Seismic Instrumentation: Indian Perspective

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Summary

In the last 10-15 years seismology has undergone a rapid transformation all over the world with the deployment of digital broadband seismographs with enhanced computing power and data exchange through internet and satellite communication. Seismology in India has seen a fast growth after the catastrophic 1993 Latur earthquake, mainly due to the deployment of digital seismographs by the Department of Science and Technology. For tsunami early warning, seismic instruments play a vital role to determine earthquake parameters, its focal mechanism and moment-tensor solution.

In this paper we tried to illustrate the development in the field of seismic instrumentation from historical era to recent time. We also discussed the principle of seismometer, strong motion accelerograph, instrumentation and installation procedure of broadband seismograph.

Introduction

‘Seismoscope’ indicating the arrival of a seismic tremor from a distant source was first invented by Chinese scientist. This instrument gives the visible evidence of a seismic event but can not trace permanent record of the seismic waves. The device consists of eight inverted dragons placed at equal intervals around the rim of pot. All dragons have bronze ball in its mouth. An open-mouth metal toad seats under each dragon. Whenever any slight tremor comes, due to internal mechanism of the device the bronze ball falls into the toad mouth. This gives enough sound to alert the people that some earthquake happened just now. It gives the direction of earthquake also by seeing which bronze ball falls into the toad mouth as shown in figure 1.

The science of seismology upgraded from the invention of the modern seismograph. It consists of a receiver and recorder. Seismograph is an instrument which gives the visible evidence of a seismic event as well as the permanent records of seismic waves. This permanent record of seismic waves is known as seismogram. By studying the seismogram, the seismologist can tell how far and how strong the earthquake was. However this record can not tell the exact location of earthquake. To locate the earthquake, we need at least three seismograms accompanied by full azimuthal coverage.

Fig.1. First seismic instrument that gives the visible evidence of seismic event known as Seismoscope.
Recently to study the earthquake parameters more precisely, borehole seismology came into light to avoid the background noise. Ocean bottom seismology presents new challenges to greatly improving our understanding of coastal and deep-sea seismic processes.

Here at INCOIS, we are receiving near-real-time seismic waveform data across all over the world from about 200 broadband seismic stations of different networks such as IRIS, GEOSCOPE and GEOFON through internet. We are also receiving the near-real-time seismic waveform data from IMD broadband seismic stations located different parts of India through VSAT communication. We are able to get location automatically and focal depth of the earthquake within 7-10 minutes with the help of SeisComp autolocation software.

**Seismograph**

A seismograph consists of a seismometer which detected and amplified the ground motion by sensor, and recorder to record the motion. In modern instruments the vibration is amplified and filtered automatically. This amplified ground motion is converted to a visible record, called the seismogram. Seismograph records translation motion. It records simultaneously three orthogonal components of ground motion viz. two horizontal components and one vertical component (E, N & Z-components respectively).

Fundamentally, seismograph is based on pendulum principle. In vertical component seismograph (Fig. 2), when the ground shakes, the base and frame of the instrument moves with it, but the mass does not move initially due to its inertia and therefore the spring extends. But relative to the recorder, the mass moves up or down in a vertical direction and this relative motion is recorded on the recorder. The mass continues to move up and down like free pendulum for some time even after ground motion stops. In order to record only ground motion, a damping factor is incorporated into seismograph (Richter, 1958 and Bath, 1979). It records vertical component (Z-component) of ground motion. Similarly, a horizontal component seismograph works on same principle and records the horizontal components (E & N components) of ground motion.

In new seismometers there are electrical coils attached to the mass such that they are moveable in the field of a permanent magnet as shown in figure 3. An electrical signal is generated when the mass moves. The magnet is attached to the frame and the coils are connected to the galvanometer whose deflection is recorded.

**Strong Motion Accelerograph**

During violent ground vibrations due to large earthquakes, sometimes seismographs go out of scale or stop functioning after recording the onset. To effectively record such strong ground motions in near epicentral zone, an instrument called strong motion accelerograph (SMA) is used. In the design of SMAs, we use electromagnetic sensors of very low period, so
as to make the output voltage proportional to ground acceleration instead of ground velocity.

In digital SMA, recording is done in the digital mode with absolute time using GPS synchronization. Since such instruments are meant to activate only during a strong motion, a triggering device is used for recording. Here we can put device on threshold level of earthquake magnitude so that it will record only greater or equal to a particular magnitude (e.g. M ≥ 7.0) of earthquakes. Modern digital accelerographs have provided excellent near-field data sets for several significant earthquakes which are useful in understanding the effects of ground shaking on structures and also to assess the attenuation characteristics of the medium (Bhattacharya and Dattatrayam, 2000).

**Instrumentation**

Each seismic station includes the instrumentation to continuously sense, record, and transmit ground motions from a wide range of seismic sources, including local and distant earthquakes, reservoir-induced earthquakes, artificial explosions, volcanic eruptions, and other natural and human-induced activities.

**Sensors:**

1. **Long-period seismometer:** If the natural period of the seismometer much greater than the period of the earth’s vibration, the record becomes proportional to actual displacement of the earth. This seismometer is called displacement meter. It is usually designed to record seismic signals with frequencies of 0.01-0.1 Hz (i.e. periods in the range 10-100 s). This seismometer gives information about regional & teleseismic earthquakes studies.

2. **Short-period seismometer:** If the natural period of the seismometer is much less than the period of the earth’s vibration, the displacement of the seismometer becomes proportional to the acceleration of the earth vibration then the instrument acts as an accelerometer. It is usually designed to respond seismic frequencies of 1-10 Hz (i.e. periods in the range 0.1-1 s). An accelerometer is particularly suitable for recording strong motion earthquakes. This data is essential to understand how an earthquake affects man made structures. A strong-motion seismometer measures acceleration. This can be mathematically integrated later to give velocity and position. This seismometer is useful only for local earthquakes studies focusing on seismic hazard analysis.

3. **Broadband seismometer:** The sensors of the broadband three-component seismometers capable of sensing ground motions over the frequency band 0.01 Hz to 10 Hz. This instrument records frequencies from long-period to short-period seismometer including intermediate frequencies of 0.1-1 Hz. It records intermediate frequencies of 0.1-1 Hz of background noise that is neither recorded by long-period nor short-period seismometer. This seismometer is useful for local, regional and teleseismic earthquakes studies.

![Comparison of recording of same event on short-period, long period & broadband seismometer](image)

This shows the comparison of short-period and long period records of a teleseismic P-wave with a broadband seismometer recording of the same event. A broadband record contains more information than the other two records separately or combined.

CMG-40T & STS-2 sensors of digital broadband seismograph are shown in figure 5a & 5b respectively.

![Digital seismograph sensors](image)

**Data Acquisition System (DAS):**

The Data Acquisition System (DAS) consists of preamplifiers, Analog-to-Digital (A/D) converters, time signal receiver, on-site data storage, telemetry interface, and provides state-of-health information to both local and remote users. Figure 6 shows the Data Acquisition System (DAS) of recent digital seismograph of REF TEK, model 130-01. Preamplifiers adjust the analog output of the sensor so that it matches impedance and gain levels on the input to the A/D converter. The effective resolution of a A/D converter is dependent on the sampling rate. The
DAS has 24-bit resolution and employs a timing device which includes a crystal clock synchronized by Global Positioning System (GPS) receiver.

**Recording System:**

In earlier days rotating drums and photographic recordings were used to record the seismic signals as shown in figure 7. Galitzin invented the electromagnetic seismometer that allows transmission of the seismic signal to the recorder as an electrical signal. In the mid of twentieth century photographic recording was replaced by magnetic recording. Later digital recording of seismic signal was developed and finally analog recording is replaced by digital recording system.

**Analog Recording**

In an early method of recording, a smoked paper sheet was attached to rotating drum, scratched by stylus and pen. Further development is based on galvanometer principle, seismic signals recorded on photographic film or on magnetic tape through light-beam reflected from a small mirror.

**Digital Recording**

In digital recording system, the analog signal from a seismometer is passed through, an electronic device called an analog-to-digital converter, which samples the continuous input signal as discrete, closely spaced time-intervals and represents it as sequence of binary numbers.

**Telemetry System:**

To provide near-real-time data access for all interested institutes, the seismic station transmits data continuously and type of telemetry varies from site to site, depending on local conditions and communication infrastructure. We can access data through internet either directly or via a short radio link. Cellular or satellite technology can also be used.

**Power System:**

Most of the recording sites are in remote areas where access to commercial power systems may not be possible. In this case we use batteries and solar panels.

**Installation of Seismograph**

We can summarize the whole installation procedure as follows:

1. Travel and select location of seismometer, establish telemetry configuration.
2. Prepare local outcrop for pier by removing weathered layer and grossly leveling, pour 2 inch thick leveling pier, install recorder and power cables.
3. Install and orient seismometer.
4. Connect Global Positioning System (GPS) for time synchronization.
5. Continue covering seismometers, adding thermal mass and return travel.

The two aspects of the installation which most influence the overall performance of the broadband seismometer are the construction of the seismic pier and the application of thermal insulation around the sensor and pier.

The preferred sites are on public lands with nearby power and telephone and away from significant sources of cultural noise (roads, highways, railway lines, machinery) and rivers. Sites with nominal exposure to direct sunlight are also preferred for thermal stability. The best seismic sites are hard rock/bed rock in relatively remote locations. Damage is also a concern so we look for sites that offer some kind of security and are not generally visible from public roads or paths.
When a potential site for a broadband seismic station is found, it is necessary to deploy a portable broadband sensor recorded by a 24-bit resolution data logger at the site for a few days in order to measure the low-frequency background noise. This is an important step because the low-frequency noise level can not be reliably predicted from the high-frequency noise level. When a suitable place for the broadband seismometer has been found the loose surface materials are removed and the exposed rock is cleaned off. A piece of plywood can also place as a shade over the thermal insulation to minimize exposure to direct sunlight. Be sure that the insulating box is not touching the seismometer. It generally takes about a half-day for the seismometer to become stable after it is set up and operating.

**Construction of the Seismic Pier:**

Site selection on low porosity, hard rock is critical. Any unconformity beneath, or within the pier will add to the ambient noise. Clay soils contact with moisture, or micrometer air pores within sand are capable of causing tilts. While construction or structural piers are often built upon compacted gravel, sand, or soil, these underlying materials are cause the tilt and thus increase ambient noise.

The primary concern is that the piers affect neither the response of the earth nor the seismometer. The concrete pier should simply hold and level the seismometer. In this regard, the concrete mixture should be as homogeneous as possible. Steel reinforcing (re-bar), wire mesh, and rock aggregates all have different coefficients of thermal expansion and should not be used in a seismic pier. A rich mixture of 50 percent cement and 50 percent sand will produce a very hard, smooth surfaced pier. An example of a newly constructed seismic pier is shown in figure 8, where STS-2 sensor is installed (U C Berkeley).

**Thermal Insulation of the Broadband Seismometer:**

Thermal insulation has perhaps the biggest impact on the overall performance of the seismometer and it has the advantage of both less economic and easy to install. The objective is to achieve a thermal time constant of sufficient length to significantly attenuate the diurnal thermal signature. Insulating just the seismometer with a 4 inch thick foam box will result in a thermal time constant of order 1000 seconds, limited ultimately by heat conduction through the pier. To achieve a longer time constant, we increase the thermal inertia by insulating the entire exposed portion of the pier with a 4 inch foam box (U C Berkeley).

**Borehole Seismology**

A common way of reducing cultural and surface noise on a seismic instrument is to install it in a borehole. It is more economic than to construct an underground vault. Boreholes also provide greater contact between the instrument and bedrock than with vault installations.

For general seismic experiments, a shallow borehole (2–5 m) is normally sufficient to provide a low noise environment even they responding to surface waves. Some experiments require the use of very deep boreholes of about 500 m.

**Ocean Bottom Seismology**

Due to advent of ocean bottom seismometer, greatly improving our understanding of coastal and deep-sea seismic processes. Ocean bottom seismology presents new challenges to the seismologist. Not only the instruments are robust and reliable, they are able to self-install, settle automatically in a position well coupled to the seafloor and produce data for several months without any outside intervention.

**Conclusion**

The period of 1997-2007 has been a revolutionary change in Seismology in India with the deployment of about greater or equal to 250 digital seismographs by IMD, various R & D institutions, universities and state governments in different parts of the country and considerable data processing capability. This along with other collateral studies has enabled fundamental knowledge of source, structure and medium properties. It has been possible to study on one hand 3D rupture modeling, crustal structure analysis, 3D tomography, regional & whole-Earth structure and on the other hand precise earthquake hypocentral locations and mechanism by waveform inversion and moment-tensor analysis for tsunami early warning centre as well as coulomb stress analysis to assess the
future probability of generating tsunamigenic earthquakes in the Indian Ocean.

References


U C Berkeley., Seismological Laboratory.