CHAPTER-III
SEISMIC INSTRUMENTATION

3.1 INTRODUCTION

Quantitative analysis of seismic waves generated by a source during an earthquake requires the time domain instrumental record of the earth’s vibration. The instrumentation is designed in such a way that it must be able to detect the transient vibrations within a moving reference frame (since the instrument moves with the earth as it shakes) and operate continuously with a very sensitive detection capability with absolute timing so as to get the ground motion as a function of time. In order to get actual ground motion, it must have known linear response to ground motion (i.e. instrument calibration). This type of instrumentation used in earthquake seismology is known as seismograph while the time history of the ground vibration recorded by it is known as seismogram. The fundamental components of a seismograph are the sensor, recorder, timing system and power supply. In digital seismograph, a digitizer is an essential component for converting the analogue signal to digital format. Seismic sensors are the mechanical or electromechanical assemblies that convert earth motion into electrical signals which can be digitized with the help of a digitizer and stored in a separate storage device. An assembly of digitizer and storage device together is known as seismic recorder.

Many successful seismic recorders and sensors have been developed over the last century. Almost all the sensors are designed based on the concept of an inertial pendulum (Richter, 1958). The early seismic instrument such as seismoscope existed in China as early as 132 AD, which can only indicate the occurrence and direction of an earth vibration. Out of different types of seismic instruments, the Wood-Anderson seismometer is used to define local Richter scale magnitude of an earthquake (Richter, 1958). Developments of instruments to record earthquake have been remarkable in view of timing accuracy, frequency of ground motion, and detection thresholds of seismic station networks. During the last ten years, recording devices based on digital technology have completely replaced the old analogue systems. This chapter deals with the brief description of the analogue and digital instrumentation of the seismic stations used for the present study.
Considering the high seismic activity in NER of India and the past history of destructive earthquakes, North East Institute of Science & Technology, Jorhat (RRL-J) collaboration with National Geophysical Research Institute, Hyderabad (NGRI) established progressively 14 vertical component and 2 three component seismic stations equipped with short period instrumentation in the year 1982. In the beginning, the seismic stations were equipped with analogue recording system. In the year 1991 two Digital Telemetered seismic station network were established in the region with central recording units located at Jorhat and Tezpur in Assam. Finally most of the seismic stations are upgraded to GPS time synchronized digital broadband seismic station since 2001. In the recent past, Gauhati University (GAU), Manipur University (MAN) and Mizoram University (AZL) have established digital broadband seismic stations for continuous monitoring of the seismic activities in the region. The locations of the seismic stations (Table 3.1) are shown in Figure 3.1. The data from these stations has been used for the present study.

This chapter deals with a brief description of instrumentations involved in earthquake monitoring in NER, India. Development of response curve to existing digital recording system is a part of this study.

3.2 SEISMOGRAPH

A seismograph consists of a sensor or seismometer installed vertically over an RCC pier constructed on a solid hard rock in order to respond to the ground motion. The pier is usually separated by about 6-inch gap all around it and filled with heat insulating material like dry sand, saw dust etc, which enables the propagation of minimum level of noise. The sensor consists of a mass with the attachment of coil suspended in a magnetic field. Due to an earthquake there will be a relative movement between the mass and frame of the seismometer that is induced as an electro motive force (e.m.f.) in the coil. The e.m.f. generated in this way is fed to the recording system after undergoing attenuation or amplification with the help of attenuation/amplifier circuitry system. In vertical component seismograph, mass of the sensor moves up or down relative to the recorder. The mass continues to move up and down for some time, like a free pendulum, even after the ground ceases to move. To avoid this, a damping arrangement is made, so that it responds only to the ground movement. Using the same principle, the horizontal component of the ground motion
can also be recorded with a suitable arrangement by making the pendulum to move like a two-way swing door. In order to get a three-dimensional representation of the ground motion, it is necessary to record it in three orthogonal (perpendicular) directions, generally, in vertical (Z), north-south (N) and east-west (E) directions. Depending on the type of recorder, there are mainly two types of seismographs: analogue and digital seismograph.

3.2.1 Analogue Seismograph

In case of analogue seismograph the seismometer senses the ground vibrations and the analogue signals are recorded continuously on a paper. All analog paper recorders are based on the principle of recording on a rotating drum and a pen which moves along an axis parallel to the rotating axis to provide a continuous trace for the whole recording period, usually 24 hour. The time marks are typically generated at each minute, hour and 24 hour and have different length. The time mark generator can usually be synchronized with an external time reference (e.g. time signal relayed by National Physical Laboratory (NPL), New Delhi). Analogue seismic station comprises various components e.g. recorder and seismometer etc.

3.2.1.1 Recorders

There are various types of analogue recording systems depending on recording media e.g. the ink recording, recording on a smoke paper, heat sensitive paper and photographic paper etc. Previously in some seismic stations the conventional photographic recording was used which now a days is getting obsolete because of high recurring costs involved in photographic charts. Portacorders and Helicorders are most commonly used in the analogue seismic stations in NER India.

3.2.1.1.1 Portacorder

The Portacorder is a visible recording system. It is a complete self contained, battery-powered unit containing an amplifier, a smoked drum recorder, an accurate chronometer and internal batteries. Four high-cut and three low-cut filter positions are selectable by switch. Portacorder of model RV-320 operates on two batteries each having 12 volt and 3 amp hours, whereas only one battery is required for the model RV-320B to ensure less power consumption. The signals are recorded on smoked paper that is changed 24 hourly basis. The drum speed is generally 60 or 120 mm/min.
and second marks are superimposed on the trace to provide precise timing. Standard radio time code is directly recorded on the seismograms twice a day, i.e., at the beginning and the end of each record, to provide absolute time. The length of a second on the traces is 2 mm. P- and S-wave arrivals on the traces are timed to one hundredth of a second by use of a microscope. Therefore, the P- and S-wave readings have an accuracy of 0.01 sec.

### 3.2.1.1.2 Helicorder (RV-301B)

In some seismic stations the rectilinear writing model RV-301B of Helicorder (M/S Teledyne Geotech make) is used which provides a versatile system that produces a distortion free seismogram. It is a drum recorder for producing traces of analogue data on a set of heat sensitive paper. The trace is a helix that translates with each turn of the drum. A variety of chart speeds can be chosen, permitting as much as 72 hours of continuous data to be recorded on a single sheet of paper. The Helicorder, Model RV-301B may be supplied with 1, 2 and 3 recording channels. Helicorder is powered from precision 115 V (AC), 50 Hz power coming from the TG-120 timing system so that drum speed is very stable. The time marks are placed on records via TG-120 timing system and the Helicorder amplifiers. The recording speed and the translation rate are generally 60 mm/min and 1 mm/revolution respectively.

### 3.2.1.1.3 MEQ-800

One of the most commonly used analog field recorders is the Sprengnether MEQ-800 which can record on either ink or smoked paper. It is a self-contained unit with amplifier, helicorder and internal clock. This recorder gives instant display of recording in the field without the use of computers and it has a very low power consumption of 0.4 Watt.

### 3.2.1.2 Seismometer

Most of the analogue seismic stations are equipped with three component seismometers. The seismometers used in analogue seismic stations are as discussed below.
3.2.1.2.1 S-13 Seismometer

The Teledyne Geotech model S-13 seismometer is a portable short period seismometer which provides high sensitivity, stable and reliable output. The seismometer may be operated in either the horizontal and vertical positions and the period is adjustable from 1.33 to 0.91 second (0.75 to 1.1 Hz). The cover and electrical connections are watertight so that the instrument may be submerged in up to 100 feet of water without leakage. All operational adjustments for the period, mass position and instrument leveling are external to the instrument. The seismometer is equipped with an electromagnetic calibrator, which consists of a calibration coil fixed to the instrument frame and a permanent magnet attached to the mass. The seismometer can give stable output within the temperature range –51° to 60°C.

3.2.1.2.2 Benioff Seismometer

Benioff seismometers are of reluctance type. The reluctance seismometer constructed by Benioff uses a transducer, which consists of permanent magnet, pole pieces of soft iron, armature of soft iron and coils. The magnet is attached to the seismometer pendulum, while the armature and the coils are fixed to the frame or vice-versa. Upon motion of the magnet in relation to the armature, the air gaps between the armature and the pole pieces of soft iron are varied and thus the magnetic reluctance. The reluctance changes with a corresponding variation of the magnetic flux through the magnetic circuit. Consequently an electromotive force is induced in the coils and this is then recorded via a galvanometer. When an earth vibration reaches the instrument site, the frame or the body of the seismometer resting on the ground vibrates with it, but the mass of the seismometer, hanging loosely from the support due to the property of inertia, tries to remain stationary. Thus, relative movements are created between the frame of the seismometer and its mass. Electromotive force is induced in the transducer due to the relative motion.

3.2.1.3 Timing System

Timing system TG-120 is used to provide accurate date/time stamps for the analogue data received from the field stations. Precision timing marks for the Helicorders are generated by the TG-120 timing system. This instrument features a temperature compensated crystal controlled clock and a built-in comparator that provides a LED read out of the exact difference in time between a radio time signal
and the clock time. If the drift does not occur, it is quickly adjusted by pressing a panel-mounted button until the read out difference is cancelled. The TG-120 also has a button in power amplifier that generates precision 115-VAC, 50Hz power for the Helicorder drum motors. The power amplifier has an output of 50VA and therefore auxiliary power amplifiers are sometimes supplied to supply the power for additional recorders.

The time maintained in most of the analogue stations is Coordinate Universal Time (UTC); the time signals relayed by National Physical Laboratory (NPL), New Delhi are taken as the reference of time standard and the accuracy is 0.1 sec.

3.3 DIGITAL SEISMOGRAPH

In analogue seismograph station there are some difficulties concerning the recording and storage of analogue records. These difficulties have been removed by replacing the analogue systems with recent digital equipments. The technological progress in digital signal processing, data storage techniques and highly integrated digital circuits leads nowadays to several instruments available, that all fulfill the basic requirements of a seismic recording instrument and offer several more advanced features as well.

In general, the digital seismic stations in NER, India are equipped with GPS time synchronized data acquisition system. REFTEK-72A series data acquisition system (M/S REFTEK make, USA) is used in these stations coupled with 3-component seismometers (e.g. CMG-40T, CMG-3ESP and CMG-3T etc.). The digital stations are operated both in continuous and event – trigger mode and recorded at a rate of 100 samples per second. In order to avoid the contamination of frequencies higher than Nyquist frequency of a spectra (aliasing effect) a sharp (higher order) low pass filter with corner frequency 50 Hz is applied. The data acquisition systems and different types of seismometers used in these stations are discussed below:

3.3.1 Data Acquisition System (DAS)

Almost all the digital seismic stations of NER, India operated by RRL-J and NGRI-H are equipped with REFTEK 72A series Data Acquisition System (usually 72A-07 and 08 type). REFTEK 72A series data acquisition system is a versatile, portable, microprocessor based high-resolution instrument for unattended field use.
The power is generally supplied by 12-volt batteries, which are charged either by electricity or by solar panel. The 72A series DAS can operate unattended for more than a month when power is supplied continuously by a 12-volt battery. REFTEK 24-bit analogue-to-digital (A/D) converters are used in both the 72A-07 and −08 types. The REFTEK data acquisition system configured for 3 channels with A/D conversion resolution 24 bits can record through as many as eight different data streams simultaneously within the frequency band 0-250Hz at the rate 1-1000 samples per second (SPS). A 24-bit digitizer can count from –8388608 (−2^{23}) to 8388608 (2^{23}) and gives a dynamic range of 138 db (Bhattacharya et al., 2000). Higher dynamic range of the digitizer gives the advantage to record the ground motion from very small magnitude earthquake as well as large magnitude earthquakes without saturation.

3.3.1.1 REFTEK 72A-07 DAS

Refraction Technology (Dallas, USA) produces three main variants of the baseline 72A-07 DAS. The first model of 72A-07 has a disk but no GPS board is available. The other modified systems are 72A-07/ND (No disk), 72A-07/G/ND (with a GPS board and no disk) and 72A-07/G/1000 (or 2000) for those units with both a GPS board and a disk drive. The minimal functional DAS consists of an input signal analogue to digital (A/D) converter board (RT373), a central processor unit (usually RT319), communication board (RT371) and a DC power converter board (RT344). The data input accommodates upto three channels and the analogue input data is digitized at 24-bit resolution. There are ten options for selecting different sampling rates. The gain setting is programmable at either unity or 30 dB on each active channel. The central processing unit (CPU) board has 1MB RAM; half is used by the system and half is available to store data. A 12-volt DC power supply is required for proper functioning of the DAS and the peripheral device like the disk. A crystal oscillator in the CPU provide time to an accuracy of better than 0.5 □□ Sec / Sec. This clock is synchronized with an external GPS clock.

3.3.1.2 REFTEK 72A-08 DAS

This is a high resolution data acquisition system configured for three channels of 24-bit recording. The 72A-08 (model-3) has only three channels of 24-bit whereas 72A-08 (model-6) has six 24-bit channels and uses two A/D converter board (RT-373). Maximum internal data storage of 12 MB is available. External data recorder
can be used in 72A-08 DAS. Data is collected based on user defined parameters using DOS based control interface like Field Setup Controller (FSC) software. In this data acquisition system user can set up maximum of eight data streams for simultaneous recording with different sampling rates. This is possible because it has digital signal processor (DSP). The A/D converter operates at 1000 SPS and the digital signal processing continuously samples at 1000 SPS then filters and decimate its output at sampling rate below 1000 SPS. Input parameters are set through data acquisition software so that an automatic data transfer to the external storage device take place when RAM is approximately 70% filled. Data is transferred over the SCSI bus to an external disk recorder. An internal crystal oscillator provides real time to $5 \times 10^{-7}$ seconds accurately, which is synchronized with REFTEK-111A Global Positioning System clock.

In most of the seismic stations, two data streams are used; one records in continuous mode and the other stream records in trigger mode at the rate of 100 samples per second. In the trigger mode recording is based on the ratio of short – term average (STA) to long-term average (LTA) of the recorded signal. Timing at which this ratio exceeds a predefined threshold value is called trigger time. Recording starts a few second (set by pre-event time) before the trigger time which continues till the signal amplitude restores to the background value, after the STA/LTA ratio falls below the threshold value (Refraction Technology, 1996).

### 3.3.2 Storage Device

A 3-component digital seismograph, recording continuously at a sampling rate of 100 SPS per channel with ADC resolution of 24 bits (3 bytes) would require a storage capacity of -

$$3(comp) \times 100\ (SPS) \times 3\ (byte) \times 24\ (hour) \times 3600\ (sec) = 77.76\ MB\ per\ day.$$  

The REFTEK series data acquisition system records the data in REFTEK recording format (Refraction Technology, 1996). DAS units format data blocks into 1,024-byte packets and store them in random access memory (RAM). Without altering the format, DAS units move the packets to external disk e.g. REFTEK 72A-05 Disk recording subsystem (SCSI hard disk) over a SCSI port. This type of SCSI hard disc used for storing data has storage capacity of 4GB. Data in Reftek format is converted into the required format of data analysis software packages like PC-SUDS (Seismic
Unified Data System ported to 16-bit DOS platform created at the U.S. Geological Survey), SEISAN (Seismic Analysis Software; Havskov and Ottermoller, 2001) and SAC (Lawrence Livermore National Laboratory’s Seismic Analysis Code).

3.3.3 Seismometers

Different seismometers used in the digital seismic stations are briefly described.

3.3.3.1 CMG-40T

The CMG-40T (M/S Güralp Systems) is a lightweight broadband seismometer consisting of three sensors in a sealed case to measure north-south, east-west and vertical ground motion simultaneously. Sensor elements are designed so that no mechanical clamping is required. The sensor does not have to be leveled or centered as long as the base is within 3° of horizontal. The response of the seismometer is flat to velocity for the frequency band 0.033-50Hz (30 sec). The seismometer draws a nominal current of 48 mA from a 12-volt power supply, when in use. The seismometer can operate over a wide temperature range (-10°C to +75°C). However the sensor mass is sensitive to fluctuation in local temperature.

3.3.3.2 CMG-3ESP

The CMG-3ESP is a 3-component seismometer of class Broadband having three sensors in a sealed case to measure north-south, east-west and vertical component of ground motion. This seismometer is suitable for local, regional and teleseismic recording. Each sensor is sensitive to ground vibrations in the frequency range 0.003-50 Hz. These instruments do not require precise leveling of the sensor package to obtain long period mechanical response and can be used without leveling the sensor case up to 2.5 degrees of tilt. A microprocessor controlled remote centering is provided. There is a sensor feedback electronics housed within the sensor package for creating the damping mechanism necessary for the seismometer. The seismometer unit is self-contained apart from its 12 V power supply. It consumes low power (0.75 Watts) and can operate over 10 to 30 Volt power input range. The damping of the seismometer is, \( h = 0.707 \). The velocity sensitivity of the seismometer is 1400 v/m/s.
3.3.3.3 CMG-3T

CMG-3T is a tri-axial seismometer consisting of three sensors in a sealed case which can measure the north-south, east-west and vertical components of ground motion simultaneously. It has been designed to provide seismic information over the complete seismic spectrum from very low frequencies (0.001 Hz) up to 50 Hz. Various frequency response options are provided for the user and optionally the high frequency corner of the sensor response can be increased beyond 50 Hz. The broadband frequency response is made possible by advanced force balance feedback electronics. Because of this wide response range, CMG-3T replaces many of the instruments conventionally used in a seismic observatory. The response of CMG-3T is the same as that of a pendulum seismometer with a free period of 120 sec, electrodynamic constant 1400 mv/(mm/sec) and damping of $h = 0.707$.

3.3.4 Global Positioning System (GPS) as Timing System

The GPS is an essential element of digital seismograph which is capable of providing both time and position information accurately. It comprises 24 satellites, each of which has an atomic clock synchronized to GPS Time (offset by a constant from International Atomic Time) and transmitting time codes. A GPS receiver receiving transmissions from several satellites can determine its position (latitude, longitude and height) and the current time. International clock comparisons are now routinely performed for seismic stations via GPS with accuracy of the order of 50 nanoseconds. Generally microprocessor based REFTEK-111A GPS system is used in the digital seismic stations. It is self-contained in a self-sealing aluminum case. The TRIMBLE GPS antenna is mounted on the top of the case. It can provide the information regarding location and time serially for the host system i.e. the DAS for synchronization of the internal clock present in the DAS.

3.4 DIGITAL TELEMETRY SYSTEM

The digital telemetry is one of the most essential systems for near real time earthquake monitoring. It is useful for the stations situated at the remote places. The signal in the form of ground motion, from out stations is transmitted via very high frequency (VHF) radio links to a central receiving station. The output signal from the seismometers is coupled to the auto ranged single or three component digital modulators for appropriate signal conditioning which involves amplification,
multiplexing, digitization and conversion of the signal into Pulse Code Modulation (PCM) bit stream. This bit stream is transmitted through VHF radio transmitter. The equipments at remote stations operate on 12-volt batteries which are continuously charged using solar panel to maintain continuous data transmission. The signal is sampled at a rate of 100 SPS for single and three component stations. At the central receiving station, the remote station signals are received through VHF radio receivers which are coupled to multi-channel line interface unit (LIU). The LIU allows PCM data from all the remote stations to be multiplexed and the data is fed to digital to analogue (D/A) converters and then into a Helicorder drum recorder for the purpose of recording.

3.5 DETERMINATION OF AMPLITUDE FREQUENCY RESPONSE CURVE FOR AIZAWL SEISMIC STATION

In order to have the knowledge of source function, the prime requirement is to obtain true ground motion due to occurrence of an earthquake. The seismic signal recorded by a station on the surface of the earth is not the true ground motion produced by an earthquake source. Recorded signal is the combined effect of properties of source, propagating media and effect caused by recording process. Correction of effect of recording media to obtain true ground motion is one of the major tasks dealt with in this study. In order to observe the effect of recording media two parameters i.e. transfer function (Poles and Zeros) and the frequency response function are utilized (Mitra and Kaiser, 1993). The frequency response describes the characteristics of seismic recording system that deals with true ground motion. Basically the concept of the frequency response function is the Fourier transform of the output signal divided by the Fourier transform of the input signal. The modulus of frequency response function is exactly the amount of magnification.

In this study the magnification curves i.e. frequency response functions are quantitatively determined which are used to ascertain ground motion amplitudes from digital seismogram with necessary conversion. Ground motion amplitudes are commonly calculated from digital seismogram by dividing the signal amplitudes in counts by the value of the amplitude of the displacement /velocity frequency response function (magnification curve) at single frequency. While working out this, an important assumption has been made that the input signal is harmonic.
Table 3.2 shows the list of poles and zeros (transfer function) for different seismometers and recording system whose data are used for signal processing in subsequent chapters. These transfer functions, positions defined for a plane, are provided in a simple ASCII file (“pole-zero file”), which is created by using “text editor”. In addition, an input signal free from any artificial noise, earthquake, etc. (i.e. zero vibration condition) is provided. From the list of poles and zeros correspondingly frequency response function is calculated. A complex multiplication of the frequency response function with the discrete Fourier spectrum of the input signal is performed. Finally inverse Fourier transform is calculated. The whole process is equivalent to convolving the input signal with the impulse response of the system. Evaluation of impulse response function is made based on potential change in onset following (Seidl and Stammler, 1984). Ultimately amplitude response function is obtained. Figure 3.2 show the amplitude frequency response for AZL (AIZAWL) station equipped with REFTEK 72A-07 digitizer cum CMG-40T.

Figure 3.2 shows approximately three regions with different slope in log-log plot. Outside of the central frequency band, roughly below 0.002 and 5Hz, the amplitude frequency response function decays rapidly, hence signals with frequencies outside this range are strongly attenuated while signal with frequencies between 0.002 to 5Hz could be well recorded. This frequency band is the passband for the recording system i.e. REFTEK 72A-07 and CMG-40T seismometer, in Aizawl seismic station, Mizoram. Within this passband, the amplitude frequency response is proportional to the angular frequency \( (\omega) \). For a velocity response function, the unit for amplitude would be counts/velocity i.e counts/nm/sec. It can be noted that the plateau value is 1.0 counts/nm/sec, which corresponds to the generator constant expressed in counts.

Determination of frequency response to the ground velocity first ascertains the true ground motion at a particular frequency. Secondly it ascertains the true knowledge of passband frequency that is required for waveform processing in subsequent chapters of the present study.