CHAPTER-2

INSTRUMENTS FOR EARTHQUAKE MONITORING AND PREDICTION

2.1 INTRODUCTION

Some geophysicists believe that earthquakes are inherently unpredictable, nonetheless, others have not given up the hope. For the last few decades, constant scientific efforts are being made to devise new methods and measurement techniques which may lead to some kind of advance clues to major earthquakes.

2.2 PRECURSORS TO EARTHQUAKE

As mentioned earlier, some important precursors to major earthquakes are— (i) Crustal deformity of the region (ii) Change in geo-conductivity, (iii) Change in geomagnetism, (iv) Geo-chemical changes, (v) Unusual change in the pattern of occurrence of microearthquakes, (vi) Drifting of the tectonic plates, and (vii) Change in some variables such as— heat flow, strain, and gravity etc. Some of these changes occur at an extremely slow rate and take fairly long time to become perceptible whereas the others are reasonably fast to be observed. To observe these changes over a large area, geo-scientists need enormous field data of exceedingly good quality. Subsequently, the data is processed, analysed and interpreted for further seismic investigations.[16].

For this purpose, specific kind of "Instruments and Systems" are required. These instruments, irrespective of
which variables they detect/measure, must be capable to distinguish the feeble signals from the dominant background noise. They must generate electrical signals corresponding to the change in variable, produce digital data in copious quantity from the multiple sensors in parallel and finally process, compress and transmit it for further interpretation [4,5,6,17].

Some of the prevailing and emerging instruments/systems for this purpose, other than those based on seismometry (to be discussed in the end in greater details), are as follows-

2.3 INSTRUMENTS BASED ON CHANGE IN EARTH CONDUCTIVITY
a) As pressure builds up slowly inside the earth eventually leading to an earthquake, the rocks subjected to stress and strain get gradually squeezed and their resistivity changes. Scientists have different approaches for measuring this change.

A voltage is generated by the movement of underground water as it is heated, ionized, and squeezed out of fissures in the rocks. This voltage is measured with very simple apparatus. Two electrodes of different material - typically a copper bar and a lead plate - are separated by 30 to 60 metres and buried about 1 metre deep. The observers take the reading at least once an hour.

It is observed that there is a sharp drop of upto 5 volts in the potential difference between the electrodes, and also fluctuations in it upto 1 V after every few minutes.
during the 24 hours immediately before the earthquake. To observe these subtle changes, advanced instrumentation based on microprocessor and computer for automatic data collection, processing and recording can be developed [18].

b) Another way to observe changes in the earth's resistivity is to measure variations in voltages associated with telluric currents. Instruments capable to detect this change are being considered [18].

c) The conductivity of the earth at two places, can be observed with the arrays of dipole antennas as shown in the fig. (2.1). Each dipole antenna is a telephone line 10 to 50 km long extending out from a central point in the array. Attached to each end of each dipole is a cylindrical copper electrode buried 1 metre deep [18].

At the array's central point, the electronic equipment samples the voltage across each dipole once every five minutes, digitizes the measurement, compares the results from all the dipoles with those of two reference dipoles, and stores the data on a hard disk. The difficulty comes in separating the signal from the noise. The noise comes from - (i) occasional breaks in the telephone-line antennas, (ii) the electrode's tendency to pick up and rectify 50-cycle hum, (iii) electrochemical changes in the earth in which the electrodes are buried, and even from (iv) changes in the earth's own self-potential.
2.4 INSTRUMENTS BASED ON DIRECT CHANGE IN STRESSES AND STRAINS

Yet another way to measure stress building up in the earth that might be a precursor to an earthquake is to observe the way the earth deforms around a fault. Strain accumulation in such cases is measured by terrestrial laser ranging [19]. "Laser based Strainmeter" is another modern instrument for this purpose.

2.5 INSTRUMENTS BASED ON MONITORING OF CRUSTAL DEFORMITY

Before an earthquake, the earth's crust near the epicentre might bulge or tilt by several millimeters over an
area of a few hundred square kilometers. This deformation can be measured by a "Tiltmeter". It is essentially a super-long spirit level, a horizontal pipe 500 to 700 metres long half-filled with water. If the earth tilts and causes the ends of the tiltmeter to move up or down by as little as a few micrometers, the changes in the water level can be detected by a white-light interferometer [18,19,20].

One major problem, however, is that the ground around each end of the tiltmeter can expand, shift, or settle during heavy rains or freezing and thawing. Geophysicists need a way to tell if tilt has been caused by seismic deformation or by soil changes. To solve this problem, the following technique is being used-

**Optical fibres** are used to anchor each end of the tiltmeter 50 to 100 metres deep in the earth. Optical fibres are very sensitive to strain. If the earth bulges before an earthquake, the tiltmeter will register a tilt but because the deformation affects an entire block of crust upto many kilometers deep, the optical fibre will not be stretched. If, however, one end of the tiltmeter moves merely because the soil at the surface expands, the device will register a tilt and the optical fibre will be stretched. Thus, absence or presence of strain in the optical fibre tips off geophysicists whether or not the tilt is seismic or not, fig.(2.2).

To anchor each end of the tiltmeter in the earth, two optical fibres are extended down a vertical borehole—one the full length of the hole, the other only 4 meters down. Each
fibre's bottom end is silvered to reflect light. A beam from a Laser is sent through a beam splitter and each half is coupled into one fibre and makes one round trip. Both returned half beams are recombined in an interferometer of relative displacement between their ends.

One problem with optical fibres is that they expand and contract with changes in temperature. But below about 4 meters, temperature tends to be constant. The short fibre identifies that part of the strain that is caused by the temperature change near the surface. A parallel bar of the Invar— a nickel—steel alloy that does not expand or contract with temperature—measures that part of the strain caused by shifts in the surface soil.
Present interferometric techniques call for sending light beams down evacuated pipes; the optical fibre technique is much cheaper because it does not require drilling perfectly straight boreholes or maintaining a high vacuum in pipes more than 50 metres deep [18,21].

2.6 INSTRUMENTS BASED ON PLATE TECTONICS (GEODETIC MEASUREMENT)

Most geologists today subscribe to the theory of plate tectonics. Earthquakes occur at the boundaries where two plates slide past each other or where one plate dives beneath another [18,22].

Satellite laser ranging (SLR) also measures plate motion over the years. Laser pulses, transmitted through a telescope to the Laser Geodynamics Satellite (Lageos), are returned by corner-cube retroreflectors to the observing station's receiving telescope. The ranges from several stations to the satellite are used to calculate baselines between stations.

FIG. 2.3a
Two independent techniques - 1) **Satellite laser ranging (SLR)** and 2) **Very-long-baseline interferometry (VLBI)** - based on advanced astronomical instruments as shown in the fig. (2.3a & 2.3b) are now being perfected to measure plate movements with unprecedented accuracy. Although neither technique is used directly in earthquake prediction, both help in understanding the mechanisms that cause earthquake. Both techniques are global, and observations from stations around the world are being coordinated through the Crustal Dynamics Project of the National Aeronautics and Space Administration's Goddard Space Flight Centre in Greenbelt, Md.

In India, NGRI-HYD, has initiated a major programme in this direction [18,22,23].

![Diagram](image-url)

**FIG. 2.3b**

Very-long-baseline interferometry (VLBI) measures, over the years, the movement of the earth's tectonic plates. Radio telescopes record radio waves from quasars—quasistellar radio sources at the edge of the universe. The time difference in the arrival of a wave front at any two telescopes is proportional to the distance between them.
2.7 SEISMOLOGY

Micro earthquakes occurrence pattern if monitored and studied closely over a long period, may lead to the prediction of major earthquake. It has been observed that the microseism data is generated by a series of smaller earth tremors which build up exponentially in number and magnitude in days just preceding to the occurrence of major earthquakes. It is, therefore, essential to collect, process and analyse the microearthquakes (micro-seism) data by deploying extraordinarily precise and reliable seismic instruments and systems of very specialised nature [4,6,18].

The type of analysis influences the instrument design. For Time domain studies (event detection, hypo-central location, magnitude, focal mechanism, and recurrence rate etc.) analog recording at variable recording rate still offers the simplest and most cost effective approach. The variable recording rates are needed to accommodate different duration of recording between service visits as well as desired level of time resolution. For Frequency domain studies (source spectra, stress drops, source time function, spatial source discrimination estimates etc.) digital recording is necessary. This implies a magnetic tape recording which in turn requires some type of event triggering device to conserve the tape supply. Sampling rates and proper signal conditioning (anti-aliasing filtering) becomes further consideration in spectral analysis [4,5,6].
Seismograph as shown in fig. (2.4) has been the principal instrument for measuring an earthquake's magnitude, time of occurrence and frequency of its shocks. But until recently, analysis of the seismograms on paper or on photographic plates required an experienced seismologist. It was a cumbersome task. Correlating the records obtained even from four to five sites (necessary to determine the earthquake's magnitude and epicentre or point of origin) took at least several hours [24].

Today, seismological instruments/systems are interdisciplinary in nature. The recent advances in electronics engineering, computer technology and data communication are now being incorporated in the development of these instruments and systems for the configuration of
"State-of-art seismic networks". In the past two decades, computer has become very effective tool to handle the enormous information contained in ground motion wave (Seismic records). The seismological evaluation of paper seismograms has now been replaced by digital evaluation carried out by computer through interactive programming [24,25,26].

On application front, the seismometry domain now covers both - the "Non-exploratory" (earthquake and nuclear explosion) and "Exploratory" geophysics (oil and minerals prospecting).[8]. The nature of application specify -
(a) the type of sensor required
(b) the frequency range of interest
(c) the dynamic range and
(d) the accuracy and resolution of the seismic record to be produced.

Under non exploratory category, for different applications such as- Micro-earthquake recording, Strong motion seismic recording, Engineering- seismology, Blast monitoring- seismology and Induced- seismicity etc. different kind of instruments with specific dynamic range, bandwidth and sensitivity are required [4,5,6].

Incorporation of latest facilities such as computer in seismic networking via land based radio telemetry and satellite communication links, have extended the area of monitoring from small domain to global level [27,28].

2.8 CURRENT TREND IN SEISMIC INSTRUMENTS (SEISMOGRAPHS)
The instrument/system used to monitor, process and analyse the seismic signal, must be capable of extracting the extremely low level signal from the exceedingly high level ambient noise. Right from the beginning till date, continuous efforts are being made to improve instrument's capabilities in this direction. Starting from very elementary analogue seismograph with photographic and subsequently smoked paper drum recording as shown in fig. (2.5a & 2.5b), the state of the art seismograph based on microprocessor and personal computer are now available to users [29].

Modern seismographs are having large frequency band width, wide dynamic range, linearity and stability of high
degree. By use of modern digital data recording techniques, the concept of broad band digital array with a wide dynamic range has been realised. The modern seismic instruments based on digital techniques provide better quality data in enormous quantity. The data generated by these instruments is in computer compatible format for direct analysis on a computer [30].

2.9 DESIGN OF NETWORK- ARRAY

The limit to the sensitivity of short period recording is not set by the "Instrumental Noise", but rather by the omnipresent seismic background noise. This background noise limits the capability to detect weak seismic signals. To
reduce the influence of ground noise and increase the detection capabilities, antenna theory is applied to the design of seismic station network array [31].

In electronic communication system involving transmission and/or reception of electromagnetic waves, antennas have long been used to increase the signal strength. The advanced antenna consists of many elements put together in a geometric configuration which may differ according to the specific application and signal frequencies concerned. The application of antenna theory to seismic network array implies the interconnection of several seismometers to form an antenna and thus to increase their capabilities to record weak signals. The fundamental principle of antenna theory is that each element of the array receives signals that are identical in form but may be shifted in time. By means of appropriate time delays, the signals are put on top of each other and added in a process known as "Beam Forming". The process is expected to give a theoretical gain in signal to noise ratio by a factor equal to the square root of the number of the sensors employed [4].

To utilize considerable amount of data produced by the large and medium size array stations, special facilities for data handling and analysis have been developed around main frame computer. These kinds of seismic network array around main computer are currently in use at Canada, Sweden, U.K., U.S.A. and W. Germany etc [32,33].
2.10 LIMITATIONS OF CONVENTIONAL SEISMOGRAPHIC NETWORK

One isolated seismological station alone, no matter how much advanced are its instruments, is of almost no utility for most of the seismological research work. While evaluating seismic hazards of a region, field data sets of individual stations are never considered in isolation. Rather the joint interpretation of several data sets obtained from different seismographs which are operating as independent field stations of one single seismic network is used to evaluate the status of seismicity or monitoring a comprehensive test ban treaty.

In a conventional seismographic network, each instrument operates as an independent outfield station. It has no centrally common timing and recording system. There is no transmission of any kind of field data to one central place. The information recorded by every seismograph (operated as one outstation) as usual is to be correlated to evaluate the earthquake parameters such as -

(a) time of occurrence of the event
(b) its epicentre
(c) focal point (depth of source)
(d) its magnitude and polarity of P wave front
(e) its Coda length ie total event duration
(f) its nature (whether it is earthquake or underground nuclear explosion).

Therefore in a conventional network (where data cannot be telemetered in realtime mode via either physical link or
wireless link), the data records of each instrument either on smoked paper or on cassette, are collected from outfield stations and brought down to the observatory (local central base station) by the operator for correlating and analysis. Therefore, the geophysical investigation of a large area with the help of either one large conventional network or a number of conventional short aperture local networks, is time consuming, tedious, error prone and is not feasible because of the physical distances involved.

For a vast region like Indian subcontinent when it is needed to cover the whole territory under seismic survey, the conventional seismographic networks configured around even the most modern seismographs are not of much help. Moreover, in order to improve signal to noise ratio, the sites for installation of outfield stations are selected to far away places which are very quite and calm and are not easily accessible. The selection of site at inaccessible remote terrain reduces drastically the effect of background and cultural noise.

But the requirement of this kind of installation of field stations at far away remote places makes the job of the operator still more tedious and tiring. Even the state of art seismograph are subjective to the limitations of frequent replacement of the cassettes. Portable seismic data acquisition system as shown in the fig. (2.6) suffers on the ground that digital data stored into CMOS memory is off loaded at the field site from them into Laptop-Personal computer by technical personnels [34].
2.11 DRAWBACKS OF NON-TELEMETERED CONVENTIONAL NETWORK

All conventional network arrays need frequent visit of technical personnel to the field stations. Also all the stations of a conventional seismographic network due to their independent seismic timing systems do not guarantee reliability and accuracy of coordinates of the source of event. It is due to the uncertainties in identifying the beginning of P and S phases correctly. The accuracy of hypocentral coordinates and the focal depth estimation are affected severely due to -

(i) non availability of seismic data from a fairly large number of remote stations (RS)
(ii) appreciable error in time correlation of individual
stations and
(iii) subjective interpretation of arrival time etc.

2.12 NEED FOR A RADIO-TELEMETERED INTELLIGENT SEISMIC
NETWORK

In order to identify the seismically active zone, faults and dislocations and to demarcate - active lineaments, it is necessary to keep on monitoring continuously and constantly the seismicity of the large region. Information on seismic level and geo-kinematic of a region is also essential for taking decision about the site selection for new township, huge industrial complexes, nuclear power station and other critical engineering structures such as hydro-dam etc.

It can be done by commissioning and operating round the clock, sufficiently large number of local telemetered seismic networks at critical places over the large region under investigation [35,36,37,38].

2.13 NEED FOR EARTHQUAKE RISK-ASSESSMENT AND MITIGATION FOR INDIAN SUBCONTINENT

As explained earlier, India and its neighbouring countries are located on a belt which is highly seismic prone. Therefore, this region has been rocked by many major earthquakes in the past and recently as well. Geophysical studies reveal that the probability of occurrence of some major earthquakes in this region in the next few
decades is very high. Inspite of the advanced scientific knowledge, the occurrence of earthquakes even today, can neither be stopped nor delayed and diverted. However, if reasonably accurate prediction about their occurrence in terms of "Time", "Location" and "Magnitude" could be made quite in advance, precautionary measures can be taken up to avoid loss of human life and property. Civil and heavy engineering structures in the regions which are declared under the cloud of likely future earthquakes, could be designed earthquake resistant.

Therefore, the state-of-art instrumentation for seismic mapping at the regional/subcontinental level may be designed and configured around-

a) Remote stations for Seismic monitoring at sites.
b) Data telemetry needed at different levels.
c) Real time data acquisition, processing and recording base- stations for local network arrays.
d) Master-station for data coordination and interpretation at regional level.
e) Centre for seismic data archiving for global exchange.