CHAPTER - 10

Earthquakes

Introduction

An earthquake is a detonation of a system underground that develops under suitable conditions of nature of fault and time. ChangHeng, a chinese philosopher invented the first earthquake recording instrument in 132 A.D, which detected an earthquake that occured at a distance of about 640 km (400 miles) away and it was not felt by the people at the site of the instrument. The mechanism of the instrument however was not known to others. Nowadays earthquakes are recorded by a seismographic network of intruments.

Earthquakes belongs to the natural hazards, associated with the geological events and stands first in natural disasters (see world's worst natural disasters in chapter1).

The Main Types of Earthquakes are

(i) Tectonic, (ii) Volcanic and (iii) Plutonic.

During an earthquake the slip of one plate (very huge block of rock) over another plate releases energy that causes the ground to vibrate and this process continues. In this way earthquake energy travels in a wave form.

Different aspects of an earthquake are measured by different ways, of this magnitude is the most common. It measures the size of the fault at the earthquake source which is commonly measured by Richter scale. Richter scale measures the wriggle (twist and turn) on the recording, but other magnitude scales measure the different parts of the earthquake.

Intensity is a measure of the shaking and the damage caused by an earthquake. Logarithemic magnitude scale measures the size of the earthquake, this is called ML scale (where M stands for magnitude, L stands for Local). This is eventually became the Richter scale. This scale is valid for certain frequency and distance range.

On similar lines of Richter ML Scale, bodywave magnitude - MB, and surface wave magnitude - MS are developed by Japanese. MB and MS scales are used beyond 6.5 and 8.3 magnitude respectively. It is observed, during the formation of an earthquake, temperature near the epicentre region rises. The susceptibility of matter is inversely proportional to the absolute temperature while the permeability of the matter varies with temperature. The variations of susceptibility and permeability changes the earth's horizontal magnetic field, Dip and Declination. Hourly changes of these magnetic elements and temperature may provide us a clue for forecasting the occurrence of an earthquake (which is lacking at present).

10.1 Interior Structure of the Earth

Seismology is the science of earthquakes. In order to understand the nature of seismic wave propagation and detection, a quick survey of the interior structure of the earth is essential.

The interior of the earth consists of : Lithosphere or earth's crust, Mantle and Core.

The earth's outer shell or layer is called crust or Lithosphere. Litho – means stone. Earth's crust is not monolithic but divided into strata. The top structure is made of sediments or sedimentary rocks, the second layer is made of granite rocks, and the third layer is made of basaltic rocks. The density of rocks increases, basaltic > granite > sedimentary rocks. The three crust layers, are found everywhere in continents. However under oceans the granite layer is missing (see Fig. 10.1).

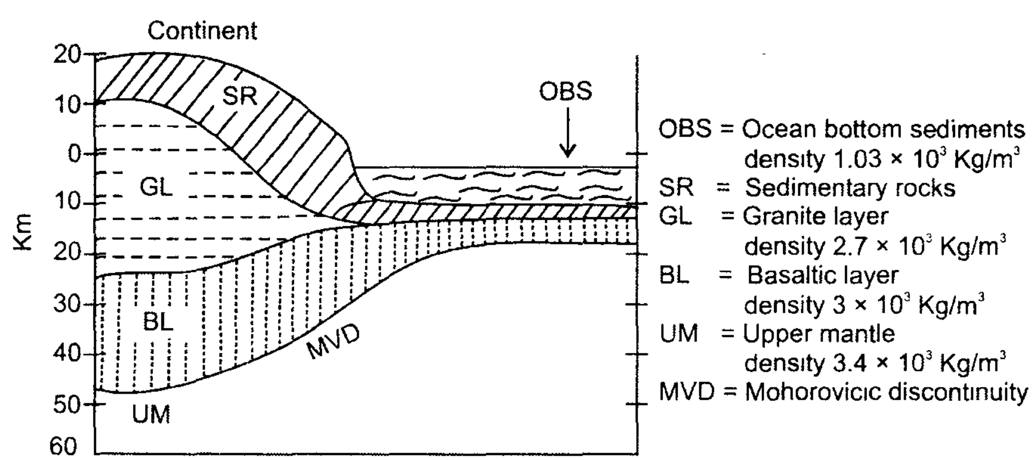


Fig. 10.1 Constituents of earth's crust.

The boundary between the sedimentary and granite rocks has not been given any name, the boundary between granite and basaltic rocks is called Konard discontinuity. The boundary under basaltic (between Crust and Mantle) is called Mohorovicic or simply Moho discontinuity.

The average thickness of the crust is about 35 km, which is very thin compared to the radius of the earth (about 6400 km). The average thickness of the earth's crust under oceans is 5-10 km, while its thickness below continental mountain ranges is about 50 km. The average density of the earth is 5.5×10^3 kg/m^3, Lithosphere 2.8×10^3 kg/m^3, Mantle 3.2 to 5.7×10^3 kg/m^3 and core 9 to 12×10^3 kg/m^3. The mass of the earth is about 6.00×10^{24} kg, Lithosphere 5×10^{22} kg, Mantle 4.05×10^{24} kg (68% of the earth) and core 1.88×10^{24} kg (31% of the earth). The depth of the Mantle is about 3000 km and Core is 3000 km.

A discontinuity means an interface and indicates marked change of material property. Below the earth's crust lies Moho discontinuity (at an average depth of 35 km, where density is 3.3×10^3 kg/m^3) which separates the earth's crust from Mantle (the interior of the earth). The Central Core (below the Mantle) probably consists of liquid outer core (thickness about 2000 km) and solid inner core (thickness about 1000 km). Gutenberg discontinuity seperates the Mantle from the central core and is located at a depth of about 3000 km, where the density is about 5.7×10^3 kg/m^3. There is still uncertainity about the composition of materials in the interior of the earth. It is generally viewed that the principal constituents of Lithosphere as oxygen (93.88%), Silica, Aluminium, Iron, Calcium, Sodium, Potassium and Magnesium (granite and basaltic rocks) all together they makeup 98.5% of the earth's crust by weight, Earth's crust mostly contains Sial (Silica, Aluminium compound) and Sima (Silica, Magnesium compound).

Mantle consists of Oxygen, Silica, Mangesium and Iron (Iron, Magnesium Silicates). The common silicate in the Mantle is probably Olivine (Formula : $[(Mg\ Fe)_2\ So_4\ ]$). These silicates are similar to those found in stoney meteorites. The core probably consists of iron, sulphure in the combined form as FeS and nickel (Fe, FeS, Ni). Core contains nife (Nickel, Iron compound).

The building blocks of Lithosphere are rocks namely Igneous, Sedimentary, Metamorphic rocks. Sedimentary layer is thick below the continents and becomes thin in ocean area, whereas the granetic layer almost absent (in ocean area).

The temperature of the interior of the earth increases with depth. In Lithosphere it increases about 1^0C for every 30 metres of depth, however this increase will not continue to the centre of the earth. Observations indicate that the average increase in temperature is about 1^oC/km. The cause of the increase of temperature with depth is suggested to be :

(i) heat generated by the pressure of overlying rocks,

(ii) primordial heat (original heat from the time of the earth's formation), and,

(iii) by the radioactive mineral disintegration.

The interior of the earth behaves like solid elastic in respect of earthquakes and earth-tides. It is known that oceans rise and fall twice in 24 hours due to gravitational attraction of the Moon on Earth. In a similar way an earth-tide occurs in the earth's crust and Mantle which causes rise and fall about 30 cm under the action of the earth-tides. Geneva based synchrotron works only during complete rest period of the crust and it will not work even if there is slightest change in earth's crust due to ebbs and flows occuring far away from the unit. It is found, the Geneva Synchrotron operates about 30 hours a week and the rest period the surface of Switzerland is vibrating. It has been scientifically proved that the entire territory of Moscow daily rises or falls about 50 cm from a certain average level. This rise and fall is caused by the gravitation of the Moon and the Sun.

10.2 Plate Techtonics

According to Indian Cosmology the earth consisted at one time of seven continents joined together. They seperated like the lotus petals (or leaves) from Mount Meru, the centre of the universe. Afterwards the continents floated and drifted away from the centre and were saperated by seven oceans. An Amateur Russian Astronomer Y.V. Bykhanov observed a remarkable coincidence of the outlines of the American and Euro-African coastlines that they fit well without a crack if these were moved together. By this observation, in 1877, he conjectured that once a uniform continent split into parts and ever since they have been moving away. In 1910, Alfred Wagener (1880-1930), a German geophysicist propounded a theory of continent Panghela (all earth) was broken up into pieces like the lotus leaves, they separated from one another and floated away giving rise to the modern continents divided by oceans. In 1960's this hypothesis was further modified by the evidence of ocean floor structure and named tectonics of plate or global tectonics (See Fig. 10.3). According to this hypothesis, instead of continental move, plates of large areas of the earth's crust containing both continents and adjoining sections of ocean floor moved.

According to this plate tectonics hypothesis there are six major plates.

1. Euro-Asiatic plate,
2. African plate,
3. Antarctic plate,
4. Indo – Australian plate,
5 American plate and
6. Pacific plate.

In addition to these major plates there are several minor plates located between them and they move to some extent independently (see Fig. 10.2).

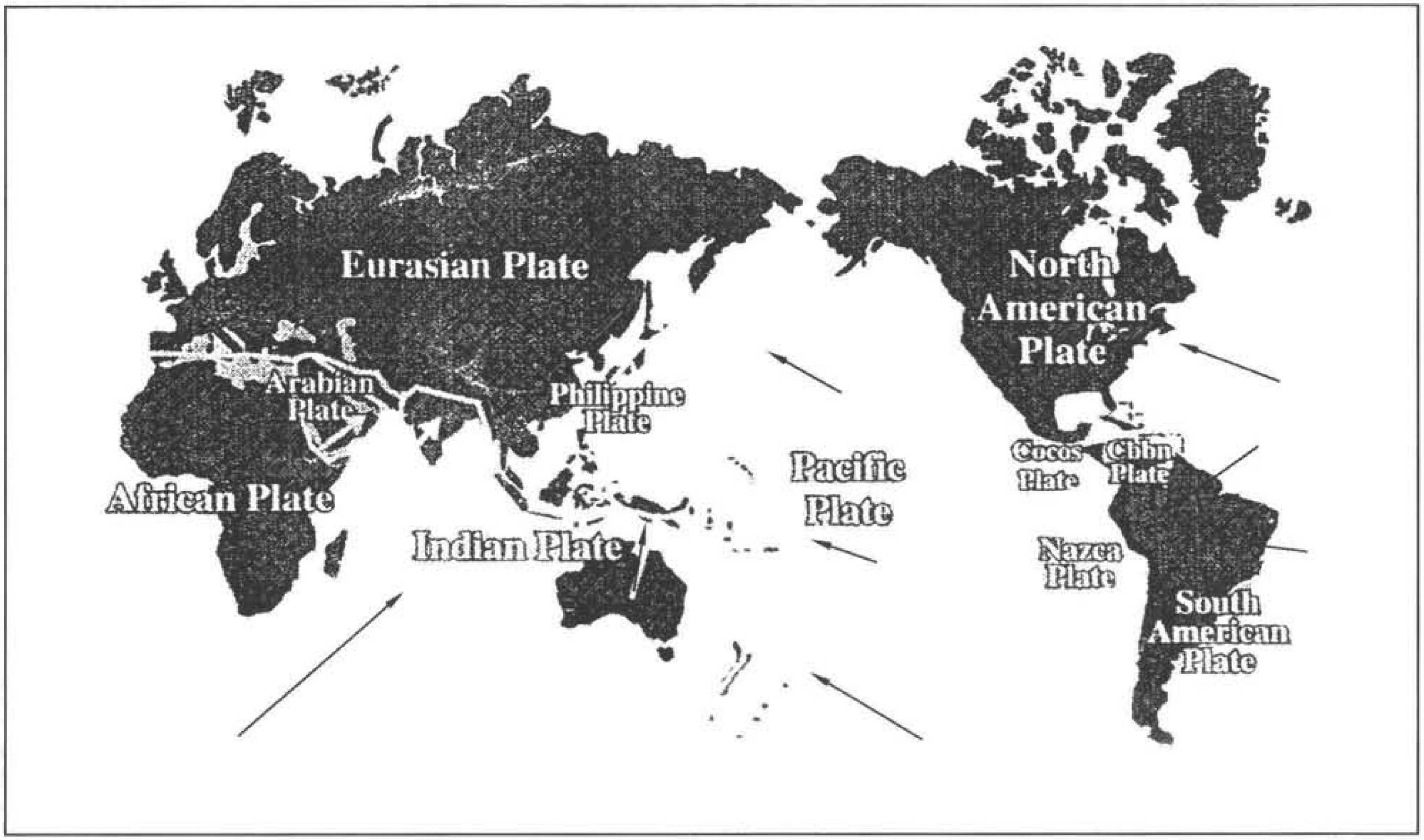


Fig.10.2 Major global tectonic plates and average direction of motion. Subduction occurs along colliding plates. After toksoz (1975).

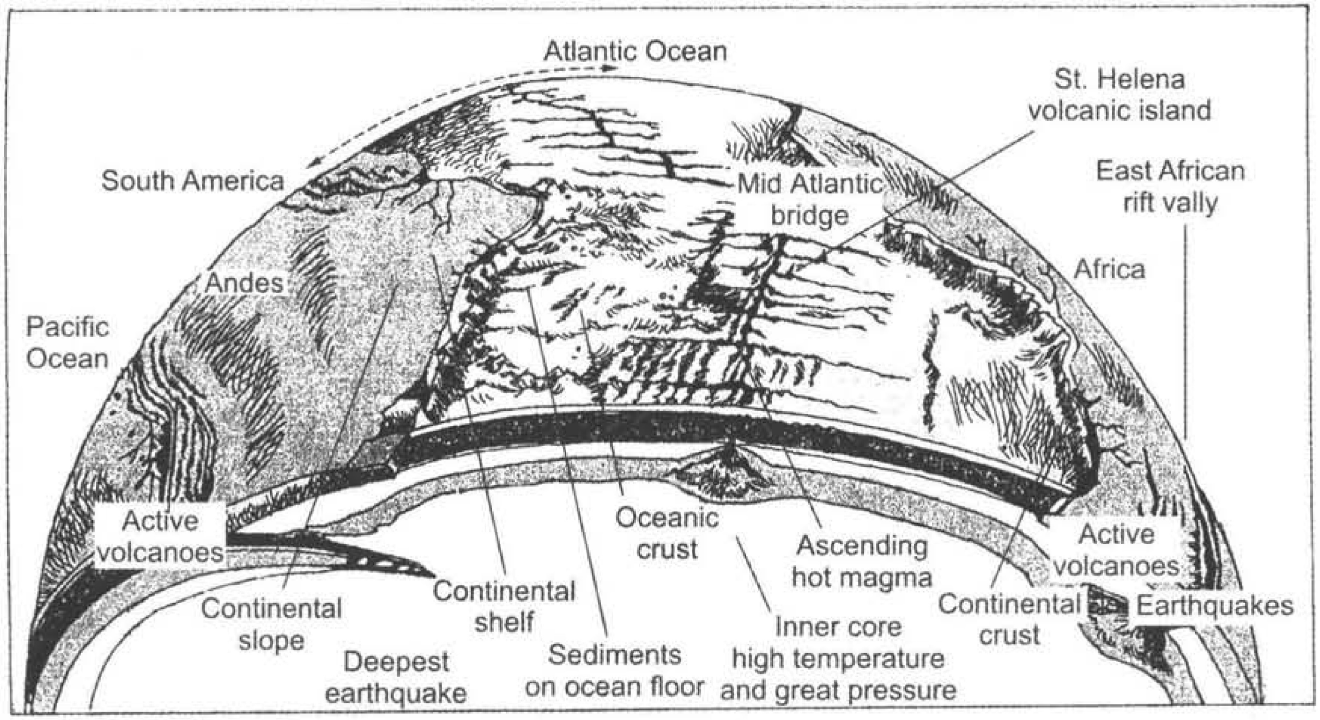


Fig.10.3 According to the sea-floor spreading theory, the splits in the mid-oceanic ridge are deep cuts in the surface of the earth (below the sea) from which molten rock gushed up to trigger earthquakes, thus moving the sea floor away from the ridge on either side.

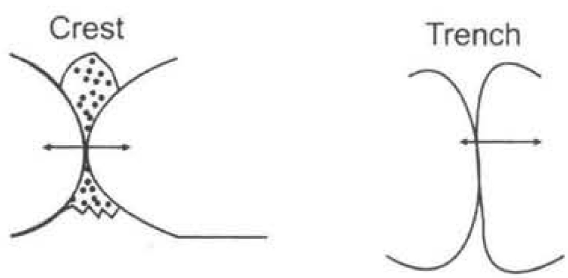
There are three types of Plate Boundaries

1. Extension or divergent boundaries
2. Compression or Convergent boundaries and
3 Transform faults.

Extension boundaries are formed when two adjacent plates move apart. Material from below swells up and a new crust is produced at the crests of the oceanic ridges. This makes both sides of the plates are added up with mass.

Compression boundaries are formed when two adjacent plates approach each other. In this case surface is destroyed. The line along which plate destruction takes place is called trench.

A third type of boundary forms when the plates move laterally relative to each other. The line along which plates move laterally is called transform faults. In this case neither crust is formed nor destroyed. It has been found that Eurasia and American plates are converging at a rate of 2 to 4 cm per year, while American, Eurasian and African plates are increasing in size and that of Indian and Antarctican plates are not changing significantly in size.



Fault : A fracture in a rock mass or rock layer whose opposite faces move independently is called a fault. The various types of fault, movements are shown in Fig. 10.4.

Folds : During tectonic movements stratified rocks develop bending. These are called folds.

Tectonics : According to one hypothesis earth's crust has large plates. These plates move due to convective forces that emanate from beneath the crust and create rifts. It is assumed that the upper Mantle consists of Newtonian Viscous fluid and the convection currents are generated due to heating from below or insitu. The lower Mantle consists of very dense fluid which inhibit convection. It is clear in case of divergent or extension boundaries a new crust is formed at the boundaries of these plates. All such boundaries are located in the oceans. The earth's crust building up towards American plate on one side and towards African and Euroasiatic plates on the other side. The plates collide at the boundaries which leads to (convergence or) submergence or subduction of one under the other plate. Such submergence taking place in case of Pacific plate under Euroasiatic plate. It is theorised that where old crusts are buried they provoke for earthquakes and volcanic eruptions. The present scientific thinking is that earthquakes are caused by the friction on the boundaries of the plates moving together. Powerful tremors are caused by the accumulated shear stresses which periodically exceed the rock strength. From the heating of the sedimentary layers of the submerging plate volcanic cruptions take place.

The various types of fault movement are shown below in Fig. 10.4.

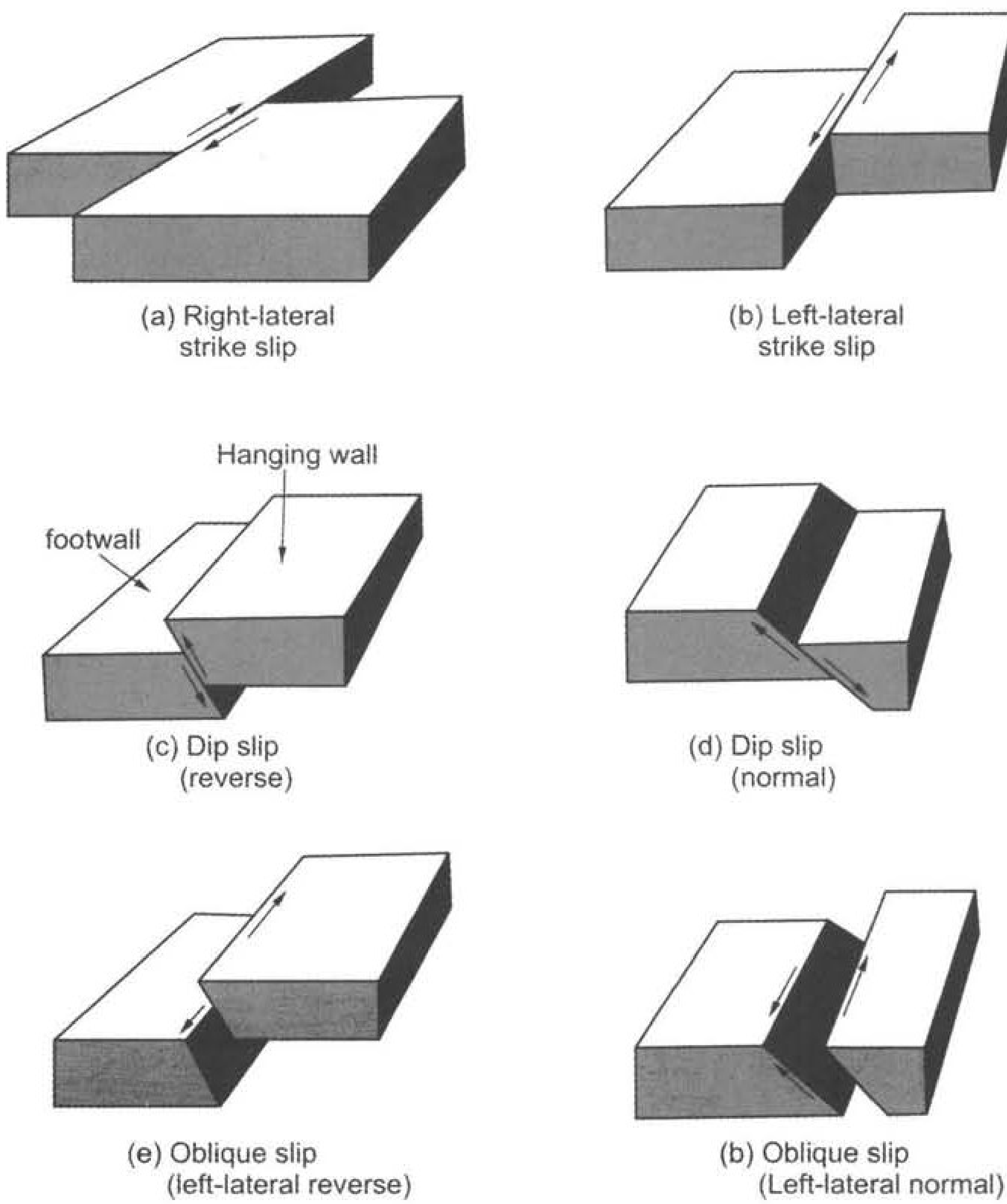


Fig.10.4 Various types of fault movement.

San Andreas is (a) type of fault; Himalayas has (c), (d), (e) and (f) types while peninsular India undergoes (d) and (f) generally. Here (c) and (e) are rare. Reverse faults are due to compression (shortening of the crust), whereas the normal faults are due to tension (stretching of the crust).

Earthquake waves

A disturbance which progresses from one point to another point in a medium with transfer of energy but without the transfer of matter is called a wave motion. Elastic waves are mechanical disturbances propagated in an elastic medium. A wave is called longitudinal or compressional if the particles of the medium vibrate in the direction of wave propagation. Longitudinal waves travel through solids, liquids and gases.

A wave motion is called transverse or shear if the particles of the medium vibrate at right angles to the direction of propagation. Transeverse waves travel through solids but not through liquids and gases.

An earthquake generates two kinds of waves. Primary or P-waves, which are compressional and travel through solids, liquids and gases. Secondary or S-waves, which are shear waves and travel only through solids. P and S-waves may not develop in actual displacement of a land mass on the surface crust.

Generation of P and S waves using springs as analogy shown in Fig. 10.5.

L-wave or long surface waves travel through surface layers of the earth.

Seismic wave motions are shown in Fig. 10.6.

The study of seismic waves produced by earthquakes provide valuable information about the nature of the matter inside the earth in its path. Seismic waves travel deep down into the earth from earthquake site and return to the earth's surface at some distant point. Seismographs are used to detect the seismic waves on their arrival at the surface of the earth. They also provide the information of type of the wave, its intensity and time of arrival. Speed of Seismic waves partly depend on the density of material through which they pass.

The markings of seismograph is shown in Fig. 10.7.

Earthquake Parameters are :

(i) **Time of origin** is the time at which earthquake has occured.

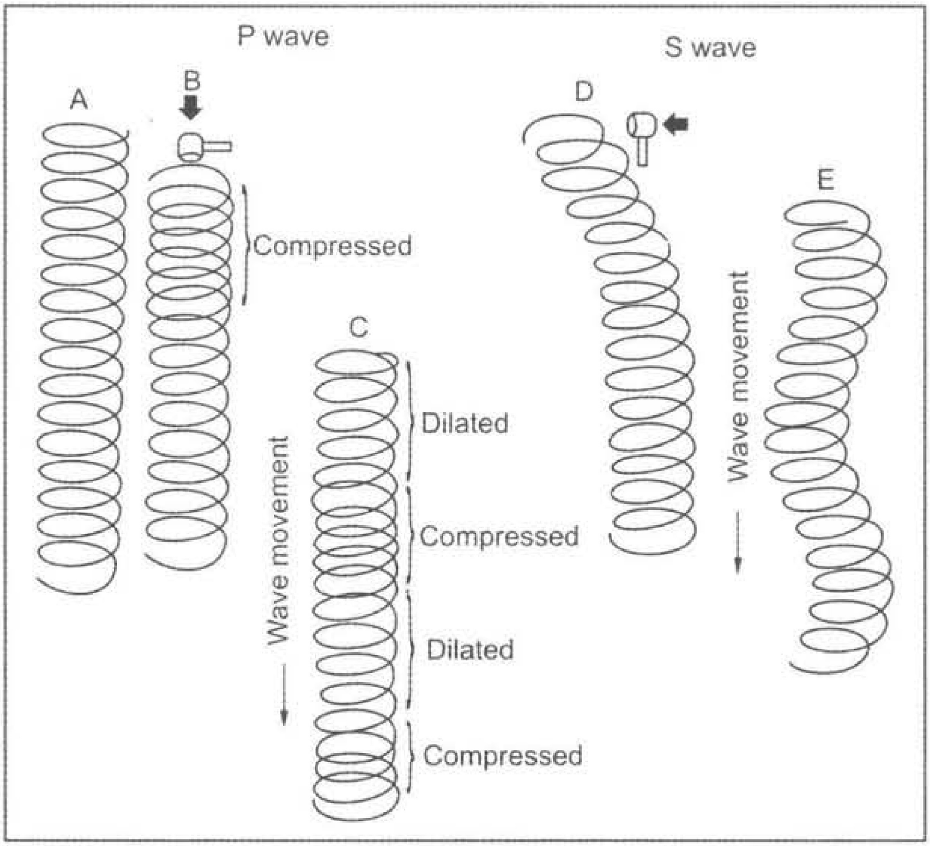
(ii) **Focus** is the point inside the earth where from the earthquake originated. See Fig. 10.8.

(iii) **Duration of an Earthquake** generally less than one minute.

(iv) **Epicentre :** the surface point vertically above the focus. It is expressed in latitude and longitude of the point. See Fig. 10.8.

(v) **Focal depth** is the depeth of the focus from the surface of the earth. See Fig. 10.8.

(vi) **Hypocentre** of an earthquake is the combination of epicentre and focal depth.



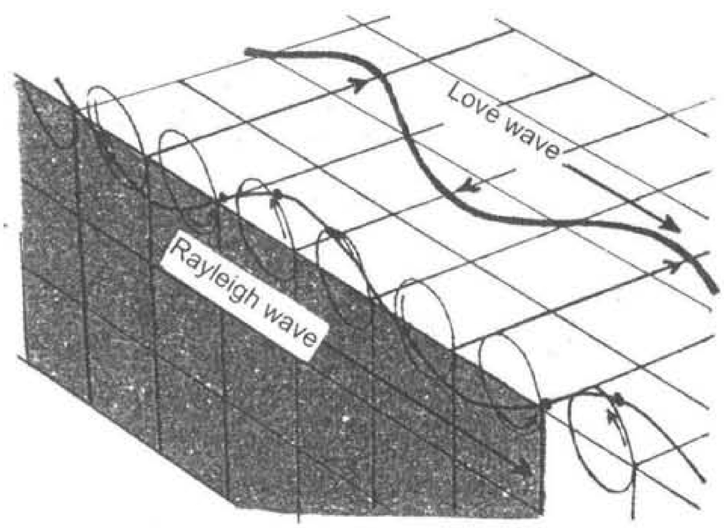


Fig.10.5 Generation of P and S waves using spring as an analogy. The figure below shows the oscillation pattern of Rayleigh and Love waves.

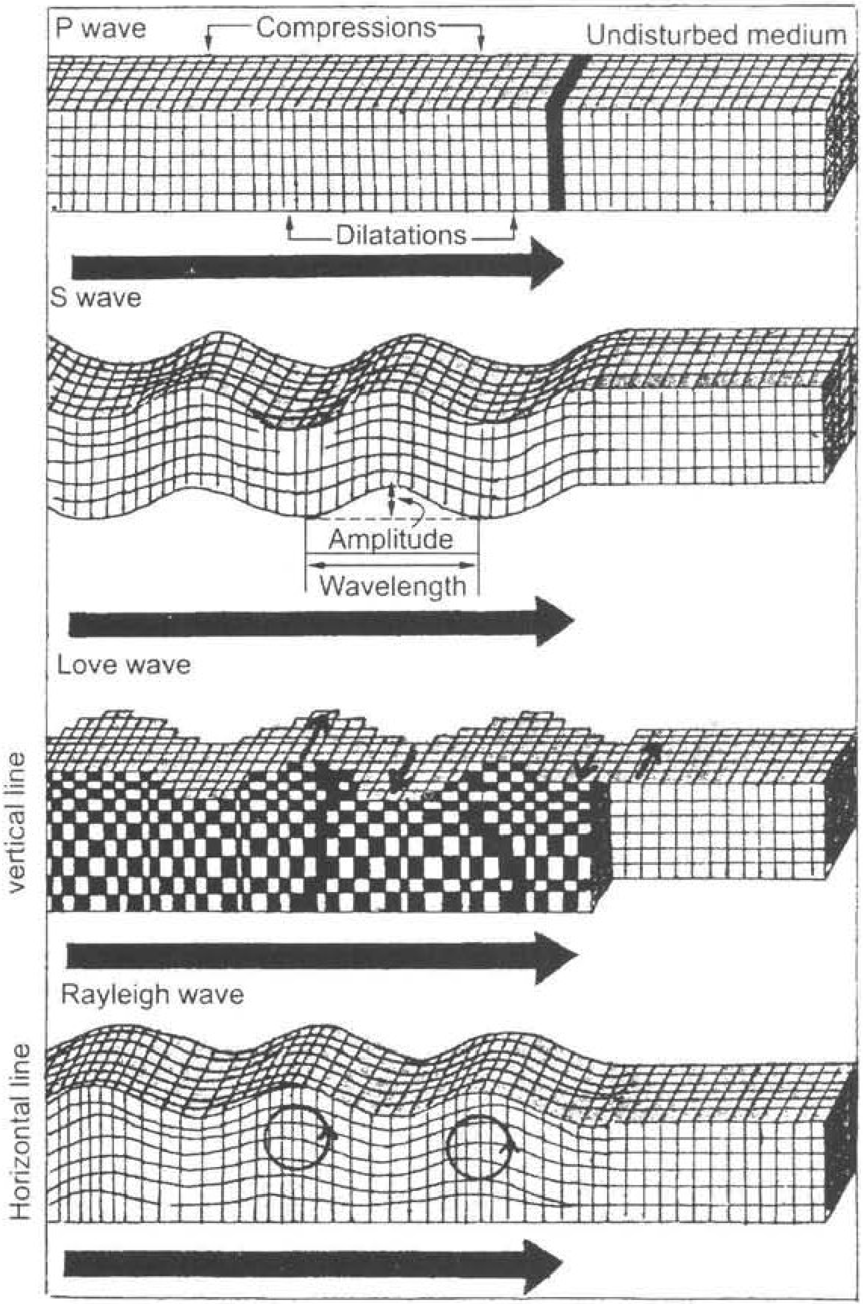


Fig.10.6 Seismic wave motions.

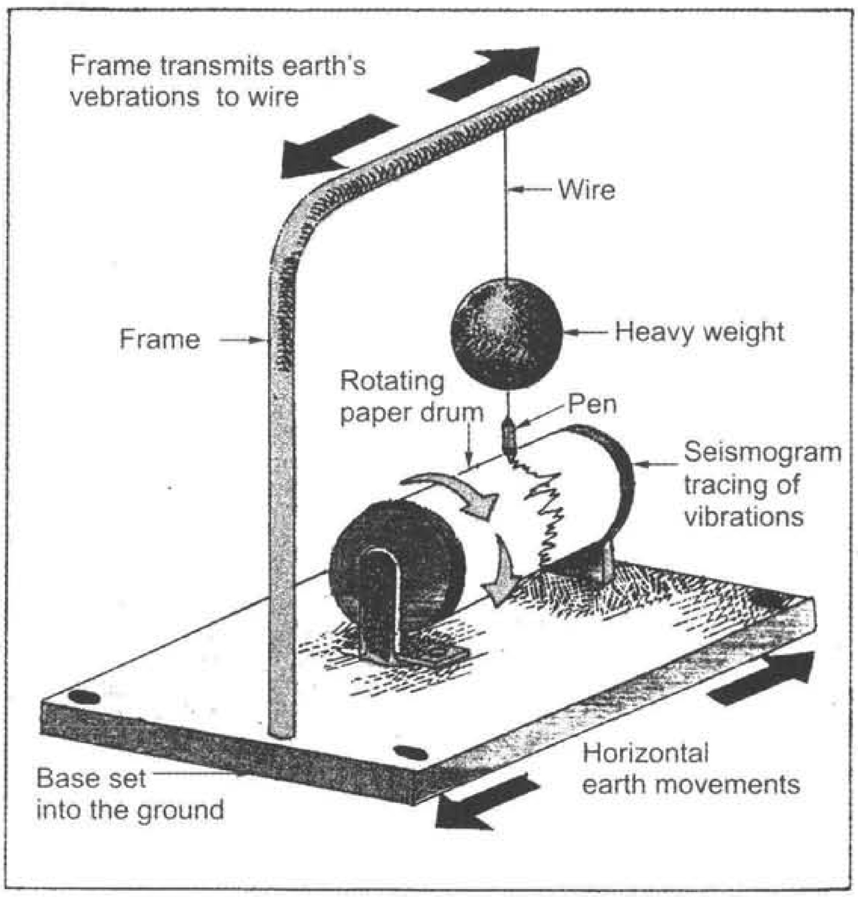


Fig.10.7 During an earthquake, the assembly together with the frame anchored into firm ground moves to and fro. A pen attached to the weight records the tremors on the paper covering the rotating drum.

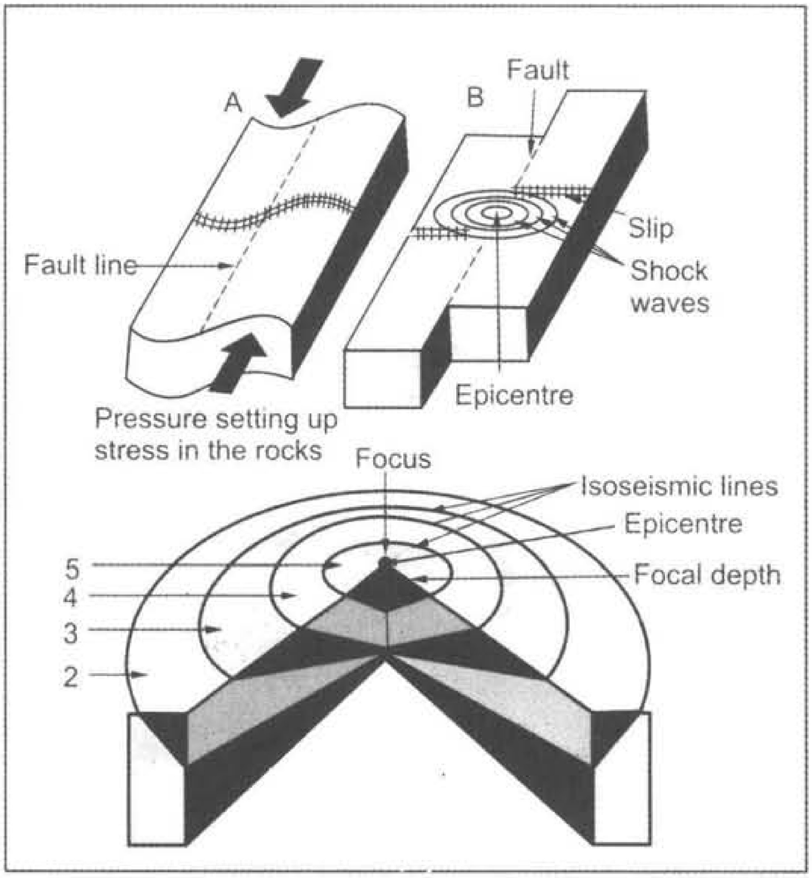


Fig.10.8 Earthquake waves begin from a point called focus located deep below the surface of the Earth. The nearest point above the focus on the Earth's surface is called the epicentre around which the maximum damage is caused. The intensity of the quake decreases as the distance from the epicentre increases. Isoseismals are imaginary lines on a map joining points of equal intensity. These are drawn based on damage survey, after an earthquake, according to modified Mercalli (MM) scale.

Classification of Earthquakes

(i) Shallow eathquakes have focal depth $\leq$ 70 km

(ii) Intermediate earthquakes have focal depth between > 70 km $\leq$ 300 km.

(iii) Deep earthquakes have focal depth > 300 km

Earthquakes have not recorded focal depth exceeding 720 km.

Magnitude (M)

The magnitude of an earthquake is a kind of instrumental measure of its size or energy (E), and is given by a linear equation

$$\log_{10} E = a + b\,M \qquad .....(10.1)$$

Or

$$E = 10^{(a + bM)}$$

where a and b are constants, E = Energy, M = Magnitude

The values of constants are generally found to be a = 11.8, b = 1.5

If $\quad M = 4$, we have $\quad E_1 = 10^{a + 4b}$

$\quad M = 6$ we have $\quad E_2 = 10^{a + 6b}$

$$\frac{E_2}{E_1} = \frac{10^{a+6b}}{10^{a+4b}} = 10^{2b}$$

or $\quad E_2 = E_1 \times 10^{2b} = E_1.10^3 \qquad$ (since b = 1.5)

Thus the energy radiated by earthquake of magnitude 6 (E_2) is 10^3 times the energy radiated by the earthquake of magnitude 4 (E_1).

If E_3 is the energy of magnitude of earthquake 8, then

$$E_3 = E_1\, 10^{4b} = E_1 \times 10^6$$

i.e., $\quad E_3$ is 10^6 times E_1.

$\log E_s = 11.8 + 1.5\,M$, where E_s in ergs, M is Richter scale magnitude.

If M = 8.25, E_s = Energy = 3.68×10^{10} kwh or 13.248×10^{23} ergs.

M = 7.5 $E_s = 2.86 \times 10^9$ kwh or 10.296×10^{22} ergs.

Seismic energy (E_s) yield for different magnitudes (M) given in Table 10.1.

Table 10.1

M	E_s in TNT	M	E_s in TNT
5 0	32000 tons	8	5 billion tons
5.5	80000 tons	9.0	32 billion tons
6.0	1 million tons	10 0	1 trillion tons
6.5	5 million tons	12 0	160 trillion tons
7 0	32 million tons	8 5	1 billion tons
7.5	160 million tons		

Intensity

It is based on effects of the earthquake on buildings, topography, land slide etc., i.e, on macroseismic effects.

The waves spreading from an earthquake centre pass through different rocks at different velocities. Seismic waves have a maximum velocity of 12.5 kmps. On passing through the Mohorovicic boundary the primary seismic waves speed up from 6.5 to 8 kmps and secondary waves from 3.7 to 4.5 kmps. However on passing from mantle into core the primary waves speed drops 12.5 to 8.5 kmps and the secondary waves from 7.5 to 5 kmps. The spreading waves from an earthquake centre pass through different rocks at different velocities. Since the waves are reflected, and refracted on their way, they reach observatories at different times. On an average more than one lakh (10^5) earthquakes of varying intensities are registered over the globe every year by the seismological observatories. The data is evaluated by using 12 grade modified Mercalli (M.M) scale. The scale can be divided into several groups :

1. ***Slight Intensity or First Group***

   It consists of first three grades which are weak and not imperceptible earth tremors. These are sensed by some animals. Most of domestic animals become restless, birds fly away from the place of earthquake. Cats fur stands on end. It is also said that second and third grade tremors are sensed by nervous people.

2. ***Moderate Intensity or Group Two***

   It consists of grades 4, 5 and 6. These shocks are felt by every one. In this group objects hanging on walls move, hanging lamps/bulbs, chandliers swing to and fro. Cracks develop in some houses. Tall factory chimneys may fall down.

3. ***Severe Intensity or Group Three***

   It consists of 7, 8 and 9 grades. The strength of this group is distructive and devasting. Tall buildings may fall down, cracks may occur in the ground and occasional human casualities are noted.

4. ***Catostrophic or Very Severe Intensity or Group Four***

   This last group consists of 10, 11 and 12 grades. The strength is described as catastrophic. Many buildings will collapse except structures on monolithic rocks which may not be affected. The shocks and yawning cracks will be very severe. These may cause eletrical fires.

Causes of Earthquakes

The most common cause of earthquake is tectonic activity. This mechanisms is shown in Fig. 10.9. The vertical dashed line (PQ) shows fissure or fault in the solid earth crust. By slow prolonged tectonic movement in the lithosphere one side X of the fault (Fig. 10.9 (a)) is displaced in relation to the other Y. This is shown in Fig. 10.9(b), by a deformation of straight lines drawn across the fault (P' Q'). This process continues until the stresses thus generated in the fault zone overcomes the friction between the two sides X and Y. Then a rupture (sudden displacement) occurs. After this the configuration is shown in Fig. 10.9(c). It is this sudden rupture constitutes an earthquake. The slow process is repeated and a new shock occurs at some time later. This mechanism of earthquake is called elastic rebound theory of tectonic earthquakes. Almost all earthquakes occur by this mechanism. However there may be some tremors by volcanic activity. Large earthquakes may occur with a volcanic explosion. The collapse of cavities can be the origin of minor tremors.

Long ago the super continent Pangea broken and drifted like the lotus leaves. A plate containing India broke away from it and drifted towards Asian land mass. When this plate collided with Euro-Asian plate sediments of ancient sea bed sqeezed together in huge folds and slowly rose to form the Himlayas.

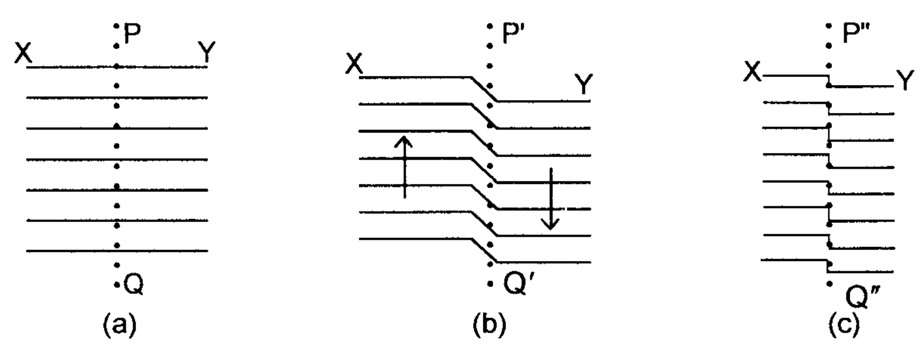


Fig. 10.9 Elastic rebound theory of tectonic earthquakes.

Indian plate consisting of India and parts of Indian ocean is moving at an average speed of 5 cm / year in the north-northeast direction and colliding with Eurasian plate along the Himalayas. This resulted in faults and fractures in the Himalayas. These are responsible for some great earthquakes in the Himalayan region in the past.

Categorisation of earthquakes	*Richter scale*
Tremor or micro-earthquake	Magnitude < 3.0
Slight earthquake	Magnitude ≥ 3 to < 5.0
Moderate earthquake	Magnitude $\geq$ 5 to < 7.0
Great earthquake	Magnitude $\geq$ 7.0

Important Seismic Belts

1. First belt, the most important Seismic belt runs along the Pacific and includes western coast of South America, North America, eastern coast of Asia, the Island of sourth coast Pacific and New Zealand.
2. Second belt runs from south Pacific Islands through Jawa, Sumatra and Central Asia mountains, further passing through Caucasus mountains to Greece, Italy and Spain.
3. Third belt which is not so important runs from north to south in the middle of the Atlantic ocean.

10.3 Seismcity of India

IMD maintains a catalogue on earthquakes in India and neighbourhood from available historical records and also instrumental data (See Fig. 10.10 and 10.11). This catalogue is continuously updated. From this records it is observed that moderate to great earthquakes have occurred all along the Himalayan region, the Rann of Kutch, Manipur, Mynmar (Burma) belt and further continuation to Andaman and Nicobar islands. Scattered earthquakes also occurred but less frequent in peninsular India with magnitude less than 6.5. Latur (Osmanabad district) earthquake had magnitude 6.3. The catostrophic earthquakes of magnitude $\geq$ 8 is given in Table 10.2.

Table 10.2

Date	Place	Magnitude
12.06.1997	Assam	8.7
15.08.1950	Arunachal Pradesh	8.5
15.01.1934	Bihar-Nepal border	8.3
26.06.1941	Andaman islands	8.1
04.04.1905	Himachal Pradesh	8.0
16.06.1819	Rann of Kutch	8.0

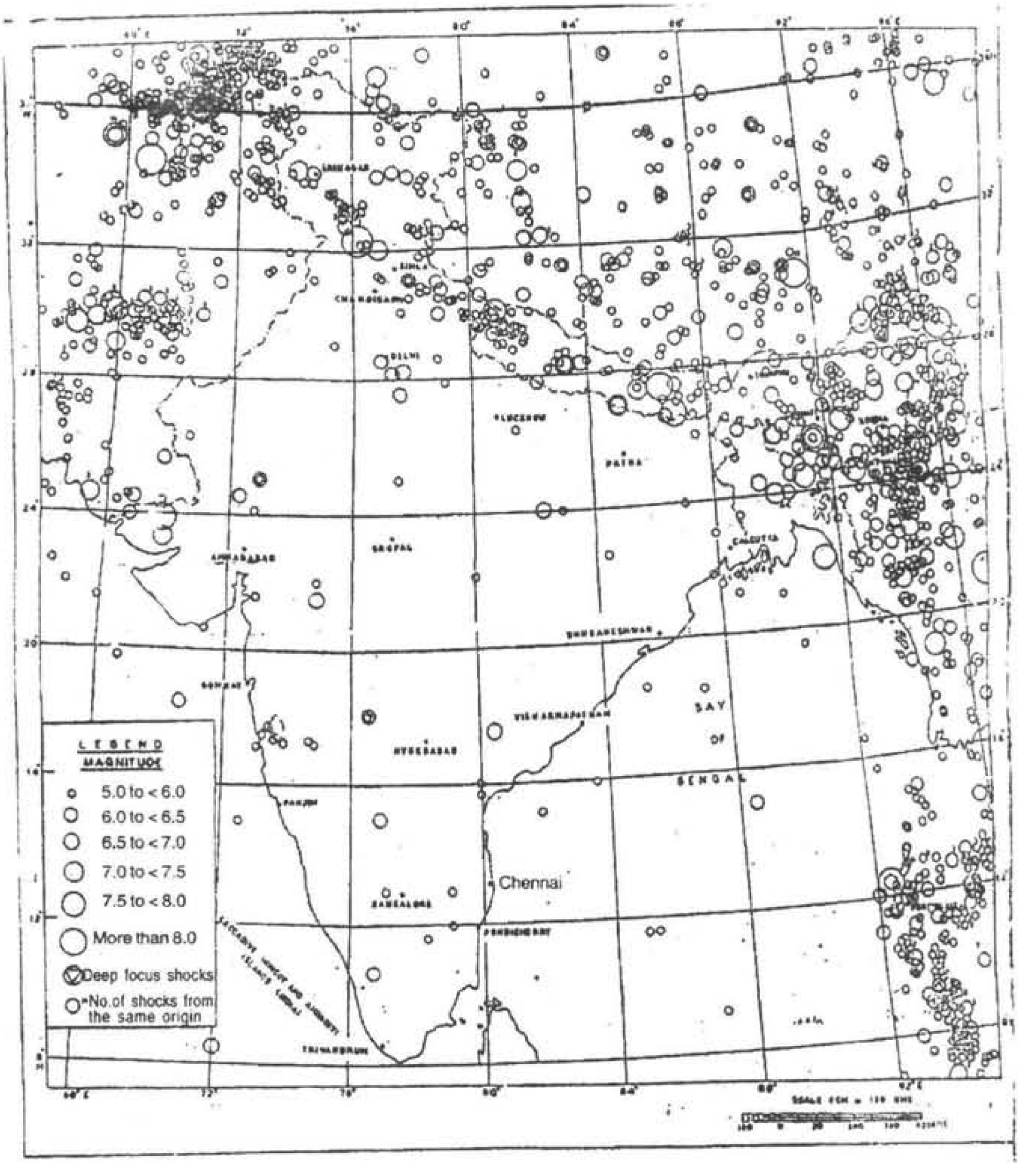


Fig. 10.10 Map of India showing epicenters (upto 1994).
Source : India Met Dept.

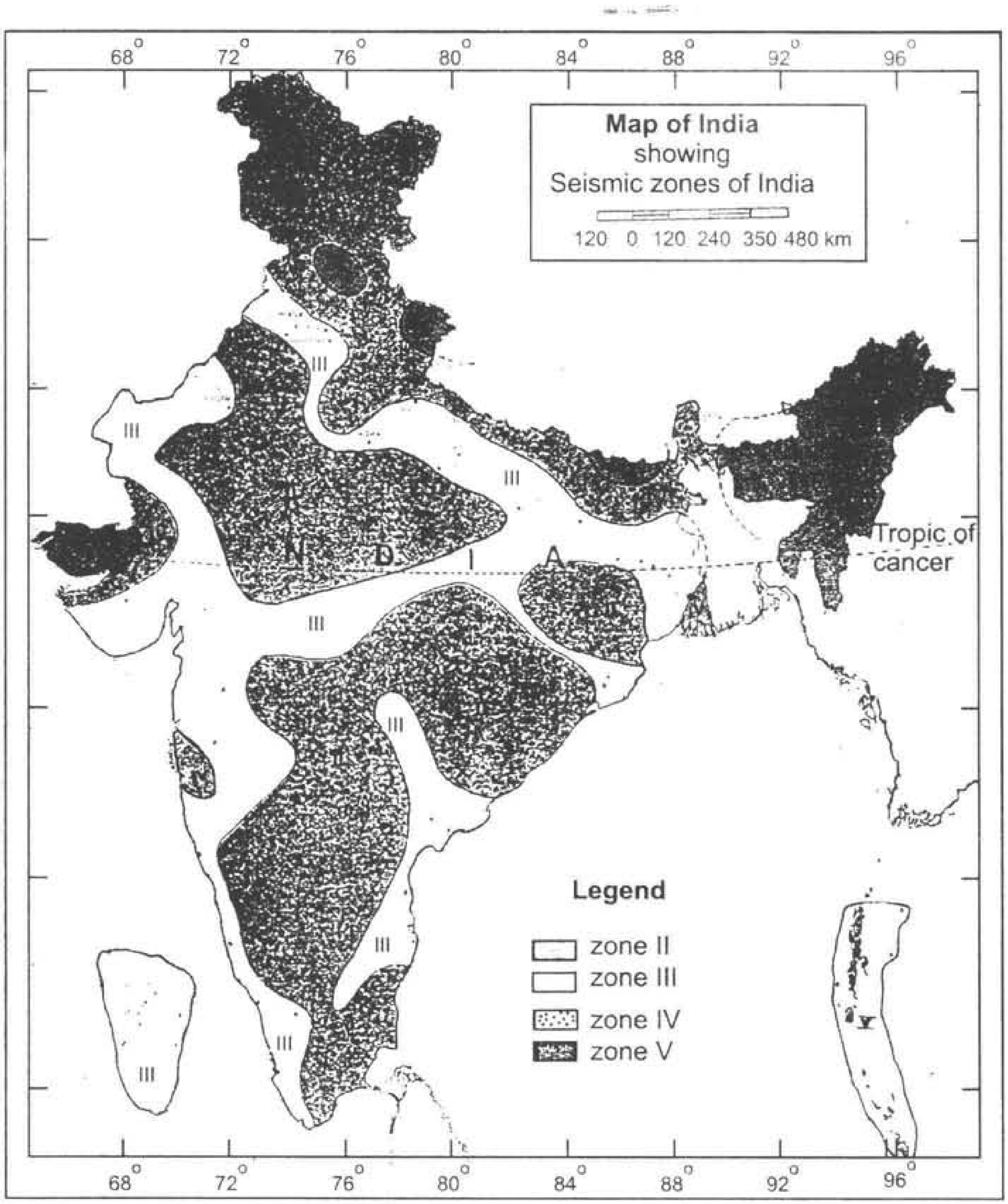


Fig. 10.11 Sketch map of India showing seismic zones (source IMD).

Research : The upgraded seismological network gave rise to useful and unique digital broad band and strong motion data sets for several significant earthquakes in the last decade including the recent great Sumatra earthquake of 26th December 2004. This helped in understanding about the earthquake process in the inter-and-intra-plate seismic regims. The Crust and upper Mantle structure of Peninsular shield region generated by the regional events. For the first time ground motions expected from future scenario earthquakes have been estimated from the Jablpur (1977) and Bhuj (2001) earthquake data.

Role of IMD

IMD is the nodal agency of Government of India, responsible for monitoring seismicity in and around India. IMD rendered more than 100 years of seismological service to the nation. The first seismological observatory of the country was set up at Kolkata in 1898. The operational task of the (IMD) department is to quickly determine the earthquake parameters immediately after the occurrence of an earthquake and disseminate the information to all the concerned State and Central Government, agencies responsible for rendering relief and rehabilitation. The information is also broadcast to public on AIR and DD and press etc.

National Seismological Network

It consists of 47 permanent observatories and 4 observatories in Northern India for special studies (See Fig. 10.12). Of the existing observatories 10 of them located at Ajmer, Bokaro, Bilaspur, Bhopal, Bhuj, Chennai, Karad, Pune, Thiruvananthapuram and Visakhapatnam, recently upgraded with global seismograph Network standard digital broadband seismograph system and 14 also been upgraded with Broad Band Seismograph systems of different makes. All 24 systems are of the state-of-art type having broadband sensors, high dynamic range (24-bit) digitizers, Global Positioning System time synchronisation and facility to access the data remotely through telephone mode or satellite communications.

A central Receiving Station has been set up at IMD HQ in New Delhi, which has the operational responsibility of keeping round the-clock watch of seismic activity, downloading the waveform data from remote field stations through dial up facility, analyse and disseminate the earthquake information to user agencies (See Fig. 10.13).

National Seismological Data base centre at IMD HQ in New Delhi, supplies a number of seismicity related reports for specific regions for establishment of Industrial units, power houses etc, and provides consultancy services to various State and Central Government Agencies on earthquake related matters. The other important activities of the division – all correspondence related to earthquake prediction, disaster management, supply of seismological data to various national and international organisations including research and academic institutions, river valley projects etc.

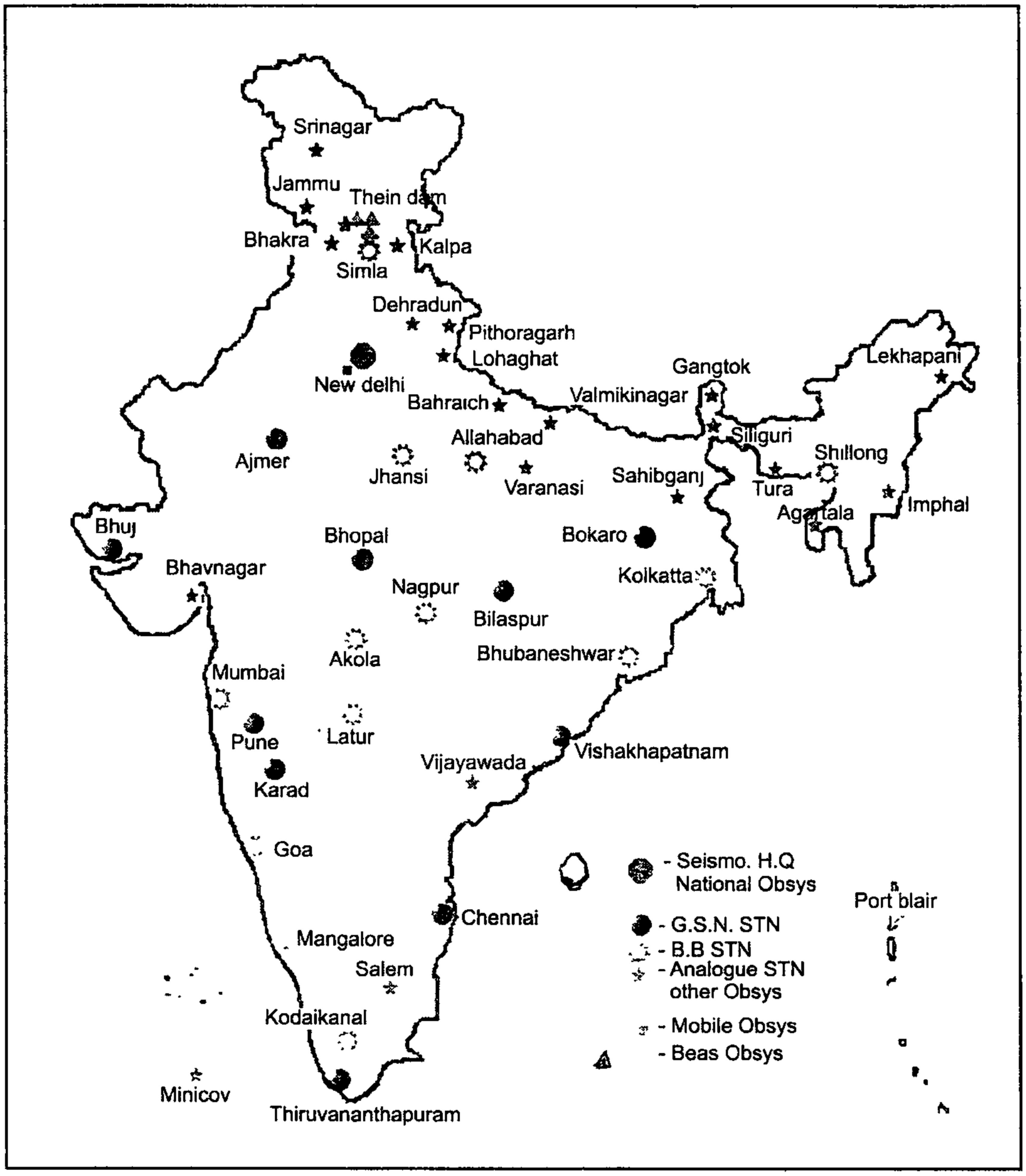
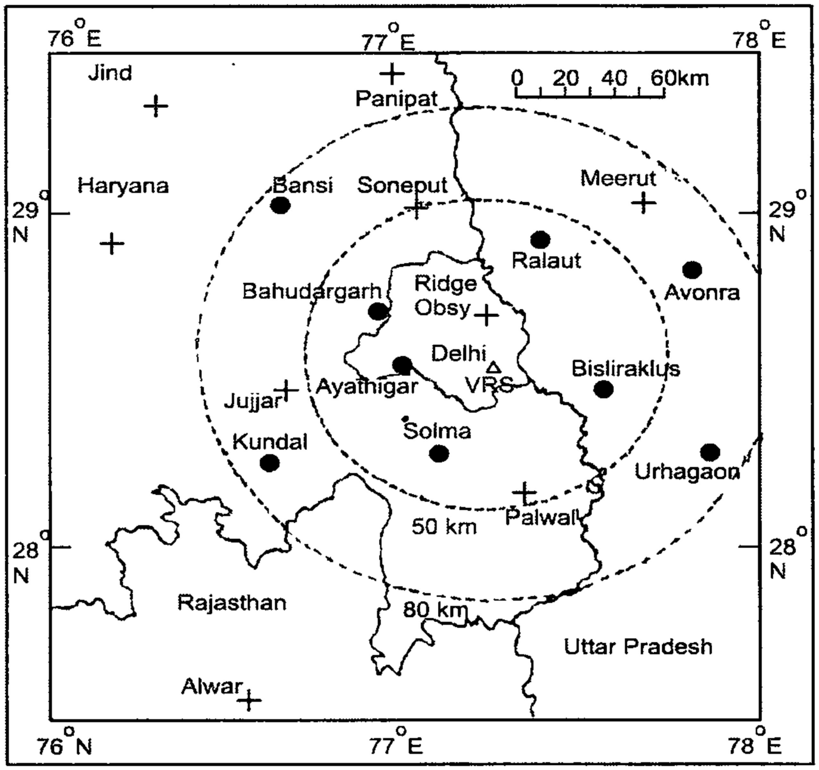


Fig. 10.12 Seismological observatories of India meteorological department.



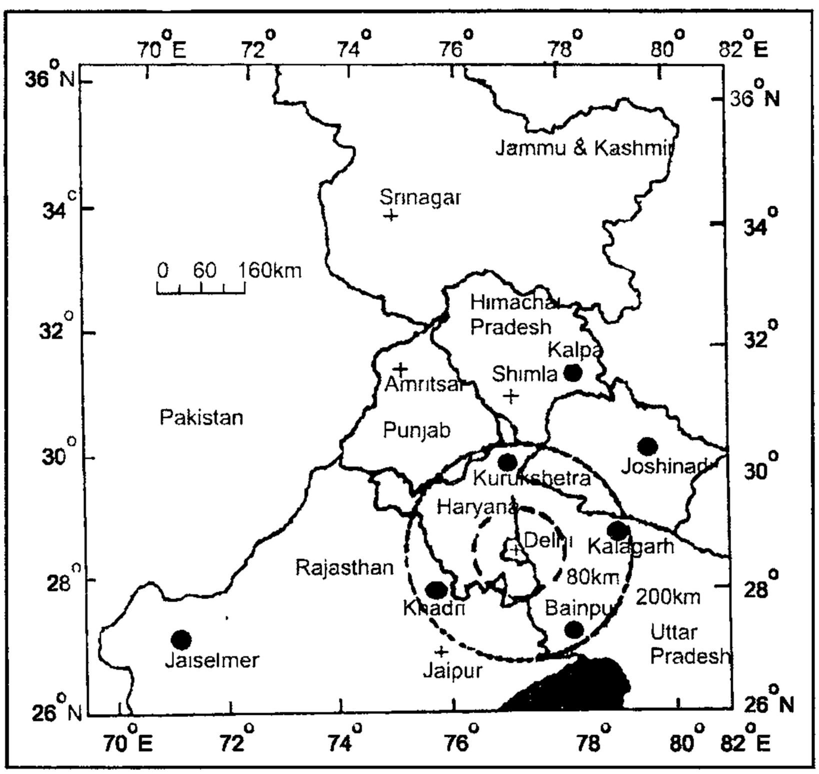


Fig. 10.13 Seismic telemetry network in and around Delhi.

The Seismological Division publishes a monthly National Seismological Bulletin which contains the phase data and the processed information on epicentral parameters of all earthquakes located by the National Seismological Network. The bulletins are periodically sent to International Seismological center (ISC) to incorporate into the global network.

IMD is a permanent Member of the International Seismological Centre UK, earthquake information, publications, bulletins are regularly exchanged by IMD and ISC.

Seismic Zoning of India : Based on Bureau of Indian standards (IS-1893 - part 1 : 2002) collection of scientific inputs from a number of agencies, the country has been divided into four Seismic zones ; Viz. zone II, III, IV and V. Of these zone V is the most Seismically active region intensity on Richter scale 9 or more, zone IV 8 to 9, zone III 6 to 8, while zone II is the least 5 or less.

Important Services of Seismological Division

Micro-earthquake surveys for monitoring after shocks, Swarm type seismic activities and site response studies by deploying portable seismographs in the affected area.

After shocks in Bhuj area is monitored at Rajkot, Surendranagar, Jamnagar for studying the explosion like blast sounds reported in the region.

As part of Tsunami warning system for the Indian ocean region, a real time Seismic monitoring and dissemination of data is in progress.

Major event in 2004 : A great earthquake of magnitude 9.3 occurred on 26 December 2004 at 06 hrs 29 minutes IST off west coast of Sumatra Island region, lat 3.3^{o} N long 96.1^{o}E. It generated destructive Tsunamis, took a toll of more than 3 lakh people. The Seismic belt extended from Sumatra to North Andaman Islands and caused several earthquakes of large magnitude. The main shock was followed by intense aftershocks. To study these an arry of five temporary field observatories set up in Port Blair and observatory upgraded deploying state-of-art digital broadband Seismograph system. The five field Seismological observatories are located at PortBlair, Baratang, Havelock, Hut Bay and Great Nicobar.

CSO Shillong (Central Seismological Observatory Shillong) was established in 1952 where Seismology, Meteorology and Radiation units are funtioning with the round-the-clock watch of seismology is functioning from 24-4-1989. All earthquakes of magnitude 4 or more within epicentral distance of 25 degrees transmitted to HQ New Delhi. Recording of plate motion with the help of Geographical Position System is continued from December 2001.

Earthquake Risk Evaluation Centre (EREC) was established in 2004 by Government of India to guide national effort in mitigating disastrous impact of earthquake and to evaluate earthquake risk. Microzonation of Jabalpur, Guwahati and Delhi is undertaken in collaboration with Global Seismological Institute (GSI), National Geophysical Research Institute (NGRI), IIT Roorkee and Central Building Research Institute (CBRI) Roorkee.

According to National Disaster Management Authority (NDMA) all new constructions must be earthquake resistant, particularly in cities located in seismic zones. The guidelines are selective seismic strengthening and retro-fitting of existing priority structures located in high-risk areas. Compliance of fresh building codes, revised town planning that will make it mandatory for all builders to incorporate earthquake-resistant features in their construction plans.

Earthquake Safety

It is said that earthquakes do not take lives but the ill constructed structures kill the people. Bhuj (Gujarat) earthquake of 26 Jan 2001, intensity 6.5 on Richter Scale took a toll of thousands, while the earthquake of higher magnitude (about 6.5 - 7.0) shook Seattle in February 2001 without any causualitiy and there were no house collapses, because the houses were constructed with earthquake safety guidelines. During an earthquake, structures (buildings) will experience two kinds of seismic wave forces. One is lateral longitudinal waves or horizontal to and fro and the other uplift (vertical or tranverse waves). The lateral or shear forces which are horizontal they shook the buildings back and forth, while the transverse waves cause the buildings move up and down. Keeping these movements in mind, using metal connectors, shear walls and fasteners, the structural stability of the building may be strengthened. This is the basis of earthquake proofing.

Retro-fitting process is reinforcing the foundation of existing buildings to bring them to the level of the present norms of earthquake resistence. The cost of retro-fitting may take about 10% more than the actual building cost. It must be noted that a single storey or a multi-storied building are eually hazardous to earthquakes but a poorly designed structure may crumbel while a well-designed multistoried structure may only shake.

When mild earth tremors are felt rush out of the house to an open area, avoid taking shelter near walls or structures which may collapse. Even if you are in sturdy house observe the safety rule of Drop-Cover and Hold.

10.4 Earthquake Forecast and Disaster Management

The causes of earthquakes are still not clear and the forecast of earthquake parameters – place of occurrence, strenght of occurrence and period of occurrence are being monitored with the help of Seismograph network but forecasting is still in infant stage. It is said that nature itself provides man with some indicators about its disastrous attack. A study of behaviour of certain animals shows that they sense the approach of a calamity better than man. These signs being used in Russia and China. There appears to be some relation between solar activity and occurrence of earthquakes. The life period of an earthquake is about one minute. Keeping the above aspects of uncertainity of forecasting, disaster preparedness (before the event) and rescue, relief and rehabilitation (after the event) are the present required action plan. The action plan before the hazard lies in zoning, construction of houses/ structures with earthquake resisting technology. As regards post disaster action plan of rescue, relief and rehabilitation is already discussed in cyclone disaster management plan which holds good for earthquakes as well. However it is briefly repeated here about **army's role**.

Rescue Operation

This includes retrieval of bodies live/dead from debries. This is the most sensitive task requiring skill, machinery and handling the existing awesome situation immediately. This work is most efficiently handled by Army in all past earthquake disasters and deserves praise. First, the bodies have to be extricated from the debries. Live people be shifted immediately to hospitals or medical camps for treatment. The extricated dead bodies and other animal caracases have to be buried or burnt after due verification by the local civil authorities. This part of action must be completed before the bodies are decomposed.

Relief Operation

The affected people have to be evacuated to relief camps or shelters like school, temples, churches, cinema halls etc. They should be provided food, medical aid besides accomodation. The personal belongings of retrieved from debries be handed over to them in the presence of local civil authorities (Sarpanch). Arrange transport (military or civil) to be provided for evacuation of the affected people and their belongings.

Medical Aid : In widely affected areas/villages, general medical checkup may be conducted to avoid the occurrence and spread of epidemic. Civil doctors may also be involved in this work. All care be taken to provide clean water, hot food in the camps. The required foodgrains be procured from civil supplies authorities or they may be asked to supply in adequate quantity. The food articles be distributed to the affected needy people involving civil authorities.

Clearance of Debris

Army is well equipped with dozers for this purpose.

Construction of Temporary Dwellings

During severe earthquakes most of the village houses get damaged or collapsed. In such cases temporary dwellings required. These will be provided by army tents or errecting tin-sheds to provide accomodation to the victims. Temporary schools may be run by army and NGOs to keep the children engaged in acadamics.

The following are exceptes from the book "Earthquakes, Animals and Man" 1987 by Dr. B.G. Deshpande. Do's Dont's before, during and after the earthquake.

What to do before an Earthquake

It is safest to remain out of doors immediately before the onset of the earthquake, if this moment can be anticipated. One should leave the house and stay out in the open or in temporary camps till the scare is over. In short, if you take proper precautions, chances are that you will not be hurt.

- Keep cool: panic causes heavy injuries.
- Secure all top heavy objects like furniture, storage cabinets, fridges, etc. to the walls.
- Keep supplies of food, water, clothings (warm, if in winter), torches or candles, emergency medicines, radios, helmets, first-aid kits, blankets ready with you. Use plastic bottles in preference to glass bottles for carrying water or other liquids.
- Keep all combustibles and explosives at a safe distance.
- Turn off gas, electric stoves, water, etc.
- Educate all members of the family as to what to do in such emergencies.
- Avoid the risk of an epidemic, which usually follows earthquakes, by using safe water and clean food.
- Evacuate old dilapidated buildings as they are sure to tumble first.

What to do during the Earthquake

There is a drill proposed as to what to do during the earthquake. Since earthquakes last for only a few seconds to a couple of minutes, the earthquake can be all around you before you are aware of it.

- Do not panic. The ground movement is frightening to all.
- If you are in a building, stand in a strong doorway or get under a table, desk or bed; avoid standing just outside the main door or near the outside walls. This is usually an unsafe place. Watch for falling objects.
- Do not rush outside without making sure you are going to be safer there.
- If you are out of a building when on earthquake strikes, stay out. If you are in an automobile, stop at the neartest safe place, away from buildings or trees.
- Watch for falling plaster, bricks, ceiling fixtures and other loose objects.
- Do not use gas stoves, candles or matches unless you are sure there is no combustible gas around.
- Avoid escalators; even stair-cases may be crowded by escapees. Await your turn.

What to do after the Earthquake

After the earthquake is over, there will be tremendous rush of rescue work. Those who have escaped injuries, will be trying to rescue persons who have been trapped. If you are one of the trapped, wait patiently for your turn; remain calm, conserve your energy; if possible tap with a metal piece, so that your call will reach rescuers.

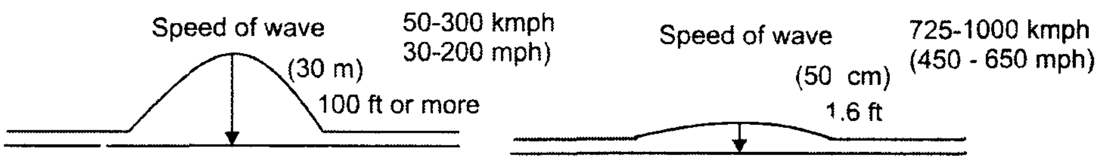
- Look for the injured in your family or neighbours' families because you know where they were and probably still are. Render such assistance as you can, unitl medical aid arrives.
- Check you electric, gas, water and sewerage connections. They may have gone haywire and damaged beyond immediate repair. You will have to live without them for some time.
- Check for fires and fire hazards, and secure fire extinguishers. Do not strike matchsticks unless you are sure that there is no gas leak around. Watch for instructions from the government rescue authorities on radio or by other means, regarding likely after-shocks and the manner in which the relief will be rushed to you.
- Keep away from hanging portions of buildings or overhanging cliffs, as they may fall due to after-shocks, which do continue for some time.

10.5 Tsunamis

In Japanese language Tsunamis meaning harbour waves. In Pacific Ocean and Hawaian Islands Tsunamis are prominent. They cause great damage to life and property in coastal areas. Tsunamis are very long waves, caused by the submarine earthquakes/explosions/volcanoes and great landslides into the oceans. Tsunami waves travel round the globe. Like Rossby waves, they have great wavelength about 600-1000 km, wave height 5.50 m and travel with a speed of about 500-1000 kmph in a circular waveform, the centre of the circle being the position of earthquake explosion/landslide. These waves show their fury in shallow waters, but not in deep water. Though they travel round the world but their destruction diminishes radially as they move further and further from the position of earthquake/explosion in the sea bed. Tsunami wave heights are mangnified when they coincide with the lunar tide. Even earthquakes also trigger more violently when they coincide with solar/lunar tides (of full moon and new moon). Any submarine earthquake intensity more than six on Richter scale may develop Tsunamis waves. Tsunami waves become more and more disastrous with the increasing intensity of the earthquake.

When a wave begins in the deep sea/ocean waters the wave height may be small, say about 30 to 60 cm (1 to 2 ft) and may look like a small rise and fall of sea surface water, but when they move to shallow waters they become very high. The following example illustrates the amplification of waves.

A Tsunami Sanriku struck Honshu, Japan on 15 June 1896. Fishermen about 35 km out at sea in deep water did not even notice the waves, height about 30 cm (1 ft) pass under their boats at that time, but when they returned to the port Sanriku they learnt about 28000 people lost their lives and about 270 km of coast line was destroyed (see Fig. 10.14).



Tsunami approaching the coast 1.5 to 30 km (500 to 10000 ft)awary from the coast

316, 800 ft away from the Coast ~ 100 km

Fig 10. 14

Tsunami in deep water can have wavelength more than 500 km and a period of about an hour (period of wave is the time taken between two succeessive waves pass through any fixed point on their way). This is entirely different from the normal California tube, which generally has a wavelength of about 100 meters and a period of about 10 seconds. As said earlier Tsunamis are shallow water (harbour) waves such that the ratio of water depth (d) and wavelenth (λ) is very small.

$$\frac{d}{\lambda} = (\mu, \text{ is very small}).$$

The wave speed (c) of these shallow water is given by the formula

$c = \sqrt{gd}$,

where $g = 9.8\ m/s^2$, gravity of the earth at the place, d = depth of the water.

Thus in deeper water λ is small and c is large.

let d = 6 km, then

$$c = \sqrt{9.8 \times 6000} \simeq 873 \text{ kmph}.$$

c is comparable to the speed of jet aircrafts.

The rate of loss of wave energy E is given by

$$\frac{dE}{dt} = \frac{k}{\lambda} \text{ where k is constant, } \lambda \text{ is wavelength}$$

This shows that Tsunami waves can travel with high speed for a longer time with little loss of energy.

Some Features of Indonesian Tsunami (26-12-2004): On 26 December 2004, The Indian Plate slipped below the Burma plate at 6.29 AM IST, releasing phenominal pressure which forced the sea water rise upwards. This slipping of Plates caused earthquake of magnitude 9.0 on Richter Scale. The Seismic yield was of the order 32 billion tons of TNT. The epicentre of the quake was in the sea Northwest of Aceh Province in the Indonesian island of Sumatra. The earthquake was felt in Andaman Islands at 8.38 AM and its magnitude was 6.1 on Richter Scale. The pressure wave travelled about 1200 km in 2 hrs 08 minutes (or about 600 kmph). The Tsunami waves travelled as far as the coast of Africa-Somalia, a distance of 6500 km from the epicentre. It took a human toll of about 3 lakh people. It hit the Kerala coast and took a toll of 162 people there.

Earthquakes are highly localised phenomena, but 26 Dec 2004 earthquake/ Tsunami caused damage in 13 countries, particularly Srilanka, Indonesia, India, Thailand. This Tsunami is called the world's worst ever natural disaster because it affected 13 countries and not because of human deaths (1970 Bangladesh cyclone took a toll of 5 lakh people in a single country).

Tsunamis have been occuring occassionally in the Pacific Ocean in the past. In 1946 a Tsunami killed 165 people in Hawai. Ever since 1946 a Tsunami warning system shared by 26 countries around the Pacific Ocean. In 2004, Srilanka, Indonesia, India and Thailand shared the destruction. In 1976 Tangshan (China) earthquake killed 2 lakh people due to structural failures, while in case Sumatra Tsunami it is due to the volume of water at great speed and height that killed the people. The wave height varied 2 to 6 meters along the coast of India with great speeds. The survivor fishermen of 2004 Tsunami reported that they observed continuous line of waves looking like dark (colour) elephants with a halo of spray, a white haze above this line at a distance of about 10 km away. The waves approached very fast while the rest of sea was relatively calm and the weather was fine with normal winds. The survived fishermen, prompted by unnatural scene, immediately cut lines which held the fishing nets to the boats and aligned the boats perpendicular to the advancing tide to avoid being overturned. This instinctive action saved their lives. When the Tsunami waves passed below the boat, they reported that the boat was lifted much higher than the normal rough sea waves in a short time. The wave travelled very fast towards the shore. They observed similar waves coming towards them and passed below them very quickly. Some of them saw the waves break on the shore in a huge wall of water. People on the shore observed similar wave movement with a frightening sound. The people who were engaged pulling "AilaVala" (team of men and women 50 to 70 the ropes around their waists and drag the net with the fish catch), one person who survived the tragedy reported that the net was very light to pull. Sensing it unnatural he untied the ropes from his body and shouted others to do the same. In that short span of time the sea wave hit the shore and all hell broke loose. He was submerged under huge wall of water and carried away inland (fortunately for him the shore had elevated dunes) where he was deposited by the waves. He saw that there were bodies around him of his collegues who were still tied to the net. He went to their rescue but found all of them dead. The chance of survival from the wave breaking on the shore upto 500-1000 m of flattish area very little. The speed of the wave on the shore was many times more than the speed of a person able to run on the sandy shore.

Adverse effects of Tsunami on fisherman

Tsunami waves destroy everything in their path. Boats, thatchet houses in the coast were badly damaged. They were deposited further into the deep sea water or on the sand shore damaged. Fishing nets were sucked back into the sea or damaged critically and rendered unfit for use. Fishing community lost their livelihood.

The following precautionary measures to be observed.

1. ***GIS*** : Acquaint the geographical information of your house, street (height above mean sea level) and the distance from the coast.
2. ***Education*** : Be familiar with the Tsunami warning signals.
3. ***Signs of Warning*** : Coastal people should always be alert with the earthquakes. Earthquakes are the first warning signals of coming Tsunami particularly if they are violent shaking.
4. If the water in the Bay harbor or along the beach suddenly sucked or rushed out to sea, leaving fish, boats stranded, it is a sure sign of advancing Tsunami in a short time (within 5 to 30 minutes) that will hit the coast.
5. When Tsunami warning issued immediately rush to the safe top floor of the strong building 50-100 m above mean sea level (or very high elevated place) or cyclone shelter, but never venture to go towards the beach which will be inviting danger.
6. Take all precautionary measures that are recommended for storm surges.
7. Tsunami is a series of waves. First wave will be less dangerous, but subsequent waves will be progressively higher wave height and invade in a very short time. Do not leave the cyclone shelter or safe multistoried house where you have taken shelter till you hear the dewarning on Radio "All clear".
8. The hit (attack) of Tsunami will cause contamination of all food and water and cracks in structures/houses. Make sure that your house is safe before entering back into it. Be careful while wading through inundated water.
9. Monitor local Radio/DD anouncements for evacuation orders when Tsunami warning issued. Do not return to low lying areas untill the Tsunami threat has passed off and the "All clear" dewarning is anounced.

Tsunami/Storm Surge Mitigation

Tsunami waves are entirely different from storm surge (tidal) waves. The later are dependent on the central pressure defect (in the eye) and movement of the cylone, while the farmer dependent on the magnitude of the earthquake.

In addition to the basic relief measures like water, food, medical aid the administrative authorities should find means of livelihood of the affected people. Forest wing of World Bank encouraged the plantation of shelter belt to minimize the losses during storm surge and Tsunamis.

In India Forest Department encourages Social forestry along the coast within the limits of coastal Regulatory zone where Tsunami tidal waves pounded the coast in December 2004. World Bank is supporting Shelter Belt plantation programme by planting casurinas, cashewnut and palm plantations along the coast. These belts will lessen the damages of Tsunamis/storm surges. The participation of communities, Self Help Groups, NGOs, Vanasamrakshana Samities is essential for the success of Social forestry.

10.6 Landslides and Avalanches

In high mountains like the Himalayas, any disturbance in the natural balance triggers landslides and avalanches. These cause disruption of road communication, loss of property and life in hilly terrain. Landslides and avalanches are of great concern to design roads and geotechnical engineers, road users, Government administration, geologists and defence services and local inhabitants.

Landslides : A landslide or mudflow is a downward movement (in hilly region) of rock, soil or debris flow under gravity. Landslides occur when the ground is stressed beyond its frictional strength. The following main factors contribute to the landslides.

1. Erosion by rivers, glaciers or ocean waves creating over steepened slopes (soil erosion is the wearing away of land surface by natural agencies of wind and water).
2. Strength of the rock or soil.
3. Seismic zones
4. Topography, ground, water and vegetation
5. Accumulation or gathering of excess weight by rain, snow, flood and waste piles.
6. Man made causes like mining, terrain cutting and filling.

Of all these the steepness of slope and amount of water have greatest correlation with landslides. In 1920 an earthquake induced lanslide in China (Kansu province) took a huge toll of human life (about two lakh people). In Columbia (in 1985) a devastating landslide wiped out town and villages. It took a humal toll of about

20000 people. In India, Jammu and Kashmir, Himachal Pradesh, Uttaranchal, Sikkim, Siachen, Kulu, Manali (southern peripheries of the Himalayas) the incidence of landslide avalaunches are a regular phenomena every year. February 2005 witnessed very intense snowfall (15 to 45 ft or 4 to 6 m depth) in Kashmir and neighbourhood. This caused landslides and avalanches for a full one week and completely cutoff the valley from rest of India. Several hundred people lost their lives despite Army and Air force best assistance on war footing to the local administration. Similarly in December 1995 a landslide near Kulu buried about 100 people.

Project "PARVAT" : It is a joint venture of DRDO (SASE), Ministry of Defence (Army, Air force) and DST (Department of Science and Technology)–IMD and National Centre for Medium Range Weather Forecasting (NCMRWF). The aim of the project is to improve weather and Avalanche forecasting over strategic areas in western Himalayas and also to cater the needs of local people. Under this project three IMS - 1500 Radiotheodolite have been installed at Manali, Sasoma and Jammu, 22 surface Meteorological observatories and 3 upper air stations, Research and Development work, issue of weather forecasting at a resolution of 50 km, 5 days in advance with minimum accuracy of 80% in Western Himalayan region.

***Landslide Preventive Measures* :** Preventive measures differ from place to place. Earth retaining structures, both cement masonery type and flexible type are strongly recommended. Afforestation and turfing of slopes with suitable plants / trees is a long term measure against landslides. People treading in hilly areas must be very careful in their movement just after heavy rains/ snowfall and they should monitor the weather forecast regularly.

10.6.1 Avalanches

An avalanche is the downward slide or descent of a large mass of snow/ice on slope having considerable velocity and force. It is a natural destructive force. An avalanche consist of snow, ice, air, water and soil impurities. A considerable part of our country in the foot of Himalayan region remains cut-off from the rest of the country due to avalanches. Snow avalanches occur in winter months and take heavy toll of life, a few highways remain blocked for several months (5-7) in a year. The frequency of avalanches are more where the slope is 35^0 to 45^0. Snow avalanches and landslides are grave problems in northwest and central Himalayan regions which are inhabited or frequently used by local population, for communication, winter sports, mountaineering and defence.

Avalanche Hazard Mitigation in India

In India there is no civil organization neither at the State level nor at the National level to mitigate the avalanche hazards. Recently, as described above project 'PARVAT' commenced for this purpose. Snow and Avalanche Study Establishment (SASE) of DRDO laboratory provides snow avalanche information and forecasting to armed forces. The SASE aims at to provide nowcasting and also forecasting about avalanche hazards to the population residing in landslide/avalanche prone Himalayan region. For this purpose SASE established snow measuring meteorological observatories in Jammu and Kashmir, Himachal Pradesh, Uttaranchal. These observatories communicate data to Avalanche Forecasting and Mountain Meteorological centres at (i) Srinagar - for Kashmir valley (ii) Sasoma–for Siachen and Nubra valley and (iii) Manali- for Himachal Pradesh. These centres collect data from Automatic weather stations, satellite remote sensing data pertaining to latest terrain, qualitative and quantitative snowfall information, precipitation and snow cover. Satellite based sensors provide high resolution data from visible and IR thermal wave lengths. This data facilitates identifying terrain conditions, avalanche sites, snow albedo, surface temperature and snow cover. GIS (geographical Information System) together with satellite data helps SASE forecasters to prepare Avalanche Bulletin. These bulletins are brodcast on AIR and DD regularly, which are proved to be very helpful to the local inhabitants, winter tourists, traffic regulation authority, winter sports, mountainearing department. It created great awareness among the users and thus helping in mitigating the avalanche/landslide hazard impact.

Preventive Measures : Soil stabilization by terracing geofabric, grouting etc., should be resorted. Afforestation on large scale in areas prone to landslides and all along the road on either side with large growing trees may help arrest slides.

10.7 Volcanoes

Valcanoes are believed to be caused by the plate tectonic movements. The movement of the molten rock material called magma of the earth's core causes earthquakes. In the weaker zone of earth's crust or faults the upwelling of magma takes place in association with plate boundaries divergence or convergence or transform faults. Thus weaker zones of earth's crust or faults are the principal locations of Volcanoes. It is theorised where old crusts are buried they provoke earthquakes and Valcanoes. (when plate boundaries move or transform faults). Valcanoes are classified into three types depending on the processes that cause them.

1. ***Subduction Volcanoes*** : When plates collide the boundaries submergence or subduction of one under the other plate takes place. Magma from the earth's core constantly upwells and cools along the mid-ocean ridges. This adds material to the earth's tectonic plates. At the points of collision or undercutting of the plates Volcanoes occur frequently. An arc shape belt of volcanoes or islands is often observed. 80% of the global valcanoes occur in the areas of subduction. "Ring of Fire" in Pacific Ocean is caused by the complex interaction of tectonic plates and many subduction zones. The following Table 10.3 gives the major volcanic zones and associated plate movements.

2. ***Rift Volcanoes*** : when plates are divergent magma reaches the surface directly. These are called Rift Volcanoes. 15% of the global volcanoes occur in divergent plate zones. The Iceland volcanic activity belongs to this category. Most of the earth's rift zones (7500 km) are under oceans. Many of the sub-oceanic volcanoes exist undetected.

3. ***Hot-spot Volcanoes*** : Some volcanoes occur in the interior of tectonic plates. It is theorized that local hot plumes rising from magma accounts this type volcanoes. Volcanoes in Hawaii belong to this category.

Table 10.3 Subduction zones and associated plate motions.

S.No.	Name of location	Plates Involved	Subduction rate	length km cm/year
1.	Kuriles - Kamchatka Hanshu	Pacific plate under Eurasian plate	7.5	2800
2.	Tonga-Kermadec-New zealand	Pacific under Indian	8.2	3000
3.	Middle American	Cocos under North American	9.5	1900
4.	Mexican	Pacific under North American	6.2	2200
5.	Sundra-Jawa-Sumatra - Burma	Indian under Eurasian	6.7	5700
6.	Solomon-New Hebrides	Indian under Pacific	8.7	2750
7.	Iran	Arabian under Eurasian	4.7	2250
8.	Himalayan	Indian under Eurasian	5.5	2400
9.	Ryukyu - Philipines	Philipine under Eurasian	6.7	4750
10.	Peru - Chile	Nazca under South American	9.3	6700

Note : Subduction volcanoes are associated with convergent plates.

Volcanoes are also classified as effusive or explosive. In effusive eruptions, most of volcanic matter is ejected in the form of lava (temperature 1000 to 1200^{0}C) which flows down the mountain slopes. Explosive eruptions spew out steam, rock materials, dust, smoke and ash particles. This is called Tephra. Tephra is a collection of fragments of magma, consists of rock materials of all sizes from blocks of materials to fine dust/ash.

Forecasting

Past history of well known volcanoes like that of Mt.St. Helens (in the State of Washington, USA) shows that it is not possible to forecast the volcanic eruption. However it is possible to infer that a significant event was going to occur by observing the events – earthquake tremors, volcanic tremors, growth of a bulge on volcanic cone.

Based on the frequency of eruption the volcanoes are classified as Active, Dormant and Extinct. Volcanoes which erupt constantly are called active. Strombolic volcano of Mediterranean sea, Barren Island volcano in Andaman and Nicobar islands (India) belong to this type.

Valcanoes which erupted earlier but now they are quiet without any activity are called Dormant.

Valcanoes which existed long back and are dead (like the Deccan trap) are called extinct.

It may be noted that the Dormant Volcanoes may erupt at any time and become dormant and while the extinct volcanoes have no such chance.

Some Features of Volcanoes : The highest active Volcano is Autofalla, Argentina, located at a height of 6450 m. The largest crater of volcano is Mt. Aso, Japan, whose circumference is about 115 km. The volcano of greatest eruption is Santorini (Thira) 1470 BC, in the Aegean sea, erupted about 63 km^3 of rock material. Krakatova Volcanic eruption, August 1883, debris/ash particles penetrated into lower stratosphere (32 km) and masked the sun for days and converted days into nights in the neighbourhood of the volcanic surrounding area.

Volcanic Matter : Volcanic matter may be molten lava or Tephra. The molten discharge of a volcano is called lava, consists mostly of moleten silica or rock (basaltic), while the composition of Tephra mostly consists of silicon dioxide and minor quantities of oxides of Aluminium, Sodium, Calcium, Potassium, Iron, Magnesium and water vapour. The speed of basaltic lava 10-100 kmph and temperature 1000 to 1200 ^{o}C. Tephra results from the earth's inner core (the magma) rising to surface and undergoes chemical and physical changes as it ejected into atmosphere by the force of volcano itself. The velocity of Tephra matter varies with the size of the debris (about 500 mps). The eruption ash debris may be pushed into atmosphere to an altitude of 80 km.

"This page is Intentionally Left Blank"

CHAPTER - 11

Hazards associated with Convective Clouds

Introduction

For practical purposes of disaster management we treat cumulus and cummulonimbus clouds as convective clouds. The weather associated with these clouds are thunderstorms, hailstorms, dust storms, tornadoes, norwesters, kalbaisakhi, dust/sand storms. The main hazards associated with these weather conditions are :

1. Lightning discharges,
2. Hail,
3. Squalls,
4. Heavy rain,
5. Poor visibility.

Convective cloud cells develop in unsaturated air when environmental lapse rate is higher/much higher than dry adiabatic lapse rate, while in saturated air environmental lapse rate is higher than saturated adiabatic lapse rate. The presence of cumulus clouds indicate that the cloud, air mass is saturated and environment is unsaturated. In any locality instability and precipitation develops in the following process.

(i) cumulus may develop in the afternoon by the heating of the lower surface through its contact with the hot ground surface, or when a cold air mass over runs a warm ground surface,

(ii) the cooling of the middle atmosphere 4-10 km asl may initiate instability in the lower atmosphere (0-4 km asl),

(iii) cumulus clouds may persist in the presence of high humidiy and large horizontal extension of cloud,

(iv) vertical development occurs in the presence of steep lapse rate,

(v) rain/showers may occur frequently in a locality where lapse rate of 6 °C/km in the presence of large humidity. In general low level convergence of winds, high humidity with associated upper level divergence is a most favourable condition for the development of cumulus and precipitation. An inversion of temperature at the top of the moist boundary layer is favourable for the development of severe thunderstorm. Vertical wind shear in lower level aids convection cloud development. Upper level divergence exists in association with jet stream. Lines of discontinuity or dry lines also aid convection clouds.

Thunderstorm

According to WMO a thunderstorm is defined as one or more sudden electrical discharges, manifested by flash of light (called lightning) and a sharp or rumbling sound (which we call thunder).

Cloud invariably cumulonimbus and generally associated with precipitation. The sound of thunder is due to the electrical discharge. In electrical discharge enormous heat develops which heats the air channel between the cloud and earth. The conducting channel is heated upto 30000^0 K, which is five times the temperature of the surface of the Sun (6000^0 K). Because of the sudden heating of the conducting air channel in a very short period, the diameter of the channel expands abruptly from a few millimeters to a few centimeters (ten fold). This sudden expansion of conducting channel generates shock waves which spread out as sound of thunder. Thunder is generally heard upto 10-15 km and rarely beyond 25 km. At any instant there are about 2000 to 3000 active thunderstorms around the globe, most of these occur in tropics. Simultaneously at any moment there are about 100 lightning flashes per second.

A thunderstorm day is defined as a local calandar day on which thunder is heard, irrespective of the actual number of thunderstorms on that day. The highest annual average of 242 thunderstorm days was recorded at Kampala, Uganda (0^o20'N, 32^o 30' E) in Africa.

A thunderstorm consists of several convective cells each having distinctive convective circulation. The dynamical building block of thunderstorm is the cell. A cell is a large compact region having updrafts (about 10 mps). Most of the thunderstorm cells have short period of life. At any instant of a thunderstorm, it consists of cells which are at different stages of evolution and each interacts with neighbouring cells or outside environment. Thunderstorms are local affairs and rarely exceed diameter of 10 km (or 100 km^2 area) and duration 1 to 2 hrs.

A thunderstorm cell has three stages of life cycle. (i) Cumulus or growing stage, (ii) Mature stage and (iii) dissipating stage.

In Cumulus stage updrafts are found throughout cloud, height grows (6-10 km) and takes a shape of cauliflower type domes on the top and cloud top temperature may be about –20 to –30 °C. Updrafts of the order 10 mps are common. The life period of cumulus stage may be 10-15 minutes. Light rain may occur at the base of the cloud.

In Mature stage both updrafts and downdrafts occur in the cell. Downdrafts are prominent below the freezing level. The lowest temperature in the cloud are found in downdrafts. At the top of the cloud, false cirrus anvil develops which mostly contain ice crystals. This stage lasts for about 30 minutes when it attains maximum height (12-18 km). In this stage severe lightning, precipitation and squalls occur. The strength of the updrafts may be 10-30 mps and downdrafts 5 to 15 mps. Downdrafts below the cloud base produces divergence of cold air and in the wake of this cold divergence new cells develop and thus trigger chain action of thunderstorms. The life period of the cell in this stage is about 0-75 minutes.

In Dissipating stage only downdrafts (speed 10 mps) are found throughout the cell. Squall speed of 10-15 mps at the ground of the cloud base is common. In this stage the entire cloud mass temperature will be cooler than the ambient air temperature. No more condensation occurs. The height of the cloud dissipates along with anvil. Cold air divergence spreads below the cloud and downdrafts cease to exist. The average life of the cell in this stage is about 10-30 minutes

Condition Favourable for the occurrence of a Thunderstorm

(i) Conditional and convective instability in the atmosphere,

(ii) Adequate supply of moisture in the lower troposphere,

(iii) Suitable synoptic situation to cause low level convergence and upper level divergence,

(iv) Suitable upper airflow which may advect warm moist air in the lower troposphere and cold dry air in the upper troposphere.

In a thunderstorm energy is released mostly in the form of latent heat. An average thunderstorm over an area of 50 km^2 with average rainfall of 2 cm releases energy about 25×10^{21} ergs, which is equivalent to about 30 Hiroshina atom bomb explosions. According to C.E.P Brooks estimates there are about 44,000 thunderstorms per day, 1800 occur simultaneously at any time, and 100 flashes of lightning per second. These discharges equivalent to a continuous current of about 2000 amperes. Assuming the potential difference 10^8 volts in the vicinity of thunderstorm area, the lightning discharges world over continuously transfers energy about 268×10^6 horse power.

11.1 Climatology of World Thunderstorms

Europe and Australia have the minimum frequency of thunderstorms about 20 thunderstorm days per annum. In southeast Asia the frequency is about 60 thunderstorm days around Bangladesh (Bangladesh, India and Myanmar). South

America, Africa and Indonesia have maximum thunderstorm days. Tropical oceanic regions around 20 °N and S and semipermanent high pressure regions are relatively free from thunderstorms. Polar regions are virtually free from thunderstorms.

The accepted record of 242 thunderstorm days per year recorded over a period of 10 years at Kamapala, Uganda 0° 20'N, 32° 36' E. There are only a few stations around the world which recorded 200 thunderstorm (TS) days or more given in the Table 11.1

Table 11.1 World Recorded TS days

Name of the station	Country	Lat	Long	No.of TS days per year
Kampala	Uganda	0°20'N	32° 36' E	242
Buma	Zaire	1° 34' N	30° 13' E	228
Kamembe	Rwanda	2° 27'S	28° 54' E	221
Bandug	Indonesia	6° 54'S	107° 34' E	218
Calabar	Nigeria	4° 57'N	8° 21' E,	215
Entebbe	Uganda	0° 02'N	32° 37' E	206
Carauri	Brazil	4° 53' S	66° 54' W	206
Mamfe	Cameroon	5° 46'N	8° 20' E	201

In India the maximum of 108 TS days recorded at Sibsagar (Assam), Krishna nagar (West Bengal) and there are very few stations which have annual frequency of 100 TS days or more.

Distribution of Thunderstorms over Sea Areas

According world map of thunderstorms, the incidence of thunderstorms over sea area is less than over land. This is clearly reflected in tropics. In tropical sea regions of Panama, Ecuador, Columbia, over gulf of Guinea along African coast, along the sea areas of western coast of Indonesia and Malaysia the thunderstorm frequency is high. High frequency is also seen in the ITCZ zone of North Atlantic and North Pacific. Minimum frequency of thunderstorms observed in the Trade wind zone between lat 10° and 30°.

11.2 Lightning

In 1600 AD, William Gilbert, the physician of Queen Elizabeth, studied about static electricity. He showed that glass /amber rod when rubbed with silk/fur attract small pieces of paper. He named this phenomena electric. In 1764, Benjamin Franklin found out positive and negative electric charges. In 1752 he showed with kite experiments, that thunderstorms have electricity. In 1753 he found that thunder clouds have negative charges, but later in one experiment he also found positive charge in the thunderstorm cloud. From his experiments Franklin propounded that a majority of thunder cloud base possess negative charge but rarely positive charge may be seen. In 1756 he developed the lightning conductor for protection of buildings, which is still in use.

Charge Seperation in Clouds

In convective clouds charge is observed from the formative stage. The positive and negative charges formed in the cloud are separated by the following mechanisms. (i) By the breaking of big rain drops, (ii) by capture of ions by rain drops and ice particles in the atmosphere, (iii) by collision of ice particles at different temperatures, (iv) by freezing of supercooled water droplets.

In the cloud the charges are separated by the combination of the above mechanisms.

In a well developed convective cloud (matured stage) updrafts transport positive charge to the top of the cloud, while downdrafts and falling rain drops transport negative charge to the base. Small ice particles or ice nuclei carry positive charge to the top of the cloud while big ice particles, soft hail carry negative charge to the base of the cloud. Generally positive charge is accumulated at the top of Cb and negative charge at the base. In contrast to this classical dipole model, modern theory assumes that there can be much lateral displacement between two charges. Most lightning flashes either transfer the lower negative charge to the ground or achieve effective partial neutralization of the cloud electrification by internal cloud discharge.

The Electric Field in the Atmosphere

In a fair weather the atmosphere carries a net positive charge everywhere on earth, the average potential gradient being 150 v/m. This implies that there is negative charge on the ground and it is assumed that the electrical potential of the ground is zero. The rate of change of potential with height is called potential gradient. The gradient decreases with altitude in free air, rapidly in the first one kilometer and slowly there after. The gradient at the surface varies during the day, being maximum at 1900 UTC and minimum at 0400 UTC, and the durinal range being about 35% of the daily mean. The potential gradient near the earth in fog is about 2000 v/m. In such conditions electric sparks (or electric discharges) may take place from the extremities of metallic conductors connected to the earth.

Critical Potential Gradient

An electric discharge (spark) takes place in the atmosphere when the electrical potential between two points reaches a certain value. In clear air of normal density the critical potential gradient is about 3×10^6 v/m. Dry air is a very poor conductor of electricity and requires a large potential gradient for eletrical discharge. However the presence of water droplets in the atmosphere increases the conductivity of the atmosphere. In cloud, the lightning discharge occurs at a potential gradiant of 1.0×10^6 v/m. It is found the average field strength within a thunderstorm cell is about 10^5 v/m.

The Lightning Discharge

In a thunderstorm the lightning stroke starts from the cloud in the form of stepped leader, with average step length of 50 m. The time period of each successive step is about 50 micro (μ) seconds. The average velocity of the individual step is about 5×10^4 km/sec and the velocity of total step is about 1.5×10^2 km/sec. The total time required for stepped leader to reach the earth is about 0.01 sec. After leader reaches the earth, a reverse stroke starts from the earth to the cloud through the channel made by the leader with an average velocity of 15×10^4 km/sec. After first discharge there may be other discharges which start from the cloud but little different from that of stepped leader. It will be a continuous leader, also called dart leader, with average velocity of about 2×10^3 km/sec.

When a lightning flash strikes near an observer, about 100 m of radius, the sound consists of (i) first a click, (ii) then a crack (like that of a whip) and (iii) finally the characteristic continuous rumble of thunder. The click is caused by a discharge streamer directed upward from the ground (towards the leader stroke before commencement of the return stroke). The crack is caused by the intense return stroke in the lightning channel nearest to the observer. The rumble comes from the multiplicity of sound sources distributed along the lightning channel. When the lightning strikes away from the observer (several hundred meters) the first sound heard like the tearing of cloth.

Types of Lightning

Lightning occurs in various forms. More than 60% of the occasions lightning discharge takes place within the cloud, or cloud-to-cloud between positive and negative charges. The second type of discharge is between cloud and the earth. This is commonly called thunderbolt. The negative charge at the base of the thunder cloud induces positive charge on the earth in the vicinity of the cloud base, which repels the negative charge on the earth. The discharge between cloud and the earth takes place at a critical potential gradient.

Ribbon Lightning : This occurs between the cloud and the earth when the wind is very strong (speed 30 kmph or more) which displaces the conducting air channel into a ribbon form.

Sheet Lightning : Sheet lightning is observed due to distant thunderstorms at the horizon, which illuminates the sky by its lightning flashes.

Air Discharge : This occurs between the cloud base and the air below but it fails to reach the ground. Air discharge generally takes place in deserts.

Bolt from the Blue : The electrical discharge which begins as an air discharge but after traveling a distance away from the cloud, the leader stroke reaches the ground. The discharge may reach the ground in some cases about 15 km away from the cloud, where the sky may be completely clear. That is why it is termed Bolt from the Blue.

St. Elmo's Fire : This form of discharge generally takes place at the top of high masts or elevated objects. When the thunderstorm cell passes over elevated masts a positive glow will be seen at the top of the masts, while the negative charge flows down. This type of discharge observed over ship masts, on aerial masts of flying aircrafts etc.

Ball Lightning : There is no scientific explanation about ball lightning. Ball lightning occurs in the form of electric balls of diameter ranging 1 cm to about 2 meters. These lightning balls may fall from thunderstorm clouds and explode or the balls may roll down a hillock and strike against some objects and then explode. The electric balls appear like soap bubles. These balls sometimes may roll down into rooms through windows, doors or electrical discharges.

Lightning Discharge between Cloud and Earth

An ionized air column that is formed by the accelerated electrons in a thunderstorm electric field is a leader stroke. The stroke constitutes air channel in the form of progressive steps of 50-100 m from the base of cumulonimbus cloud to the earth.

Generally the first leader stroke is not visible but the first one which steps on the earth is visible. This looks like an illuminated river with tributaries. The speed of the leader stroke may range 160 km/s to 1600 km/s. The return stroke which goes (in the reverse direction) from the earth to the cloud base appears as a flash. This we call lightning. The speed of return stroke may be 14×10^4 km/s which is approximately half the speed of light (speed of light $C = 3 \times 10^8$ m/s). The period of lightning discharge may vary from a few micro seconds to a full second. If T seconds denotes the duration of time between the flash and thunder, then the distance of thunderstorm from the observer is approximately T/3 km, that is every three seconds is equal to one km.

Lightning

An electrically active convective cell within a thunderstorm has a life period about 30 minutes to 1 hour. During this period flashings may occur 1 to 10 per minute with maximum of 20 flashes per minute after first flash. During the life of the cell the mean flashing rate is about 3 per minute.

11.3 Some Effects of Electric Shock

Electricity produces its immediate effects on the body. It causes disturbance in body function but they do not always cause structural changes. Two principal mechanisms that cause death are : (i) Ventricular fibrillation and (ii) Respiratory arrest.

Ventricular Fibrillation

The human heart has two main pumping chambers for blood circulation. One chamber to pass blood around the body (the left ventricle) and the second to pump it through the lungs (the right ventricle). The thick walls of the ventricle consists almost entirely of muscle. It is the simultaneous contraction of all the individual muscle fibres establishes a pressure within the ventricle which is sufficient to circulate blood. An electric current passing through the heart disturbs the coordination of these individual muscle fibres so that instead of contracting simultaneously they contract individually each at its own rate. A head pressure is no longer established in the ventricles and blood circulation ceases so that death ensues within about 4 minutes. If the ventricles are viewed in this state when the muscle fibres are contracting individually, the ventricles, instead of showing forceful regular contractions "heart beats" are seem to be lying in a flacid state, with irregular twitchings, 'fibrillation'.

Respiratory Arrest

An electric shock might affect respiration in two ways. It may cause enduring arrest of respiration persisting after the shock current has ceased to flow or the path of the current may cause the chest muscles to contract and thereby preventing respiratory movement. In the later case, the effect lasts as long as the current flows and because a lightning current flows only for a very short time (a few tenths of millisecond), the effects caused by very short period respiration arrest is negligible. On the other hand, the first way in which the arrest of respiration persists even after the shock current has ceased, deserves further consideration.

These two ways (circulatory arrest or respiratory arrest) in which death might be caused are likely to be the most common. Though both cases result from changes in function unaccompanied by alteration in structure, there is nothing to prove (in post-mortem reports) that either or both had occurred. Therefore, man may die due to direct lightning stroke either by respiration arrest or due to malfunctioning of cardiac nerves. On such occasions the life of a man can be saved by heart massage or by mouth-to-mouth resuscitation.

In all types of lightning strokes only one-third of the victims loose their lives while the rest two-thirds recover partially or completely.

Types of Lightning Stroke on a Human Being

Injury/death from lightning may occur either by direct strike, by side flash over from an adjacent struck object or by ground currents. Direct strikes are the most severe which often leads to death. If the victim is struck directly, he will be initially (at least), conduct the whole current and is said to receive direct strike. His body resistance to earth may exceed that of the surrounding air, so that a flash over to the earth occurs. If the victim is near to another object which is struck, one of three things can happen. If he is actually in touch with the conducting object which is struck, he is then subject to contact voltage. If he is standing nearby, a part of the current may cross the air gap and discharge to the earth through him, in that case he is the victim of a side flash. If he is at a relatively long distance from the object which is struck, he may receive a side flash if a step voltage generated in the ground near the strike. A person in contact, generally by his feet, with two points at differing potential on the ground will receive an electric shock through the body between the two points of contact.

11.4 Favours and Frownings of Thunderstorms

(a) Favours

Thunderstorms, are also called atmospheric hot towers, are one of the main natural agency which transports sensible and latent heat energy from the surface of the earth (ocean surface or water bodies) to the atmosphere. A consequence of this is the transport of heat from equatorial region to polar regions.

Thunderstorms maintain the electrical field of the earth's atmosphere.

Fixation of atmospheric Nitrogen is mainly achieved by thunderstorms. By thunderstorm Nitrogen fixation, atmospheric Nitrogen is converted into nitrogen compounds which are brought down to earth by rain, which is utilized by the plant kingdom and aids agricultural production. Thunderstorm lightning produces about 30% to 50% nitrogen compounds in the atmosphere. In arid regions, the lower atmosphere is very dry and that the light rain or drizzle droplets which fall from clouds completely evaporate before reaching the ground (called virga). Only large drops can survive and reach the ground. Such large drops are effectively produced by thunderstorms.

(b) Frownings or Hazards

Lightning

Lightning causes death to human beings and animals and damages property by fire. To protect houses and tall buildings lightning conductors are fitted.

Hail

It causes damage to life and property, particularly crops, fruits and fruit trees. Hail storm is a severe hazard to aviation and aircrafts.

Thunder Squalls

Strong winds associated with thunderstorms are called thunder squalls. These cause damage to buildings, structures, parked and moored aircrafts, electric poles, huts and uproot even big trees.

Dust Storms

Over dry area with loose soil, thunder squalls raise lot of dust/sand into atmosphere, which may be suspended in the air for days and sometimes weeks. These are locally called Andhi (meaning blinding). This is hazardous for air and surface transportation services.

Heavy Rain and Flash Flooding

Heavy to very heavy rains are generally associated with thunderstorms, even during cyclones. These heavy falls cause flash flooding in urban areas and in small rivulets and cause havoc to life and property.

Aviation Hazard

Thunderstorm area is an aviation hazard not only for parked and moored aircraft in hangers but also for aircraft in flights due to steep wind shears, poor visibility (this is hazardous during landing and take off of aircrafts). Lightning causes radiostatic interruption in communication system. If an aircraft enters into a thunderstorm cloud, it will be tossed violently up and down (in severe cloud turbulence), causes severe icing on aircraft frames and fatigue to airframes. On small scale, severe local thunderstorms (known as Kalbaisakis) generate Tornadoes on land, and water spouts on water bodies. These cause devastating spell on life and property.

Safety Measures from Lightning Hazards during

Active Thunderstorms

1. All tall buildings, masts (minarets) must be fitted with lightning rods on their tops to discharge electric energy directly to the ground without touching beams, pillars etc.
2. ***Indoors***

   During active thunderstorm it is safer to be inside the house on an insulated bed. Keep off from electrical conductors, telephone wires, T.V. Antennas and radio aerials. Switch off radio, TV, fans, grinders, gas stoves etc. One should not touch any conducting material such as telephones, sewing machines, iron bars (picklocks, doors, grills, chains), water taps, pumps etc. Avoid smoking, better remove wrist watch, key chains etc.

3. ***Out doors***

   In open fields/areas one should not seek shelter under trees (particularly tall trees like palmer, coconut etc). It is better to lie down on the ground drenching in rain rather than seeking shelter under trees. One should avoid elevated places, rocks etc., which are the favorable places of lightning discharge. During active thunderstorm, in corn field one should not seek shelter even in a sheaf of corn. It is safer to set up two sheaves some 3 meters apart and then sit down half way between them. One should not ride on a horse/camel back, instead dismount from the horse/camel back and walk slowly.

Forecasting

Lightning may strike in a matter of seconds and as such there is no prediction of time and space of occurrence of lightning.

11.5 Hailstorms

Hail is one of the byproducts of a severe thunderstorm. Thunderstorm that is associated with hail is called hailstorm. Hail is formed in a well developed cumulonimbus cloud, which is characterized by severe updrafts. A typical hailstone when cut, shows layer structure like that of an onion. Hail is a climatic element, varies with time and space. The frequency occurrence of hailstorm is more in middle latitudes and it abruptly reduces to zero towards poles. Over the world, the western coasts of continents have maximum frequency during spring season. Hailstorms are not confined to any part of the world. Most hailstorms occur around lat 10 °N in April to September period and about lat 8 °S in October to March. However the whole of the northern hemisphere between lat 20 °N and 50 °N is prone to incidence of hailstorm in summer. Generally the size of hail is small (pea size, diameter less than 10 mm) and occurs over an area less than one square kilometer. But they cause heavy damage to fruit trees. It is estimated that on an average about 1% of the world's crop is damaged by hail. The mass of hail in general does not exceed 10% of the mass of that thunderstorm.

Hail has several shapes and is classified by its size and compared with the familiar objects. If the diameter is less than 5 mm, it is called shot, 5-10 mm is called pea size, 10-20 mm is called grape size, 20-30 mm is called walnut size, 30-50 mm is called golf ball size, 50-60 mm is called hen egg size and if it exceeds 60 mm it is called tennis ball size see Fig. 11.1. However in general the solid precipitation from cloud is classified into four types. (i) Grauple or soft hail, (ii) small hail, (iii) ice pellets and (iv) hail.

Soft Hail : They are white, opaque and conical in shape. Diameter is less than 5 mm, density 800 kg/m^3

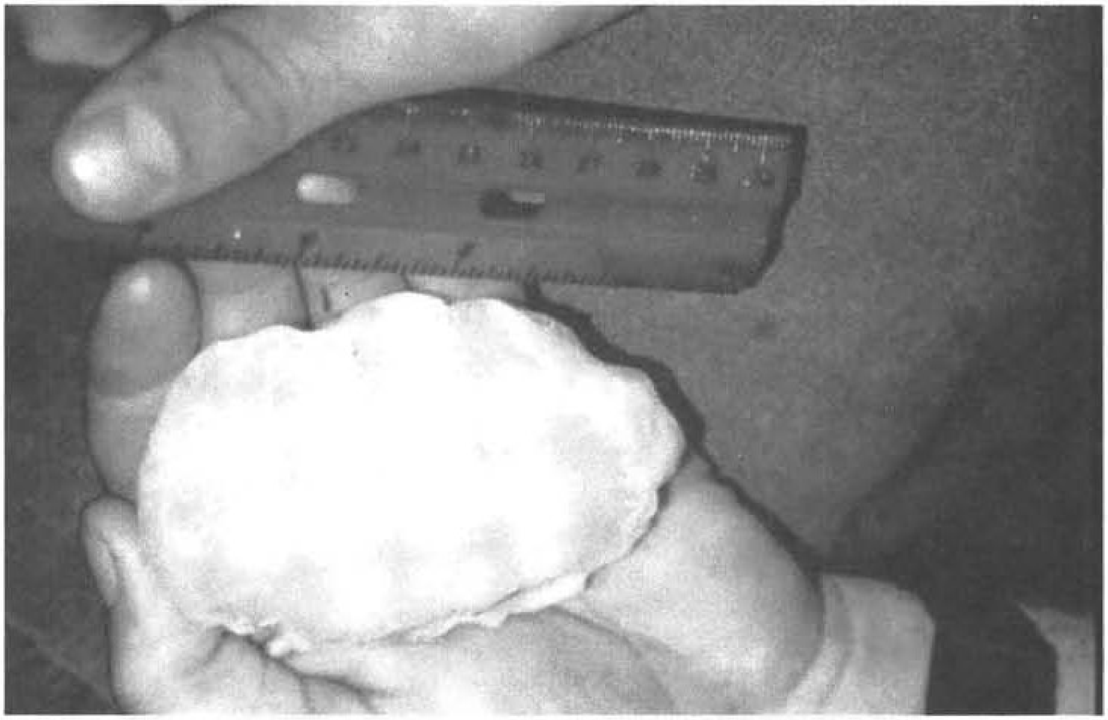


Fig. 11.1 Hail-tennis ball size.

Small Hail **:** They are partly transparent, round or conical in shape. Diameter upto 5 mm, denisity 800-900 kg/m^3.

Ice Pellets : They are transparent, spherical or irregular in shape. Diameter less than 5 mm, density the same as that of ice. They form by the freezing of rain drops.

Hail **:** They are lumps of ice or ice and water with air inclusion. Diameter more than 5 mm (up to 5 cm). They are partly transparent or opaque. They have alternating layers of ice and air babbles. Generally they are spherical or conical in shape.

Largest Hail

As mentioned earlier, the size of hail generally varies from 5 to 50 mm in diameter. But there are reports of very large size hail. On 30 April 1888, Moradabad in Bihar, India reported large hailstones of cricket ball size, which took the life of 246 human beings and 1600 goats and sheep. In Germany, in 1925, Talman measured an ellipsoidal hail 26 × 14 × 12 cm in size and weighed 2.04 kg. On 11 March 1957 Begumpet Airport (Hyderabad) India reported average hailstones of size 5-8 cm in diameter. On 27 May 1959, in Delhi, India, hail size of 200 mm diameter caused holes in aircraft frames and there were reports of hail size 250-375 mm diameter. On 3 September 1970, at Coffey Ville, Kansas, USA, a hailstone was weighed 758 gm, diameter 190 mm and circumfrence 444 mm. The substantiated reports of hail of 1.9 kg fell in Kazakisthan. 970 gm hail fell near Strasbourg, France in August 1958. The other reported hail weights are 4.5 kg recorded in China, 4 kg in

Hungary and 3.4 kg in India. These reports probably were groups of hailstones clustered or frozen together. There were also many reports of hailstones lying more than one meter deep on the ground. These consists mostly pea to walnut size and piled up drifting by wind from hill sides. During 11-13 March 1981, there were widespread hailstorm over Telangana (A.P), India which caused damage to 33000 acres standing crop, damaged 85000 houses and taken a toll of 18 human lives and 13000 live stock. The size of hail ranged 100 to 1200 gm.

Hail Formation in the Cloud

It is believed that some kind of ice nuclei when falls in the supercooled water, hail embryos are formed. It then grows by collision and accretion process. Hailstones have concentric accretions of clear and opaque ice. When embryo is carried aloft by updraft it is frozen. By repeated circular trips within updrafts of thunderstorm cell, that carry hailstone above and below freezing level, hailstone is formed. Depending on the time spent above freezing level milky hail layer forms by rapid freezing, while the clear ice layer is formed below the freezing level. The number of trips above and below freezing level (see Fig. 11.2) gives the number of layers within the hailstone. In one hailstone twenty five separate layers have been counted. Calculations show that an updraft of 95 kmph is required to support the hail of diameter 25 mm. A hailstone of 80 mm diameter requires an updraft of 200 kmph to support and a 130 mm diameter hailstone requires an updraft of 377 kmph to support.

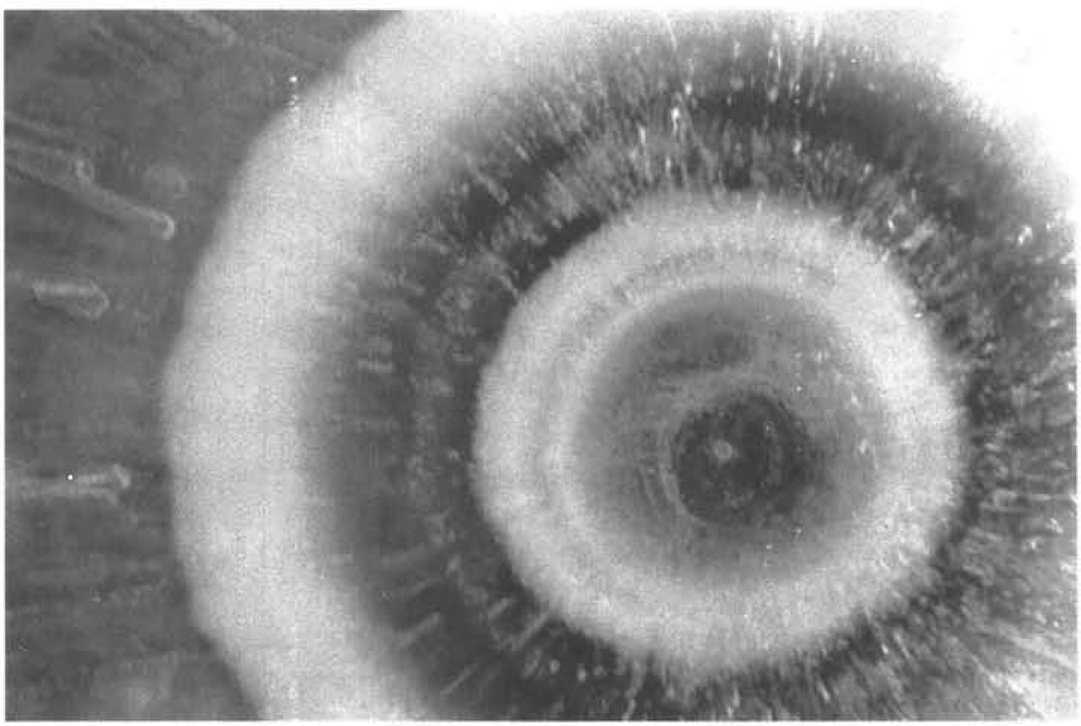


Fig. 11.2 Section of a large hail.

Favourable Synoptic Conditions

Various studies indicate the following favourable conditions for occurrence of hailstorm.

(i) Wind shear in middle troposphere (850 to 200 h Pa).

(ii) Surface high humidity and also in the lower levels.

(iii) Low level convergence of moist air masses of contrasting characteristics (such as continental and maritime air masses).

(iv) In tropics, movement of upper air trough in zonal westerlies Jet stream (200 h Pa), preferable location of hailstorm is along the axis of trough.

(v) North-South trough on sea level chart with associated wind discontinuity/ cyclonic circulation in the lower troposphere.

(vi) Steep lapse rate of temperature in the lower levels (surface to 500 h Pa).

A number of factors must be considered simultaneously and it is possible that a non-linear combination of parameters will be required. For example, wind shear plays an important role in the organization of the most severe hail storm, but it is likely that if shear is too strong, storm development will be inhibited. A major source of non-linearity in the forecasting problem is the existence of several distinct types of hailstorms.

Some principal types are:

(i) an airmass or pulsating multiple bubble storm,

(ii) a multicell strom and

(iii) a large severe super cell storm.

The first type requires great thermal instability and occurs in the absence of wind shear or strong winds. The second type requires moderate to strong instability and a proper vertical wind profile. The third type may occur without great instability, requires strong winds with a properly organized vertical wind profile and is associated with a strong organized downdraft fed by rain cooled air from the middle troposphere. It can produce very large stones, great crop damage and severe wind damage. It seems to be a type of storm associated with tornadoes.

Divergence exists from a trough to downstream crest in upper tropospheric (westerly) wave. In a sinusoidal wave, maximum upper level divergence is located about midway between trough and ridge. Its intensity is greatest for waves with short lengths and large amplitude and large wind speed in the jet stream. It seems that jet stream is a major factor in the development of severe thunderstorm.

A study revealed that wind speed from surface to 500 h Pa was very different from that compared to the wind speed from 500 h Pa to 250 h Pa. The difference between the two was related to the size of the hailstones produced. A wind shear of 65 kmph (35 kt) between the two layers correspond to heavy hail (3-5 cm diameter), 61 kmph (33 kt) to moderate hail (1-2 cm diameter) and 48 kmph (26 kt) to light hail (diameter less than 1 cm), and less than 44 kmph (24 kt) indicate no hail formation.

The terminal velocity of hail is given by an approximate formula

$$V = \sqrt{2W/C_d \, \rho_a \, A}$$

where W = weight of the hail

A = cross-section area

C_d = drag coefficient

ρ_a = density of air, which varies with height.

The fall speed of large hail stones is of the order 40-100 mps.

Low Level Wind Shear

Low level wind shear is associated with the following meteorological situations.

(i) Ground layer inversion during winter months, which results in strong jet like winds aloft.

(ii) At the boundaries of air masses.

(iii) Sea breeze circulation.

(iv) Sharp changes due to topographical features over aerodromes.

(v) In the vicinity of thunderstorm.

Microburst

Downdrafts in thunderstorms encircling horizontal gusts of large magnitude is called downburst or micro-bursts. A downburst may be defined as a localised intense down draft with vertical currents exceeding a downward speed of 3.6 mps (12 ft/sec) at an height of 91 m (300 ft) above ground. This speed is comparable to the normal descent rate of a jet aircraft during landing. This threshold speed of downburst tends to double the sinking speed of such an aircraft to adjust balance (or trimmed) for normal approach near touch down at usual 3^{0} glide slope below 150 m (500 ft). A microburst is a smaller but rather more intense version of the downburst. The horizontal extent of the downburst is 4-10 km and the microburst is 1-4 km. When downburst/microbursts reach the surface they spread out horizontally (see Fig. 11.3) and causes strong gusty surface winds with average maximal gusts 50 to 60 mps. In such an encounter aircraft loses balance and crashes.

Hailstorm Damages : Hailstorms damage valuable cash crops, fruits, orchards, vegetables besides damage to life and property, howver it is localised. In India highest annual frequency of hailstorm occurence is found over Vidarbha (February),

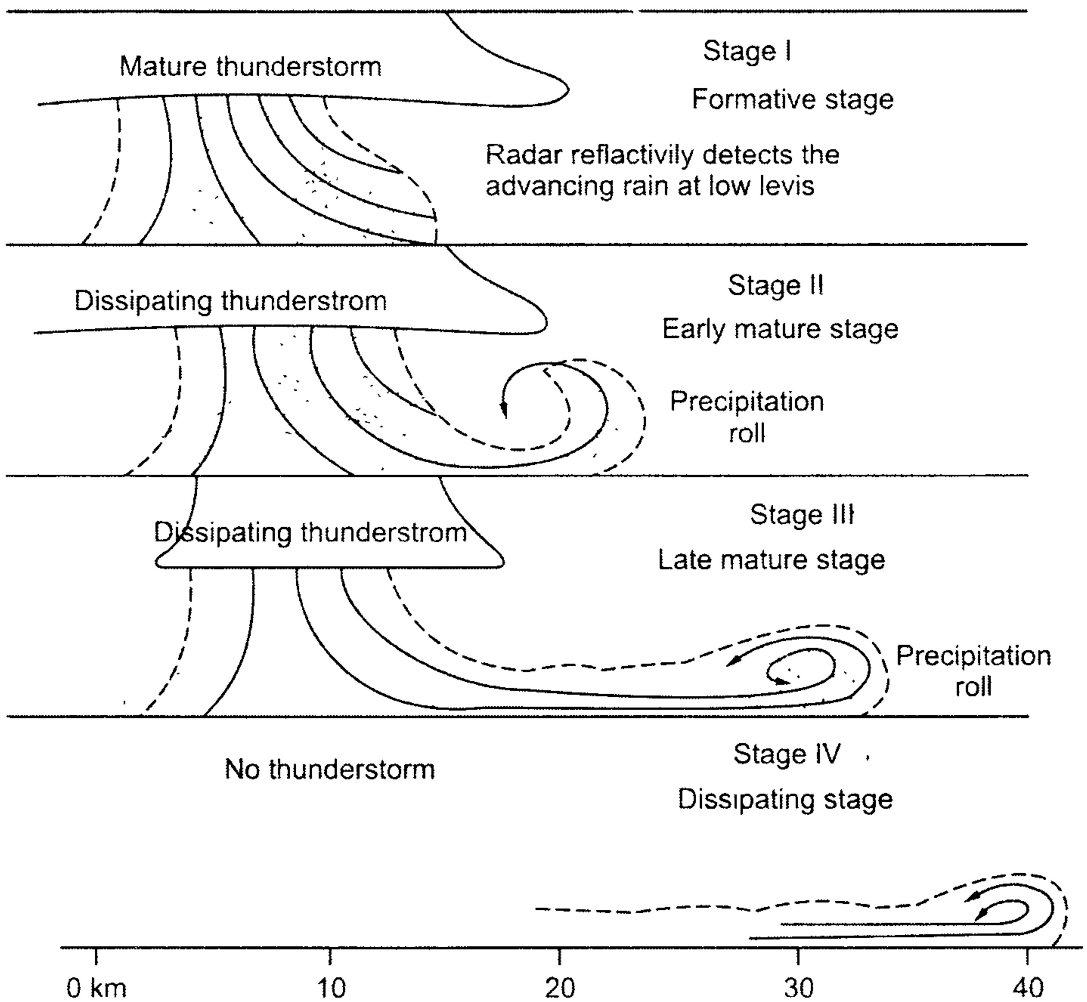


Fig. 11.3 Four stages of cold down draft air spreading ground.

Himachal Pradesh, Madhya Pradesh, Chettisgarh and Assam. Monsoon season is free from hailstorms. Hailstorms in India are mostly confined to the months of January to April. Winter months are more prone to hailstorms over Vidarbha, MP and neighbouring area. The major damages of hailstorms during February (1976-2003) are given below.

28-2-1982 Kanpur, Mathura, Unnag districts of Uttar Pradesh suffered hailstorm damage 60% of standing rabi crops. 8 persons died, 25 injured.

9-2-1986 Hailstorm around Nagpur killed 125 cattle heads, injured 16 persons, damaged standing crops worth Rs. 10 crores.

11-2-86 Hailstorm over Yavatmal District killed 4 persons, injured 5 persons and damaged property worth Rs. 2 crores.

19-2-1987 Hailstorm over Faridabad near Delhi, damaged standing crops worth Rs. 20 crores.

16-2-1988 Hailstones weighing 2 to 3 kg reported in Sambalpur, Puri districts. Several people injured and standing crops over 2000 acres damaged.

11-2-1991 Hailstorm in Delhi killed 3 persons and injured 4 persons. In Faridabad 5 killed and 4 injured.

28-2-1991 Hailstorm in Karimnager, Hyderabad (A.P.)killed hundreds of sheep and goats, damaged crops of cotton, castor and vegetables worth Rs.10 crores.

21-2-2001 Hailstorm over Bashirhat, West Bengal reported heavy hail injured 200 persons, 400 cows and many cattle.

Preventive Measures : All preventive safety measures of lightning have to be observed. In western countries particularly in Russia, Germany, rockets are fired loading with silver iodide into thunder clouds to suppress hail. Earlier long Gaigar guns were fired. Now weather modification technics with silver iodide seems more effective in suppressing hail. Such cloud seeding technology may be introduced in India for suppressing hail damage. The nowcasting and forecasting of hailstorm can be made precise using Doppler radars.

11.6 Tornadoes

Tornadoes are the most violent storms on earth, but they miss detection on synoptic chart. A Tornado is a violent rotating column (spiral motion) of air. It appears as pendent cloud extending from cumulonimbus cloud base to the ground. The column (or funnel) does not always extend to the ground and may be masked by the dust. A funnel cloud is similar to a tornado, except that the funnel does not reach the ground. The diameter of the column is about 100 m. In general tornadoes are more frequent in extra-tropics than in tropics.

The word Tornado is derived from the Spanish word Tronada, meaning thunderstorm. In northern and western parts of Africa tornado still refers to a thunderstorm. In Latin Tornare means "to turn", thus tornadoes are also called twisters. Tornadoes have different names in different parts of the world. In France and Germany they are called Trombe, in Spain and Italy Tromba, in Russia Symerch, in JapanTatsumaki, in India Hatishnura (meaning Elephants trunk)

Life Cycle of a Tornado

Tornado funnel may be seen as thin rope, conical shape, cylindrical shape or thick dense cloud mass touching the ground. Generally tornadoes rotate in an anti clockwise direction but there may be some that rotate in clockwise direction. During the life span of a tornado the funnel undergoes many changes. The life cycle of a tornado may be divided into five stages.

1. ***Dust Whirl Stage :*** In this stage whirling of dust is observed below cumulonimbus cloud but it does not touch the ground.
2. ***Organising Stage :*** In this stage the funnel from the base of Cb cloud touches the ground and intensity increases.
3. ***Mature Stage :*** In this stage funnel attains maximum diameter (100-250 m). Central pressure in the eye drops (25-200 h Pa) and attains maximum wind speed. Circulation usually stays in continuous contact with the ground through stages 3, 4 and 5. The funnel creates havoc, destroys buildings, poles, trees and sucking debris and dust raises to great heights into the air. Sometimes motor cars, animal and heavy objects sucks in, lifts aloft and thrown away at considerable distance. The destruction of buildings is also caused by explosive effect due to sudden fall of pressure (in less than a minute) by over 50 h Pa or more. The large pressure defference between inside a closed building and the outside atmosphere leads to an explosion, which bursts the walls and the ceiling outwards. According to some empirical theory, a pressure drop of 100 h Pa causes wind speed 600 kmph around the vortex.
4. ***Shrinking Stage :*** In this stage the width of the funnel decreases and tilt of vertical axis increases, fury drastically decreases.
5. ***Decay Stage :*** In this stage the shape of the funnel spreads like a spiral of rope, decreases in height and ultimately disappears.

   Major tornadoes pass through all five stages while minor tornadoes abort in stages one – two – five.

Size of a Tornado

The diameter of the funnel generally varies 100-250 m, rarely reaches to 1000 m. The vertical depth of tornado circulation extends to the middle of Cb cloud (about

10 km). The average path length is 5-10 km but it may range 30 m to 500 km. Life span varies 2-3 minutes to 3 hours. Short lived tornadoes have wind speed 50 mps, path width 100 m and travel length 2 km, whereas long life period tornadoes have wind speed 100 mps, path width 200-600 m and travel length 200 km. Life period varies 15 seconds to 8 minutes at a point. An extreme duration of 7 hours along the ground observed in Illinois on 26 May 1917. They generally move in a straight line path over a flat country for a long distance. Movement becomes zig-zag when it passes through hills, tall buildings and limits speed, on some occasions dies down. The average energy of tornado is 10^{-11} times the solar energy received by the earth (3.67×10^{7} cal/min).

Central Pressure Drop in a Tornado

The central pressure drop (in the eye) may 100 to 200 h Pa. On 20 Aug 1904, at Minnesota, aneroid barometer recorded a pressure fall of 200 h Pa. The eye of a tornado behaves like a vacuum, consequently strange things happen near the vortex such as, trees are stripped of their barks, sheep lose their wool, chickens lose their plumes, corks of bottles fly off, chests explode and splinters fall in all directions and bursting of closed buildings etc. People who had the experience narrated that they had the bursting experience in their chest and ears.

Synoptic Situations Favourable

The first signs of a Tornado development is a large active cumulonimbus cloud with mammatus. The cloud may acquire green and yellow colour. Green colour lightning or ball lightning also be observed. On some occasions a Tornado may occur without any thunderstorm activity but there will be heavy rain, showers and hail. Cb is associated with every tornado. It is probable a supercell type convective cloud is the genesis of a tornado. The synoptic conditions favourable for the development of a supercell type convective cloud are:

(i) Low level convergence with associated upper air divergence,

(ii) lot of moisture in low levels,

(iii) super adiabatic lapse rate in the lower-mid levels,

(iv) strong vertical shear in the horizontal wind (upto 300-250 h Pa or more).

Radar Echoes

As mentioned earlier in thunderstorms hook (6) type echo is associated with a tornado, which is an indication of meso-cyclone. It may be noted here that every hook type echo is not a tornado, it only indicates severe thunderstorm. The echo reflectivity is to the order of 4 or more.

Tornado Vortex Signature (TVS)

A pulsed Doppler Radar \when directed to a stationary cyclonic vortex, it will show particles moving away from the radar to the right (positive velocities) of the line joining the radar and the centre of vortex and the left of this line particles will appear to be moving towards the radar (negative velocities). Doppler radar will indicate positive velocities to the right of the centre of the vortex and negative velocities to the left of the vortex centre and zero along the line of the vortex centre. The velocity distribution configuration detected by Doppler Radar is called Tornado Vortex Signature (TVS). TVS is detected in the middle region of Cb. A tornado takes about 15 to 20 minutes to touch the ground after TVS is detected.

Electrical Phenomena

Increased lightning activity will be observed about half an hour before touch down of a tornado.

Acoustic Phenomena

A peculiar whining sound like buzzing of an army of bees is heard when the funnel cloud is high up in the air. When the funnel touches the ground a terrific roar, like the sound of a cannon fire, is heard for a few minutes. Snake hissing sounds heard before tornado touches the ground. This is attributed to the vibrations of the air masses rotating around the funnel.

Precipitation

Heavy rain sometimes associated with hail precede and follow a tornado. The eye of the tornado, like the cyclone eye, is generally free from precipitation.

Tornado Hazards

Prediction of a tornado is still in infant stage as its mechanism of formation is not clearly understood. However with the help of radar nowcasting is done (forecasting its movement and severity in a very short period) to alert people to save their lives. Property damage due to tornadoes seems at present inevitable (see Fig. 11.4). The average death toll in United States of America is about 150-250 per annum, but the injury seems many folds of this. This is caused by the flying objects hitting the people and the subsequent fire. The greatest loss of life due to a single day tornado was 689 people recorded on 18 March 1925, while the greatest loss on a single day was about 1200 people recorded on 19 February 1884.

Some Recorded Tornado Incidence

On 30 May 1879 an iron bridge weighing 108 tons was lifted over the River Big Blue in Irving (USA). This incident was recorded in great detail in a book by Finley (1881). A tornado in Minnesota lifted a passenger car with 117 passengers, total

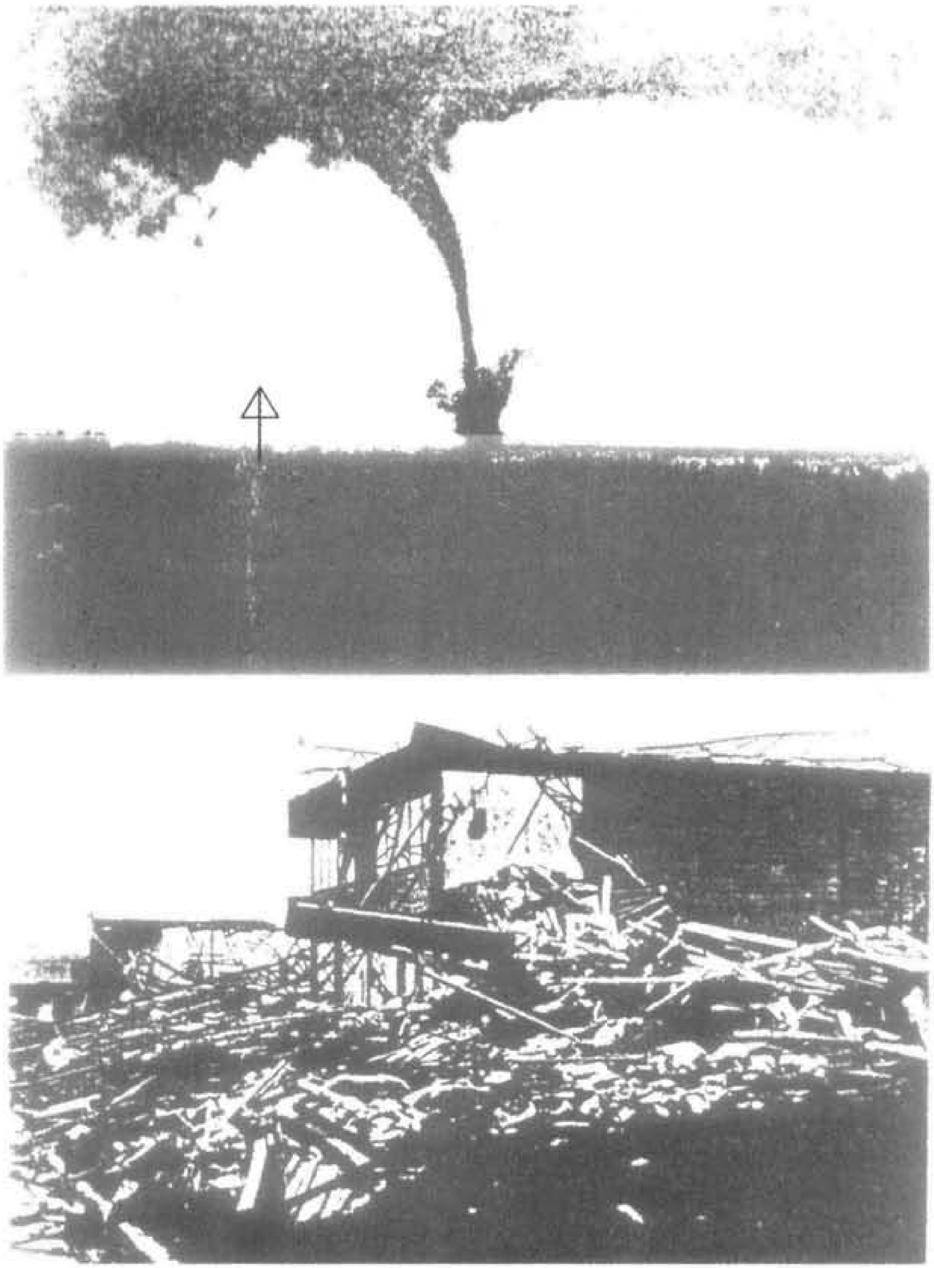


Fig. 11.4 The tornado (upper photo) which struck Edmonton, Canada on 31 July 1987 left 26 dead and cause damage amounting to US$350 million (*lower photo*)
(***Photos** : Atmospheric Environment Service Canada*).

weight about 72 tons. In 1879, in Missouri, a horse was lifted and carried a distance of few hundred meters and deposited without any injury. In New Delhi (India) on 17 March, 1978 a tornado in about three minutes took a toll of 28 people, caused injuries to about 700 people and damaged property worth more than one crore rupees. The same tornado lifted a passenger bus with 70 passengers and deposited twenty meters away in a canal. A tempo vehicle was also lifted from a petrol pump and thrown 100 meters away. In a Germany city market a man who was standing under the vortex was lifted high in the air, pelted with hailstones and thrown. When he came back to senses he found himself under two men, one woman and a horse. Another man who was standing close to a post in front of an emergency ward of a hospital in Lefortova was lifted five meters high in the air, carried a distance of 100 m in the garden and deposited on the lawn.

Development of Tornadoes Associated with Fire and Volcanic Eruptions

Under favourable circumstances widespread fire may develop a tornado. On 1 September 1923, a fire broke out in Tokyo after an earthquake. Within 24 hours about 120 tornadoes and smoke devils developed in Tokyo after the great earthquake. Some tornado acquired intensity of wind 50-70 m/s, picked up cars, people outside the fire line. About one lakh forty two thousand (142000) people died in Tokyo, more by fire than by earthquake itself.

Tornadoes/waterspouts may develop after volcanic eruptions over land/water surface. In 1963, there was volcanic eruption of Surtsey in the middle of the sea, off the coast of Iceland. Each intense volcanic eruption gave rise to an enormous dense cloud. From these clouds tornadoes of different sizes developed on the leeward side.

Safety Measures

People can adopt safety measures to protect themselves by listening to tornado advisory bulletins broadcast on national TV channel. The following measures to be adopted as in case of lightning strokes and cyclones. Shut off immediately, after alert, electric power, gas supplies and extinguish all fires. Seek shelter quickly in a tornado cell or in sturdy reinforced pucca concrete building. Do not drive a car which may be hit by missile debris or it may even be lifted and thrown away by strong winds. If caught in an open place, run to a nearby culvert or ditch, lie down and hold on to a fixed object to protect from being blown off. Protect your head from the injuries of flying objects.

Fujita-Pearson (FPP) Tornado Intensity Wind Scale

This was proposed by Fujita in 1971. This wind scale designed to link the Beaufort scale of Force 12 with Mach No.1 in twelve steps. The scale is derived from the formula

$$V = 6.30\ (F + 2)^{3/2}$$

where V = wind speed in mps. The scale specifications are given in Table 11.2.

Table 11.2

Scale	Wind	Damage description
F0	18-32 mps	Light damage: such as breaking of tree branches, falling of sign boards.
F1	33-49 mps	Moderate damage: Beginning of hurricane wind speed. Moving autos pushed off the roads. Peel surface off roofs. Mobile homes overturned
F2	50-69 mps	Considerable damage: Box cars pushed over; Mobile homes demolished. Large trees uprooted or snapped. Light object missiles generated.
F3	70-92 mps	Severe damage: Roofs and walls tornoff well constructed homes. Trains overturned, Heavy cars lifted off ground and thrown. Most forest trees uprooted.
F4	93-116 mps	Devastating damage: Well constructed houses levelled; cars thrown and large missiles generated, structures with weak foundation blown off some distance.
F5	117-142 mps	Incredible damage: Automobile sized missiles fly through the air beyond 100 meters; strong frame houses lifted off foundations and disintegrated at consider-able distance. Trees debarked; incredible phenomena will occur.
F6-F12	142 mps to Mach-1	The maximum wind speeds of tornadoes (=speed of sound) not likely to reach F6 wind speeds.

Tornado Statistics

Tornadoes can occur in any latitudes, but they are more frequent in extra-tropics than in tropics, and rare in equatorial belt. The annual frequency of occurrence of tornadoes in USA is about 200. The Mississippi valley has maximum occurrence in the world. Generally tornadoes move from south westerly direction (in northern hemisphere) at the average speed of 15 mps. The maximum wind speed does not exceed 142 mps. The average travel length is about 2 km (range 100 m to 600 km), in USA 7 km. The average width of track is 50 m to 250 m. There may be erratic movement as well. Average life span varies from 2 minutes-2 hours.

11.7 Waterspouts

Waterspouts are of two types. Type one that develops downward from a cumulonimbus cloud and it is also called fair-weather waterspout. Type two is simply a tornado over the water. Type two develops upwards from the surface of water and is not directly associated with a cloud. In both of these types water gets sucked up into air along with aquatic creatures such as fish, frog etc. These aquatic creatures may be found in rain associated with waterspout. In the world over Florida keys and Palm beach Florida have the highest frequency of incidence of waterspouts about five per annum per 100 sq km.

Waterspouts undergo a life cycle similar to that of tornado on land. It has five stages of life cycle which are briefly described below.

1. ***Initial or Dark Spot Development Stage :*** First visible sign of a vortex is a dark spot on the sea surface. In this initial stage a short funnel pendant may develop from the super cell (Cb cloud). The dark spots may occur in bunches of two or more, of which one may be dominating the others. The dominant one becomes waterspout and the others decay. The life span in this stage may be about 1-20 minutes. Many may dissipate after this stage. From the droppings of tracers it is gathered that the dark spots are developed by the rotation imposed from above.
2. ***Spiral Stage :*** In the second stage, formation of spiral occurs on the sea. Only one dark band (150-1000 m) comes out from a nearby shower band. Spiral bands indicate the lines of confluence or difluence on sea surface while the regions of flow away from the vortex seen along the surface.
3. ***Ring Spray Stage :*** In this stage wind strength increases beyond a critical value of about 22 mps and throws up a ring of spray from the surface. In this stage funnel increases in size and the axis of funnel tilts. It begins to move rapidly along the surface as it comes under the influence of the wind shift line. The wind shift line is believed to be associated with the cool breeze from close by shower.
4. ***Mature Stage :*** Mature stage lasts about 2 to 18 minutes. This stage is characterized by the strongest wind, funnel tilt and associated with forward wind speed 4-8 mps. In this stage the funnel may acquire double eye wall like that of cyclone and generally moves along a gentle curved path. The spray ring becomes spray vortex. Waterspout may not be visible all through from cloud to water surface. On radarscope hook echo may be seen.
5. ***Decay Stage :*** The last stage is decay stage. This stage generally lasts about 2 to 3 minutes. Spiral and funnel disappears, and rain cooled air takes over waterspout. However in decay stage spiral rain may still be seen which lasts about 5 minutes.

Waterspout Statistics

The maximum tangential wind speed estimated by photogrammetric technique is 85 mps in the lowest levels of 10-15 m (amsl). Waterspouts carry objects weighing 5 tones to a height of about 40 m over coastal waters out at sea. The helical funnel of waterspout may go upto about 300 m in air. Waterspout vortex may generate waves of moderate to high amplitude over the sea surface. According to Schroder (1977) statistics Hawaiian island has maximum incidence of water spouts about 7 per annum. Photogrammetrically estimated wind speed at an altitude of 38 m is about 55 mps and vertical velocity 25 mps.

According to aircraft penetration of waterspouts observation the principal funnel features are:

(i) A warm central core region.

(ii) Funnel core deficit 1 to 10 hPa depending on waterspout intensity.

(iii) In the core upward vertical velocities 5-10 mps.

(iv) Tangential velocities at penetration altitude of 400 m is about 30 mps.

(v) Both cyclonic and anti-cyclonic vortices encountered.

In general waterspouts are more common than tornadoes and the average frequency is about 400 per annum per 10^4 sq km in favorable locations. Compared to tornadoes, central pressure of waterspouts have higher pressure and lower pressure defect and relatively less ferocious/violent.

11.8 Dust-Devils

Dust-devils are a frequent phenomena in tropics and sub-tropics, however they can be seen at any latitude under suitable environmental conditions. Generally dust-devils are observed during scorching hot sun in deserts and semi deserts. They are generally much smaller in size and less violent than tornadoes. The funnel core is warm with temperature anomaly of 1 to 10 °C. The core has low pressure with pressure defect 1 to 4 h Pa. Dust and sand whirls in a funnel shape but no pendant cloud is involved. The rotation of wind may be cyclonic or anticyclonic. The horizontal rotation and upward flow of wind in dust-devils exceed 30 kmph with average height of column being 200 m. Duration of life varies from few minutes to 7 hours with horizontal path distance of about 50 km.

Favourable condition for formation of Dust-Devils

(i) Hot or intense insolation (ii) Dry dusty ground (iii) Steep lapse rate of temperature at the ground (iv) calm or light surface wind.

11.9 Nowcasting

In Western countries, the disaster management associated with tornadoes are successfully executed with Nowcasting method, which we shall discuss briefly.

Some hazardous weather events occur in very short periods of time and there will be no lead time for warning. Flash floods, snow avalanches, mud-slide which cause havoc in a matter of few minutes. Lightening can strike in seconds and there seems an increasing trend of thunderstorm activity and lightning hazards and deaths which is attributed to atmospheric pollution and climate change. It is next to impossible to give exact prediction of the time and place of occurrence. In such situations the best course is left with the meteorologist is to issue warnings of the risk of their occurrence in a fairly wide area over an extended period of time. The people at risk must keep an eye open and judge for themselves whether it would be wise to move to a safer location.

For effective working of National Disaster Management Agency in such events is beyond imagination. However real time information would give local authorities a vital lead time in saving lives. Nowcasting system, which is in vogue in western developed countries, providing an impetus to the forecasting value and helping in disaster mitigation work. Nowcasting aims at a six-hour city specific prediction. This system would integrate the data from Doppler radars, automatic weather stations, satellite data and wind profilers to enable meteorologist to detect a phenomena like 26 July 2005 Mumbai rainfall deluge and allow the executive authorities a critical window to evacuate the likely affected people or warn them to move to safer locations nearly in a couple of hours.

Nowcasting will be of great value to urban users, to improve long and short time forecasts which help agriculture and industry.

Improving the network of Automatic weather stations and Doppler radar network would provide real time data of temperature, precipitation, humidity and wind. Automatic raingauge stations and wind profilers provide vital information at critical times for decision making.

11.10 Summer Thunderstorms over India

During hot weather period (March-May) rapid rise of surface temperature, fall of pressure, intensification of southern Indian ocean anticyclone, Northward movement of equatorial trough, Norwesters, Dust storms, Dust raising winds, Hail storms are common features over India neighborhood. Thunderstorm activity continues in monsoon season but less marked. The main thunderstorm activity observed during the period are :

(i) The area from Northeast India to east Madhya Pradesh, east Vidarbha and adjoining Andhra pradesh.,

(ii) Southwest Peninsula (Kerala and neighborhood),

(iii) Northwest India excluding Rajasthan.

Squalls associated with summer thunderstorms are very strong/violent. They uproot trees and there were instances in the past that trains being thrown out of tracks. On an average 15 to 20 thunderstorm days recorded in the season. Assam and adjacent States, south Kerala have the highest frequency (30 to 40 days). Entire India is susceptible to thunderstorm activity but Gujarat State has the lowest frequency (about five days in whole of the season).

Thunderstorm activity progressively increases from March. During March the areas of maximum activity (frequency more than 6-days) are Assam and adjacent States and Kerala. The other areas are foot hills of the Himalaya (J & K), Punjab, Himachal Pradesh, east Madhya Pradesh, Bihar, Bengal. The lowest activity lies in Saurastra, Kutch, Gujarat and Konkan coast.

In April thunderstorm activity increases. Maximum frequency (12-14 days) lies over Assam and Kerala. The other area of high frequency (about 8 days) are east Madhya Pradesh, Vidarbha, Deccan Plateau. The lowest frequency (about one or two days) lies in south coastal Andhra Pradesh, coastal Tamilnadu, Saurastra, Kutch, Gujarat and KonKan coasts.

May is the month of peak thunderstorms activity. The maximum frequency zone runs from Assam to south Kerala. Assam and Bengal have frequency of about 16 days, while Gujarat, Saurastra and Kutch have the least frequency or no activity.

The chief atmospheric features during this season are :

(i) a number of meteorological parameters show large diurnal variation,

(ii) formation of heat low over central/interior parts of the country,

(iii) weak to moderate westerly wind flow in the lower troposphere, and

(iv) intense convective activity associated with conditional convective instability (steep lapse rate).

Thunderstorm activity continues in monsoon and post monsoon season and becomes least in winter. The highest frequency of thunderstorms (more than 80 days in a year) extends from Assam to east Madhya Pradesh. Assam and neighbouring Bengal have frequency of more than 100 days, Silchar has 101 days, Mohanbari 106 days. Gauhati 102 days and Sibsagar, Krishnanagar have 108 days. The other high frequency zone is central Kerala and hilly regions of extreme north India. The lowest frequency, less than 10 days in a year, are in coastal Saurastra and Kutch.

11.10.1 Norwesters

The severe Thunderstorms of hot weather period over Bengal and Orissa are known as Norwesters. They are locally called 'Kal Baisakhi' or the fateful thing of the month Baisakh (15 April to 15 May). These severe thunderstorms usually approach a station from northwest direction (and hence the name Norwester) and burst over a station with great violence raising clouds of dust. The squalls associated with these Norwesters reach tornadic violence (120 to 150 kmph). They cause considerable damage to life and property in their path. Tornadoes rarely occur in north east India. Assam and adjacent States are more susceptible to tornadoes locally called Hatishmura (frequency once in a few years). Generally the direction of the squalls is Northwesterly direction.

Favourable Synoptic Situations

(i) induced low over Punjab, Haryana, Rajasthan, West Uttar Pradesh or northwest Madhya Pradesh,

(ii) conditional convective instability in the lower-mid troposphere,

(iii) adequate moisture supply in the lower troposphere (Note: Horizontal distribution of moisture at the ground can be ascertained by dew point temperature of surface observations while vertical distribution of moisture is known through Radiosonde ascents),

(iv) an extension of trough east-south-east wards from induced low to Bihar Plateau and westwards,

(v) penetration of easterlies upto 850 h Pa level over Bihar plains,

(vi) in mid-and upper troposphere mainly westerly wind flow over north-east India.

Thunderstorms in Gangetic West Bengal, Bihar, Orissa have definite sequence of time. They generally develop over Bihar plateau, south Madhya Pradesh or west Orissa. They travel east or south-eastwards towards Gangetic West Bengal or Head Bay of Bengal.

The severe thunderstorms of north-east India are classified into four types.

Type A : They develop over Bihar plateau and adjoining area in the after noon and move with fury in a southeasterly direction.

Type B : They originate in submontane districts of north Bengal and move southwards. They generally form and move during night or early morning.

Type C : They originate in the hills of Nagaland, Manipur and Mizoram and move westwards.

Type D : They develop near the Khasi hills and move southwards.

In fact perturbation in the westerlies caused by a trough or jet stream or a cut-off low, deep westerly trough causes widespread thunderstorm activity over north-east India.

11.10.2 Thunderstorms and Dust-storms over north-west India

During March-June (in all months), thunderstorms occur in north-west India and Uttar Pradesh. The activity is more in western Himalayas as compared to the plains. Thunderstorm activity progressively increases from March and attains peak in May and June. Dust storms occur in plains of UP, Punjab, Haryana and north Rajasthan. They begin in April and attain peak in June. The dust storms locally called Andhi – meaning blinding.

Dust-storms are of two types :

(i) Pressure gradient type and,

(ii) convective type.

In pressure gradient type, strong winds raise loose dust from the surface of the earth into the atmosphere. In this case no Cb is involved. In convective type dust is raised into the atmosphere by strong downdrafts from Cb cloud. In convective type dust storm proceeds a thunderstorm.

The maximum frequency of dust-storms occur in Rajasthan. In pressure gradient type strong surface winds are built up due to steep gradient around low. Wind raised dust suspends in the atmosphere and reduces the visibility to below one km. Pressure gradient of 1 to 1.5 h Pa or more per degree latitude prevails over a longer

Fig. 11.5 Photo of dust wall of an advancing convective dust storm.

period. Winds of the order 30 to 50 Kt prevail upto 1.5 km (850 hpa level). Dust raising winds may commence in the morning and continue for the whole day with maximum intensity in the afternoon when the lapse rate near the ground reaches superadiabatic. In convective type dust-storms the duration of strong winds is of short duration (few minutes or fraction of an hour). Even after dust storm/dust raising winds subside, the raised dust in the atmosphere may go upto 700 hPa level and remain suspended for days together and reduce the visibility.

Favourable Synoptic Situation

Shallow heat low forms over central and northwest India. Quasi Stationary wind discontinuity in low levels run in north-south direction to Peninsula and another south-east Madhya Pradesh to Assam. A shallow anticyclone over Bay of Bengal feeds moisture from the south on one side of the wind discontinuity and contrasting dry northerly or north-westerlies prevail on the other side of the discontinuity line. Over north India in the mid-and upper troposphere sub-tropical jet stream runs, which provides upper divergence. Near the surface of the earth and in planetary boundary layer superadiabatic temperature lapse rate favours convective activity.

11.10.3 Thunderstorms over South Peninsula

During March-May high frequency of thunderstorm activity prevails over Kerala (about 15 days each month) and neighborhood. Orography plays an important role. Abundant moisture feed comes from the neighbouring sea. Kodaikanal: seasonal 34 days, annual 75 days; Trivendrum: seasonal 36 days, annual 70 days.

Hailstorms

Hailstorms in India occur in northern parts of the country. They are much less common over Peninsula. Hailstorms are always associated with Cb cloud only. Hailstorms are common in winter (Dec-Feb) over northwest India, Uttar Pradesh, Madhya Pradesh, and in premonsoon period over north-east India, Peninsula, Vidarbha and Madhya Pradesh. No hailstorm reports from any part of the country during monsoon (June-September) period. During post monsoon (October-November) there is little activity in isolated pockets north of Lat 20 ^{o}N and west of long 90^{o}E.

The annual frequency of hailstorms over northeast India is about 10 days, over Uttar Pradesh, east Bihar and Agartala about 6 days, over east Madhya Pradesh, Chattisgarh, Jharkhand is 2 to 3 days. Maximum activity over south Peninsula is 1 to 2 near Madurai. The entire west coast, south coastal Andhra Pradesh are free from hailstorm activity.

Favourable Synoptic Features

Intense convective conditional instability, large Cb cloud extending to upper troposphere (12 to 14 km). In lower and mid-troposphere high moisture content, strong vertical wind shear surface to mid-troposphere, low freezing level, lowering of trough in the jet core.

11.12 Cold Waves and Heat Waves

Introduction

Absorption of solar radiation and long IR radiation effects man in two ways.

(i) It can heat or cool (thermal effects) and

(ii) Photochemical effects.

These effects are caused through skin and eyes. Skin of white people reflects visible and near IR radiation to the extent of 40%. Radiation is accepted or rejected by the skin according to its surface properties and colour. Black skin absorbs about 44% more solar energy than white skin, but the horny layer of white skin transmits 3.5 times more UV light than that of Negroes. Irrespective of the skin colour white, yellow or black, human body radiates energy in the long wave (IR) as that of black body at 32 °C. The main wave lengths of emission are for IR at 6 and 9 mm (range 2-14 mm). The important parts of the humans body that react to severe meteorological elements are skin, lungs, throat, nose, eyes and nervous system.

Human heat balance = heat gain [(from metabolism + skin absorbed (solar radiation + long IR radiation)] – heat loss (IR radiation from body + convection + evaporation).

UV radiation (near 0.3 μm) causes photochemical inflammation of cornea of the eyes. This damage is caused by reflected solar UV-radiation by snow.

Photochemical action of the skin causes production of Vitamin-D, sunburn, early aging of the skin, strengthening of the horny layer, skin cancer through pigmentation.

Natural sunburn is caused by solar UV-radiation around 0.3 μm, which penetrates deeper into living skin layers. It first causes white skin or tender spots of the skin reddening (after 5-20 minutes of exposure), painful reddening (30-70 minutes of exposure), larger dose oedema and finally blisters. UV-radiation larger dose causes sunburn under nose, lips, nostrils, upper and inside portions of ears, eyelids, chin and cornea of the eyes.

Protection against sunburn achieved by lowering the dose (shortening the exposure time at high sun and clear sky), window glass and skin creams application (which absorb radiation below 0.32 μm) dry cloths and vegetation completely attenuates. Over dose of UV-radiation leads (after exceeding the minimum dose of reddening) to severe erythema, oedema and blistering. Frequent exposure leads to ageing of the skin and loss of elasticity in skin and causes skin cancer in exposed areas of face, neck etc. (there are about (2.3 million) 2.3×10^6 eccrine sweat gland in human). Sunburn blocks human sweating and hence loses body cooling inbuilt capacity. Skin registers thermal conduction, convection and IR radiation. Human body does not sweat at skin temperature of 28 °C.

UV-radiation Effects

It causes increase in vitamin-D and histamines. Increases gastric acid secretion and protein metabolism. In blood, increased hemoglobin, Ca, Mg and phosphate levels. It causes direct lethal effects on bacteria and indirect effect on human.

Frostbite (freezing of tissues)

At very low temperatures when wind removes body heat faster than the body can replace it, frostbite occurs.

Frostbite or hypothermia occurs either by drop in ambient air temperature or increase in wind speed.

Hypothermia

The lowering of central body temperature is called hypothermia. Normal body temperature is maintained by muscular activity (muscular metabolism) and basal metabolism. The process in which food is converted into living matter and useful form of energy is called metabolism – which depends on energy supplied by food and water as intake. Hypothermia begins when ambient environmental temperature is much lower and body loses heat as compared to what it produced. The symptoms of setting of hypothermia are :

1. Weariness and reluctant to continue moving.
2. Trembling and shivering.
3. False feeling of well-being.
4. Clumsiness and loss of judgement.

Hypothermia progress with fall temperature is given in Table 11.3.

Table 11.3

Temperature		
F	C	Symptoms
99-96	37.2-35.6	Uncontrollable shivering
95-91	35.0-32.8	sluggish thinking and violent shivering, difficult in speaking. Beginning of amnesia.
90-86	32.2-30.0	shivering decreases but shows muscular rigidity. Unclear thinking and dull comprehension of surroundings. Total amenesia begins.
85-81	29.4-27.2	Irriationality, muscular rigidity, lost contact with environment. Pulse and respiration slows down.
80-78	26.7-25.6	Victim does not respond to spoken word. Reflexes mostly cease to function, erratic heartbeat, unconsciousness begins.
Below 78	Below 25.6	Cardiac fibrillation and failure idema and hemorrhage in lungs; death.

Heat Effects

In thermal balance, the deep body temperature of man will be 98.6 °F or 37 °C. The normal skin temperature lies between 31-34 °C.

When deep body temperature increases by 2 to 3 °C (3.6-5.4 °F) i.e., 39-40 °C (102.2 to 104 °F) heat stroke occurs - circulatory failure,

at 41 °C (105.8 °F) Coma sets in,

at 41-44 °C (106-111 °F) death imminent,

at 45 °C (113 °F) certain death.

Altitude Sickness

Without proper acclimation (about a week) if people are abruptly transported to high altitude (say about 2 to 3 km from a station level) they feel over exertion, fatigue after arrival. This is called altitude sickness. After arriving at high altitudes even a few minutes of work cause them grasping for breath, chest pain. Over exertion may cause headache, nausea and vomiting, dizziness and weakness. The remedy is rest. In all such cases slow down your work till acclimated. Breath through nose (not through your month) to keep yourself free from dehydration.

11.11.1 Cold Waves in India

During the period November to March and sometimes in the months of October and April, cold dry air blows from northwesterly/northerly direction and lowers the day and night temperatures significantly. On some occasion temperature falls so much that it leads frost formation and causes damage to crops and loss of life. There is no regular periodicity of occurrence but occurs two to three times in a season. According to IMD convention the 24 hr minimum temperature changes and departure from normal (cold waves) defined as follows.

Cold Waves

A. When the normal minimum temperature of a station is $\geq$ 10 °C.

Magnitude of change °C	Description of 24 hr change	Description of departure from normal
– 1 to 1	Little change	Normal
– 2	Fall	Below normal
– 3 to – 4	Appreciable fall	Appreciably below normal
–5 to –6	Marked fall	Markedly below normal or Moderate cold wave condition
–7 or less	Large fall	severe cold wave

B. When the normal minimum temperature of a station is < 10 °C

Magnitude of change °C	Description of 24 hr change	Description of departure from normal
– 1 to 1	Little change	Normal
– 2	Fall	Below normal
– 3 to – 4	Marked fall	Cold wave
–5 or less	Large fall	Severe cold wave

It is obvious from the above definition, only the departure from normal (pentad normal) that defines cold wave condition. For example a station in northwest India on a winter day may record minimum temperature of the order 4 or 5 °C, but it may not be a cold wave at all (because normal itself is low). On the contrary a station in Maratwada or Telangana recorded temperature may be little higher say 6 or 7 °C but it may be classified as cold wave condition (normal being high). In general strong cold winds cause human discomfort. People residing in a place for a long time, they get acclimatised to the normal weather conditions of that place. Thus a person from Hyderabad (AP) feel a normal winter day at Delhi to be severe cold wave condition.

The characteristic wave aspects like amplitude, frequency, periodicity etc., are not associated with cold wave situations but it appears cold waves tend to move in a preferred directions. They move eastwards and also southwards.

In general cold waves are frequent over northwest India in comparison to other parts of the country. Cold waves do not occur over Bay islands, Lakshadweep, Tamilnadu, coastal Andhra Pradesh, Coastal and South interior Karnataka and Kerala. Jammu and Kashmir is haunted by severe cold waves (on an average four per annum) while neighbouring Punjab, Uttar Pradesh have less frequency (once in two years). This neighbouring phenomena may be attributed to adiabatic compression (warming) of cold air mass during its descent on the mountain slopes. Rajasthan, western parts of Madhya Pradesh, Saurastra and Kutch are affected by severe cold waves once in a year. Ladakh recorded maximum duration of severe cold wave for 30 days.

During October Saurastra and Kutch, Rajasthan, Bihar plateau and neighborhood are affected by a few cold waves (about 1 % of annual). During November from Jammu and Kashmir to west Madhya Pradesh (or west of long 80^0E) are affected by cold waves of the order of 5% annual incidence. During December, Jammu and Kashmir, Uttar Pradesh, Bihar, Maratwada, Telangana, Orissa, Rayalaseema are affected by cold waves, about 11% of annual.

January and February are the peak periods of cold waves. About 28% of the annual occur in this period and entire country is susceptible to cold waves except Tamilnadu. The main targets in these months are Jammu and Kashmir, Rajasthan, Madhya Pradesh, Gujarat, Maharastra, Telangana, Uttaranchal, Utter Pradesh, Chattisgarh.

During March and April the frequency of cold waves falls, the whole Peninsula is free from cold waves.

The lowest temperature of –45 °C (departure from normal – 9.7 °C) was recorded at Dras in Jammu and Kashmir on 28 December 1910, world record – 89.2 °C recorded at Vostok, Antarctica on 21 July 1983.

The chief synoptic features associated with cold waves are, the rear of active WD and inflow cold air from northern latitudes. Cold waves are associated with cold core troughs in which a pool of cold air mass exists. The cold pool westerly troughs are classified as severe cold core trough, moderate cold core trough and warm core trough depending on the anomaly of temperature (which is the difference of actual dry bulb and mean dry bulb temperature). In severe cold core trough the anomaly is –6 °C or less extending upto a depth of 300 h Pa level. In moderate cold core trough the anomaly is –1 to –5 °C extending upto a depth of 700 hPa level. In warm core trough the anomaly is –1 to + 5 °C extending upto a depth of 600 h Pa level. Cold waves are not generated in warm core troughs.

11.11.2 Heat Waves in India

According to IMD convention the 24 hr maximum temperature changes and departure from normal (heat waves) defined as follows.

Heat Waves

A. When the normal maximum temperature of a station is $\leq$ 40 °C

Magnitude of change °C	Description of 24 hr change	Description of departure from normal
– 1 to 1	Little change	Normal
2	Rise	Above normal
3 to 4	Appreciable rise	Appreciably above normal
5 to 6	Marked rise	Markedly above normal or Moderate heat wave
7 or more	Large rise	Severe heat wave

B. When the normal maximum temperature of a station is > 40 °C

Magnitude of change °C	Description of 24 hr change	Description of departure from normal
– 1 to 1	Little change	Normal
2	Rise	Above normal
3 to 4	Marked rise	Heat wave
5 or more	Large rise	Severe heat wave

During hot whether period (March to July) surface temperatures over many parts of India abnormally shoot up particularly over North India. This heat wave conditions progessively invades the neighbouring region. The incidence of severe heat wave occurs mostly in Uttar Pradesh, but there is no region where reccurs successively every year. Bay islands, Lakshadweep, Tamilnadu, Kerala, Coastal and South Interior Karnataka are not affected by heat waves. Rest of the country is prone to the incidence of heat waves.

During March Saurashtra and Kutch are prone to the incidence of severe heat waves (about 17% of annual). In April the frequency of heat waves fall (7%) and mostly occur in Jammu and Kashmir, Punjab, Rajasthan, Madhya Pradesh and to thence Konkan, Bihar plains, West Bengal, south Assam. In May the heat waves activity slightly increases (10%) and mostly occurs over Jammu and Kashmir, Telangana, Rayalaseema, Vidarbha and Orissa. The month of June is the peak period of heat wave activity (about 54%) particularly in places where the onset of monsoon not taken place/delayed. Uttar Pradesh, Madhya Pradesh, Chattisgarh experience severe heat waves which are locally called 'Loo". Rajasthan is the hottest part of India but rarely records heat waves. Entire west coast, Saurastra and Kutch to Kerala is free from heat waves.

The month July also records heat waves but they are confined to Uttar Pradesh and Punjab.

During severe heat wave conditions maximum temperature departure from normal goes up to 8 to 10 °C, particularly over Uttar Pradesh and Bihar. Alwar (in east Rajasthan) recorded the highest day temperature of 50.6 °C on 10 May 1956 (world record of highest day temperature is 58.0 °C recorded at Alazizyah, Libya on 13 September 1922).

Heat wave conditions in any part of the country does not last more than 5 to 6 days and severe heat waves one to two days. The maximum period of 15 days heat wave lasted over Jammu and Kashmir. Heat waves generally develop over Punjab, Saurastra and Kutch and spread to east and southwards but not westwards.

Favourable conditions for the formation of heat waves

Prevalence of dry air over the region with little or no moisture in the lower troposphere. The area should be cloud free and lapse rate may be dry adiabatic in the lower troposphere

Global Warming likely to increase the frequency and intensity of extreme weather events. It is in this context heat wave condition likely to increase during summer over the globe including India. In recent times it has been observed extreme temperature recorded at many stations over central and northwest India broken the past records. Abnormal increase in atmospheric temperature causes severe physiological stress and adversely effects the life, health of society and individuals. Many people become the victims of heat strokes/sun strokes over several interior parts of India.

Precautionary Measures : Drink water very frequently. Avoid hard physical work out doors during afternoon (say 10 A.M to 4 P.M). Wear white clothes covering whole body. Use white cap or umbrella when you move outside house in the sun during heat wave conditions or forecasted. Before leaving house drink a glass of water, when you return from hot sun do not eat sweets or lick honey. Take slightly cold lemon juice or coconut water or simple water. Do not take ice cold drinks which may effect your throat. While moving outside in the hot sun if you feel giddiness, rush to the nearby doctor for first aid against possible heat stroke or sun stroke.