

Lecture7: Earthquake recording instrumentations; concept of seismograph, Seismic station; build your own seismograph.**Topics**

- Seismoscope
- How Seismograph Work?
- Build Your Own Seismograph
- Seismic sensor-seismometers
- Types of Seismographs
- Types of instruments to record earthquakes
- Strong motion (Accelerograph)
- Seismic Station
- Station Distribution and Site Selection
- SMART 1

Keywords: *Recording instruments, Seismographs, Seismic Station*

Topic 1**Seismoscope**

- Seismograph is an earthquake recording instrument which measures, in details, the ground shaking. The first earthquake recorder was an artistic device invented by a Chinese scholar, Chang Heng, about 132 A.D (Fig 7.1). The instrument was a seismoscope, unlike seismograph it did not record the complete time history of the earthquake waves but did record the direction of principal impulse due to an earthquake (Fig 7.2).
- The instrument was said to resemble a wine jar of diameter six feet. On the outside of the vessel there were eight dragon heads, facing the eight principal directions of the compass. Below each of the dragon heads was a toad, with its mouth opened toward the dragon. The mouth of each dragon held a ball.
- At the occurrence of an earthquake, one of the eight dragon-mouths would release a ball into the open mouth of the toad situated below. The direction of the shaking determined which of the dragons released its ball. The instrument is reported to have detected a four-hundred-mile distant earthquake which was not felt at the location of the seismoscope.
- The inside of the Chinese seismoscope is unknown. Seismologists of the nineteenth and twentieth centuries have speculated on mechanisms which would duplicate the behavior of Chang Heng's seismoscope, but would not be beyond the Chinese technology of Chang Heng's time.



Fig 7.1: Left: photograph showing Chinese scholar Chang Heng with the seismoscope he designed (about 132 A.D.). Right: Maori god of earthquake Chang Heng's seismoscope.



Fig 7.2: Chang Heng's seismoscope

- All assume the use of some kind of pendulum as the primary sensing element, the motion of which would activate one of the dragons. In his translation of the original Chinese description of Chang Heng's seismoscope.
- The Chinese seismoscope was reported to have indicated the azimuth of the earthquake. It has been suggested that Chang Heng's "earthquake weathercock" was calibrated empirically for its direction-determining properties.

- The first effective seismographs were constructed just before the beginning of the twentieth century. Seismometer is a sensor part of a seismograph. A variety of suitable components (vertical and/or horizontal) high-gain seismometers are now commercially available to meet various network requirements.

Topic 2

How Seismograph Work?

- A seismograph records the vibrations (seismic waves) caused by earthquakes and produces a seismogram. A seismogram is simply the recording of these seismic waves, detected by a seismograph. Accurate interpretation of the seismogram tells us not only a lot about the earthquake but also about the nature and composition of planet Earth.

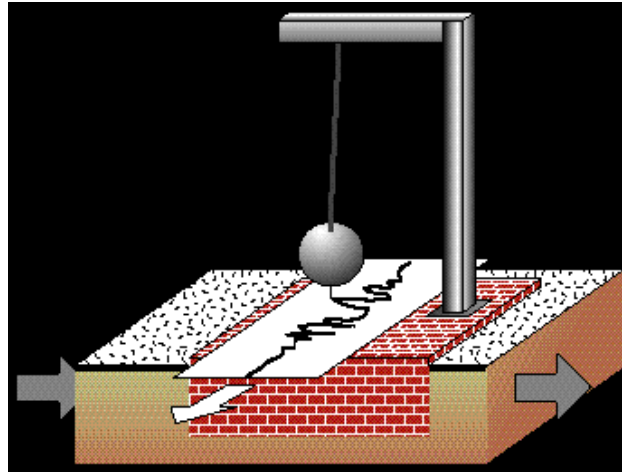


Fig 7.3: Representation of a simple seismograph

- A seismograph consists of a pendulum mounted on a support base. The pendulum in turn is connected to a recorder, such as an ink pen. When the ground vibrates, the pendulum remains still while the recorder moves, thus creating a record of the earth's movement as shown in Figure 7.3.
- The simplest form of seismograph can be illustrated by mass-spring dashpot system as shown in Figure 7.4. A rotating drum is connected to the housing by a spring and dashpot system arranged in parallel and the housing is connected to the ground. Since, the spring and dashpot are not rigid, the motion of the mass will not be identical to the motion of the ground motion during an earthquake. The relative movement of the mass and the ground will be indicated by the trace made by the stylus on the rotating drum.

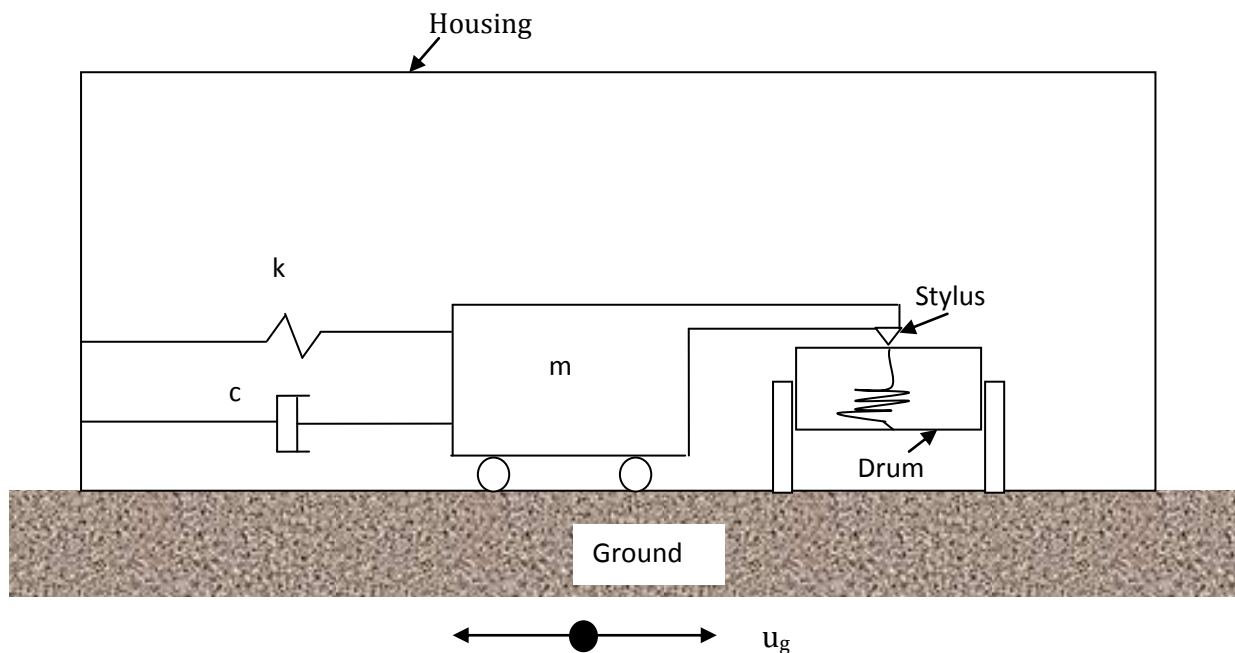


Figure 7.4: Simple mass-spring-dashpot type of seismograph. The housing is firmly connected to the ground. When the ground shakes, the stylus marks a trace on the rotating drum that shows the relative displacement between the mass and the ground.

- Seismographs can be designed to measure various ground motions characteristics. To understand how this can be done it is necessary to consider the dynamic response of a simple seismograph such as one shown in Figure 7.4. Based on equilibrium equation for a force damped system shown in Figure 7.4, the equation of motion can be given as;

$$m\ddot{u} + c\dot{u} + ku = -m\ddot{u}_g \quad (7.1)$$

Where, u is the seismograph trace displacement (the relative displacement between the seismograph and the ground) and u_g if the ground displacement, m is the mass, c is the coefficient of damping and k represent the stiffness of the spring.

- If the ground displacement is simple harmonic at a central frequency ω_g , the displacement response ratio (the ratio of trace displacement amplitude to ground displacement amplitude) will be

$$\frac{|u|}{|u_g|} = \frac{\beta^2}{\sqrt{(1 - \beta^2)^2 + (2\zeta\beta)^2}} \quad (7.2)$$

Where, β is the tuning ratio ($=\omega_g/\omega_o$), ω_o [$=\sqrt{(k/m)}$] is the undamped natural frequency and ζ [$=c/2\sqrt{(km)}$] is the damping ratio. Figure 7.5 shows how the displacement response ratio varies with frequency and damping ratio.

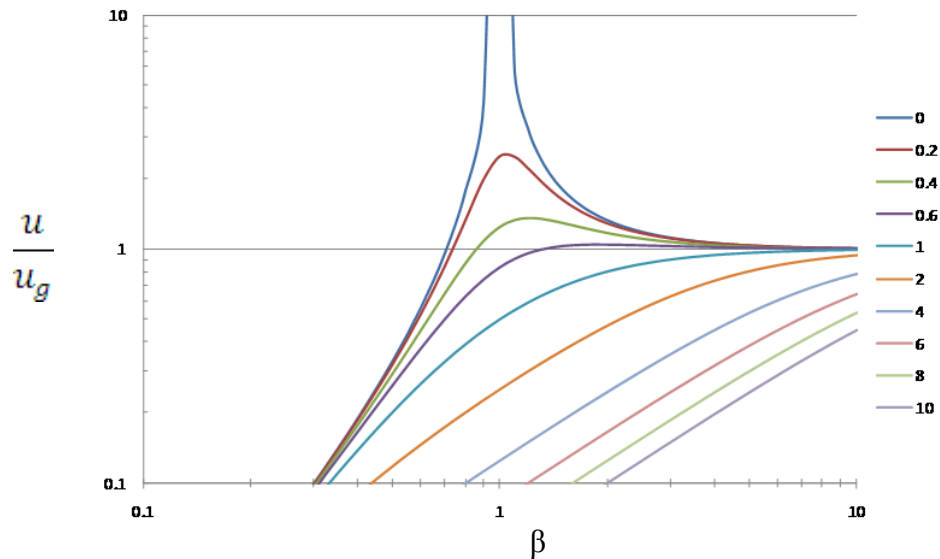
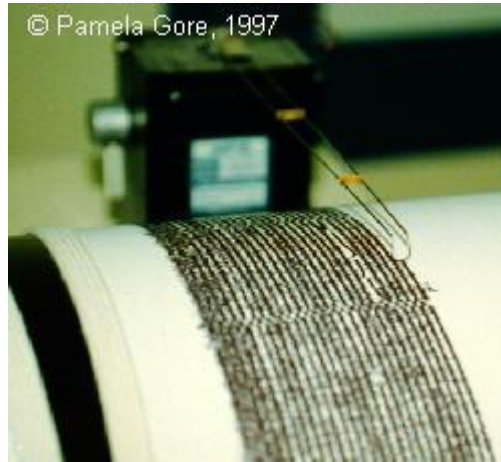


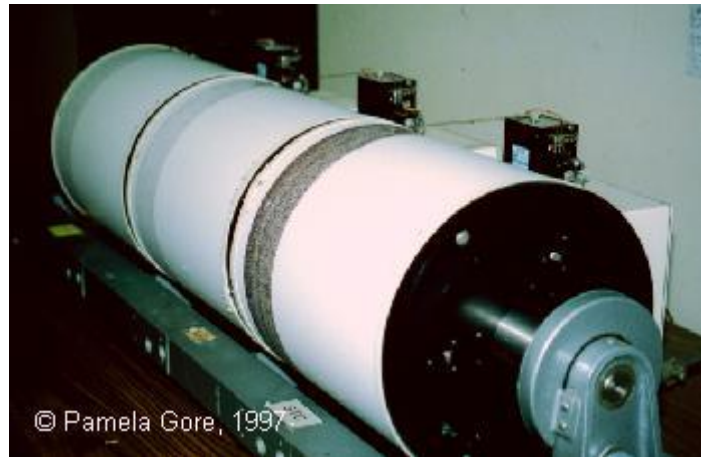
Figure 7.5: Displacement response ratio ($\omega_o=1$)

- A typical seismograph contains 3 pendulums: one to record vertical movement and two to record horizontal movement. A typical seismograph station may have three components oriented to two horizontal directions and one vertical direction.
- The first accurate seismographs were developed in Japan in 1880 by the British geologist John Milne, often known as the father of seismology. Together with fellow expatriate scientists James Alfred Ewing and Thomas Gray, Milne invented many different seismological devices, one of which was the horizontal pendulum seismograph.
- This sophisticated instrument consisted of a weighted rod that, when disturbed by tremors, shifted a slitted plate. The plate's movement permitted a reflected light to shine through the slit, as well as through another stationary slit below it. Falling onto light-sensitive paper, the light then inscribed a record of the tremor.
- Today most seismographs still rely on the basic designs introduced by Milne and his associates, and scientists continue to evaluate tremors by studying the movement of the earth relative to the movement of a pendulum.
- Most modern seismographs work electromagnetically (Figure 7.6). A large magnet is used for the mass and the outside case contains numerous windings of fine wire. Movements of the case relative to the magnet generate small electric signals in the wire coil. These signals are then amplified electronically and stored

digitally on a computer or played out on a recording drum called a seismogram. Sample seismogram is shown in Figure 7.7.



(a)



(b)

Fig 7.6(a,b): Modern Seismographs

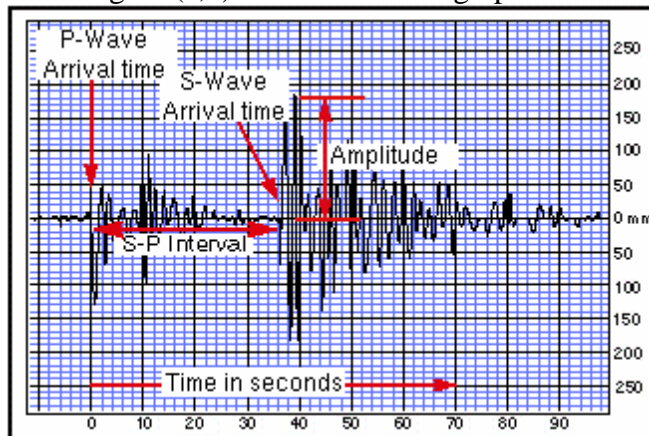


Fig 7.7: Sample Seismogram

Topic 3

Build Your Own Seismograph

http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/8/1.SeismographModel-Lahr.pdf

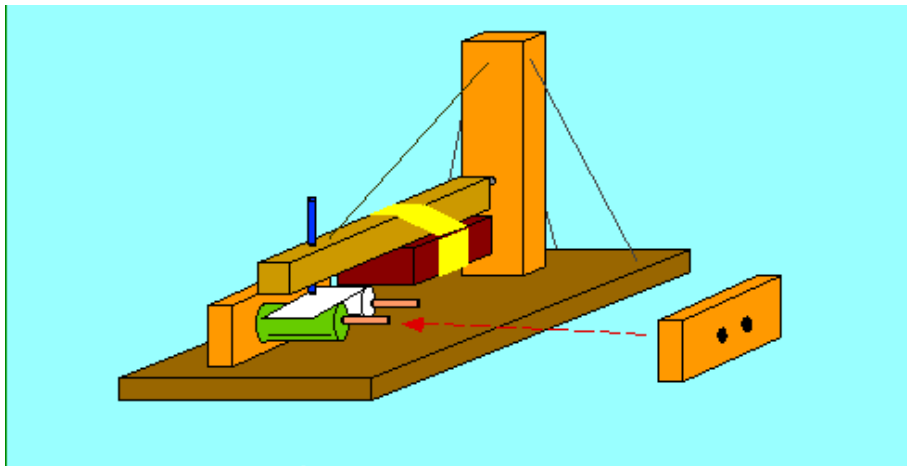


Fig 7.8: Home Made Seismograph

- Simple homemade seismograph construction is presented here and refer Fig 7.8 for each step
- If you have a drill, you can mount the two wood dowels in holes drilled through the two wood support blocks. If you do not have a drill, saw two slots into the upper edge of each wood support block and then drop the dowel into these slots.
- The pen must write easily when pulled down onto the paper roll by the brick. Cap it when not in use. You may try substituting a soft lead pencil, a charcoal pencil, a crayon, etc.
- Fasten the wood stand securely to the wood base by nailing upward from underneath the wood base. The wire (or cord) attached to the back and side of the wood stand will help to keep it stable.
- Fasten the screw securely into one end of the wood beam. This screw will rest against the wood stand so that the wood beam hangs level over the base. To help the screw stay in place and not slip off of the wood stand, drill or carve a small hole 1/4-inch deep out of the stand and slightly larger in diameter than the screw head. The head of the screw can sit in this hole and press against the wood stand.

- Both the adding machine paper roll and the smooth can should be able to rotate. The smooth can rotates when you crank the nail at one end of its wood dowel; the paper roll can turn either with its wood dowel or separately from the dowel. Tape down the end of the paper roll onto the can so that when you crank the can, the paper should wind up around the can and cause the paper roll to rotate as it feeds paper to the can.
- If you want to be creative, see if you can devise a way to make the paper roll feed onto the smooth can automatically so that you do not have to crank the can by hand. You might try buying a miniature battery-operated motor that can turn the wood dowel of the can.
- If the ground does not move, the rod does not swing, and the pen stays in place, so the ink line is smooth and straight. If the ground shakes, however, the rod swings and so the pen draws a zigzag line as the paper turns. The stronger the shaking, the sharper the zigzags. This zigzag picture made on the paper roll is called a seismogram.

Topic 4

Seismic sensor-seismometers

- A seismic sensor is an instrument to measure the ground motion when it is shaken by a perturbation. This motion is dynamic and the seismic sensor or seismometer also has to give a dynamic physical variable related to this motion.
- In the earlier seismometers, this variable was also a displacement of a stylus representing the amplified ground motion. In present day instruments, the physical output that a seismometer yields is always a voltage.
- Ideally, we can consider a seismometer as a black box whose input is ground motion (represented by a kinematic variable: displacement, velocity or acceleration) and its output is voltage -or pen displacement, in older equipment.
- Our objective is to measure the earth motion at a point with respect to this same point undisturbed. Unfortunately it is not so easy to measure this motion and the seismic sensor is the single most critical element (and can be the most expensive) of a seismograph (seismometer and recording unit).

Table 7.1 : Typical frequencies generated by different seismic sources

Frequency in Hz	Types of Source
0.00001-0.0001	Earth tides
0.0001-0.001	Earth free oscillations, earthquakes

0.001-0.01	Surface waves, earthquakes
0.01-0.1	Surface waves, P and S waves, earthquakes with $M > 6$
0.1-10	P and S waves, earthquakes with $M > 2$
10-1000	P and S waves, earthquakes, $M < 2$

Topic 5

Types of Seismographs

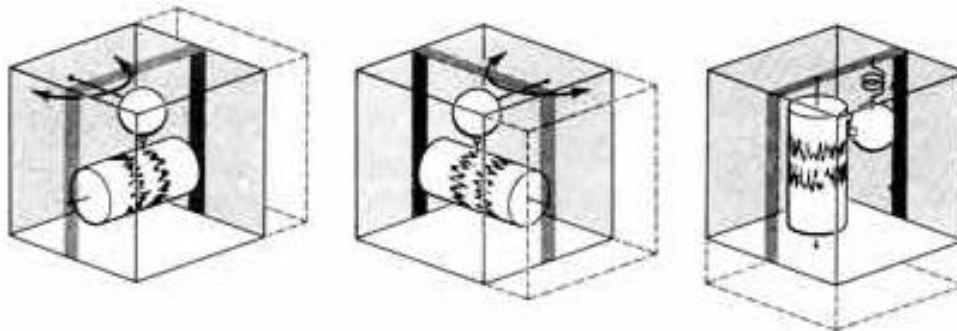


Fig 7.9: Simple models of pendulum seismographs recording the vertical and horizontal directions of ground motion. The pendulum must be damped in order to separate seismic pulses

- During an earthquake, the ground moves simultaneously in three dimensions: for example, up-down, east-west, and north-south (Figure 7.9). A single seismograph records only one of these three components of motion. In most seismograph recordings, the relative motion between the mass and the frame is not the true motion of the ground. The actual motion must be calculated by taking into the account the physics of the pendulums motion.
- Displacements of the rock in earthquakes vary in direction throughout the motion. From the three components of a seismograph (, up-down, east-west, and north-south), the complete wave motion as it evolves with time can be reconstructed. By combining the records of an earthquake by a series of seismographs, the seismologist can create a representation of the ground shaking by identifying the predominantly P (Primary) and S (Secondary or Surface) waves on an earthquake, enabling the total energy of the shaking to be calculated (Magnitude). Three component digital seismographs and becoming more commonly used.

- Different types of seismographs are used to measure short and long seismic waves. The Press-Ewing Seismograph records long waves at least 800 kilometres in length. The Benioff Linear Strain Seismograph measures changes in distance between two piers attached to the ground. There are more than 1,000 seismograph stations throughout the world
- Today, three types of seismographs are used in earthquake research, each with a period corresponding to the scale of the vibrations it will measure (the period is the length of time a pendulum requires to complete one full oscillation).

Short-period seismographs

- Short-period seismographs are used to study primary and secondary vibrations, the fastest-moving seismic waves. Because these waves move so quickly, the short-period seismograph takes less than a second to complete one full oscillation; it also magnifies the resulting seismograms so that scientists can perceive the pattern of the earth's swift motions.

Long-period seismographs

- The pendulums in long (intermediate) period seismographs generally take up to twenty seconds to oscillate, and they are used to measure slower-moving waves such as Love and Rayleigh waves, which follow primary and secondary waves. The WWSSN currently uses this type of instrument.
- The seismographs whose pendulums have the longest periods are called ultra-long or broad-band instruments. Broad-band seismographs are used increasingly often to develop a more comprehensive understanding of global vibrations.

Topic 6

Types of instruments to record earthquakes

- **Strong motion instruments** - Digital strong-motion seismometer, or accelerograph data is essential to understand how an earthquake affects human structures. A strong-motion seismometer measures acceleration. This can be mathematically integrated later to give velocity and position. Strong-motion seismometers are not as sensitive to ground motions as teleseismic instruments but they stay on scale during the strongest seismic shaking.
- **Weak motion instruments** – seismologists prefer recording weak motion displacements or velocity, for easy interpretation of seismic phases, while engineers use strong motion acceleration, whose peak values are directly related to seismic load on structures.

- **Broad band recorder** - Broad band sensor is one of the most precise earthquakes monitoring equipment which is based on the principle of a velocity sensor. It consists of a sensor, recorder, a hard disk and a GPS. The recorder consists of 6 channels and is connected to both hard disk and the sensor.

Topic 7

Strong motion (Accelerograph)

- An accelerograph can be referred to as a strong motion seismograph, or simply as an earthquake accelerometer. They are usually constructed as a self-contained box (Figure 7.10), more commonly now being connected directly to the Internet.
- Accelerographs are useful for when the earthquake ground motion is so strong that it causes the more sensitive seismometers to go off-scale. There is an entire science of strong ground motion that is dedicated to placing accelerographs in the vicinity of major faults. The type of information gathered (such as rupture velocity) would not be possible with the standard seismometers. The best known example is the Parkfield Experiment which involved a massive set of strong motion instrumentation.



Fig 7.10: This model is a K2 made by Kinemetrics and part of the Pacific Northwest Seismograph Network.

- Within the accelerograph, there is an arrangement of 3 accelerometer sensing heads. These are usually micro-machined (MEMS) chips that are sensitive to one direction. Thus constructed, the accelerometer can measure full motion of the device in three dimensions.
- Unlike the continually recording seismometer, accelerometers nearly always work in a triggered mode. That means a level of acceleration must be set which starts the recording process. This makes maintenance much more difficult without a direct Internet connection (or some other means of communication). Many trips have been made to accelerometers after a large earthquake, only to find that the memory was filled with extraneous noise, or the instrument was malfunctioning.

- Accelerometers are used to monitor structures for earthquake response. Sometimes, with the data, a response spectrum is computed. Other analysis is used to improve building design, or to help locate important structures in safer areas.

Topic 8

Seismic Station

- An individual seismic station consists of a seismometer for sensing ground motion, a clock for determining time, and a recorder for collecting data. While an individual station can provide interesting information on the occurrence of seismic events, multiple stations are required to locate events accurately and determine their nature. The characteristics of multiple stations vary depending on their application, but can be considered in the following general categories:

Regional Networks

- Regional networks typically consist of tens to (occasionally) hundreds of stations spaced at intervals of tens of kilometers. Such networks monitor seismic activity within and surrounding the network, and are used to characterize a particular region.
- Regional networks are often sensitive to seismic events as small as magnitude one or less and, because of their wide distribution, they can be used to determine with high accuracy the location and depth of seismic events. Their primary use is the evaluation of seismic hazards, but they are also useful for determining Earth structure and for recording large distant earthquakes and explosions.
- Because their focus is on small to moderate sized earthquakes at regional distances, the instrumentation for regional networks is tuned to the higher frequency part of the seismic spectrum where regional waves are seen.
- In the past, regional network stations have been equipped with single-component, short-period sensors. Today, increasing use is being made of broadband three component sensors, thus greatly enhancing the use of regional network data in global studies.

Global Networks

- Global Networks have traditionally been used to investigate both Earth structure and the phenomena that create seismic signals, i.e., earthquakes and explosions. Global stations are designed to be sensitive to seismic events anywhere in the world.

- Global seismic stations have three-component, broadband instruments that enable seismologists to reconstruct the complete three-dimensional ground motion over a broad range of frequencies.
- The optimal geometric distribution of stations in a global network depends on the application. If the primary interest in the network is for earthquake location, a concentration of stations in areas of known seismicity is appropriate.
- For nuclear monitoring, areas of special concern for testing and proliferation will require a dense population of stations. Enhanced monitoring of specific areas can be achieved by adding more stations to improve location capability and to decrease the detection threshold, or by adding supplemental sensors around the single station to enhance the seismic signal as is done with arrays. For studies of global Earth structure, an even distribution of stations is more desirable.

Seismic Arrays

- Seismic arrays are clusters of seismometers distributed over a relatively small area, typically a few kilometers across. In contrast to networks, which look within the region where they are located, arrays improve the detection of events at great distance by being sensitive to particular waves from particular directions.
- To imagine how an array works, consider an example of a seismic wave coming from a known location and with a known speed. The time it takes for the wave to travel to each sensor in the array can be predicted from the known direction and speed.
- The seismic background noise, however, will vary randomly from sensor to sensor. The recorded signals from each sensor in the array can then be shifted in time to allow for propagation across the array and combined.
- The background noise, which varies less predictably than the signal, cancels out when the records are added together. Thus it is possible to suppress the noise relative to the signal and make the signal easier to detect.

Topic 9

Station Distribution and Site Selection

- For an effective microearthquake network (permanent or temporary), which can provide reliable data for earthquake location, the station sites should be evenly distributed by azimuth and distance.

- The maximum azimuthal gap between the stations should be less than 180° , and the distance between the stations should not be more than twice the average focal depth of the earthquakes. For example, the focal depths of the earthquakes are typically within 20-30 km in the Shillong Plateau. So, it is desirable that the station spacing is not greater than 40-50 km.
- Optimal distribution of stations has been studied by Sato and Skoko (1965) and Uhrhammer (1980), which suggest that if the earthquakes are uniformly distributed over a region A, then a network of approximately A/S^2 stations is needed, where S is the station spacing. If earthquakes are concentrated along a fault zone, the total number of stations required could be less.

Site Selection

- There are various constraints in site selection, which affect station distribution. If seismic noise is high, benefit of modern instrument is lost and poor detection will result. If stations are situated on soft ground, even Broadband (BB) or Vary Broadband (VBB) records will be useless and SP responses will not be interpretable due to local noises.
- For example, Quaternary alluvium causes higher background noise compared to bedrock or competent rock. Inaccessible terrain or large bodies of water may also put serious constraints on the station selection.
- Similarly, cultural noise e.g. near large cities, highways, farming lands or the livestock and wind noise may cause poor quality of records. One way to reduce cultural noise is to place the seismometers at some depth. For example, Steeples (1979) placed seismometers in steel cased boreholes, 50-60 m deep, for a telemetered network, which reduced the cultural noises like those of vehicle and livestock by as much as 10 db.
- Takahashi and Hamada (1975) have described the results of placing seismometers in deep boreholes in the vicinity of Tokyo. A seismometer is also placed in a 60-70 ft deep borehole in Jorhat (Assam) at the Central Recording Station of the RRL (J) telemetered network (Sitharam M.V., Pers. Comm., 1999).
- When no bedrock exposure was available in the field the seismometers were kept on 5-8 ft thick concrete floors in 6-10 ft deep dug wells. This effort enhanced the gain of the recording instruments by at least 6 db.
- Further, a few more pertinent points may be considered for making temporary microearthquake networks. First, office studies (at headquarter) should be made in selecting potential sites. The exercise of preliminary design of the network may be done with the help of a good seismo-geological map.

- The bedrock having higher seismic impedance (which is the product of density and velocity of the rock) produces less noise and provides high gain seismic station. It should be away from man made cultural or traffic noise.
- Second, the sites should have easy accessibility for daily servicing and changing of records and batteries, particularly for an analog network. With the availability of GPS, the station coordinates and elevation should be obtained more precisely, with ± 10 m accuracy.
- Maintaining of timing accuracy in analog system is very tricky; the radio signal should be regularly synchronized with the built-in quartz clock of the system.

Topic 10

Smart 1

- SMART 1, the first large digital array (with radius 2 km and 37 accelerometers) to record substantial ground motion (up to 0.24 g horizontal acceleration), became operational in September 1980 in a highly seismic region of Taiwan (see Figure 7.11).
- During the first year of operation, SMART 1 recorded 15 earthquakes with local magnitudes ranging from 3.4 to 6.9. Installation and operational details and likely errors in the data processing are presented.
- For this major preliminary study, recorded wave forms across the array were analyzed for two earthquakes. The correlation coefficient between the acceleration waves forms of the same component recorded at any two array sites was studied.
- Representative measurements were made of seismic wave coherency, Fourier wave number, and response spectra. Comparisons of power spectra as a function of wave number, frequency, azimuth of propagation, and wave type were made.
- The engineering analysis included
 1. Transformations to principal axes,
 2. Development of generalized response spectrum ratios for characterizing multi-support excitations, and
 3. Moving window analysis in the time and frequency domains for studying spectral variations of recorded ground motions. The dynamic properties of site conditions and spatial correlations of earthquake motions were studied.

- A technique using the principal variance ratio was developed to identify the wave direction and type of waves.
- Located over an alluvial basin (the instrument at EO2 is on rock) in Taiwan. At the top, the recorded ground displacements (in centimeters) from a November 14, 1986, earthquake 80 kilometers away to the south can be seen growing in amplitude and duration as it travels from south to north into the soft basin.

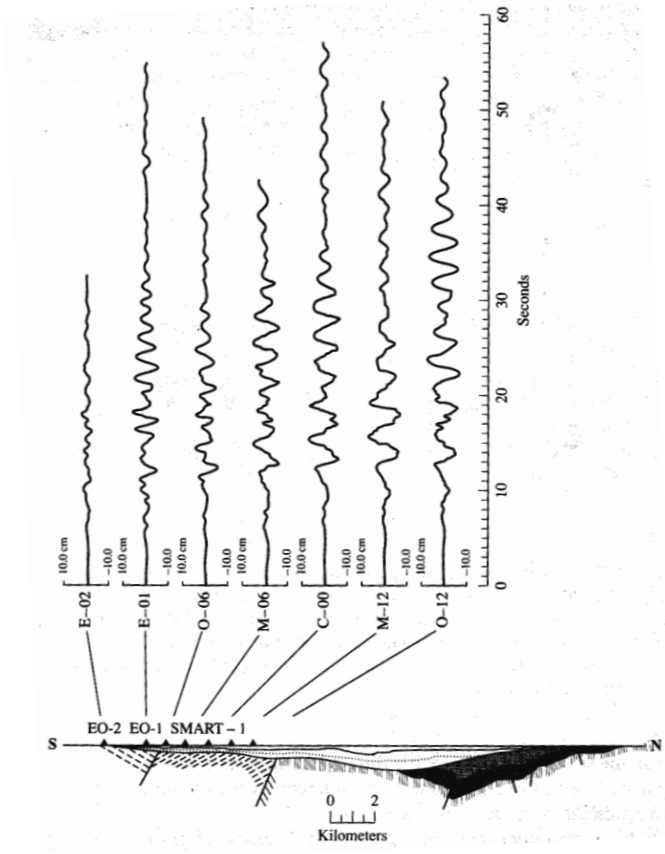


Fig 7.11: The geological cross section (bottom) shows the array called SMART-1

End of Lecture 7 in Earthquake recording instrumentations; concept of seismograph, Seismic station; build your own seismograph.