caused a strong stress build up which is now in recent times is released. The 1934 earthquake and 2015 earthquake are considered to be linked and a consequence of this tectonic stress release.

Nepal is tectonically very active and there are so many devastating earthquakes that have occurred in Nepal. The earthquake occurred on 25th April, 2015 was one of them.

## 2.2 The Nepal Earthquake

Nepal earthquake occurred on April 25, 2015 at 1156 hours. It was a shallow focus earthquake with the hypocentre at a depth of 15 km below surface and a epicentre distance of 34 km near Lamjung, Nepal. It lasted for around 50 second. The earthquake as reported by USGS was of 7.8 on moment magnitude scale while CENC reported it as 8.1 on $M_s$ scale. IMD reported two quakes first at 0611 hours UTC and second at 0645 hours UTC with a magnitude of 7.8 on moment magnitude scale and 6.6 on moment magnitude scale respectively. The epicentre of first recorded earthquake by IMD estimated to be 80 km NW of Kathmandu. And the second quake's hypocentral distance was around 10 km from the Earth's surface. After these two main shocks, there were numerous aftershocks. More than 30 aftershocks of magnitude greater than 4.5 on moment magnitude scale was recorded in a single day with a highest aftershock of 6.8 in magnitude on moment magnitude scale. The aftershocks were mainly at an interval of 15-30 mins. The aftershock caused avalanches on mountainous region of Nepal covered with snow caps and landslides of loose material on some highways in India and Nepal. It was felt in different states of India with a close proximity to Nepal. There are reports of building collapses in Bihar , Uttar Pradesh with minors cracks in some buildings in Odisha.

USGS modelled the fault that caused Nepal earthquake of 2015. It was inferred that the dip of the almost horizontal fault is 11° with dip direction toward North, strike angle of 295°. The fault was estimated to be 150 km long and 50 km wide and has slipped around 3 m during this earthquake.

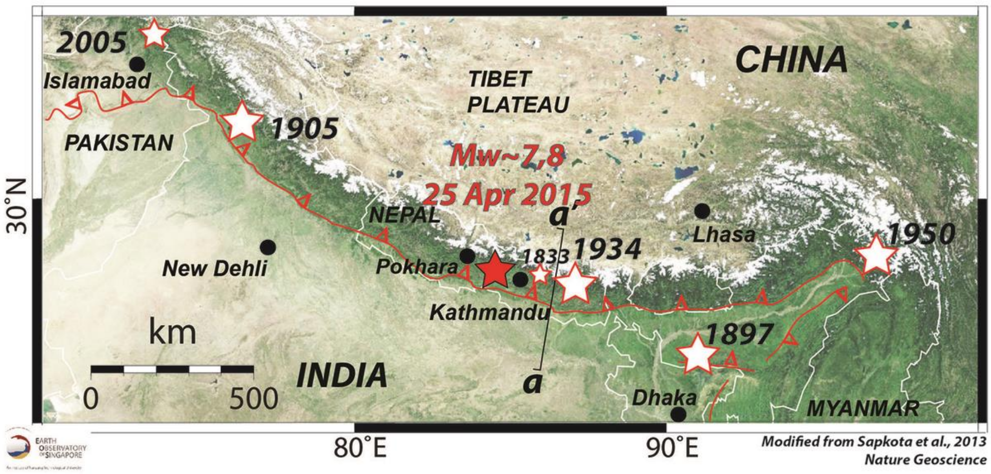



**Figure 29: Location of the April 25, 2015 earthquake (red star) and previous major earthquakes on the Himalayan frontal system (white stars)**

# CHAPTER 3: Theoretical Aspects and Methodology

## 3.1 Phase Identification and Earthquake amplitudes

A seismic station records continuous wave form data of the earthquakes. In order to delineate earthquakes in terms of their location and magnitudes, it is necessary to identify the phases and record the arrival times of the different phases of the seismic wave. Once the earthquake has been identified, we can use the same approach and apply it to a number of other stations for increased durations of time. This will lead to identification of the fault patterns. The present work deals with local earthquakes, which have prominent phases belonging to P and S waves.

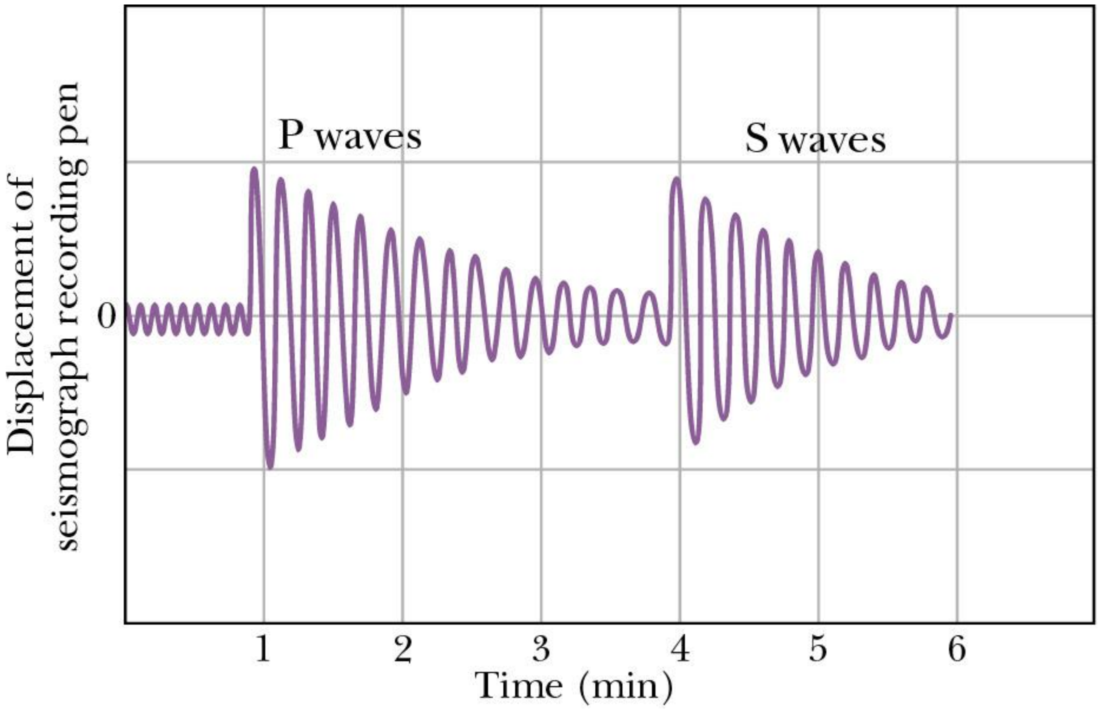



**Figure 30: Arrival of P and S wave**

Longitudinal waves that travel through a medium by compressions and dilations are called P waves and they are the first waves to arrive from an earthquake. It is the fastest seismic wave to arrive and recorded at a station, hence its arrival time can be accurately and easily noted for low noise conditions.

. Secondary waves which oscillate in a motion parallel or perpendicular to the medium of propagation are termed S waves. S waves have higher energy than P waves and are slower than the latter. Due to the higher energy, they are represented by sudden peaks on the seismograph.

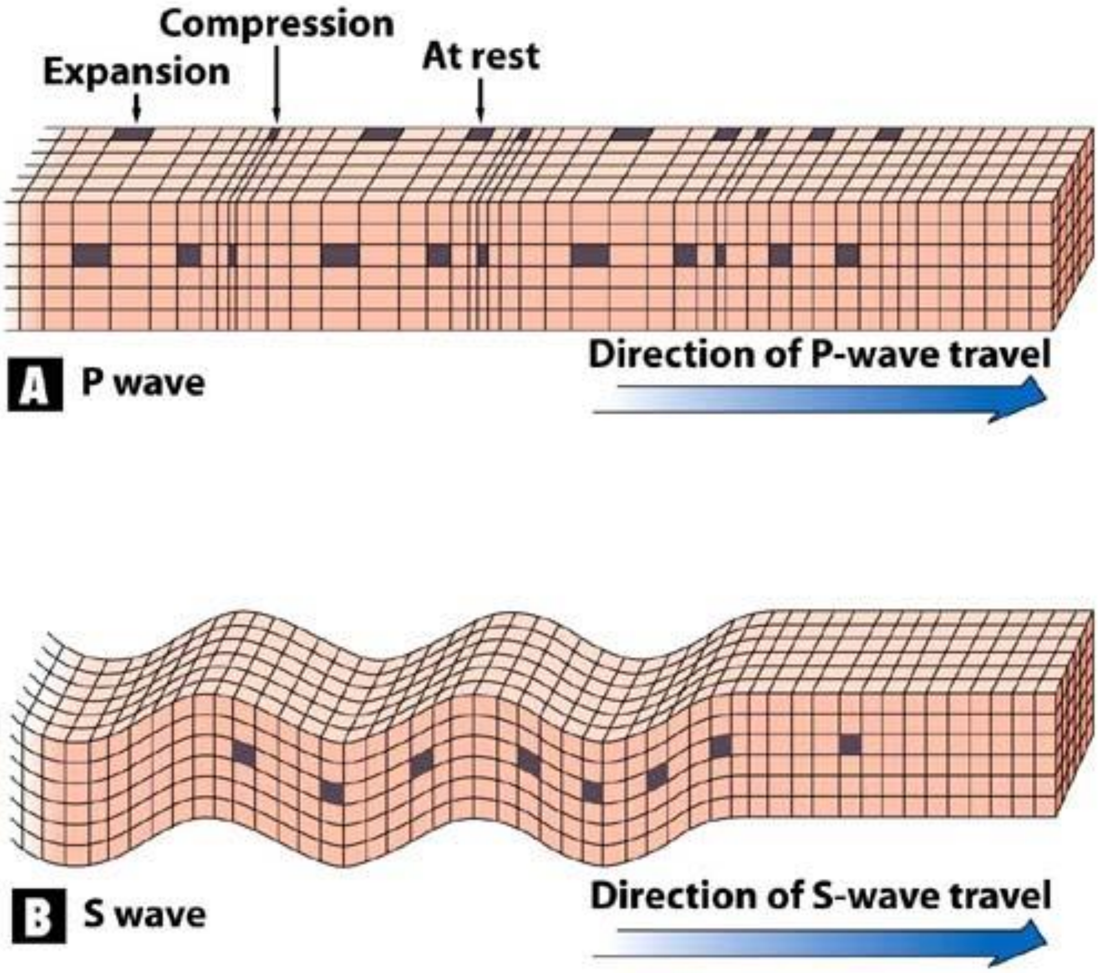



Figure 31: P and S wave

The presence of noise hampers the P wave recording, as the low amplitude P waves combine with the abundant noise. Low noise conditions are more suitable for recording S waves simply due to the fact that in such cases, the wave onset can be easily spotted. Even in higher noise conditions, though the onset is not clearly identifiable, the visibility of the peak is ensured due to its higher amplitudes. Good results can still be achieved when certain filters are used.

The earth's crust has several heterogeneities spaced at uniform intervals. The waves that are scattered back from those heterogeneities are a form of Coda waves in them. They are recorded at the end as they are form the last part of the decay curve. They are useful in delineating the Coda magnitude of the occurred earthquake from the corresponding s phase peak. Due to their log signal strength, they are often undetected due to their similarity to the signal noise.

It is important to measure the S wave amplitudes in order to calculate the local magnitude for an earthquake. Amplitudes have to be picked uniquely for the corresponding magnitudes due to the availability of numerous magnitude scales. A way that this can be done is to simulate a filtered seismograph response from the response file of the same instrument. The filtered response is used for generating the Local Magnitude. For every magnitude scale used, there is a corresponding filter and the filter has to be rendered on the response before the amplitudes are picked. The scope of the present work lies within the boundaries of IAML or Local Magnitude. The working of the Wood Anderson (WA) filter has been explained in the succeeding sections. This work also includes the calculation of moment magnitude $M_w$ and coda magnitude $M_c$. Following magnitude scales are supported on the working software SEISAN-

- Wood Anderson(WA) for calculation of Local Magnitude
- $M_b$ : Body wave magnitude
- $M_{s:}$ Surface wave magnitude.

## 3.2 Earthquake Source Characteristics

### 3.2.1 Coda Duration Magnitude

Coda wave corresponds to the energy that has been scattered by the medium. Biszticsany propagated the idea of Coda wave in 1958. Coda duration refers to the length of record on seismogram starting from the first P arrivals to the last arrivals. Longer the duration of Coda waves i.e. longer the wave train in the seismic records, the larger will be the Earthquake.

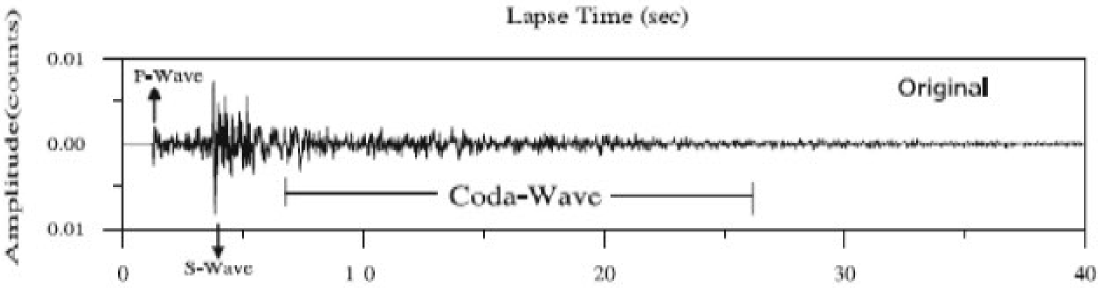



**Figure 32: Coda wave duration**

This wave train consists of the usual body and surface waves followed by a seemingly disorganized collection of seismic waves that eventually disappear into the background noise. This latter part of the wave train is called the coda wave. It is believed to be made up of waves arriving at a seismograph station after being scattered or reflected off lateral variations in the earth's structure. They can also be interpreted as backscattering waves from numerous anomalies or heterogeneities encountered by the wave from source to receiver. When they are considered alongside the absorption by medium, they can give apparent attenuation characteristic of the wave that can be interpreted as thumbprint left behind by the heterogeneities on the seismograms. They are used as a vital element in the determination of source and medium parameters.

### 3.3.2 Richter Local Magnitude

The first seismic magnitude scale was developed for characterizing California Earthquake by C. Richter in 1930s. He included several events to capture source parameters rigorously. Richter observed that the logarithm of maximum ground motion decayed with distance along parallel curves for many earthquakes. Simple woods – Anderson seismometer was used to catalogue all the observations. The seismograph with torsion suspension of the mass developed by H. O. Wood and J. Anderson (or its equivalent) is used as a standard for estimation of local magnitudes. The farther the earthquake source is from the seismograph, the smaller the amplitude of the seismic wave, just as a light appears dimmer as the observing distance from the source increases. Because earthquake sources are located at all distances from seismographic stations, Richter further developed a method of making allowance for this attenuation with epicentral distance when calculating the Richter magnitude of an earthquake. Hence, the magnitude scale quantifies the amount of energy released during an Earthquake in terms of base 10 logarithmic scale.

Since these scales are solely based on Woods Anderson Seismographs designed for California Earthquakes, they are rarely used in their original form. However, Local magnitude is still been calculated using Wood Anderson filter and Richter magnitude scales.

### 3.3.3 Seismic Moment Magnitude

It was developed to eliminate most of the limitations of the various previously developed magnitude scales. It proved to be beneficial as it was applicable to earthquakes of all sizes, locations and depths. It is based on the concept of Seismic Moment, an important property categorizing source parameters. Geologically, it is a description of the extent of deformation at the earthquake source.

Seismologically, moment is measured at epicentral distances much larger than, and using wavelengths much longer than, the dimensions of the earthquake fault rupture. It can readily be determined from seismograms by techniques that utilize long period seismic waves or the long-period (low frequency) end of the spectrum (Bullen and Bolt, 1985). The advantages of seismic moment over body or surface wave amplitudes used in other magnitude measurements is that moment is directly related to the size of the earthquake source and, specifically to quantities which are often measurable in the field. In addition, because it is determined from very long period seismic waves. It can be used to quantify even the largest earthquake. It does not rely upon a single wave or wave type which may or may not be observed depending on earthquake depth or epicentral distance. Its disadvantage is that, in contrast to other parameters. It cannot be measured directly from the seismogram without some additional analysis.

For convenience, and in order to be consistent with past practice. Kanamori (1977) and Hanks and Kanamori (1979) devised a moment magnitude scale ($M_W$ or M) as:

$$\mathbf{M_W = (\log M_o - 16.05) / 1.5}$$

**Or**

$$M_W = (\log M_o) / 1.5 - 10.7$$

Where, $M_0$ is the seismic moment of the earthquake in dyne-cm. The moment magnitude has the advantage (as a measure of size in earthquakes) that it does not saturate at the top of the scale.

### 3.3.4 Stress Drop ($\Delta\ \sigma$)

The difference between the stress levels across a fault before and after an earthquake rupture is known as Stress drop. Effective stress generally refers to the difference between two indirectly related types of stress namely hydrostatic and lithostatic stress. Stress-drop is related to the energy released as a consequence of an earthquake rupture (expressed by its seismic moment or magnitude) and to the dimensions of the rupture. As rupture size increases, amount of energy released per unit area of fault rupture can be given by constant stress-drop with increasing magnitude. Changing physical properties of the Earth, particularly with depth is a major cause of varying stress-drop from earthquake to earthquake or with the dimensions of an earthquake. The earthquake source has been increasingly modelled by Stress drop for ground-motion attenuation relations. There has be much debate regarding the relation between the behaviour of stress drop with increasing magnitude. However, it had a very significant impact on seismic hazard as well as estimated ground-motions.

Since different magnitude scales are unable to capture the difference in the levels of stress between two Earthquakes, one with large rupture area and small slip and other with small rupture area and large slip, Stress drop levels becomes of utmost importance. It thus refers to drop in stress levels during an Earthquake.

### 3.3.5 Corner Frequency

Different magnitude scales gets saturated at different magnitudes thus unable to observe Earthquake amplitude greater than the saturated value. Their recorded amplitude gets flattened (saturated) after certain level at a frequency termed as corner frequency. The reason for these magnitude scales to saturate for large Earthquakes can be traced back to source spectrum. They form the part of spectral parameters and together with source parameters (Fault area and slip). They are obtained at the intersection of the division between low and high frequencies carried out during modelling of spectra of an Earthquake.

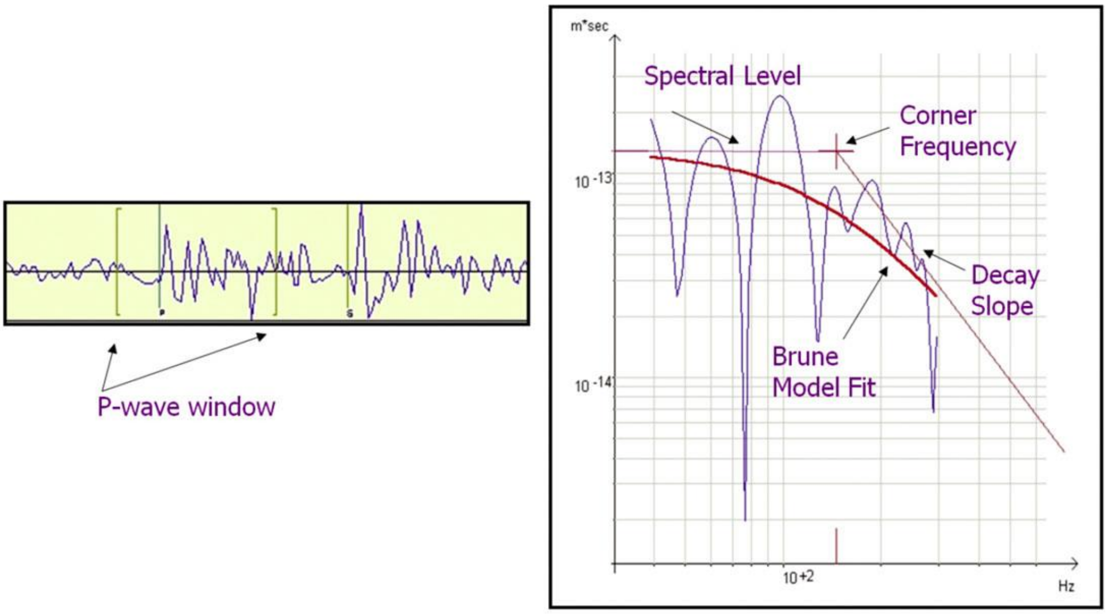



**Figure 33: Brune model to calculate corner frequency**

### 3.3.6 Seismic Moment ($M_0$)

Size of an Earthquake is measured by Earthquake seismologists by Seismic Moment. It is an important characteristics of an Earthquake as it quantifies the inherent properties of Earthquake namely fault area, slip and rigidity influencing the energy released during an Earthquake. Hence, determination of Seismic Moment can be directly linked to the estimation of source parameters, which are relatively difficult to account for separately in other magnitude scales. It can be defined as:

$$\mathbf{M_o = \mu\ A\ D}$$

Where, μ is the rigidity constant, A (in dyne/$cm^2$) is fault or rupture plane area (in $cm^2$) and D (in cm) is slip of the fault.

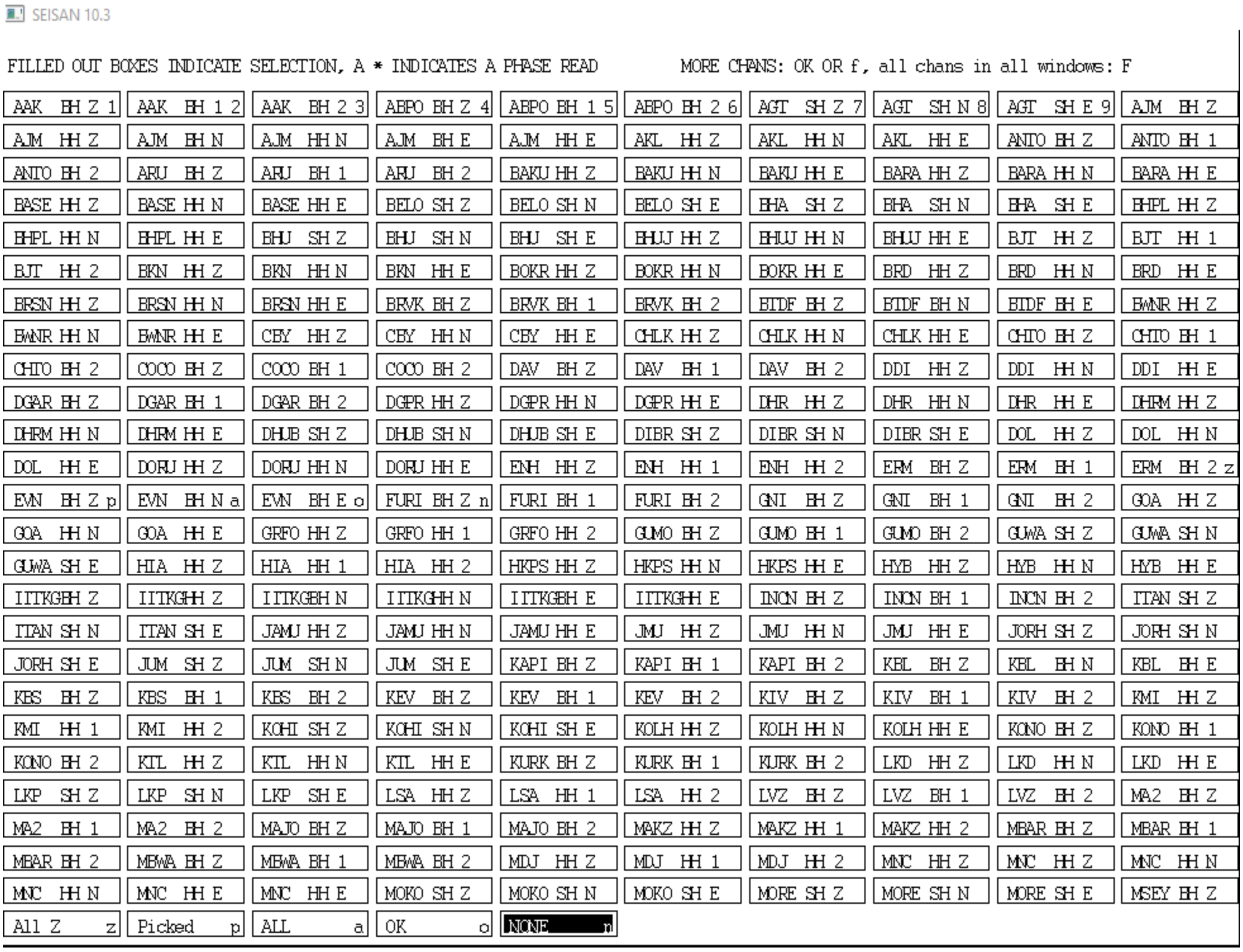
### 3.3.7 Source Radius (R)

It categorises one of the most important characteristics of an Earthquake source parameter i.e. shape of a fault rupture plane. It is generally been assumed to be either circular or rectangular during modelling of source parameters. But, lately other shapes have also been developed as a model to account for increasing varsity in source parameters. In case of circular shaped fault, source radius directly corresponds to the radius of the circle.

# Chapter 4: Data Analysis

## 4.1 About Data

The data of Nepal Earthquake was collected from the Wadia Institute of Himalayan Geology (WIHG). WIHG has a number of stations and a high quality 3-component seismic data has been recorded at every station. Three channels were recorded for every station which comprises oscillations in north, east and vertical directions. There are a total of 369 events recorded at 123 stations



SEISAN 10.3

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| ANTO BH 2 | ARU BH Z | ARU BH 1 | ARU BH 2 | BAKU HH Z | BAKU HH N | BAKU HH E | BARA HH Z | BARA HH N | BARA HH E |
| BASE HH Z | BASE HH N | BASE HH E | BELO SH Z | BELO SH N | BELO SH E | BHA SH Z | BHA SH N | BHA SH E | BHPL HH Z |
| BHPL HH N | BHPL HH E | BHU SH Z | BHU SH N | BHU SH E | BHUJ HH Z | BHUJ HH N | BHUJ HH E | BJT HH Z | BJT HH 1 |
| BJT HH 2 | BKN HH Z | BKN HH N | BKN HH E | BOKR HH Z | BOKR HH N | BOKR HH E | BRD HH Z | BRD HH N | BRD HH E |
| BRSN HH Z | BRSN HH N | BRSN HH E | BRVK BH Z | BRVK BH 1 | BRVK BH 2 | BTDF BH Z | BTDF BH N | BTDF BH E | BWNR HH Z |
| BWNR HH N | BWNR HH E | CBY HH Z | CBY HH N | CBY HH E | CHLK HH Z | CHLK HH N | CHLK HH E | CHTO BH Z | CHTO BH 1 |
| CHTO BH 2 | COCO BH Z | COCO BH 1 | COCO BH 2 | DAV BH Z | DAV BH 1 | DAV BH 2 | DDI HH Z | DDI HH N | DDI HH E |
| DGAR BH Z | DGAR BH 1 | DGAR BH 2 | DGPR HH Z | DGPR HH N | DGPR HH E | DHR HH Z | DHR HH N | DHR HH E | DHRM HH Z |
| DHRM HH N | DHRM HH E | DHUB SH Z | DHUB SH N | DHUB SH E | DIBR SH Z | DIBR SH N | DIBR SH E | DOL HH Z | DOL HH N |
| DOL HH E | DORU HH Z | DORU HH N | DORU HH E | ENH HH Z | ENH HH 1 | ENH HH 2 | ERM BH Z | ERM BH 1 | ERM BH 2 z |
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| GOA HH N | GOA HH E | GRFO HH Z | GRFO HH 1 | GRFO HH 2 | GUMO BH Z | GUMO BH 1 | GUMO BH 2 | GUWA SH Z | GUWA SH N |
| GUWA SH E | HIA HH Z | HIA HH 1 | HIA HH 2 | HKPS HH Z | HKPS HH N | HKPS HH E | HYB HH Z | HYB HH N | HYB HH E |
| IITKGBH Z | IITKGHH Z | IITKGBH N | IITKGHH N | IITKGBH E | IITKGHH E | INCN BH Z | INCN BH 1 | INCN BH 2 | ITAN SH Z |
| ITAN SH N | ITAN SH E | JAMU HH Z | JAMU HH N | JAMU HH E | JMU HH Z | JMU HH N | JMU HH E | JORH SH Z | JORH SH N |
| JORH SH E | JUM SH Z | JUM SH N | JUM SH E | KAPI BH Z | KAPI BH 1 | KAPI BH 2 | KBL BH Z | KBL BH N | KBL BH E |
| KBS BH Z | KBS BH 1 | KBS BH 2 | KEV BH Z | KEV BH 1 | KEV BH 2 | KIV BH Z | KIV BH 1 | KIV BH 2 | KMI HH Z |
| KMI HH 1 | KMI HH 2 | KOHI SH Z | KOHI SH N | KOHI SH E | KOLH HH Z | KOLH HH N | KOLH HH E | KONO BH Z | KONO BH 1 |
| KONO BH 2 | KTL HH Z | KTL HH N | KTL HH E | KURK BH Z | KURK BH 1 | KURK BH 2 | LKD HH Z | LKD HH N | LKD HH E |
| LKP SH Z | LKP SH N | LKP SH E | LSA HH Z | LSA HH 1 | LSA HH 2 | LVZ BH Z | LVZ BH 1 | LVZ BH 2 | MA2 BH Z |
| MA2 BH 1 | MA2 BH 2 | MAJO BH Z | MAJO BH 1 | MAJO BH 2 | MAKZ HH Z | MAKZ HH 1 | MAKZ HH 2 | MBAR BH Z | MBAR BH 1 |
| MBAR BH 2 | MBWA BH Z | MBWA BH 1 | MBWA BH 2 | MDJ HH Z | MDJ HH 1 | MDJ HH 2 | MNC HH Z | MNC HH Z | MNC HH N |
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Figure 34: Seismic stations

.This data was loaded in waveform file format on to the seismic software named SEISAN.

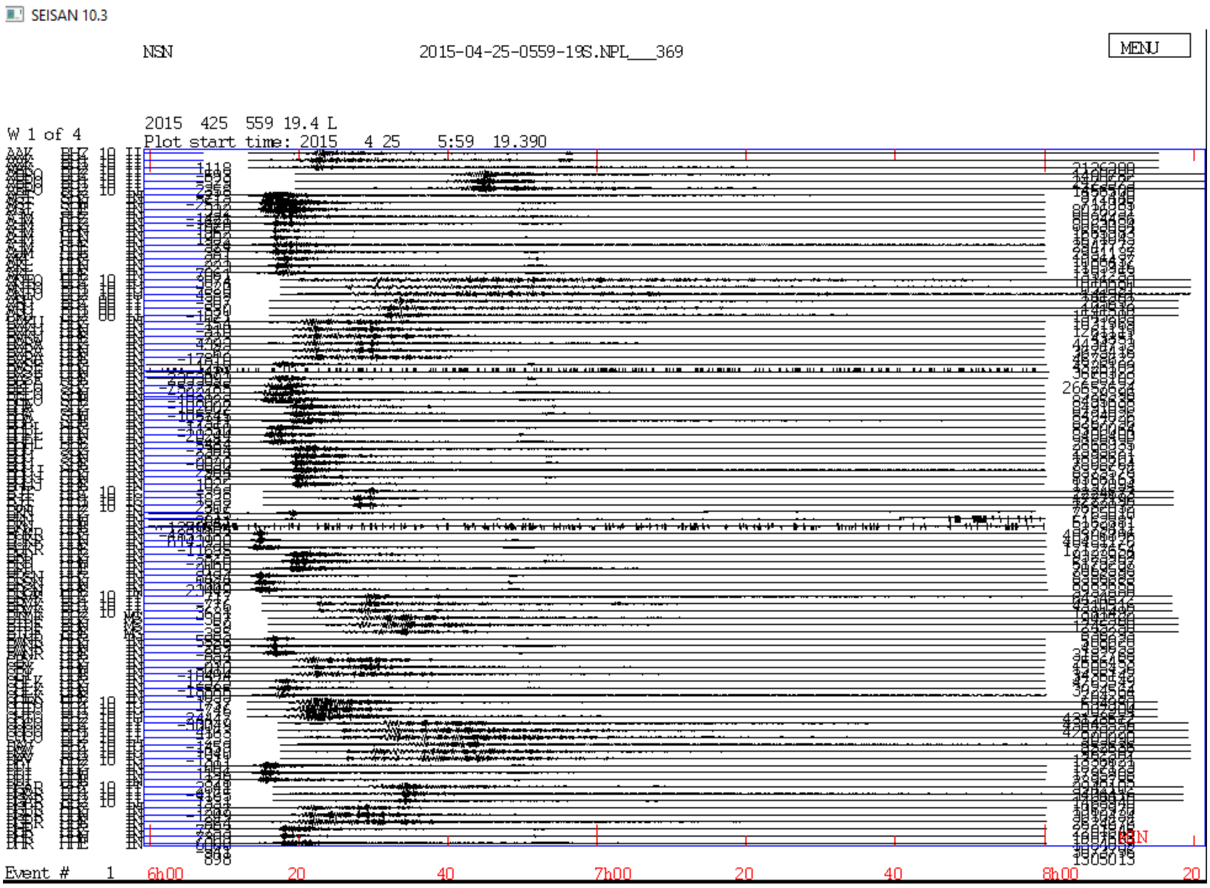



Figure 35: Waveform data of Nepal earthquake

## 4.2 About Software

The SEISAN software is a very efficient tool for working and analysing on earthquakes. It uses a various programs which are built around the data to predict the result. Both digital as well as analogue data can be used to work on the software. The very common programs in SEISAN has been used to pick the earthquake and to mark the onset time of the phases and to calculate the amplitude with the application of filter. Events are managed well with the help of many programs inbuilt in the software. Now user can work on a group of events or a single event. There is a file system in which events are distributed with unique ID. With the help of this unique ID of the events, user can get an instant access to them. A directory is installed in the system by SEISAN in which new data can be moved. The results generated can also be used with other software as the generated results are on text files. There are tools to plot earthquakes and Google map is also associated with it. User can also edit the parameters of the software directly from the word file.

SEISAN can work with almost all formats of seismic data. It can handle broadband, multi-channel and high quality seismic data. SEISAN is very portable as its structure is directory type. Seismic hazard studies can also be studied with the help of SEISAN. These are the advantages and many are not mentioned here, which make this software a potential and complete tool to study and analyse the earthquakes.

## 4.3 Working Steps

The software is installed under C:\Seismo and it creates many directories under there. All of these directories contain important files for example the parameters and readings are under REA, calibration files under CAL and files of other parameters under DAT directory. First of all we have to make a new directory and move our data in that directory. Then we have to register each event and to create the s file for every event. For this we use mulplt command by which every event is registered. A list file is created in order to load all the events simultaneously. The list file numbers all the waveform files. The dirf command is used to do this. Now response file is made and saved in CAL directory, for every station where data is stored. Command resp is used to create files. In addition to creating the response files, we have to also edit the station.hyp file and to add the longitudes, latitudes and depths of different stations.

### 4.3.1 Picking Phases

Once registered, the events can be picked with the use of mulplt window. Now we pick P, S and coda wave phases. For picking P phase, z component of the station is used. P phase is picked at the first oscillation of the wave. To do this we press 1 near the first oscillation. S phase can be picked either in North or East component of the station selected. To pick S phase we press 8 near the pick. In this way P and S phases are picked in the s file.

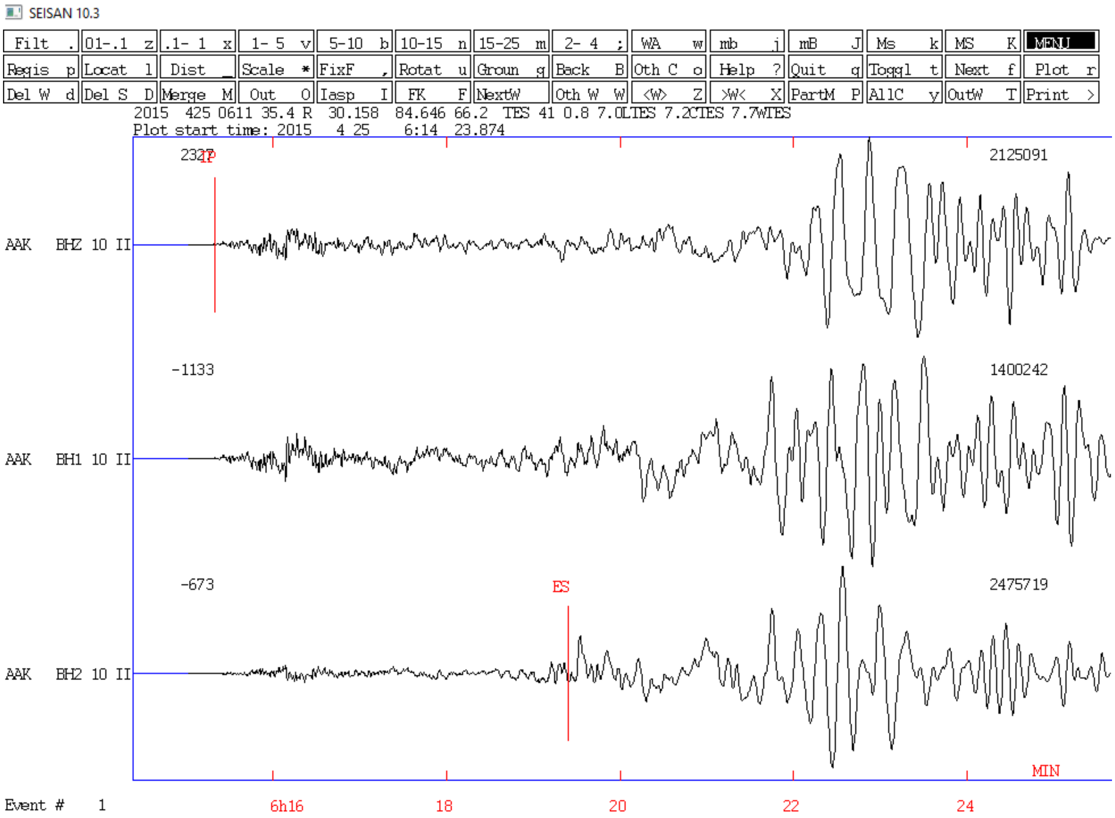



**Figure 36: Picking P and S phase**

The coda phase is picked on the z component. It is picked by pressing c where the wave train is decaying. The coda phase can also be picked automatically by pressing C.

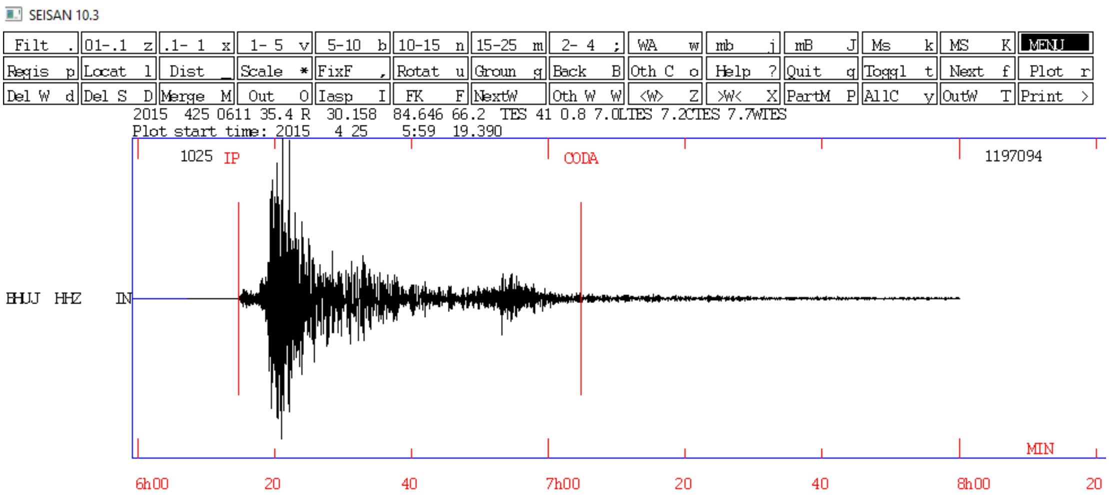



**Figure 37: Picking Code wave**

We can again pick the P or S phase at separate point on an already picked event. This deletes the previously picked phases and the s-file is edited in the database. A pick can also be deleted by pressing d near the pick.

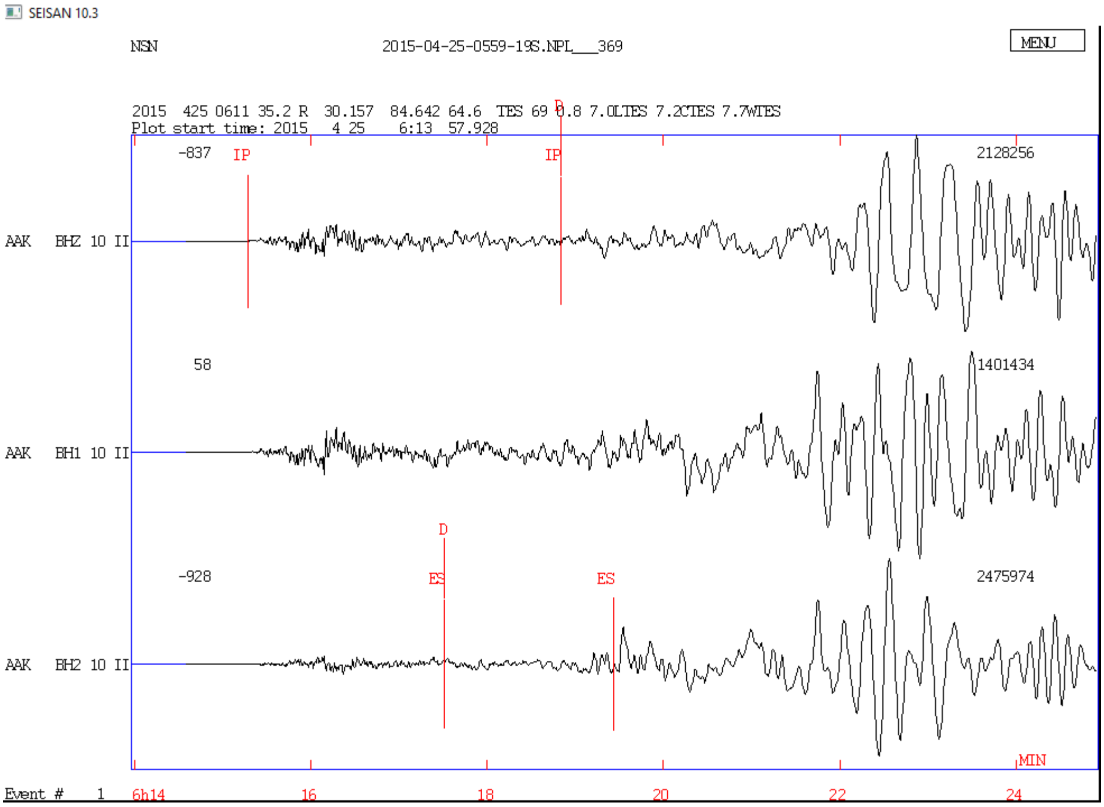



**Figure 38: Picking phase at separate locations on previously picked events**

In this way we pick phases at all the stations. Once picking is done we can locate the events by pressing l in the software database viewer. In this way we get the depth, latitude and longitude and also the residual error in the phases picked. At every step we can update our s-file, where all the information is saved.

| date | hrmn | sec | lat | long | depth | no | m | rms | damp | erln | erlt | erdp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 425 | 611 | 35.51 | 30 9.97N | 84 38.7E | 66.6 | 74 | 3 | 0.87 | 0.000 | 3.3 | 3.8 | 5.4 |

| stn | dist | azm | ain | w | phas | calcphs | hrmn | tsec | t-obs | t-cal | res | wt | di |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DDI | 634 | 273.2 | 98.3 | 0 | P | PG | 612 | 57.7 | 82.18 | 82.16 | 0.02 | 1.00* | 3 |
| DDI | 634 | 273.2 | 81.7 | 0 | S | Sn | 614 | 2.3 | 146.78 | 146.96 | -0.18 | 1.00* | 4 |
| SMLA | 725 | 280.4 | 81.7 | 0 | P | Pn | 613 | 8.9 | 93.43 | 93.30 | 0.14 | 1.00* | 3 |
| BHPL | 1050 | 224.8 | 76.1 | 0 | P | PN6 | 613 | 45.7 | 130.14 | 128.65 | 1.49 | 0.93* | 1 |
| BHPL | 1050 | 224.8 | 80.3 | 0 | S | Sn | 615 | 34.1 | 238.58 | 238.63 | -0.05 | 1.00* | 3 |
| AJM | 1062 | 249.8 | 76.1 | 0 | P | PN6 | 613 | 44.7 | 129.15 | 130.01 | -0.86 | 0.98* | 1 |
| AJM | 1062 | 249.8 | | 0 | P | | 613 | 59.1 | 143.6 | | | | |
| BWNR | 1099 | 173.6 | 80.1 | 0 | S | Sn | 615 | 44.4 | 248.92 | 249.28 | -0.36 | 1.00* | 3 |
| BWNR | 1099 | 173.6 | 81.0 | 0 | P | Pn | 613 | 54.7 | 139.15 | 139.23 | -0.08 | 1.00* | 2 |
| HYB | 1541 | 205.0 | 72.4 | 0 | P | Pn | 614 | 48.1 | 192.62 | 193.24 | -0.62 | 0.99* | 1 |
| HYB | 1541 | 205.0 | 78.0 | 0 | S | Sn | 617 | 21.1 | 345.54 | 346.15 | -0.61 | 0.99* | 3 |
| KBL | 1545 | 292.3 | 78.0 | 0 | S | Sn | 617 | 22.9 | 347.42 | 347.23 | 0.19 | 1.00* | 4 |
| POO | 1689 | 222.7 | 68.1 | 0 | P | Pn | 615 | 6.7 | 211.17 | 210.54 | 0.63 | 0.99* | 1 |
| POO | 1689 | 222.7 | 77.4 | 0 | S | Sn | 617 | 54.1 | 378.57 | 378.37 | 0.20 | 1.00* | 3 |
| KMI | 1868 | 103.0 | 63.7 | 0 | P | Pn | 615 | 25.0 | 229.47 | 231.04 | -1.57 | 0.92* | 1 |
| KMI | 1868 | 103.0 | 76.8 | 0 | S | Sn | 618 | 32.9 | 417.35 | 417.66 | -0.31 | 1.00* | 4 |
| CHTO | 1915 | 127.8 | 62.9 | 0 | P | Pn | 615 | 31.6 | 236.12 | 236.00 | 0.12 | 1.00* | 1 |
| CHTO | 1915 | 127.8 | 76.6 | 0 | S | Sn | 618 | 41.5 | 425.99 | 427.44 | -1.45 | 0.93* | 3 |
| GOA | 1965 | 216.6 | 76.4 | 0 | S | Sn | 618 | 52.6 | 437.09 | 438.24 | -1.15 | 0.96* | 2 |
| PBA | 2213 | 156.1 | 51.7 | 0 | P | P | 616 | 3.4 | 267.89 | 266.11 | 1.78 | 0.90* | 0 |
| PBA | 2213 | 156.1 | 53.4 | 0 | S | S | 619 | 45.0 | 489.48 | 487.23 | 2.25 | 0.84* | 2 |
| XAN | 2326 | 73.0 | 51.1 | 0 | P | P | 616 | 13.6 | 278.11 | 277.09 | 1.02 | 0.97* | 1 |
| XAN | 2326 | 73.0 | 52.5 | 0 | S | S | 620 | 4.4 | 508.91 | 507.35 | 1.56 | 0.92* | 1 |
| ENH | 2387 | 83.4 | 50.7 | 0 | P | P | 616 | 18.3 | 282.79 | 282.99 | -0.20 | 1.00* | 1 |
| ENH | 2387 | 83.4 | 51.9 | 0 | S | S | 620 | 13.2 | 517.65 | 518.14 | -0.49 | 0.99* | 1 |
| PALK | 2566 | 190.0 | 49.3 | 0 | P | P | 616 | 37.0 | 301.51 | 300.13 | 1.38 | 0.94* | 0 |
| PALK | 2566 | 190.0 | 41.0 | 0 | S | S | 620 | 43.8 | 548.33 | 546.93 | 1.40 | 0.94* | 3 |
| QIZ | 2825 | 110.1 | 41.0 | 0 | P | P | 616 | 57.3 | 321.80 | 321.31 | 0.49 | 0.99* | 0 |
| QIZ | 2825 | 110.1 | 39.6 | 0 | S | S | 621 | 19.7 | 584.15 | 584.14 | 0.02 | 1.00* | 1 |
| BJT | 3057 | 60.5 | 40.3 | 0 | P | P | 617 | 16.4 | 340.87 | 339.92 | 0.95 | 0.97* | 1 |
| BJT | 3057 | 60.5 | 39.4 | 0 | S | S | 621 | 54.3 | 618.74 | 616.73 | 2.01 | 0.87* | 1 |
| BJT | 3057 | 60.5 | | 0 | S | | 621 | 54.5 | 619.0 | | | | |
| SSE | 3489 | 78.9 | 39.4 | 0 | P | P | 617 | 51.6 | 376.08 | 374.44 | 1.65 | 0.91* | 0 |
| SSE | 3489 | 78.9 | 38.9 | 0 | S | S | 622 | 54.4 | 678.94 | 677.83 | 1.11 | 0.96* | 1 |
| HIA | 3632 | 44.3 | 39.1 | 0 | P | P | 618 | 1.6 | 386.12 | 385.55 | 0.57 | 0.99* | 1 |
| HIA | 3632 | 44.3 | 38.7 | 0 | S | S | 623 | 12.4 | 696.89 | 697.55 | -0.66 | 0.99* | 1 |
| TATO | 3667 | 89.9 | 39.0 | 0 | P | P | 618 | 2.8 | 387.25 | 388.50 | -1.25 | 0.95* | 0 |
| TATO | 3667 | 89.9 | 38.6 | 0 | S | S | 623 | 17.9 | 702.40 | 702.82 | -0.42 | 0.99* | 1 |
| GNI | 3767 | 298.1 | 38.8 | 0 | P | P | 618 | 11.4 | 395.86 | 396.35 | -0.49 | 0.99* | 1 |

```
GNI   3767 298.1 38.4 0 S       S        623 31.3 715.76 716.77  -1.01 0.97* 2
BTDF  3773 144.1 38.8 0 P       P        618 10.7 395.23 396.80  -1.57 0.92* 0
BTDF  3773 144.1 38.4 0 S       S        623 32.4 716.89 717.59  -0.70 0.98* 2
INCN  3938  66.7 38.1 0 S       S        623 53.7 738.21 740.24  -2.03 0.87* 1
RAYN  3939 268.8 38.3 0 P       P        618 25.8 410.33 409.75   0.58 0.99* 0
RAYN  3939 268.8 38.1 0 S       S        623 56.4 740.86 740.69   0.17 1.00* 3
OBN   4686 320.4 36.1 0 P       P        619 21.0 465.47 465.34   0.13 1.00* 1
OBN   4686 320.4 36.4 0 S       S        625 35.4 839.86 840.65  -0.79 0.98* 2
YAK   4800  29.2 35.7 0 P       P        619 29.5 473.95 473.61   0.34 1.00* 1
YAK   4800  29.2 36.1 0 S       S        625 51.5 856.03 855.62   0.41 0.99* 1
COCO  4862 162.6 36.0 0 S       S        626  0.3 864.77 864.52   0.25 1.00* 3
COCO  4862 162.6 35.5 0 P       P        619 34.2 478.69 478.51   0.18 1.00* 0
NAL   4910 298.1 35.3 0 P       P        619 37.7 482.15 482.08   0.07 1.00* 0
MAJO  4973  67.1 35.1 0 P       P        619 41.9 486.39 486.48  -0.09 1.00* 0
MAJO  4973  67.1 35.7 0 S       S        626 13.2 877.70 879.00  -1.30 0.95* 1
DAV   4975 112.5 35.1 0 P       P        619 42.6 487.05 486.77   0.28 1.00* 0
DAV   4975 112.5 35.7 0 S       S        626 15.4 879.87 879.53   0.34 1.00* 1
YSS   5265  52.3 34.9 0 S       S        626 52.1 916.56 916.30   0.26 1.00* 1
YSS   5265  52.3 34.2 0 P       P        620  2.5 506.96 506.94   0.03 1.00* 0
FURI  5317 253.5 34.0 0 P       P        620  7.3 511.80 511.35   0.45 0.99* 0
FURI  5317 253.5 34.8 0 S       S        626 59.9 924.38 924.32   0.06 1.00* 3
ERM   5327  58.9 34.0 0 P       P        620  7.0 511.52 511.31   0.21 1.00* 0
ERM   5327  58.9 34.8 0 S       S        627  1.0 925.48 924.31   1.17 0.96* 1
KAPI  5396 130.1 33.8 0 P       P        620  9.9 514.39 516.36  -1.97 0.87* 0
KAPI  5396 130.1 34.6 0 S       S        627  8.9 933.42 933.56  -0.14 1.00* 2
KEV   5666 337.8 32.9 0 P       P        620 30.2 534.73 534.13   0.60 0.99* 1
KEV   5666 337.8 33.9 0 S       S        627 41.4 965.90 966.21  -0.31 1.00* 2
KONO  6343 324.2 30.8 0 P       P        621 14.2 578.70 578.66   0.04 1.00* 0
KONO  6343 324.2 32.0 0 S       S        629  4.01048.511048.62  -0.11 1.00* 2
PET   6356  43.7 30.7 0 P       P        621 14.9 579.35 579.53  -0.18 1.00* 0
PET   6356  43.7 32.0 0 S       S        629  4.11048.621050.24  -1.62 0.92* 1
GRFO  6371 312.3 30.7 0 P       P        621 16.2 580.73 580.60   0.14 1.00* 0
GRFO  6371 312.3 32.0 0 S       S        629  7.81052.291052.21   0.08 1.00* 2
GUMO  6413  92.7 30.5 0 P       P        621 18.9 583.40 583.75  -0.34 1.00* 0
GUMO  6413  92.7 31.9 0 S       S        629 12.81057.291058.06  -0.77 0.98* 1
MBAR  6637 249.4 29.8 0 P       P        621 32.8 597.29 597.95  -0.66 0.99* 0
MBAR  6637 249.4 31.2 0 S       S        629 40.01084.511084.55  -0.04 1.00* 3

2015  425 0611 35.5 R  30.166  84.645 66.6  TES 69 0.9
OLD:  425 0611 38.2 R  30.169  84.613 75.9  TES 71 6.3
```

Figure 39: Locating picked events

### 4.3.2 Picking Amplitudes

We have to pick the Local amplitude to calculate the local magnitude. We use response of wood Anderson seismograph in mulplt window to pick the amplitudes. To pick the amplitude we select 2 points corresponding to the lowest and the highest amplitudes. We pick amplitudes usually on the East or the North components of the stations. We can generate the coda magnitude automatically at the coda picked position. In order to generate th moment magnitude, we have to work with the S phase spectra.

To pick the amplitudes events are opened in single trace mode. An appropriate filter is applied and user has to press the key at the top and the bottom extremes of the amplitudes. After pressing the key, a mark is made there which shows the picked amplitudes.

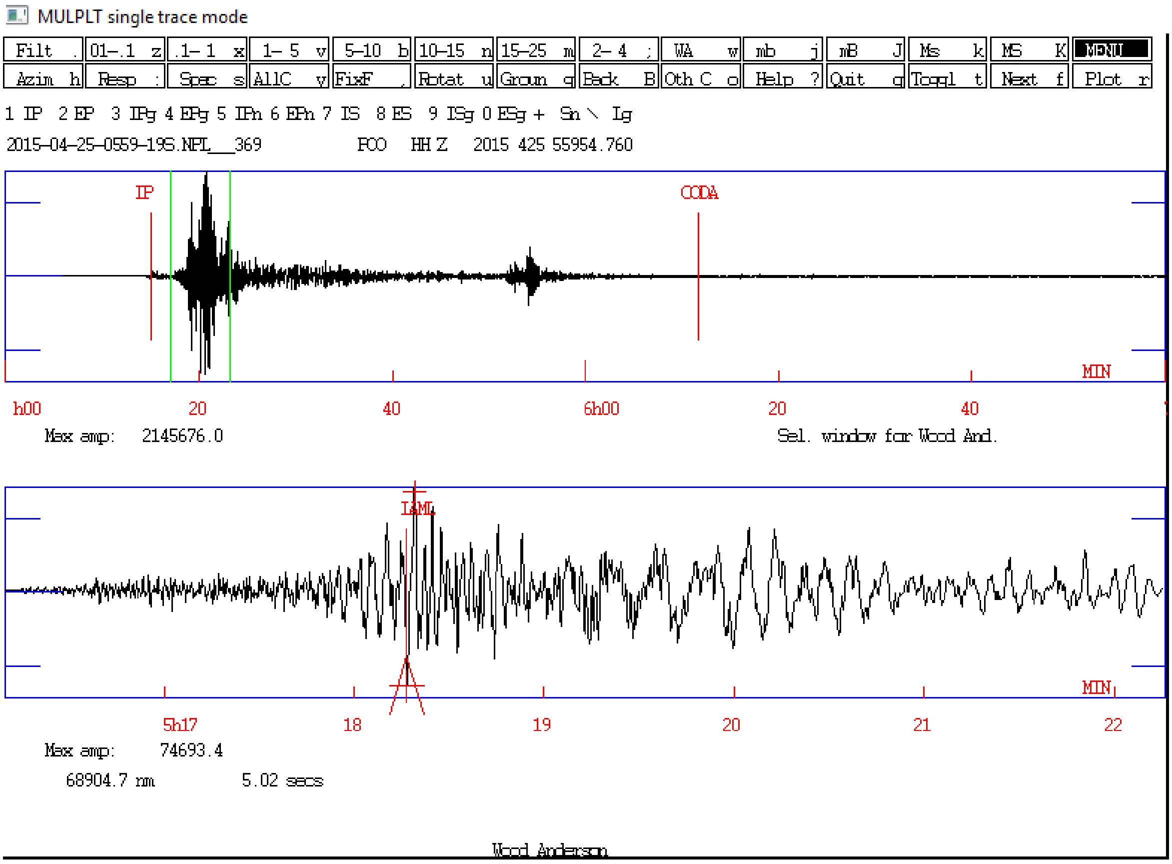



**Figure 40: Picking Richter Local Magnitude**

All the amplitudes are recorded in nanometres in SEISAN. We can also pick amplitudes automatically by pressing A, but it can be erroneous in several cases. The picked Amplitude is indicated on the plot as IAML and s-file saves it.

### 4.3.3 Analysing the S Phase Spectra

Once the phases and amplitudes are picked and saved in database and the hypocentre locations are calculated, we can generate the S phase spectra. This spectra is used to generate various source characteristics. Spectral analysis is done in the toggle mode. In toggle mode we zoom in on the part containing S phase and a window is selected containing the S phase data. The spectrum is generated by this portion. There is generation of single spectra when we press s button and generation of noise and signal spectra when we press s button. We can do spectral analysis both manually and automatically.

To do it manually, we have to choose three points in the S phase spectra. It gives us the amplitude spectral parameters which includes moment magnitude, corner frequency and stress drop. When we press f after selecting three points, it displays all the determined characteristics.

We can also choose to do spectral analysis automatically which is done by selecting the auto fit spectrum (s) command Often fitting the spectra automatically is more reliable.

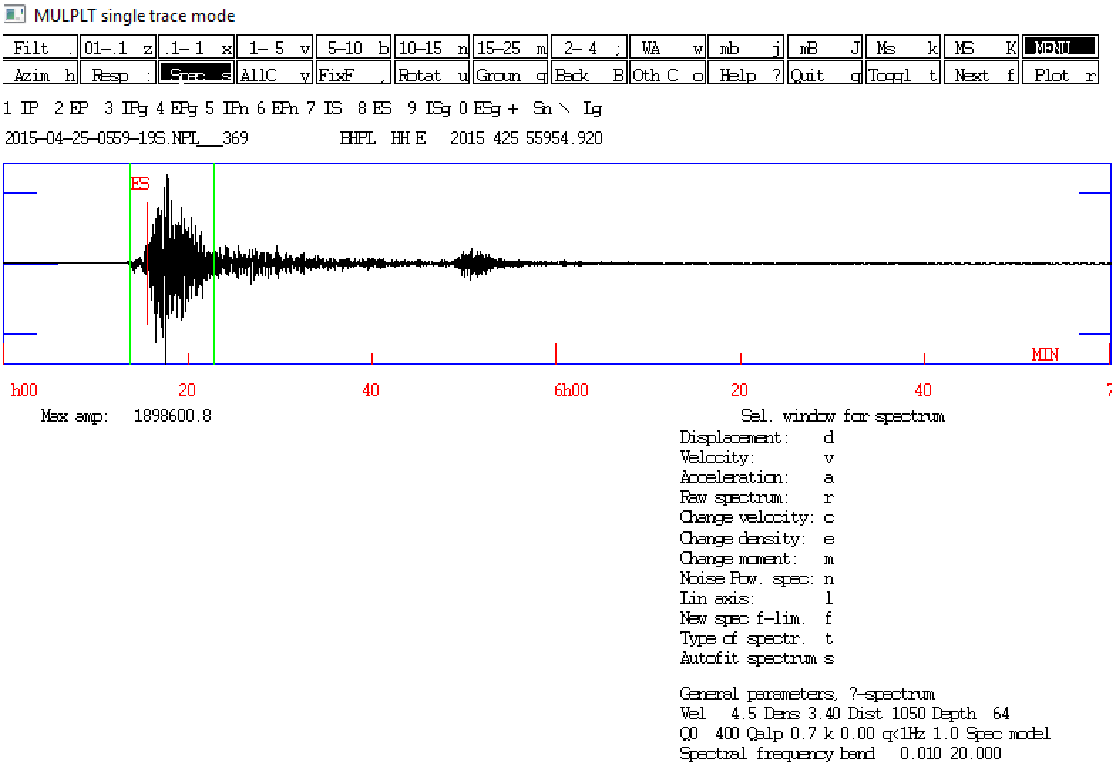



**Figure 41: analysis of S phase spectra**

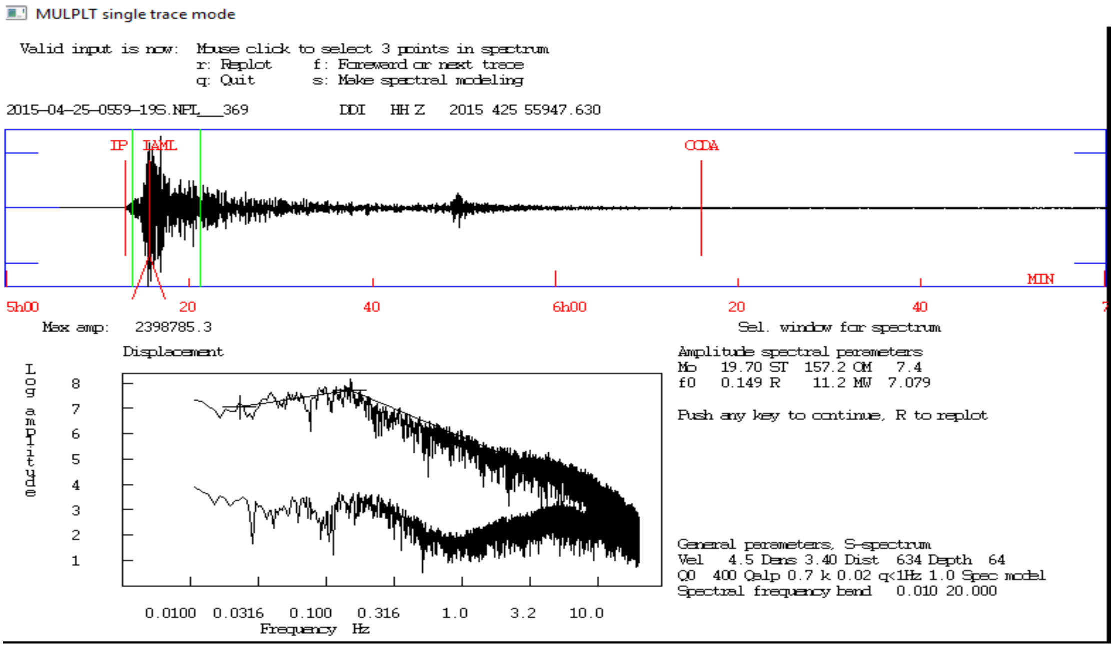



Figure 42: Manual picking of 3 points on spectrum

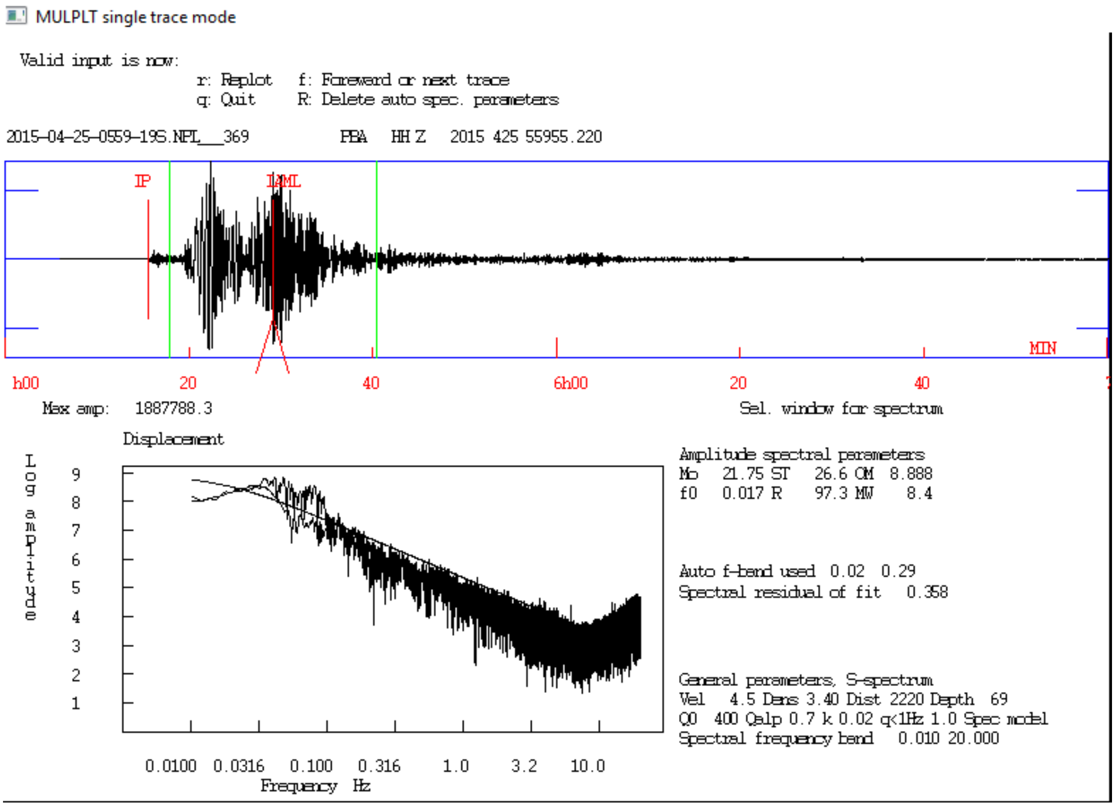



Figure 43: Auto fitting the spectrum

# Chapter 5: Results and Interpretation

Source characteristics namely Stress drop, Moment magnitude, Corner frequency, Source radius and Seismic moment are determined. These parameters can be determined from the spectral analysis.

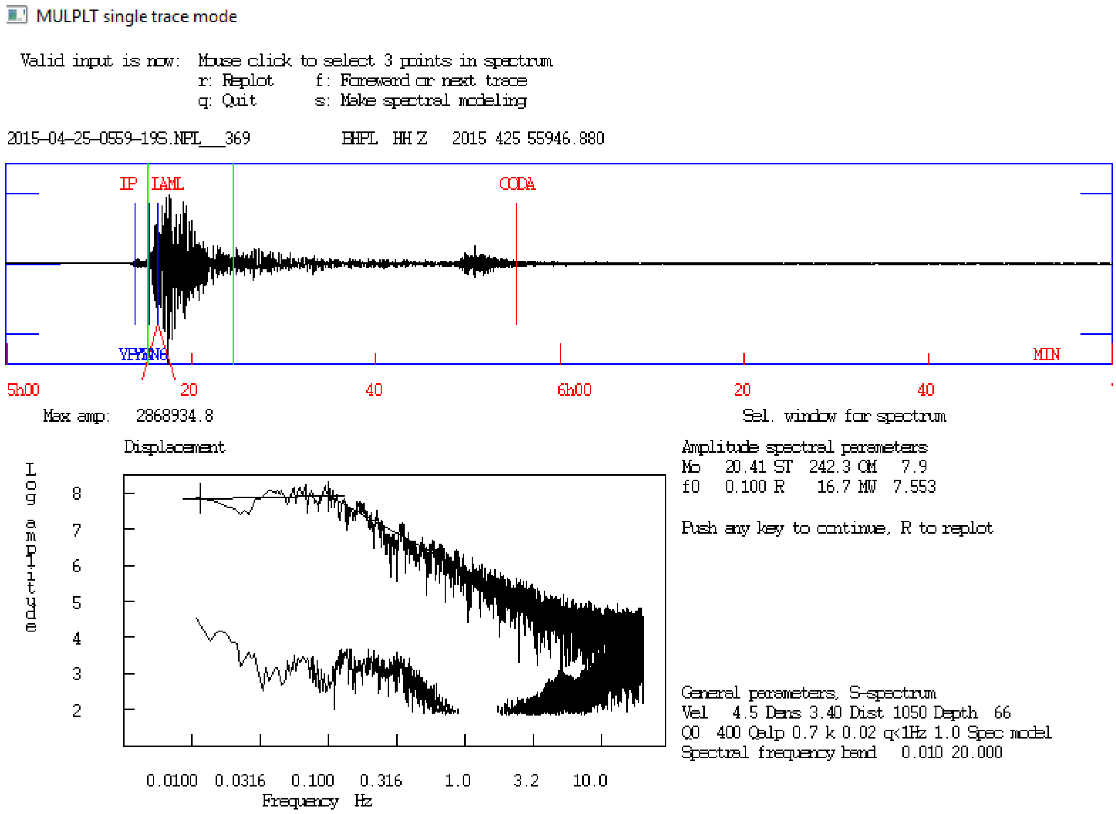



**Figure 44: S phase Spectra for event BHPL HH Z**

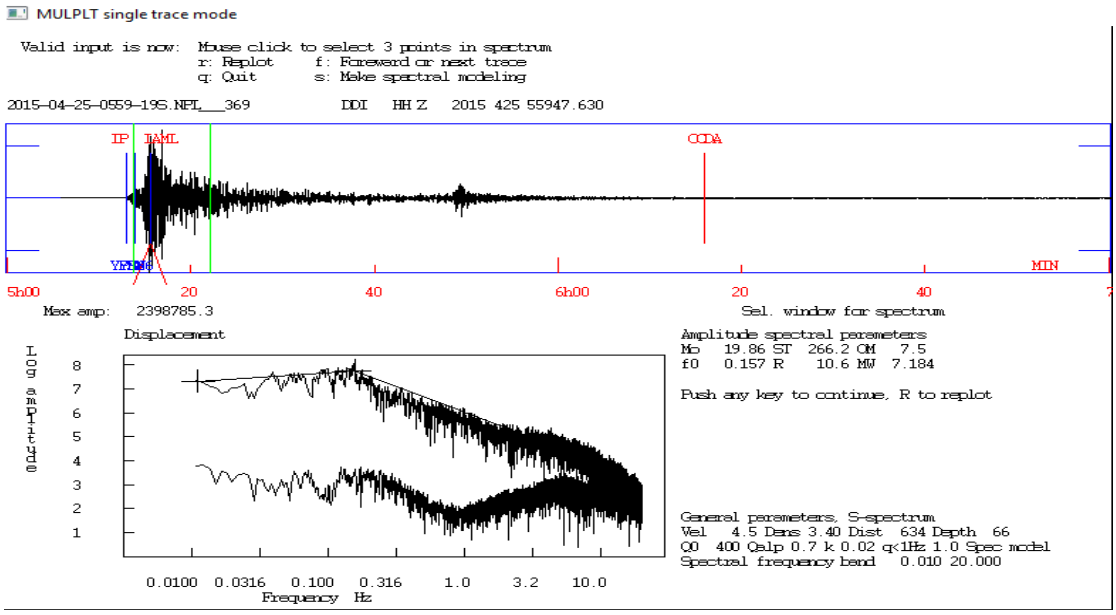



**Figure 45: S phase spectra for event DDI HH Z**

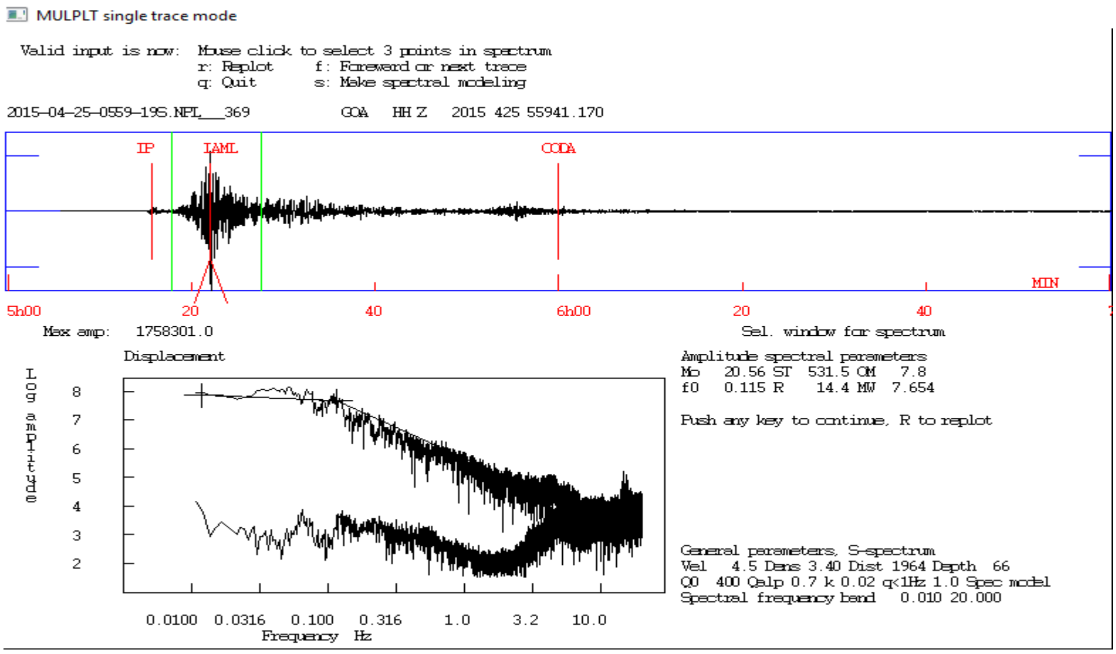
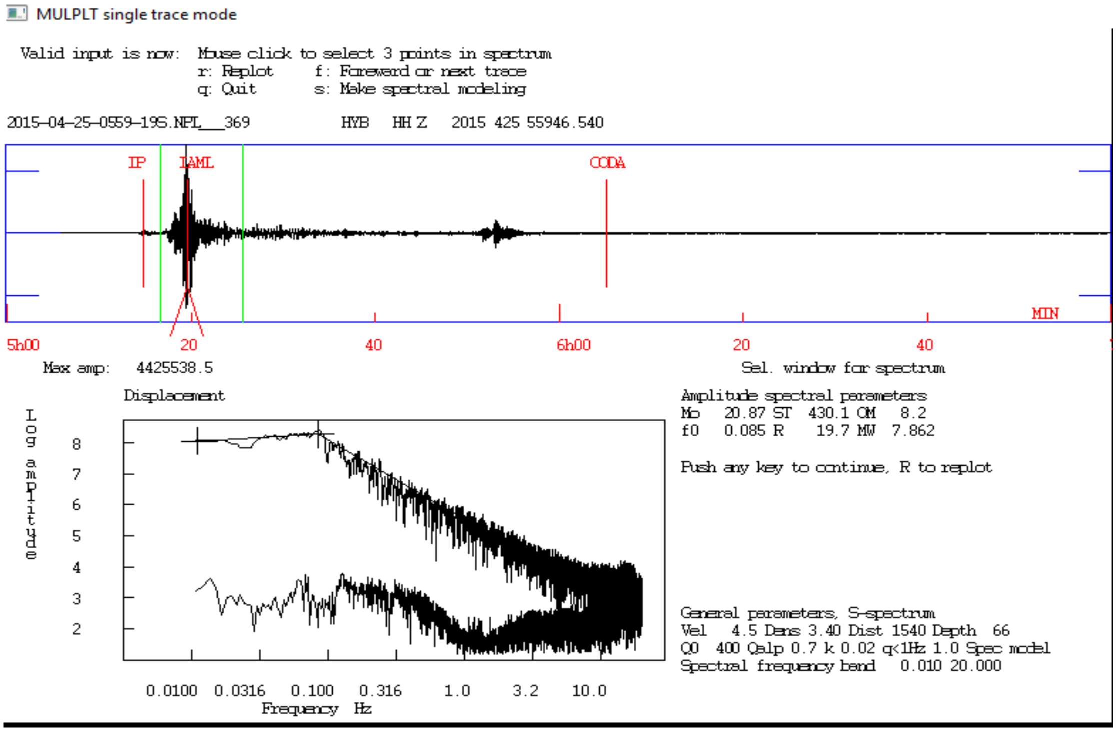



**Figure 46: S phase spectra for event GOA HH Z**



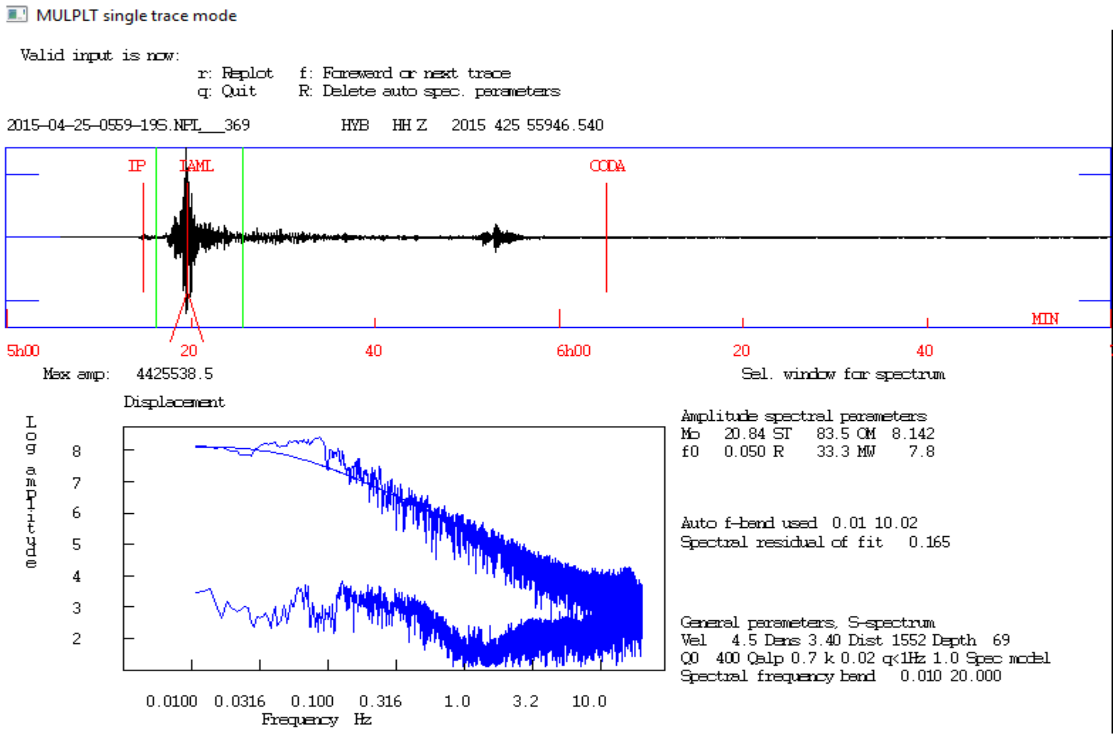
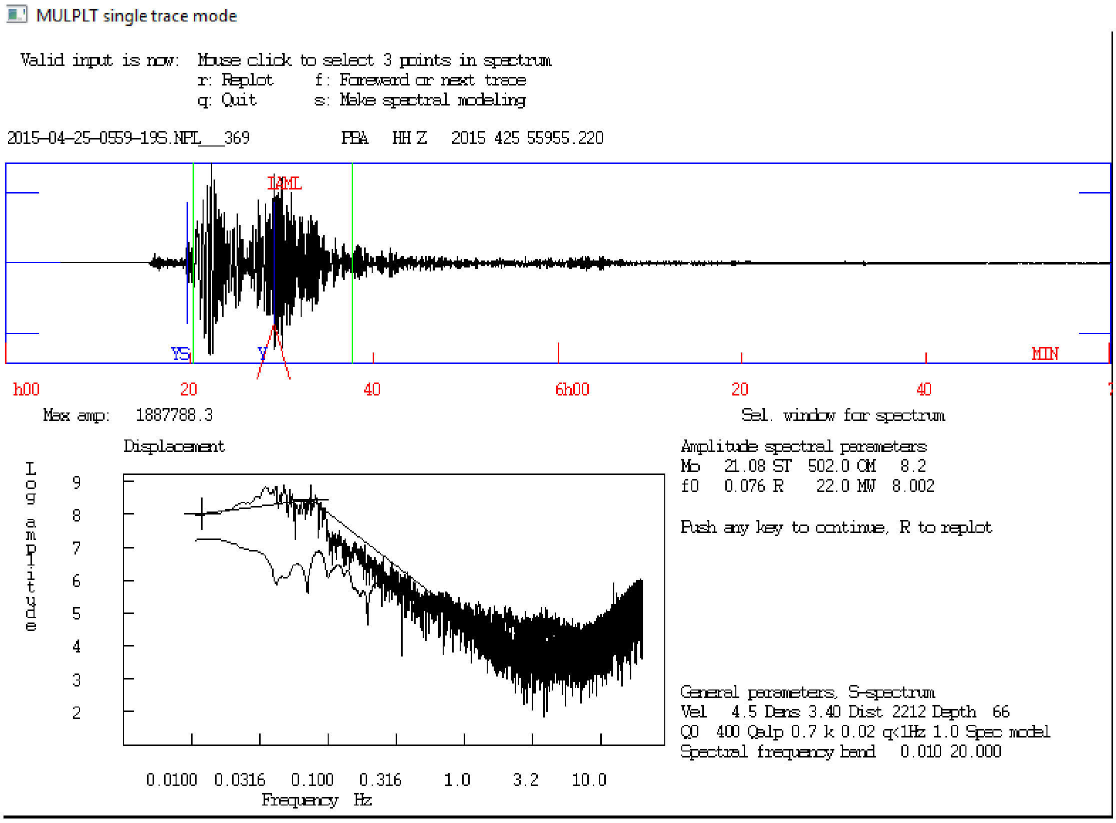
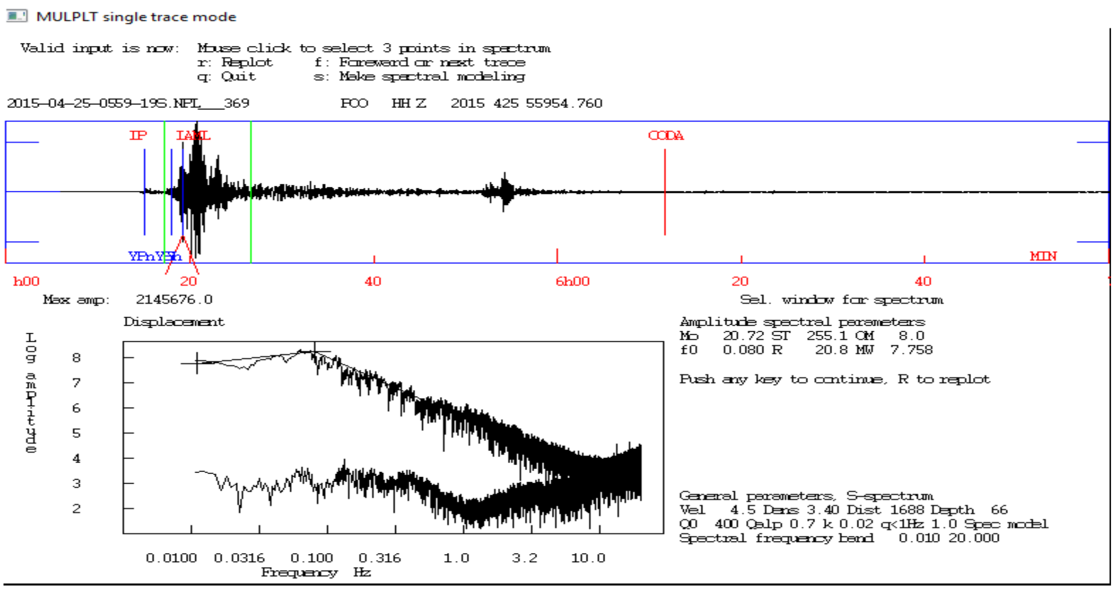




Figure 47: S phase spectra for event HYB HH Z




## Figure 48: S phase spectra for event PBA HH Z




## Figure 49: S phase spectra for event POO HH Z

```
2015  425 0611 26.4 R  28.088  84.667 13.6  TES112 1.4 8.2LTES 8.2CTES 7.6sTES1
2015  425 0611 26.4 R                       TES        7.7WTES                1
SPEC AVERAGE  MO 20.6 ST420.5 OM  8.0 f00.153 R 25.03 AL 0.87 WI306.2 MW  7.7 3
SPEC SD       MO  0.6 ST376.8 OM  0.6 f00.118 R 20.93 AL      WI      MW  0.4 3
GAP= 21        3.08       3.2     2.4  5.1  0.1399E+01 -0.9165E+00 -0.2480E+01E
SPEC SMLAHH N MO 19.9 ST109.7 OM  7.8 f00.094 R 15.04 AL 1.97 WI297.2 MW  7.2 3
SPEC SMLAHH N T 61411 K 0.020 GD  748 VS 3.82 DE 2.87 Q0400.0 QA 0.70 Q1 1.00 3
SPEC ITANSH Z MO 20.7 ST610.4 OM  8.4 f00.100 R 15.65 AL 0.00 WI380.6 MW  7.8 3
SPEC ITANSH Z T 61421 K 0.020 GD  840 VS 4.23 DE 3.18 Q0400.0 QA 0.70 Q1 1.00 3
SPEC TAWASH Z MO 21.3 ST136.9 OM  8.5 f00.062 R 39.86 AL 1.94 WI275.0 MW  8.1 3
SPEC TAWASH Z T 61325 K 0.010 GD  712 VP 6.68 DE 2.87 Q0500.0 QA 0.70 Q1 1.00 3
SPEC BOKRHH Z MO 20.7 ST999.9 OM  8.1 f00.297 R8.3219 AL 1.39 WI297.3 MW  7.8 3
SPEC BOKRHH Z T 61246 K 0.010 GD  491 VP 6.68 DE 2.87 Q0500.0 QA 0.70 Q1 1.00 3
SPEC POO HH Z MO 21.1 ST132.4 OM  7.8 f00.078 R 35.67 AL 0.00 WI345.6 MW  8.0 3
SPEC POO HH Z T 61746 K 0.010 GD 1529 VP 7.52 DE 3.18 Q0500.0 QA 0.70 Q1 1.00 3
SPEC GOA HH Z MO 20.4 ST999.9 OM  7.2 f00.293 R8.4355 AL 1.94 WI353.7 MW  7.5 3
SPEC GOA HH Z T 61922 K 0.010 GD 1787 VP 6.68 DE 2.87 Q0500.0 QA 0.70 Q1 1.00 3
SPEC DGPRHH Z MO 21.1 ST 10.7 OM  8.5 f00.019 R 82.37 AL 0.00 WI432.5 MW  8.0 3
SPEC DGPRHH Z T 61821 K 0.020 GD 1712 VS 4.23 DE 3.18 Q0400.0 QA 0.70 Q1 1.00 3
SPEC SHL HH Z MO 20.9 ST999.9 OM  8.1 f00.308 R8.0247 AL 1.33 WI261.8 MW  7.9 3
SPEC SHL HH Z T 61342 K 0.010 GD  769 VP 6.68 DE 2.87 Q0500.0 QA 0.70 Q1 1.00 3
SPEC DHUBSH Z MO 20.5 ST217.4 OM  8.4 f00.082 R 19.09 AL 0.00 WI204.5 MW  7.6 3
SPEC DHUBSH Z T 61311 K 0.020 GD  542 VS 4.23 DE 3.18 Q0400.0 QA 0.70 Q1 1.00 3
SPEC BHPLHH Z MO 20.9 ST155.3 OM  7.8 f00.098 R 28.39 AL 0.00 WI303.6 MW  7.9 3
SPEC BHPLHH Z T 61533 K 0.010 GD  904 VP 7.52 DE 3.18 Q0500.0 QA 0.70 Q1 1.00 3
SPEC SMLAHH Z MO 18.9 ST567.8 OM  6.8 f00.364 R3.8830 AL 1.97 WI339.1 MW  6.5 3
SPEC SMLAHH Z T 614 2 K 0.020 GD  748 VS 3.82 DE 2.87 Q0400.0 QA 0.70 Q1 1.00 3
SPEC GUWASH Z MO 21.0 ST105.9 OM  8.8 f00.044 R 35.57 AL 0.00 WI183.3 MW  8.0 3
SPEC GUWASH Z T 61346 K 0.020 GD  681 VS 4.23 DE 3.18 Q0400.0 QA 0.70 Q1 1.00 3
```

**Figure 50: Values of source parameters in s-file**

The values of the source characteristics for different stations are shown in the following table.

| S. No. | Station Name | Stress Drop ($\Delta\sigma$) (in bars) | Source Radius (R) (in km) | Corner frequency (f0) (in Hz) | Seismic Moment (Mo) (Nm) | Moment magnitude (Mw) |
|---|---|---|---|---|---|---|
| 1 | SMLA HH N | 109.7 | 15.04 | 0.094 | 19.9 | 7.2 |
| 2 | ITAN SH Z | 610.4 | 15.65 | 0.100 | 20.7 | 7.8 |
| 3 | TAWA SH Z | 136.9 | 39.86 | 0.062 | 21.3 | 8.1 |
| 4 | BOKR HH Z | 999.9 | 8.32 | 0.297 | 20.7 | 7.8 |
| 5 | POO HH Z | 132.4 | 35.67 | 0.078 | 21.1 | 8.0 |
| 6 | GOA HH Z | 999.9 | 8.43 | 0.293 | 20.4 | 7.5 |
| 7 | DGPR HH Z | 10.7 | 82.37 | 0.019 | 21.1 | 8.0 |
| 8 | SHL HH Z | 999.9 | 8.02 | 0.308 | 20.9 | 7.9 |
| 9 | DHUB SH Z | 217.4 | 19.09 | 0.082 | 20.5 | 7.6 |
| 10 | BHPL SH Z | 155.3 | 28.39 | 0.098 | 20.9 | 7.9 |
| 11 | SMLA HH Z | 567.8 | 3.88 | 0.364 | 18.9 | 6.5 |
| 12 | GUWA SH Z | 105.9 | 35.57 | 0.044 | 21.0 | 8.0 |

Table 1: Table showing the values of source parameters

# Chapter 6- Conclusion

The source parameters determined have an importance in providing basic information for the assessment of seismic hazard. The seismic moments calculated for these events range from 18.9 to 21.3 Nm; source radii from 3.88 to 82.37 km and stress drops from 10.7 to 999.9 bars which are similar to the events recorded in other parts of the Himalayan regions. The moment magnitude is varying from 6.5 to 8.1 which show the devastating character of the earthquake. Earthquakes of such magnitude are not uncommon in the Himalayan region due its high seismicity.

Global study has revealed that for larger magnitude earthquakes corner frequency decreases with increasing magnitude much more rapidly. Stress drop increases with increasing magnitude. This is unusual as globally most of the earthquakes show that stress drop is more or less constant for five order of magnitude variation. Radius of fault zone also increases with increasing magnitude. So larger the fault area over which slip occurs during an earthquake, more energy is released, hence magnitude will be more. Stress drop and corner frequency are also dependent on each other. The dependency and non-dependency of the source parameters depends of the actual physical process that is involved in the occurring of the earthquake.

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