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ANALOG AND DIGITAL INSTRUMENTS FOR EARTHQUAKE ANALYSIS

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Abstract:

Over the past few years, recording devices based on digital technology have completely replaced the old analog systems. Instruments have been developed to record earthquakes keeping in view timing accuracy, frequency of ground motion and detection thresholds of seismic station networks. Modern instruments use electronic sensors, amplifiers and recording instruments. The most common recorder is a computer with an analog-to-digital converter. This paper is a short introduction to the principle concepts of seismic recording systems and should help researchers to decide which instrument is suitable for their specific requirements.

Key Words: Seismometers, Recorders, Sensors, Analog, Digital & Instrumentation

1. Introduction:

The way in which earthquakes are recorded and the data are analyzed have changed drastically in the past few years. The digital instruments and the computers have replaced the traditional drum recorders of seismographs. Over the years, there have been significant improvements in seismograph coverage and cost efficiency. Analog seismometers required daily seismogram paper changes, in contrary to the modern digital seismograph recorders which provide more and better data. The processing part of seismographs starts with electronic amplifiers, whose output is directly recorded by analog recorders or connected to numeric values for digital recorders [6]. For earthquake analysis, analog strong motion records must be digitized and processed in a form suitable for subsequent analysis. The analog seismographs are being steadily replaced by digital seismographs at many seismological observatories in India.

With the advent of digital instruments, the earthquake analysis became possible not only in time domain but also in frequency domain. Thus, more detailed information about earthquake source and the earth's interior can be inferred. Bhattacharya and Dattatrayam [2] have given a brief review of the recent advances in seismic instrumentation and data interpretation in India. Boore [3] explained the development of the Richter Scale and its use for determining earthquake sources parameters. Jaiswal and Mistra [4] illustrated the development in the field of seismic instrumentation from historical era to recent time. Lee [5] presented a review of the developments in hardware and software for digitization of strong motion accelerographs, data processing and data dissemination. In this paper, we present a brief review of the various seismographs, analog recording systems, and advances in seismic instrumentation, the developments in digitization and various digital recording systems.

2. Various Analog and Digital Earthquake Recording Systems:

Seismograph is an instrument which records the ground displacement or velocity. The main function of seismograph is to record the ground motion arising due to natural and manmade disturbances, specially to monitor earthquakes. The response of a seismograph to the ground motion depends on the parameters of the seismograph. It consists of a seismometer, which senses the ground motion and a recorder to record the motion.

In seismograph, a heavy mass is made to hang through a spring from a rod fixed to the ground as shown in Fig. 1. With the movement of the ground, the rod as well as the recorder move, but the mass does not move due to its inertia and therefore the spring extends. Due to this, the mass moves up and down in the vertical direction and this relative motion is recorded on 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 (applying a force to oppose its motion) is made so that it may respond only to the ground movements. The motion of the ground is measured by observing either directly or indirectly, the relative motion of the moving ground and moving center of oscillation of some form of pendulum. It is the inertia reaction that makes the mass of a pendulum oscillate in a manner different from that of the ground that supports the pendulum. Two types of recorders were used to record the seismic waves (i) Direct Recorder, (ii) Electrical Recorder

(i) Direct Recorder: In this type of recorder the motion of the pendulum is registered directly on the recording paper through a simple mechanical or optical lever system. In this case the seismogram gives a uniformly magnified picture of relative motion between pendulum and ground and offers the simplest computation of actual ground motion from the seismographic record [9]. The direct recorder is much better suited to measurement of actual ground motion from the seismograph record. It is less suitable for high magnifications. The best example of this type is Wood Anderson seismometer which is used to record magnitude in Richter scale of local earthquakes. Vertical and Horizontal direct recorders are shown in Fig. 1.

(ii) Electrical Recorder: In these recorders the motion of the pendulum is measured indirectly by generating an electrical current that depends primarily on the motion of the pendulum. In these recorders generally a coil of wire is fixed to the pendulum in such a way that, when the pendulum oscillates the pendulum moves between the poles of the strong permanent magnet. The generated current is proportional to the velocity of the relative motion between pendulum and ground. The current is not registered on the seismogram because the recording galvanometer has oscillatory characteristics of its own that can control the entire character of seismographic record. The principles of the electrical induction, reluctance and variable capacity have all been employed in electrical recorders. So the electrical conditions are frequently checked to assure constancy of calibration. It is concluded that the electrical recorders are useful for obtaining the arrival times of seismic waves, the determination of epicentral distances and location of the earthquakes.

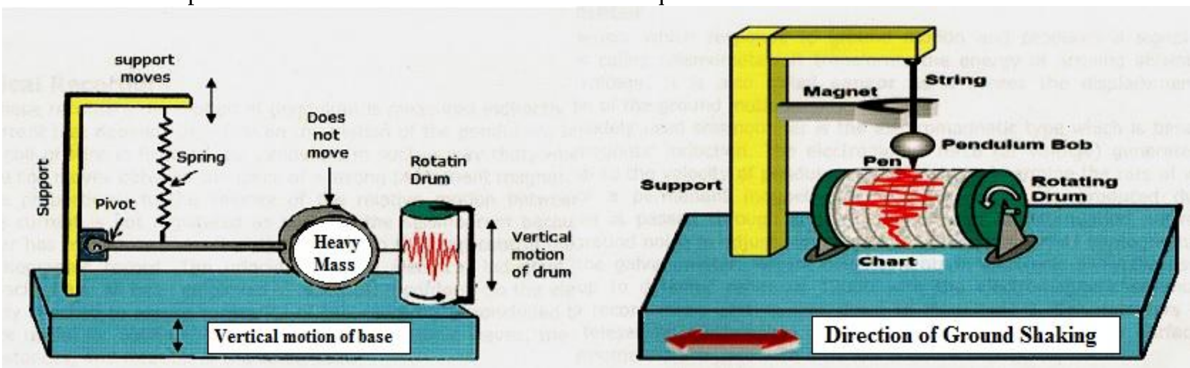

Figure 1: Vertical and Horizontal direct recorders

Seismometer:

A sensor which responds to ground motion and produces a signal that may be recorded is called seismometer (Figure 2). The seismograph is based on pendulum principle. When 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 move up and 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 sometime even after ground motion stops. In order to record only ground motion, a damping factor is incorporated in seismograph [1, 7, 8]. Seismometer converts the energy of arriving seismic waves into electrical voltage. It is also called a sensor because it senses the displacement, velocity or acceleration of the ground motion. The most widely used seismometer is electromagnetic type which is based on the principle of electromagnetic induction. The electromotive force (or voltage) generated is generally proportional to the velocity of pendulum motion which determines the rate at which the lines of force of a permanent magnet are cut. The current so produced due to seismic disturbances is passed through a galvanometer with an attenuation network depending upon the ground noise to adjust overall gain, and finally recorded photographically from the mirror of the galvanometer.

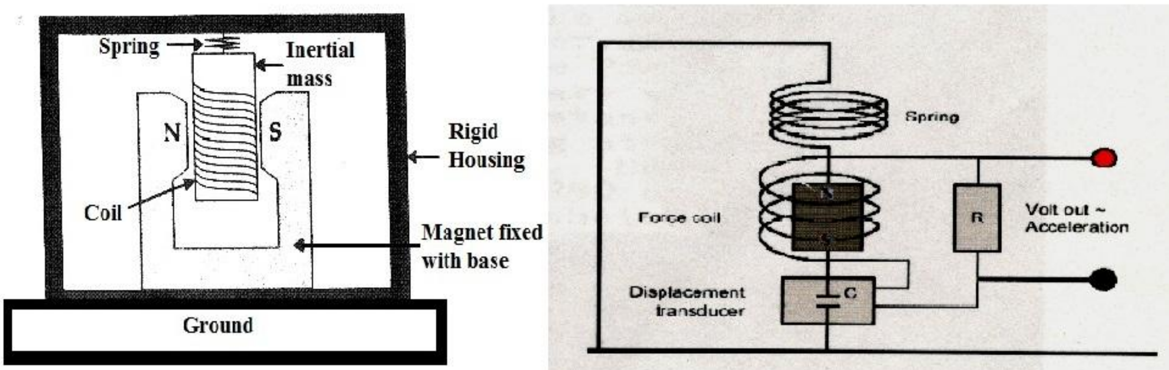

Figure 2: Construction of seismometer

Recent development in electronics allow the use of high gain amplifier up to dynamic range of 120db with the electromagnetic seismometers which enables to record micro earthquakes down to magnitude of scale 3. Seismometers for measuring local and teleseism earthquakes are also designed separately. For surface waves long period seismometers are used with period 30 seconds.

In order to get a three dimensional representation of the ground motion, three seismometers are required at a standard seismological observatory in vertical (Z), north-south (N-S) and east-west (E-W) directions. The horizontal component (N, E) of the ground motion can also be recorded with a suitable arrangement by making the pendulum to move like a two-way swing door. Modern technology uses electronic sensors, amplifiers and recording instruments. The difference between modern and obsolete seismometers is that the modern seismometers utilize zero-length spring. A zero-length spring has a constant force for some part of its stretch. So a pendulum driven by the spring can have (theoretically) an infinitely long period. It is thus able to sense very long-period seismic waves that easily penetrate great distances through the earth. In order to record small ground movement, a seismograph recorder records waveform after magnifying ground movement. Various types of sensors are explained below:

(i) Long-Period Seismometers: If the natural frequency of the seismometer is 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. time period range is 10-100 sec.). This seismometer records the regional and teleseismic earthquakes waves. For example: S-13 seismometer and Benioff Seismometer.

(ii) 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 to seismic frequencies of 1-10 Hz (i.e. time period 0.1-1 sec). An accelerometer is particularly suitable for recording strong motion earthquakes. For example: S-13 seismometer.

(iii) Broadband Seismometer: The sensors of the broadband three-component seismometers are capable of sensing ground motions over the frequency band 0.01-10 Hz (i.e**.** time period 0.1-100 sec.). It is used as both long–period and short-period seismometers. It records intermediate frequencies of 0.1-1.0 Hz of backward noise that is neither recorded by long-period nor by short-period seismometer. This seismometer is useful for local, regional and teleseismic earthquake studies. For example: CMG-40T seismometer.

Figure 3: Various types of seismometers

Based upon the construction, the long-period, short-period and broadband seismometer are explained below:

(i) Benioff Seismometer: Benioff seismometers are reluctance type seismometers. 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 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 the earth vibration reached to the instrument, 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.

(ii) S-13 Seismometer: It is a portable short period seismometer which provides high sensitivity, stable and reliable output. The seismometer may be operated in either the horizontal or vertical positions and the period is adjustable from 1.33 to 0.91seond. (0.75 to 1.1 Hz). The cover and the electrical connections are water proof 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 calibration coil fixed to the instrument frame and a permanent magnet attached to the mass. The seismometer gives the stable output within the temperature range -51° to 60°.

(iii) CMG-40T: It is a lightweight broadband seismometer consisting of three sensors in a case to measure north-south, east-west and up-down ground motion simultaneously. Sensors materials are so designed 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 0.033-50 Hz (30 sec). The seismometer draws a nominal current of 48 mA from 12-volt power supply, when in use. The seismometer can operate over a wide temperature range (-10° to $+75^{\circ}$).

Analog Recording System:

Recording of earthquake on paper charts with seismic instruments is known as analog recording system. In analog seismograph the seismometer senses the ground vibrations and the analog 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 hours. Details regarding various types of seismographs are as follows:

Name of Seismograph	Paper Used	Visible or Covered
Wood Anderson	Photographic	Rotating drum covered in box
Electromagnetic	Photographic	Rotating drum covered in box
Long-period and Short-period (Benioff)	Heat Sensitive	Visible
MEQ-800 Recorder	Smoke paper or ink recording	Visible

(i) Wood Anderson (W.A) Seismogram: It is a horizontal seismograph. Here the pendulum consists of a metal cylinder (generally made of copper), which is attached to a vertical suspension wire. During ground motion, the cylinder rotates around the wire and a mirror attached to the cylinder, reflects a light beam towards the photographic paper on a recording drum. Here a horse-shoe magnet surrounds the copper cylinder to give the damping. Here maximum magnification, V_{max} = 2800 at short period less than 1 second. Fig. 4 shows the W.A. recorder and its seismogram.

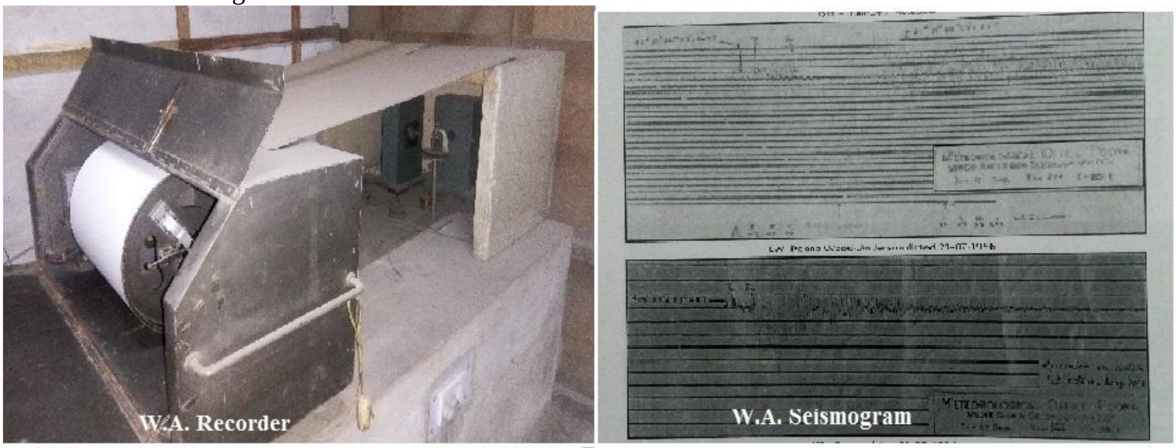

Figure 4: W.A. recorder and W.A. seismogram

(ii) Electromagnetic Seismograph: An electromagnetic seismograph is a great step forward to the mechanical ones. Here a coil is attached to the mass of the pendulum and the coil is kept in a magnetic field as shown in Fig. 5. As the ground moves, the coil moves through the magnetic field and generates the voltage across the coils terminal; the voltage is proportional to the relative velocity between the mass and the magnet. This voltage is passed to a sensitive mirror galvanometer. This mirror reflects a light beam towards the recording photographic paper.

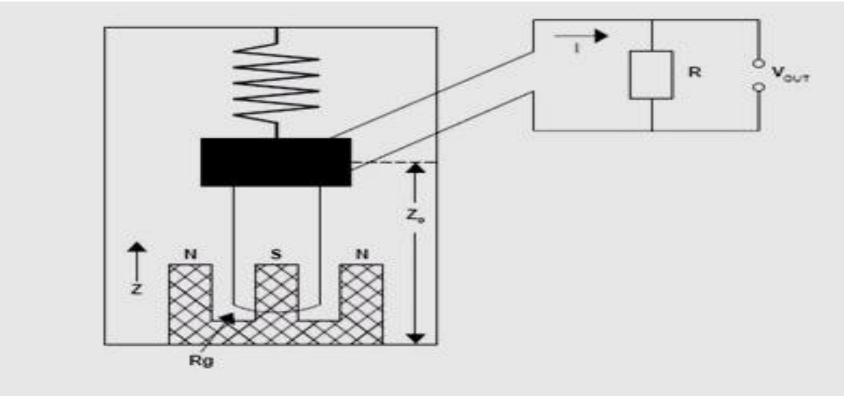

Figure 5: Electromagnetic sensor

(iii) Short-Period and Long-Period Seismographs: The photographic recording by mirror galvanometer can be seen only after developing. It is sometimes needed to note the recording continuously. At present, the voltage from the seismometer can be highly amplified through electronic devices. The amplified voltage is fed to the galvanometer in which a pen is attached and this pen writes on recording paper. This type of galvanometer is rugged one whereas mirror galvanometer is to be handled very carefully. Different types of seismographs with different magnification are used for long-period seismographs and short-period seismographs. During the earthquake earth particles are displaced and this actual displacement of the ground is measured by increasing magnification of the measuring instruments. In small earthquake displacement is less so that it is to be magnified more to record on instruments. In short-period systems, magnification is kept more so that these can record all small tremors also. In long-period system, magnification is kept comparatively less because it records distant and large earthquakes better. If magnification of long-period is kept more, then it may mix all local disturbances with the earthquakes and it will be difficult to recognize the actual seismic waves. If magnification is raised, it increases the recorded background, which becomes so large that interferes with the reading and interpretation of seismograms. Recording conditions can be improved by reducing cultural noises and better site selections for installing seismological observatories. Mechanical direct recording instruments provide low magnification.

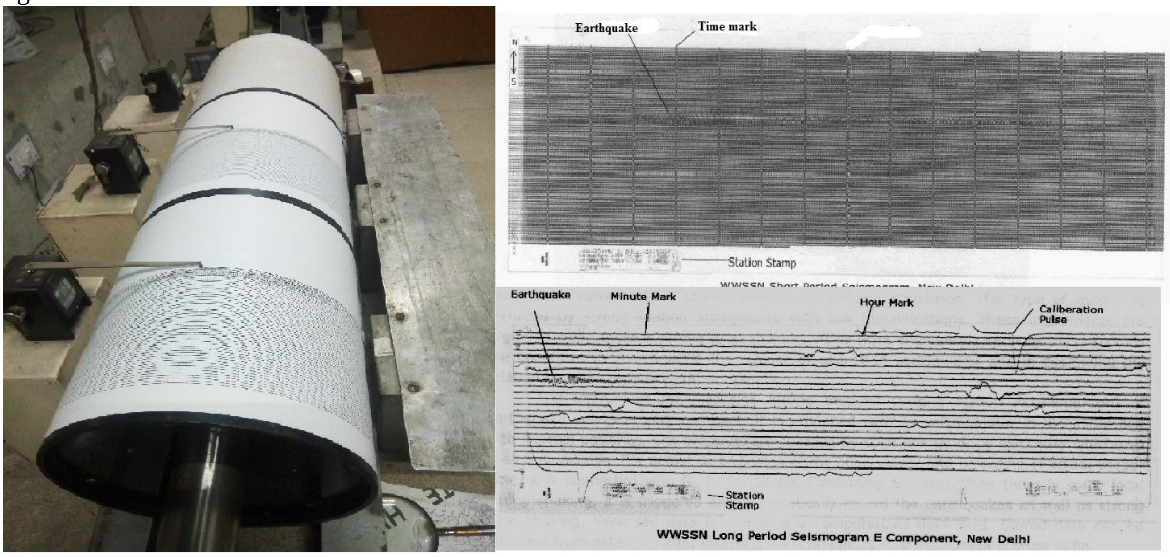

Figure 6: WWSSN (Benioff) Recorder, short-period and long-period seismogram

In WWSSN (World Wide Standardized Seismograph Network) instrumentation system in India, magnification of short-period systems ranges from 50,000 (in New Delhi) to 2,00,000 (in Shillong) and in long-period systems, it ranges from 750 (in New Delhi) to 3,000 (in Shillong). Magnification has no unit, it is only multiple of displacement of earth.

(iv) MEQ-800 (Micro Earthquake Recorder): One of the most common used analog field recorders is the Sprengnether MEQ-800 which can record on either ink or smoke paper (Fig. 7). It is a self-contained unit with amplifier, stylus 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.

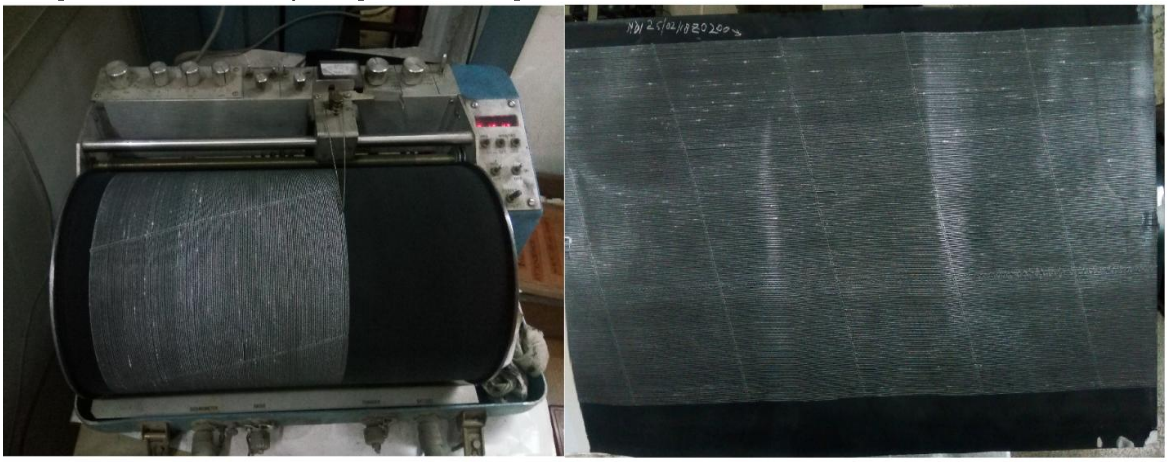

Figure 7: MEQ-800 Recorder and its recorded seismogram

Timing System for Analog Recorders:

An accurate time marking device usually a crystal clock is used to impinge the time with separate hour marks and minute marks on the seismograms for Wood Anderson seismograph, short-period and long-period seismograph. To provide for a common time basis, Seismologists all over the world use Universal Time Coordinated (UTC) time. The clock attached with seismogram is set at UTC time and compared with the signals of UTC daily for correction, if any. The time marks on the seismograms enable us to find the onset time of various seismic waves from which we can determine the origin time, epicenter, magnitude, epicentral distance and focal depth of an earthquake. Velocity of various seismic waves can also be calculated with the accuracy of time in different layers of earth.

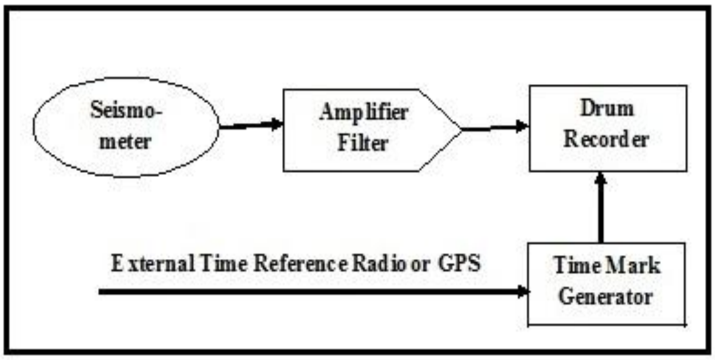

Figure 8: Time marking system on seismograms

Digital Recording System:

In digital recording, a system consists of a seismometer generating an analog recording signal and an analog to digital converter which transforms the signal to a corresponding digital format. Now a days there is international exchange of digital recorded data. About 2,000 seismographic stations are installed around the world and are involved in recording, analysis and international data exchange. It is possible to store digital records and the records are fed directly in to the memory of digital computers. These instruments are connected by GPS for accurate timing system and accurate co-ordinates of the recording station.

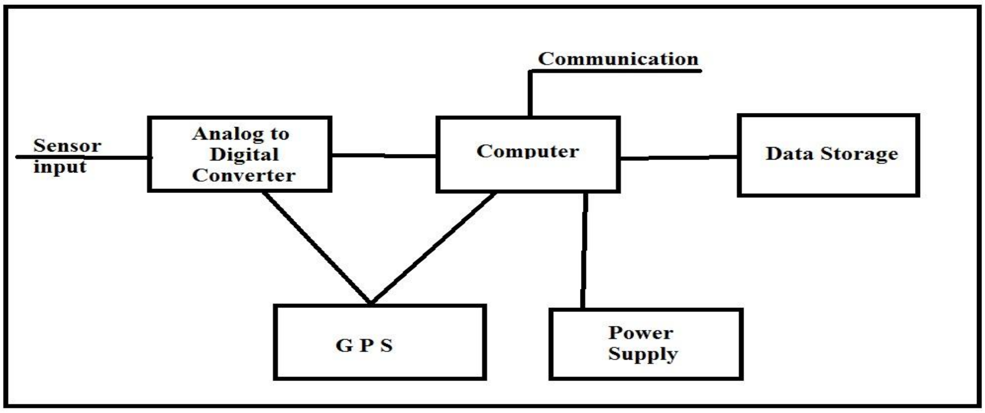

Figure 9: Digital recording system

Digital recording is more useful than analog recording in all respects. It is cheaper than analog recording and preserving the data. The data volume can be reduced by saving only selected seismic signals and deleting the rest of records which have no seismic events. Recording and analysis is easy in digital records. The interesting portion of records can be extended (zoom) up to our interest and undesired frequency components can be filtered out (Fig. 10). The seismograph axis can be rotated up to any orientation and the wave particle motion can also be displayed. In these records, the response characteristics can also be changed and recorded events can be displayed at any extent.

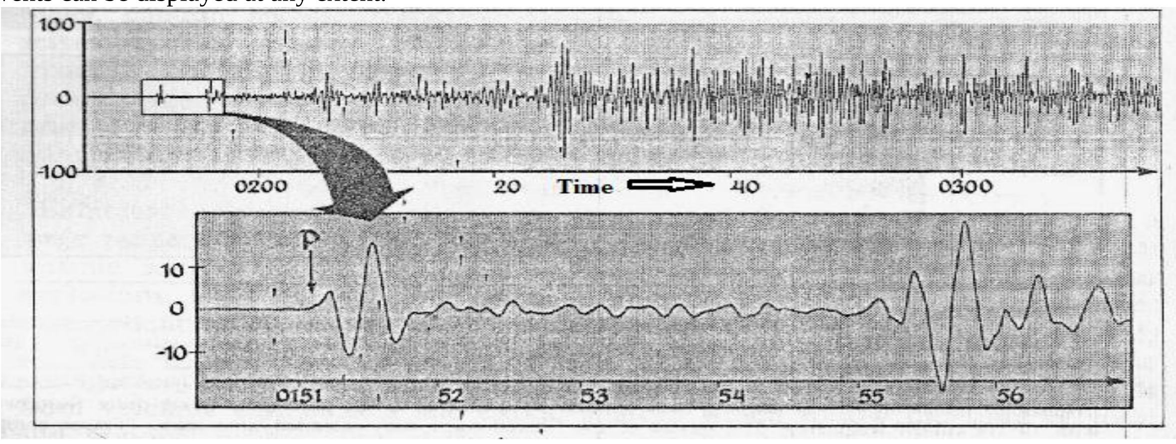

Figure 10: Zooming of selected seismic signals in digital records

Various digital recording systems are as follows:

(i) 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 it provides state-of-health information to both local and remote users. Fig. 11 shows the data acquisition system (DAS) of recent digital seismograph of REFTEK, model 130-01. Preamplifiers adjust the analog output of the sensor so that it matches impendence and gain level on the input to the A/D converter. The effective resolution of an 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.

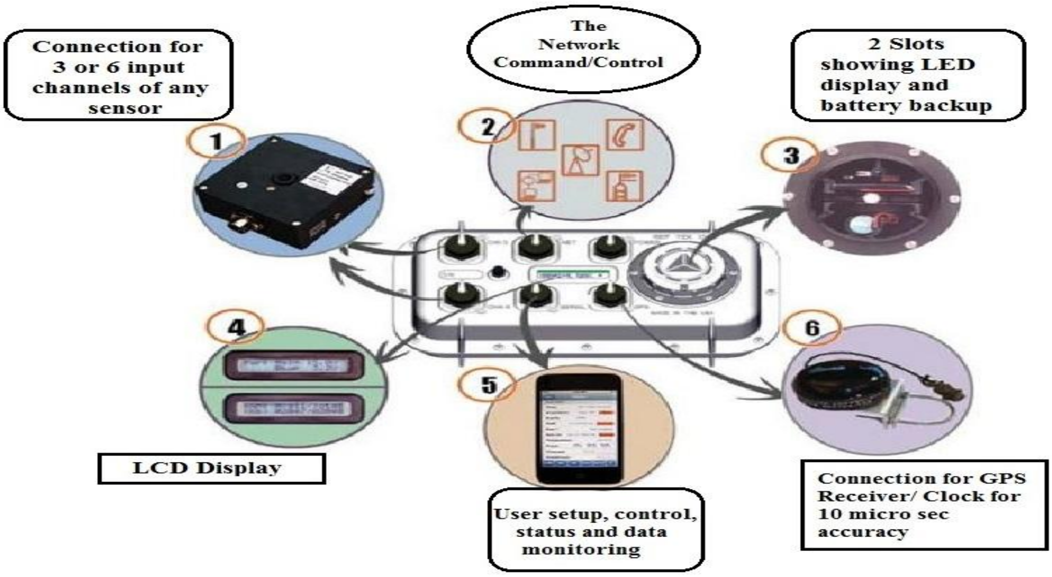

Figure 11: Data Acquisition System (DAS) (Courtesy: REFTEK)

(ii) Strong Motion Accelerograph (SMA): For construction of well engineered structures, engineers are interested in earthquake wave motion, strong enough to damage structures. This type of motion is recorded by strong motion instruments with low magnifications. These instruments are triggered when there is strong local shaking. Aside from engineering services these records are important in investigating the release of energy in earthquakes and in examining the relation between intensity and acceleration. SMA is very compact instrument and is equipped with its seismometer in the same box with internal batteries (Fig. 12). The batteries are charged by solar energy or by electricity whichever is easily available. For actual co-ordinates of the observatory and recording of actual trigger time, it is connected with GPS (Global Positioning System).

Figure 12: Strong Motion Accelerograph (SMA)

When there is some local strong shaking, it is triggered and automatically record the earthquakes. Recorded data is stored in a memory card and data can be retrieved easily when required. If several earthquakes occur within a few hours these can be easily identified separately by study using SMA's data. When there is total damage of observatory and instruments then it is possible to know the trigger time of shaking or earthquake. It records all three dimensional motions of waves so no three seismometers are required.

(iii) Real Time Seismic Monitoring Network (RTSMN): as part of the Indian Tsunami Early Warning Center, India Meteorological Department (IMD) has established 17 stations Real Time Seismic Monitoring Network

(RTSMN). The 17 field stations are located at Bhuj, Hyderabad, Chennai, Shillong, Dehradun, Pune, Bokaro, Dharamshala, Visakhapatnam, Shimla, Goa, Bhopal, Trivendrum, Diglipur, Minicoy, Portblair, and Campbell bay. The ground motion data from all the stations is sent simultaneously in real time through V-SAT communication facilities to the two Central Receiving Stations (CRS) located at IMD at New Delhi and INCOIS, Hyderabad for processing and interpretation.

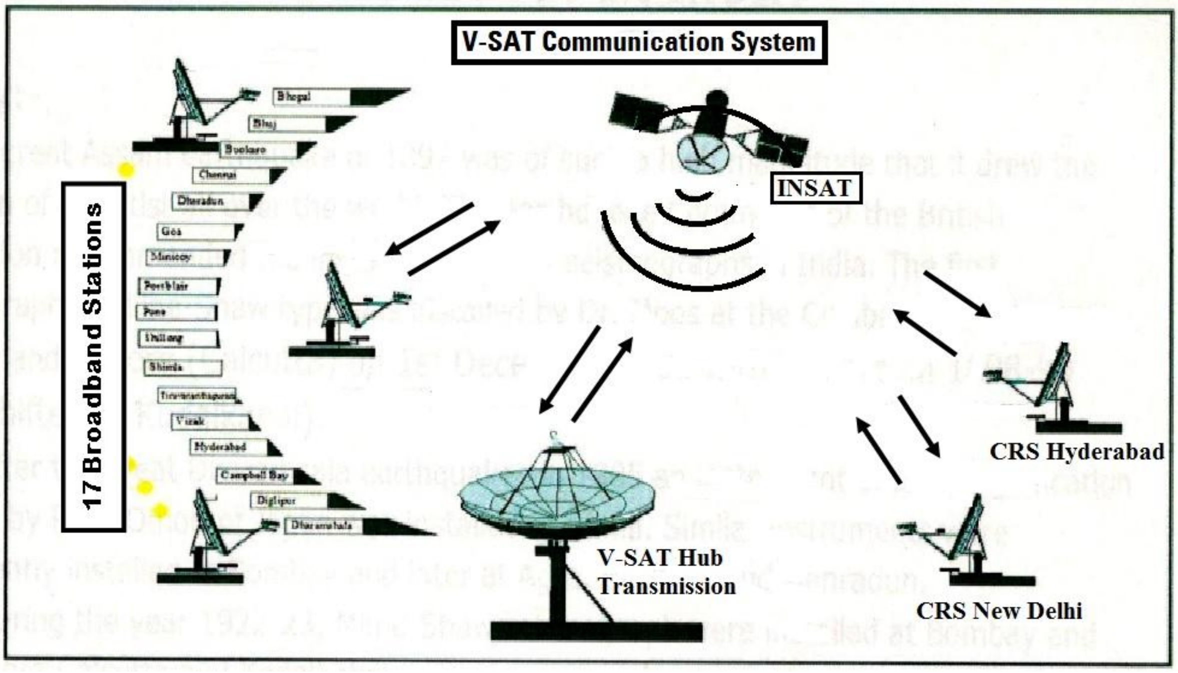

Figure 13: Communication link in real-time seismic monitoring network

The network monitors and reports the occurrence of earthquakes in least possible time. Broadband sensors have been installed at various seismic stations. RTSMN provides fast, reliable and accurate locations and magnitudes of worldwide, regional and local earthquakes, depending upon the network configuration and density. The system generates immediate alarm based on first arrival of phases. The software of RTSMN requires availability of at least five quality P-phase picks from five stations for attempting auto-location of an earthquake. The data from 17 broadband seismic field stations installed under this project is transmitted though V-SAT communications facilities to the CRSs and earthquake information is sent to all the concerned user agencies in a fully automated mode. From the 17 stations, Portblair, Bhuj, Shillong and Hyderabad share data with the international community for earthquakes of magnitude greater than 6.

3. Acknowledgement:

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