Amaravathi Popular Science Series

Earthquakes

Dr. N. Purnachandra Rao

Andhra Pradesh Akademi of Sciences
Advancement of Science for Society

About the Amaravathi Popular Science Series

Amaravathi Popular Science Series launched by Andhra Pradesh Akademi of Sciences APAS with the feasible objective of delivering basic information along with illustrative web based references on various topics related to popular science and technologies. The core belief that the Executive committee of APAS, shares and wish the readers to comprehend is: "The forthcoming is going to be good, and science and technologies are the assisting potencies that will help make it better ". No matter what one does, they need to be able to think that there are basic principles of science even at popular level that are to be learnt both for acting, reacting and understanding the surroundings. It is expected that this popular science series will enable people to meet this objective. This series aspires further stimulation of the Gray Matter. We talk now a days more on "Smart works" - smart cities, smart technologies etc., and it does mean that hard core technologies are driving behind, to make us adopt the smart paths.

As the Editor of publications of APAS, Educator and as a Scientist, I care only that more and more people are scientifically literate. The more informed people are, the more empowered are the people, who can think for themselves in a better manner, and possibly the more representative our society will be.

The series is intended to take up publications on all aspects that help the penetration of popular science at all levels. After all, the information enriched society is a knowledge society and that shall lead to smartness. An illustrative list of themes proposed to be part of this series includes - interrelated to Earth, Environmental, Natural disasters, Space applications, Astronomy, Mathematics, Antarctica, Basic Sciences, Rivers, Oceans, Health, nutrition, Rural and Urban aspects, Social Sciences, etc… APAS welcomes suggestions and offers from potential authors to contribute articles under this series- Amaravati Popular Science Series.

I thank Dr. N. Purnachandra Rao, Chief Scientist, National Geophysical Research Institute, for readily agreeing to contribute under these series for the benefit of the society.

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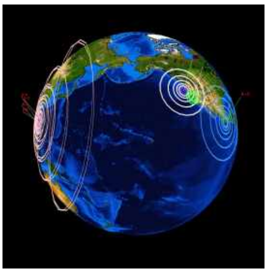
Amaravathi Popular Science Series



Earthquakes

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About APAS

The "Andhra Pradesh Akademi of Sciences" (APAS), come into existence with the initiative of the great visionary Sri P.V.G. Raju, the then Education Minister, Govt. of Andhra Pradesh, who mooted the formation of a forum for all scientists and researchers in this state. The "Andhra Pradesh Akademi of Sciences (APAS)" was founded in 1963, comprises distinguished Scientists, Engineers, Technologists including Medical fraternity covering the entire spectrum of Science and Technology disciplines.

The aims and objectives of the Akademi are mainly the advancement of science in Andhra Pradesh by providing a forum for discussing the scientific developments, propagating scientific knowledge among the people and publication of books and Journals on Science.

Consequent to the Andhra Pradesh reorganization Act, 2014, the Andhra Pradesh Akademi of Sciences is also bifurcated into Andhra Pradesh Akademi of Sciences (APAS) and Telangana State Akademi of Sciences (TSAS). The General Body elected the New Executive Council to A.P. Akademi of Sciences, which has started functioning independently with effect from 30th April, 2015, under the presidentship of Dr. B.L. Deekshatulu. The Akademi has decided to bring out Publications under Amaravathi Popular Science Series and I appreciate the efforts of Dr. I.V. Muralikrishna, Editor of Publications, initiated in this direction.

Prof. K.R.S. Sambasiva Rao
Hon. Secretary, APAS

Date: 22-1-2016

ANDHRA PRADESH AKADEMI OF SCIENCES • AMARAVATHI •

APAS

Contents

Earthquakes

An **earthquake** can be defined as the shaking or trembling of the ground caused by a sudden release of energy inside the earth, usually associated with faulting or breaking of rocks. The general mode of occurrence of an earthquake is a simple sliding of a block of rock mass over another along a plane. The point inside the earth from where seismic waves initiate is called the **focus** or **hypocenter** and its vertical projection on the earth's surface is called the epicenter (figure 1).

Most earthquakes are caused by geological or tectonic causes, and are referred as **tectonic earthquakes**. Another type of earthquakes is those due to volcanic activity although in conjunction with tectonic forces, which are called **volcanic earthquakes**. There are two other types of earthquakes which are isotropic in nature which means that they radiate energy uniformly in all directions. The first one is the **collapse earthquake** which is a small earthquake occurring in underground caverns and mines due to roof collapse. The other is the **explosion earthquake** similar to a chemical or a nuclear blast.

For centuries earthquakes were regarded as an expression of fury of the nature. With the development of science this myth was broken and a new branch of Earth Sciences emerged which was called **Seismology**. It is defined as the study of earthquakes and seismic waves that travel through the earth. A **seismologist** is a scientist who studies earthquakes and analyses seismic waves. Every day there are about fifty earthquakes worldwide that are strong enough to be felt locally, and every few days an earthquake occurs that is capable of damaging structures. Each earthquake radiates seismic waves in all directions which propagate through the earth, and several earthquakes per day produce distant ground motions which although too weak to be felt, can be detected by sensitive instruments all over the world. Seismic waves can also be used to study the structure of the earth apart from understanding the physics of earthquake processes. This is very similar to the way in which doctors scan the human body to elucidate detailed structure or anomalies in the body parts. Seismology has been the main source of information about the earth's deep interior, where direct measurements are impossible, and has provided many important discoveries regarding the structure and nature of our planet earth.

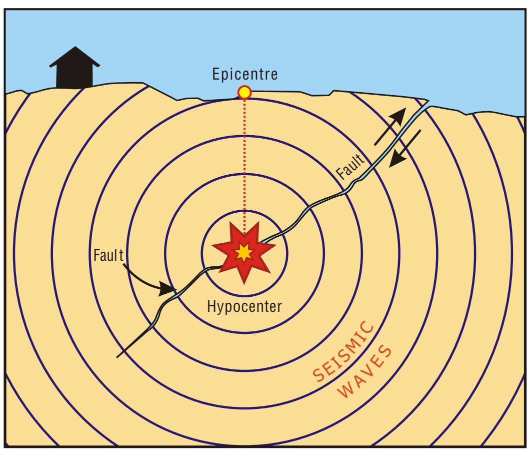


Figure 1: Earthquake epicenter, focus (or hypocenter) and the fault plane

Seismology occupies an important position in the field of **Geophysics** and in Earth Sciences in general. It comprises a wide range of studies of the earth's structure ranging from thousands of kilometers below the surface, to a detailed mapping of very shallow structure to help locate minerals and ore deposits. Incidentally, this is the most important tool used by the oil industry to detect petroleum deposits inside the earth. On the societal front, it plays an important role in understanding the physical processes that cause earthquakes and seeking ways to reduce their destructive impacts on structures and human beings.

What are Seismic waves?

The energy released during an earthquake travels as seismic waves in all directions through the earth's layers, reflecting and refracting at each interface. These waves are of two types - **Body waves** and **Surface waves**. Body waves can travel through the earth's inner layers, but surface waves can move only along the surface of the earth like ripples of water waves. Earthquakes radiate seismic energy as both body and surface waves.

Types of Seismic waves

Body waves: There are two types of body waves as described below.

P waves (Primary waves): The first type of body wave is the P wave or **Primary wave** (figure 2). This is the fastest kind of seismic wave that travels with a velocity of about 6 km/s. The P wave can move through solid rock and fluids, like water or the water filled layers of the Earth. It pushes and pulls the medium that it moves through, since it is longitudinal in nature like the sound waves.

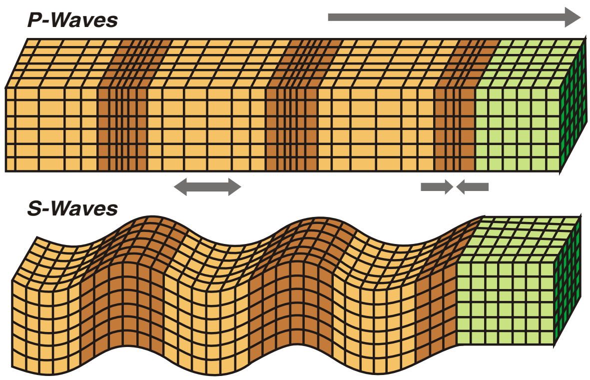


Figure 2: Schematic diagram showing the propagation of body waves

S waves (Secondary waves): The second type of body wave is the S wave or **Secondary wave** (figure 2), which travels slower than the P wave, with a velocity of about 3.5 km/s. The S wave is transverse in nature like the light waves, and cannot move through a liquid medium.

Surface waves: These are the waves that travel along the earth's surface and are the most damaging ones, having the largest amplitudes. These are of two types as described below.

Love Waves: The first kind of surface wave is the **Love wave**, named after A.E.H. Love, a British mathematician who worked out the mathematical formulation for this type of wave in 1911. It is the fastest surface wave and moves the ground from side-to-side (figure 3). It is a little slower than the S wave and hence arrives after the P and S waves.

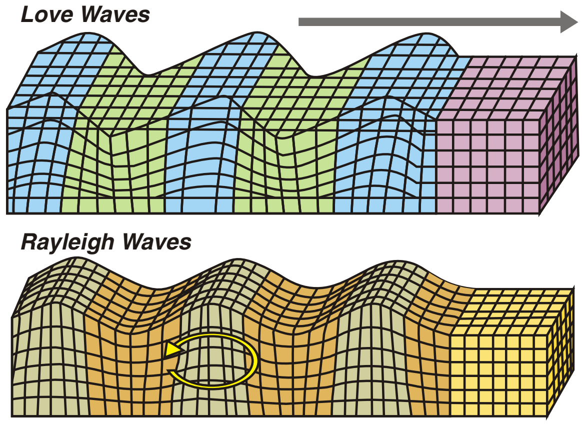


Figure 3: Schematic diagram showing the propagation of surface waves

Rayleigh Waves: The other type of surface wave is the **Rayleigh wave**, named after Lord Rayleigh, who mathematically demonstrated the existence of such waves in 1885. This wave rolls along the ground like a wave rolls across a lake or an ocean. Hence, it moves the ground up and down and side-to-side in the same direction as that of the wave propagation (figure 3). Most of the ground shaking during an earthquake is due to the Rayleigh waves, which can be the largest waves.

Structure of the Earth

The earthquake waves travel through the layers of the earth, and hence the study of structure of the earth has a vital position in Seismology. The earth, with a radius of about 6371 km, has a layered structure which can be broadly classified as the **crust**, **mantle** and **core** (figure 4). The crust is the top-most layer, which is a thin, brittle shield around the earth with a thickness of about 30-40 km in the continents and just about 5-10 km in the Oceans. The thickest crust is known to be in Tibet where it goes up to 70 km. The mantle layer below the crust is about 2500 km thick and can be further classified into upper mantle, which is a 500 km solid layer compared to the lower mantle in a fluid or molten state with about 2000 km thickness. The core constituted by mostly iron and nickel can be sub-divided into the 2200 km thick outer core which is in a molten state compared to the 1220 km thick, solid inner core. The temperature at the center of the earth is as high as 6000 degrees Celsius. However, the extremely high pressure inside the inner core is responsible for its solid state.

What are Tectonic Plates?

The crust and the upper-most mantle constituting the hard and rigid outer layer of the Earth, is referred as the **Lithosphere** which moves on the lower mantle medium which is in a fluid state called the **Asthenosphere** (figure 4). The lithosphere of the

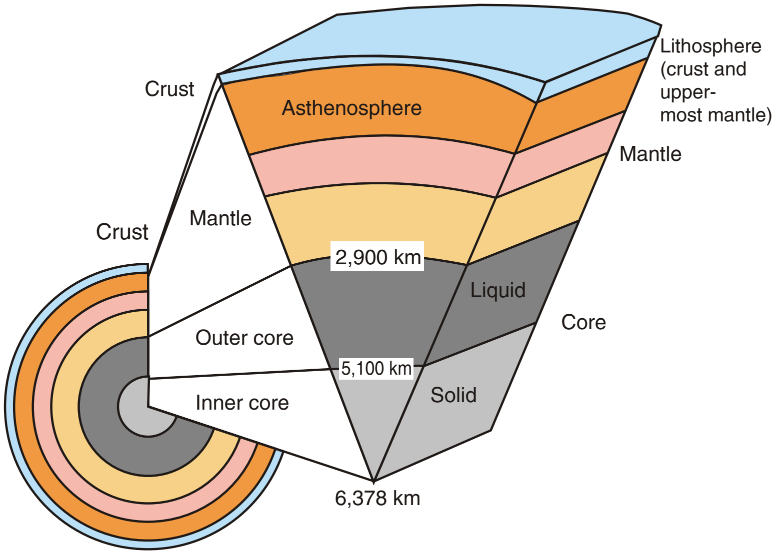


Figure 4: Internal structure of the earth.

earth is broken into broadly 13 pieces called the **Plates** which are in constant motion with respect to each other (figure 5). The plate motions are due to convective currents in the lower mantle due to temperature gradients, which are the main cause driving plate tectonics. Sometimes plates collide and converge, resulting in mountain building, like in the Himalayas. On the other hand, hot molten magma comes out with high pressure at zones with thin and weak lithosphere, usually in the middle of Oceans, resulting in creation of two plates which start moving away from one another. Such regions are called **mid-oceanic ridges** which comprise diverging plate boundaries. In another type of plate boundary, two plates can move side-by-side, as in the case of the San Andreas Fault in the United States. These three types of plate interactions are called convergent, divergent and transform plate boundaries, respectively. In a convergent zone one of the plates, usually the denser one dives beneath the other. Such a plate boundary is called a **subduction zone**. However, a convergent boundary can sometimes be a **collision zone**, like the Himalayas, where there is an equal tussle between colliding plates. The relative movement of plate boundaries varies across the earth. On an average, it is of the order of a few cm per year. Depending on the movement between the plates or blocks adjacent to the faults, earthquakes are classified into three types - **Thrust**, **Normal**, and **Strike-Slip** corresponding to the three types of plate movements (Figure 6).

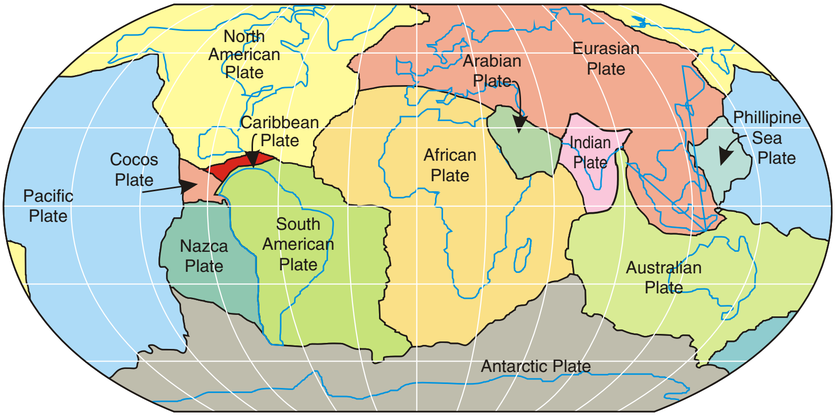


Figure 5: A map of the world's plates

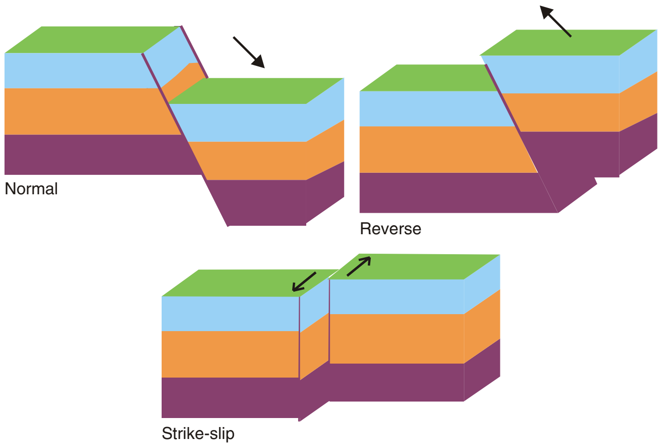


Figure 6: The three types of faulting mechanisms

Where do Earthquakes occur?

Earthquakes occur at all times, all over the globe. However, about 90% of the energy is released along the plate boundaries. The world seismicity map (figure 7) clearly shows that the seismicity distribution is not random but follows a trend along the major plate boundary zones. One of the most prominent belts is the circum-pacific belt, also referred as the **Ring of Fire**, which is an area where a large number of earthquakes and volcanic eruptions occur along the border of the Pacific Ocean. It is associated with a nearly continuous series of oceanic trenches and volcanic arcs. The next most seismically active region including 17% of the world's largest earthquakes is the Alpide belt, which extends from Java to Sumatra through the Himalayas, the Mediterranean, and out into the Atlantic. The Mid-Atlantic Ridge is the third most prominent earthquake belt.

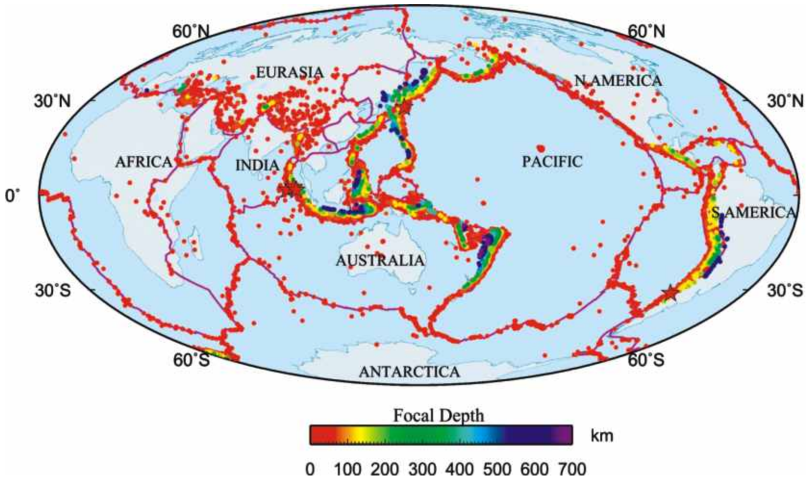


Figure 7: Global distribution of earthquakes of magnitude 5 and above during the last 40 years. Stars represent earthquakes of magnitude 8.5 and above.

Why do Earthquakes occur?

Earthquakes are usually caused when a subsurface rock suddenly breaks along a plane called the **fault plane**. Such a sudden release of energy produces seismic waves that make the ground shake. When two blocks of rock or two plates rub against each other, they do not simply slide smoothly against each other rather they get stuck due to friction. When the stress reaches a critical limit, it gets released and the rock breaks, leading to an earthquake. This is called the **elastic rebound theory** as explained by seismologist H.F. Reid after studying the 1906 San Francisco earthquake. He proposed that as rocks on opposite sides of the fault are subjected to force they accumulate energy and slowly deform when their internal

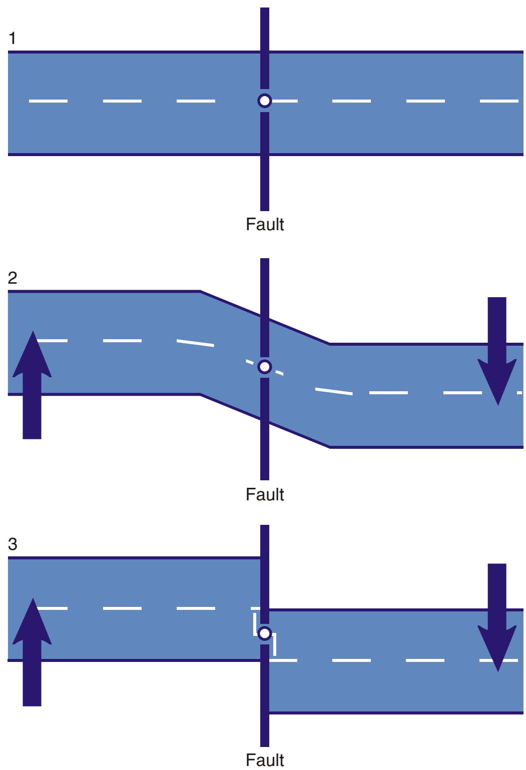


Figure 8: The elastic rebound theory of earthquake occurrence proposed by H.F. Reid

strength is exceeded, leading to release of the accumulated energy causing the rock to snap (Figure 8).

Magnitude and Intensity of an earthquake?

Magnitude is a measure of the size of an earthquake while the damage effect of an earthquake at various places around the epicenter is termed as **Intensity**. The Magnitude is a quantitative measure of the amount of energy released at the hypocenter during an earthquake. Hence, for a given earthquake the magnitude value is fixed where as the intensity values vary from place to place, usually decreasing as we move away from the epicenter. There are different types of magnitude scales, but the standard one which has been most widely used is the **Richter Scale** or the Local Magnitude (ML), which was proposed by Charles Richter in 1934. There are other types of magnitude scales like **Body wave magnitude (mb)** which uses the amplitude of the initial P wave. However, this magnitude scale saturates at higher values beyond 6 to 6.5, which means it tends to remain same even for larger earthquakes. Hence, another scale called the **Surface wave magnitude (Ms)** was defined in 1950 based on amplitude of the Rayleigh wave. Modern Seismology uses a better scale called the **Moment Magnitude (Mw)**, which is based on analysis of digital waveform data using the **Seismic Moment**.

The earthquake magnitude is on a logarithmic scale to base 10, and is expressed as a relative amplitude of the seismic wave with respect to a smaller reference amplitude value. Hence, magnitude is simply a ratio, and is given as a number without units. The size of the earthquake does not increase linearly with magnitude. For instance, an earthquake of magnitude 6 has 10 times the amplitude of ground shaking compared to that of magnitude 5. The energy release of the former is however, 31.6 times more than the latter. The average rate of occurrence of earthquakes globally, is given in table 1.

Table 1: The average frequency of occurrence of earthquakes globally with respect to magnitude.

Descriptor	Magnitude	Average Annually
Great	> 8	1
Major	7 - 7.9	17
Strong	6 - 6.9	134
Moderate	5 - 5.9	1319
Light	4 - 4.9	13,000
Minor	3 - 3.9	1,30,000
Very Minor	2 - 2.9	13,00000

Table 2: The Modified Mercalli Intensity scale

Modified Mercalli Scale	
I	Detected only by sensitive instruments
II	Felt by only some people, especially on upper floors; Suspended objects may swing
III	Felt noticeably but not always recognized as an earthquake; standing vehicles rock slightly; vibration like that of a passing truck
IV	Felt indoors by many and outdoors by a few; at night people are woken up; windows, doors dishes, disturbed; vehicles rock noticeably
V	Felt by most people; some breakage of dishes, windows, and plaster; Tall objects disturbed
VI	Felt by all; people are frightened and run outdoors; falling plaster and chimneys; damage is small
VII	Everyone runs outdoors; variable damage to buildings depending on quality of construction; noticed by driver of autos
VIII	Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed
IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracks; underground pipes get broken
X	Most masonry and frame structures are destroyed; ground cracks, rails bend, landslides occur
XI	Few structures remain standing; bridges are destroyed, fissures in ground, pipes broken, landslides, rail bent
XII	Damage total; waves seen on ground surface, lines of sight and level distorted, objects thrown up in air

The intensity is a qualitative measure of the actual ground shaking and damage caused at a location during an earthquake (Table 2). The most popularly used Intensity scale is the Modified Mercalli Intensity (MMI) denoted by Roman capital numerals. For any earthquake, the magnitude remains the same but the intensity changes at each location depending on the distance from the earthquake and the damage caused by it.

Figure 9: The world's first Seismograph in China

How are Earthquakes recorded?

The instrument used to record the seismic waves due to an earthquake is called a **Seismograph**. The world's first seismograph was invented by the Chinese astronomer and mathematician Chang Heng. It was called an

Earthquake-weathercock and comprised eight dragons and eight toads (Figure 9). Each dragon has a bronze ball in its mouth. When there is an earth tremor, the mouth of one dragon would open and the bronze ball would fall into the open mouth of one of the toads indicating that an earthquake has occurred. The direction of the earthquake could be deciphered by the position of the ball.

The seismograph measures the movements of the earth, and comprises a ground motion detection sensor, called a seismometer, coupled with a recording system. To understand the concept of a seismometer one can imagine a spring and weight suspended from a frame attached to the earth's surface (Figure 10). As the earth moves, the relative motion between the weight and the earth provides a measure of the vertical motion. If a recording system is installed, such as a rotating drum attached to a frame, and a pen attached to the mass, then the relative motion between the weight and the earth, during an earthquake can be recorded to produce a record of the ground motion, which is called a seismogram. However, modern seismometers are based on highly sophisticated electronics and use the concepts of electromagnetic induction and feedback circuits. In this case, the relative motion between the weight and the frame induces an electrical voltage that is recorded on a computer. Such an arrangement can be made in all the three directions vertical, north-south and east-west, resulting in a 3-component seismometer. Seismometers can also record ground motions caused by a wide variety of natural and man-made noises, such as trees blowing in the wind, cars and trucks on the highway, and ocean waves crashing on the beach. Incidentally they also record nuclear explosions carried out by different countries, often for test purpose.

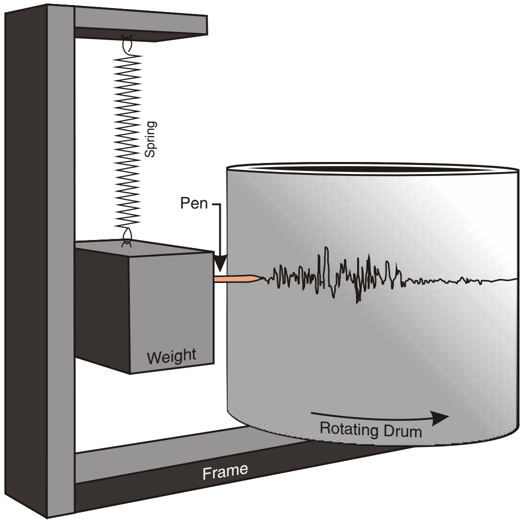


Figure 10: The working principle of a Seismograph

Propagation of seismic waves

Seismic waves travel through the earth in the form of elastic waves of different kind which arrive one after the other depending on their velocity of propagation. Also, the velocity itself depends on the density and elasticity of the medium. Velocity increases with depth and ranges from approximately 2 to 8 km/s in the earth's crust and up to 13 km/s in the deep mantle. The seismic waves also get attenuated as they pass through the earth, a factor that decides the shape of a seismogram recorded at any station. The different travel times of the P, S and surface waves, in addition to those of several other phases derived from the reflection and refraction of these waves, help scientists to locate the earthquake source, and to understand its mechanism.

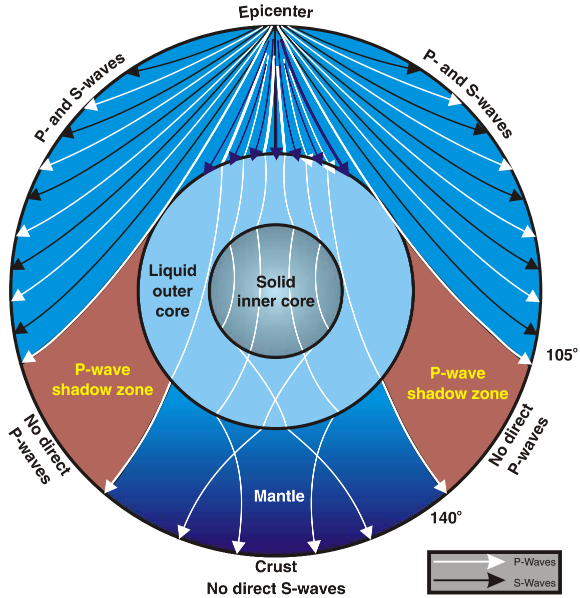


Figure 11: The propagation of seismic waves through the earth

The propagation of seismic waves can be visualized in the form of rays emanating from the earthquake focus and ending at a seismic observatory anywhere on the globe (figure 11). The rays are generally bent and not straight lines due to the phenomenon of refraction. The location and amount of bending depends on the physical properties of the earth. For instance, it was clear to seismologists that the outer core is in a liquid form since the S wave is missing for rays going through it. Also, due to the bending property of the P wave, it is not recorded at stations which are at angular distances of 104 to 140 degrees, which is approximately the other side of the globe, with respect to a given earthquake location. This zone for any earthquake is called the **shadow zone** which does not record any of these waves.

How to read a Seismogram?

In a typical seismogram (figure 12), the P wave of an earthquake is the first to arrive and is generally prominently seen over and above the background noise. Since it is the fastest wave, it is recorded first. The next set of seismic waves on the seismogram are the S waves that travel slower, at about 0.6 times the velocity of P waves, due to the shearing or transverse motion. The S waves, however, have much higher amplitude than the P waves. The surface waves (Love and Rayleigh waves) are the largest and longest waves on the seismogram. These waves travel a little slower than S waves, and along the surface of the globe. For an earthquake very close to the seismograph station, the S wave and surface waves may appear mixed up. The amplitude of seismic waves depends upon (1) the magnitude of the earthquake, (2) the distance between the earthquake and the seismograph station and (3) the medium of travel. In a hard transmissive medium, seismic waves would not get attenuated as compared to a loose or weak rock mass. However, in a special case of soft sediment or alluvial fill beneath the station, seismic waves can actually get trapped and amplify due to multiple reflection and resonance within the layer, causing much greater damage.

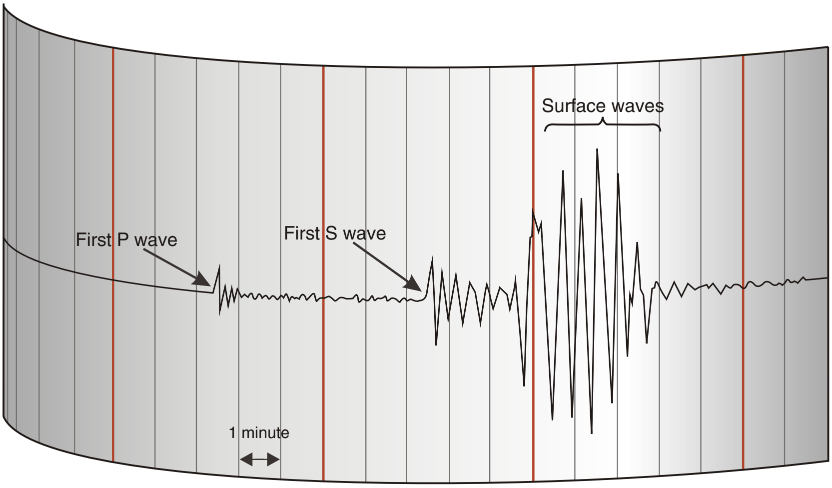


Figure 12: A sample seismogram indicating the P, S and Surface waves

How to Locate an Earthquake?

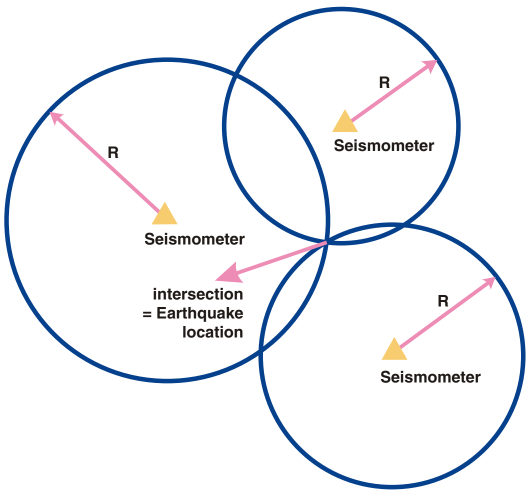


Figure 13: Earthquake location using three seismic stations

When an earthquake occurs, its waves propagate in all directions and are recorded at several seismograph stations in different parts of the world. The arrival time at each station varies depending on its distance from the earthquake. Also, at each station the P and S waves arrive at different times since they travel with different speeds. A seismic station close to the earthquake records P and S waves within a short time span, compared to a distant station. With increasing distance the difference in the arrival times of P and S waves (S-P) goes on increasing. Hence, the S-P time is proportional to the epicentral distance. An approximate measure of distance is the S-P time multiplied by the average velocity. If the distance to the earthquake is estimated from at least three stations, then the location can be estimated by drawing a circle around each station with a radius equal to its distance from the earthquake. The earthquake epicenter is the point where all the three circles intersect (Figure 13). However, in practice more sophisticated methods using seismic data from several stations are used to accurately locate the earthquakes.

What is Earthquake Hazard?

In reality, earthquakes do not pose any direct danger to a person. This means that people cannot be shaken to death by an earthquake. The real problem is due to collapse of buildings that are shaken due to the ground motion during an earthquake. Hence, earthquake risk is more in highly populated areas with a large number of houses and buildings, especially those constructed with poor quality material and design. Apart from this, each location responds to the ground motion due to an earthquake differently, depending on the local soil conditions. This is called **Site response**. The response of a site is mainly controlled by amplification of the seismic waves trapped in the top soft soil layer having a high impedance contrast with respect to the underlying hard rock (Figure 14). This effect is called Site Amplification. Hence, earthquake hazard can be greater in regions of loose alluvial or sedimentary fill as compared to those built on a hard rock site.

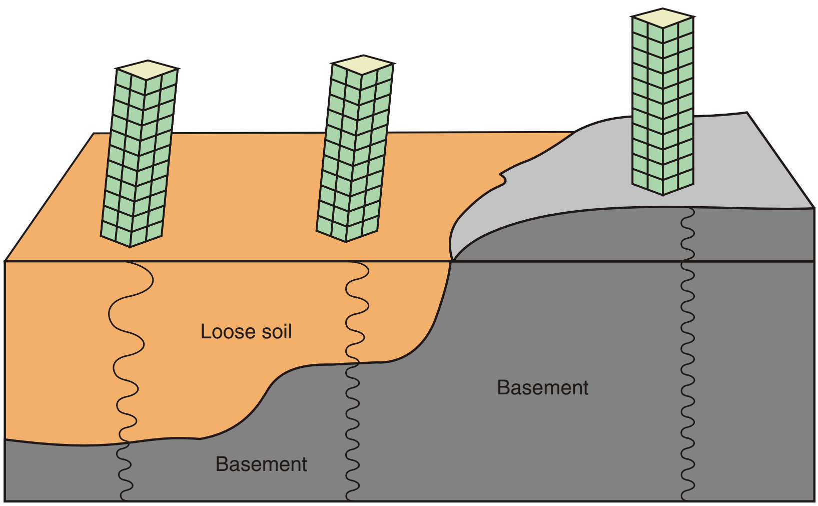


Figure 14: Variation in seismic wave amplitudes with change in local soil conditions above the basement (the seismic waves are highly amplified in soft soil sediments than on hard bedrock).

Site Amplification

The local soil conditions at a site can amplify seismic waves as they travel from bedrock to the ground surface. This transfers a large part of the ground accelerations to structures and buildings, causing destruction, particularly when the seismic wave frequencies match the resonant frequencies of the structures. Hence, for designing earthquake resistant structures, it is very important to have a good idea about the local Site Amplification and also the frequency response spectrum at the ground surface.

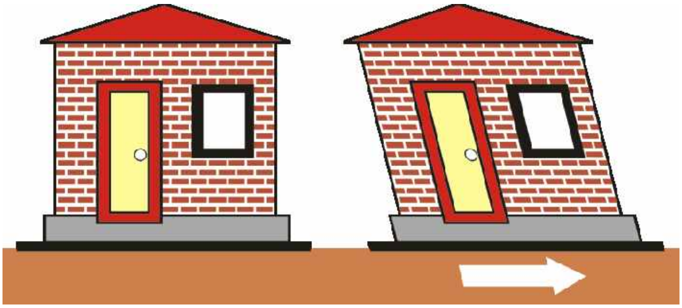


Figure 15: Engineering considerations only take care of vertical loads but not the horizontal strength required to survive an earthquake.

Earthquake Liquefaction

Liquefaction is the phenomenon where the soil which is partially or fully saturated with water loses its strength and stiffness in response to an applied stress during earthquake shaking. In such a case the soil tends to behave like a liquid and can lead to complete sinking of a building or a structure, or drastic and irregular settlement of the building causing structural damage, or may leave the structure unusable even without any damage.

Earthquake Resistant Construction

Buildings are basically designed to support vertical load due to gravity, which takes care of support to the walls, the roof and everything else connecting them. Earthquakes, however, present a lateral or sideways load to the building or structure which is unaccounted, leading to a total collapse of the structure (figure 15). Hence, one of the principles to make a structure more resistant to these lateral forces is to keep the walls, roof and foundations tied up as a single unit that holds together when shaken by a quake. To make a building or a structure strong enough to completely withstand a large earthquake by using strong, high quality materials would be a very expensive proposition. Hence, earthquake resistant design is about allowing some acceptable level and type of damage at some not so critical points that are pre-determined, while ensuring that the overall structure doesn't collapse. According to building codes, earthquake-resistant structures are designed to withstand the largest possible earthquake with a certain probability level that is likely to occur at that location. This means that the loss of life should be minimized for large earthquakes by preventing collapse of the buildings, while the loss of functionality should be restricted for the smaller ones.

Seismic Retrofitting and Vibration control techniques

Seismic retrofitting is the modification of existing structures to make them more resistant to earthquakes or liquefaction effects. There are several techniques of retrofitting like Base isolation, Supplementary dampers, Tuned mass dampers, Slosh tank, Active control system, and external structural support. Figure 16 shows an example of **base isolation** where the base of the structure is free to move in isolation from the ground which is shaking due to an earthquake. This keeps the building in motion but intact from deformation or possible collapse during an earthquake.

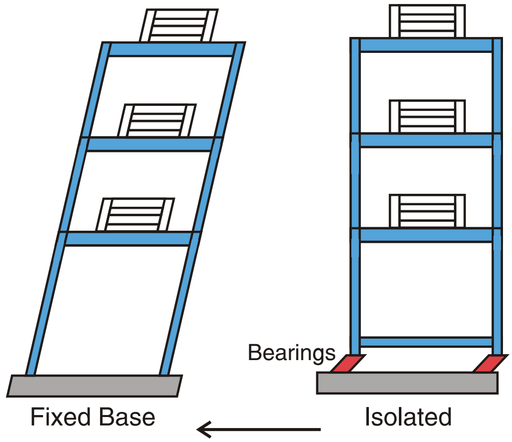


Figure 16: Base Isolation Technology

Important Earthquake facts

The largest earthquake recorded in the world is the 22 May 1960 Chile earthquake of magnitude 9.5. The seismic waves of this earthquake shook the entire earth for many days! This phenomenon is called the free oscillation of the Earth. Since then there have been about 6 earthquakes of magnitude greater than or equal to 9.0 (Table 3) including the 2004 Sumatra-Andaman earthquake of M9.1. The world's deadliest earthquake on record is the 1556 earthquake in central China which struck and caused collapse of cave dwellings carved from soft rock, killing an estimated 830,000 people. In 1976 another deadly earthquake struck in Tangshan, China, where more than 250,000 people were killed. The world's deepest earthquakes typically occur at plate boundaries where the Earth's crust is being subducted into the mantle, as deep as 750 km from surface.

Table 3: The world's largest earthquakes of magnitude 9 and above.

Date	Location	Name	Magnitude
22 May, 1960	Valdivia, Chile	1960 Valdivia earthquake	9.5
27 March, 1964	Prince William Sound, Alaska, USA	1964 Alaska earthquake	9.3
26 December, 2004	Indian Ocean, Sumatra,	2004 Indian Ocean earthquake	9.1
4 November, 1952	Kamchatka, Russian SFSR, Soviet Union	1952 Kamchatka earthquake	9.0
11 March, 2011	Pacific Ocean, Tōhoku region, Japan	2011 Tohoku earthquake	9.0
13 August, 1868	Arica, Chile (then Peru)	1868 Arica earthquake	9.0

Do's and Don'ts of an Earthquake

It is a wrong notion that earthquakes kill people. In reality it is the collapse of buildings, especially those which are poorly constructed that takes a huge toll of life and property. Hence, it is very important to have a general awareness about earthquakes and take precautionary and preventive steps to protect oneself and others.

What to do before an earthquake ?

- Keep available the following items - a fire extinguisher, a first aid kit, a battery-powered radio, a flashlight and extra batteries at home.
- Learn how to use the first aid kit in case of injury.
- Learn how to turn off the gas and electricity.
- Decide a meeting point with your family in case of a major earthquake
- Do not keep heavy objects on shelves since they can fall on you during an earthquake.
- Keep heavy furniture, cupboards and appliances anchored to the walls or to the floor.
- Be familiar with the Earthquake plan at your school or workplace.

What to do during an earthquake ?

- Remain calm! If you are indoors, stay inside. If you're outside, stay outside.
- If you are indoors, stand against a wall near the middle of the building, stand in a doorway, or crawl under some heavy furniture like a desk or a table. Stay away from windows and outside doors.
- If you are outdoors, stay in the open away from power lines and anything that might fall. Stay away from buildings since they may collapse on you.
- Do not use matches, candles, or any flame.
- If you're inside a vehicle, just stop it and stay inside until the earthquake stops.

What to do after an earthquake ?

- Check yourself and others for injuries and provide first aid to the needy.
- Look for any damage in the water, gas, or electricity lines. If there is any damage, then shut it off.
- Check for the smell of gas and open all the windows and doors if you smell it, and leave the place immediately.
- Turn on the radio for updates.

- Stay out of damaged buildings.
- Wear proper foot wear to protect from damage to feet from broken material and debris.
- Stay away from beaches since there could be a tsunami caused by the earthquake.
- If you are at school or work place, then follow the emergency plan or instructions of the person in-charge.
- Expect aftershocks to happen in the next few hours and days.

Plate tectonics of the Indian Sub-Continent:

The Indian plate is bordered by the Eurasian plate in the north, the Burma-Andaman plate in east, the Australian plate in the south and the Africa and Arabia plates in the west. Earlier it was a single entity referred as the Indo-Australian plate, and was a part of the Gondwanaland along with the Antarctica, Africa, Madagascar and South America plates. The Indian plate broke away about 150 million years ago and started drifting northward. It subsequently crossed the equator and reached the current position where it collided with the Eurasian landmass about 40 million years ago (figure 17). The Tethys Sea separating these plates before the collision got consumed into the mantle below, and further convergence led to formation of the majestic Himalaya, the highest mountains, and the Tibetan plateau, the tallest plateau further north.

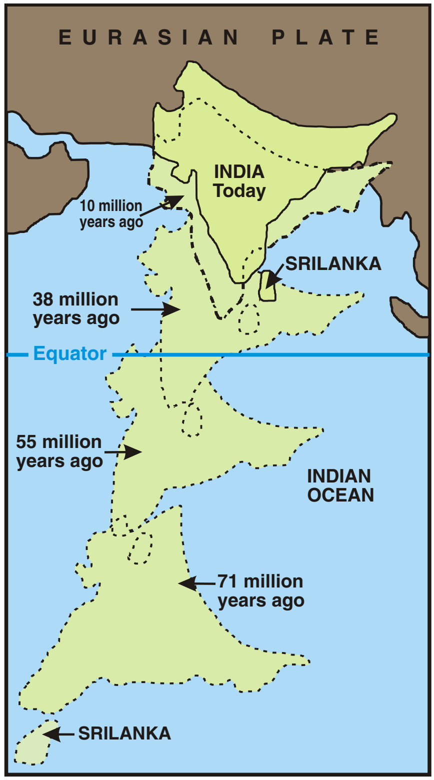


Figure 17: The long northward journey of the Indian plate since it broke away from the Gondwanaland near south pole about 150 million years ago.

Earthquakes in the Indian Plate region

The Indian plate is surrounded by seismicity along all its plate boundaries with the neighbouring plates (figure 18). The India-Eurasia plate convergence which is currently of the order of 4-5 cm/yr has resulted in a large number of earthquakes along the Himalaya and in the northeastern India. Similarly convergence on the eastern and south-eastern sides with Burma and Andaman arcs respectively resulted in several large to great earthquakes. This includes one of the world's largest earthquakes of magnitude 9.1 which initiated in Sumatra and ruptured about 1500 km northward through the Andaman Islands, and was also responsible for the world's deadliest tsunami. To the south lies a young plate boundary that started developing between India and Australia plates a few million years ago leading to enhanced seismicity. On the west there are earthquakes caused by the separation of the India and Africa plates along a mid-oceanic ridge. Further to the west and north-west seismicity can be attributed to a strike-slip motion between India and Arabia plates.

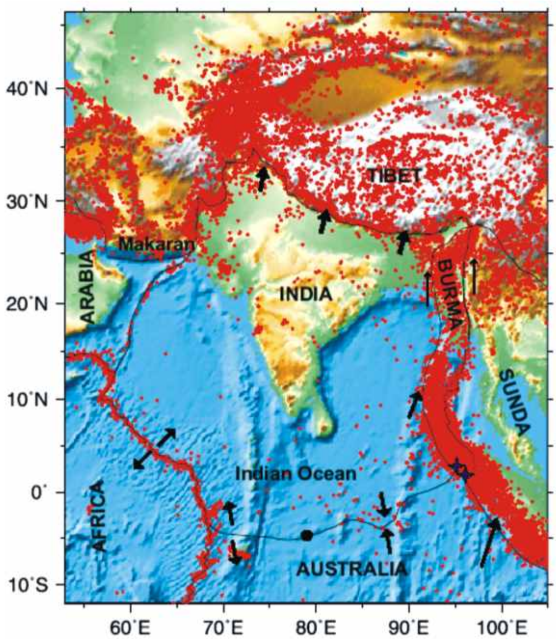


Figure 18: Earthquakes in the Indian-continent along with the neighbouring plates, their boundaries and plate motion indicated by arrows.

In the instrumental era of over a hundred years, there were four great earthquakes (magnitude ≥ 8.0) in the Himalayan belt, namely the 1897 Shillong, the 1905 Kangra, the 1934 Bihar-Nepal and the 1950 Assam earthquakes, apart from several other disastrous earthquakes. The largest one, however, was of magnitude 9.1 witnessed in the Andaman region in 2004. In general the Indian plate region has evidenced many large magnitude earthquakes due to the stress accumulation associated with collision and convergence on the place boundaries. Due to this, several earthquakes also occur within the plate interior, which are called **intra-plate earthquakes**. Some of the famous moderate to large intra-plate earthquakes in the Indian region are the 1967 Koyna, 1969 Bhadrachalam, 1970 Broach, 1993 Latur, 1997 Jabalpur and 2001 Bhuj earthquakes. Figure 19 shows a plot of the significant earthquakes in the Indian region, both on plate boundaries and plate interiors, as listed in Table 4.

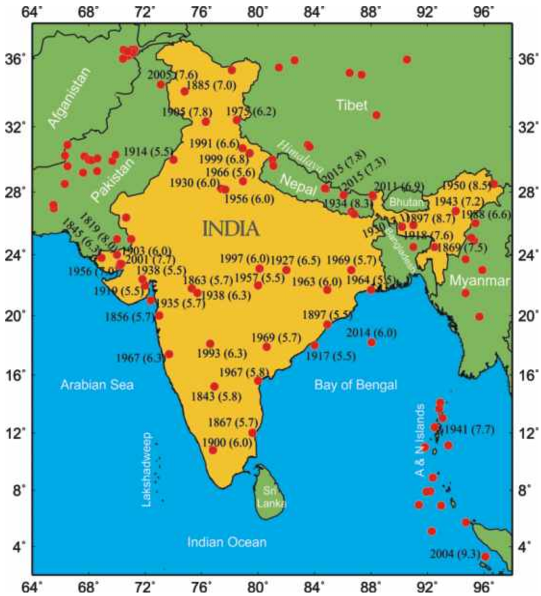


Figure 19: Significant earthquakes in the Indian region. Magnitudes ≥ 6.5 for the plate boundaries and ≥ 5.5 for the plate interiors are plotted for convenience. Source: as given in Table 4.

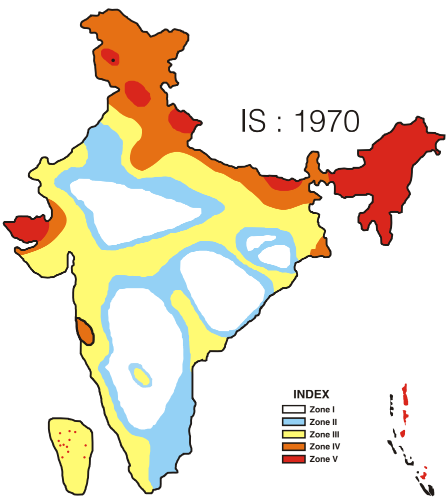
Table 4: Significant earthquakes in the Indian region during the last 200 years with Magnitudes ≥ 6.5 on the plate boundaries and ≥ 5.5 in the plate interiors as plotted in figure 19. Sources: Rao & Rao (1984) Gowd et al. (1996) Rajendran & Rajendran (1998), USGS.

Date	Latitude	Longitude	Region/Place	Magnitude
1819 Jun 16	24	70	Kutch, Gujarat	8.0
1843 Mar 31	15.2	76.9	Bellary, Karnataka	5.8
1845 Jun 19	23.8	68.9	Luckput	6.3
1856 Dec 25	20	73	Near DAHANU	5.7
1863 Nov 8	21.8	75.3	Burwani	5.7
1867 Jul 3	12	79.6	Villupuram	5.7
1869 Jan 10	24.5	92.5	Near-Cachar, Assam	7.5
1885 May 30	34.1	74.8	Sopore, Jammu & Kashmir	7.0
1897 Jun 12	25.9	91	Shillong Plateau	8.7
1897 Jun 22	19.4	84.9	Berhampur	5.5
1900 Feb 7	10.8	76.8	Coimbattore	6.0
1903 Jan 14	24	70	Kutch	6.0
1905 Apr 4	32.3	76.3	Kangra, Himachalpradesh	7.8
1914 Apr 30	30	74	Punjab-Rajastan Border	5.5

1917 Apr 17	18	84	Vizianagaram, Andhrapradesh	5.5
1918 Jul 8	24.5	91	Srimangal, Assam	7.6
1919 Apr 21	22	72	Bhavangarpura	5.5
1927 Jun 2	23	82	Son Valley	6.5
1930 Jul 3	25.8	90.2	Dhubri Assam	7.1
1930 Aug 27	28.2	77.40	Gurgaon, Haryana	6.0
1934 Jan 15	26.6	86.8	Bihar-Nepalborder	8.3
1935 Jul 20	21	72.4	Neardumas	5.7
1938 Mar 14	21.5	75.7	Satpura	6.3
1938 Jul 23	22.4	71.8	Paliyad	5.5
1941 Jun 26	12.4	92.5	Andaman Islands	7.7
1943 Oct 23	26.8	94	Assam, Northeast India	7.2
1950 Aug 15	28.5	96.7	Arunachalpradesh-China Border	8.5
1956 Jul 21	23.3	70.2	Anjar, Gujarat	7.0
1956 Oct 10	28.15	77.67	Khurja-Bulandshahr, Uttarpradesh	6.0
1957 Aug 25	22	80	Balaghat	5.5
1963 May 8	21.7	84.9	Thethanagar	6.0
1964 Apr 16	21.7	88	Midnapora	5.5
1966 Aug 15	28.67	78.93	Moradabad, Uttarpradesh	5.6
1967 Mar 27	15.6	80	Ongole, Andhrapradesh	5.8
1967 Dec 11	17.4	73.7	Koyna, Maharashtra	6.3
1969 Apr 13	17.9	80.6	Bhadrachalam, Telangana	5.7
1969 May 3	23	86.6	Bankura	5.7
1975 Jan 19	32.4	78.5	Kinnaur, Himachalpradesh	6.2
1988 Aug 6	25.1	95.1	Manipur-Myanmar Border	6.6
1991 Oct 20	30.7	78.9	Uttarkashi, Uttrakhand	6.6
1993 Sep 30	18.1	76.6	Latur-Osmanabad, Mahrashtra	6.3
1997 May 22	23.1	80.1	Jabalpur, M.P.	6.0
1999 Mar 29	30.4	79.4	Chamoli, Uttarakhand	6.8
2001 Jan 26	23.4	70.3	Bhuj, Gujarat	7.7
2004 Dec 26	3.3	96.1	West-Coast-Of Sumatra	9.1
2005 Oct 8	34.5	73.1	Muzaffarabad, Pakistan	7.6
2011 Sep 18	27.8	88.1	Sikkim-Nepal Border	6.9
2014 May 21	18.2012	88.0376	Bayof Bengal	6.0
2015 Apr 25	28.2305	84.7314	Khundi, Nepal	7.8
2015 May 12	27.8087	86.0655	Kodari, Nepal	7.3

Seismic Zonation Map of India

The **Seismic Zonation map** of India is prepared by a team of experts comprising seismologists and earthquake engineers of the country under the aegis of the Bureau of Indian Standards, Government of India. In this map the level of perceived hazard in different parts of the country is classified into zones based on the earthquake intensities sustained during past damaging earthquakes and the presence of active faults which pose a potential threat for future. The previous version of the Seismic Zonation map of India released in 1970, comprised five zones I, II, III, IV and V (Figure 20). Zone V is the most hazardous one comprising parts of Himalaya in the north, the Northeastern India, the Kachchh area in the west and the Andaman-Nicobar Islands. The seismic Zonation maps are revised from time to time as more understanding is gained on the geology, tectonics and seismic activity in the country. The latest revised version of the zonation map appeared in 2002 (Figure 20) which has only four seismic zones II, III, IV and V. The areas falling in seismic zone I in the previous map are now merged with those of seismic zone II indicating that a minimum hazard level of II exists anywhere in the country. Also, there are modifications in the peninsular region. For instance, in the revised map Chennai city falls in seismic zone III as against zone II in the previous map. The Seismic Zonation map of India only presents a broad view of the expected earthquake hazard in the country. Effects of local variations in soil type and geology cannot be represented at that scale. Therefore, for important projects, such as major dams or nuclear power plants, the seismic hazard is evaluated in detail specifically for that site at a micro level. This type of study is called **Seismic Microzonation**. Also, for the purposes of urban planning, metropolitan areas need to be micro-zoned.



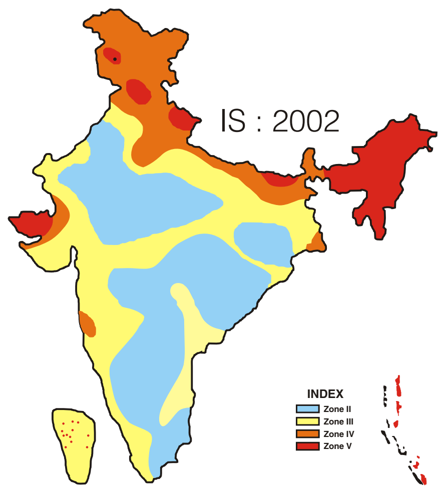


Figure 20: Seismic Zonation map of India in 1970, and later revised in 2002.

Seismic Hazard and Microzonation in India:

The observed increase in seismicity in the Indian subcontinent, together with the rapid urbanization and population growth raises serious concerns regarding the seismic hazard potential of the Indian region. In this situation, the major thrust has now shifted from earthquake forecasting or prediction to earthquake hazard assessment and mitigation. The probabilistic and deterministic seismic hazard maps provide very useful information, but are regional in nature. For site-specific considerations, particularly for the mega-cities, one has to adopt the more detailed seismic microzonation approach, which involves estimation of local geological effects and local site amplification, soil stability and liquefaction, among other geotechnical aspects. For the purpose of delineating seismic microzones, detailed mapping of tectonic features, thickness and characteristics of soil cover in different parts of the city has to be undertaken. A number of smaller zones are to be described, based on the finer seismotectonics, lithological, geomorphological and other considerations specific to the region. A set of microzoning maps may be prepared, each depicting different characteristics of the rock types, eg. soil thickness map, soil amplification map for different frequencies of ground motion, liquefaction potential map, etc. Finally, one can combine the basic seismic hazard values with microzone characteristics detailed above and produce a single microzonation map of the city or a region. Seismic hazard microzonation map can be further refined to include the actual vulnerability of the city in terms of the anticipated loss to human life and damage to properties and major structures. This provides the **Seismic Risk Microzonation map** which is extremely important for planning of pre-disaster mitigation measures or to initiate a new infra-structural development programme.

Earthquake Prediction

Earthquake prediction implies specification of the time, location, and magnitude of a future earthquake. Earthquake prediction is different from earthquake forecasting, the latter being a probabilistic assessment of general earthquake hazard, including the frequency of occurrence and magnitude of a damaging earthquake possible in a region over a period of time. While some scientists believe that earthquake prediction might be possible with some more effort, many others maintain that it is impossible. In China and Japan, several experiments were also carried out to investigate animal behavior as a precursor to an impending earthquake, although without much luck. Some of the earthquakes that were predicted are the 1975: Haicheng, China, 1985-1993: Parkfield, USA, 1987-1995: Greece, 1989: Loma Prieta, USA, 1990: New Madrid, USA, 2004 and 2005: Southern California, USA, and 2009: L'Aquila, Italy earthquakes. However, there are serious questions and doubts regarding the reliability and repeatability of such predictions.

Some of the major precursors that are found to vary before the occurrence of an earthquake are changes in the ratio of P and S wave velocity, helium and radon gas emissions due to stresses and fracturing of rocks beneath, intense foreshock activity, electromagnetic variations and water level changes in wells due to local stresses. While observations of these precursors still show a great promise for earthquake prediction in future, till date no reliable and repeatable observation has been conclusively accepted, and research in this direction still continues.

Earthquake Early-Warning System

An **Earthquake Early Warning System** is based on the fact that the destructive surface waves of an earthquake would arrive several seconds after the fastest travelling P wave arrives at a seismograph station (figure 21). If the P wave can be detected and analyzed very quickly, then this small delay of a few seconds, although very short, provides an opportunity for short term preparedness. Countries like Japan, U.S and Canada have combined earthquake research and communication technology to develop alert systems which are used to warn people about an impending earthquake disaster within a few seconds. The few seconds of advance warning provides scope for some quick action to protect life and property from the earthquake.

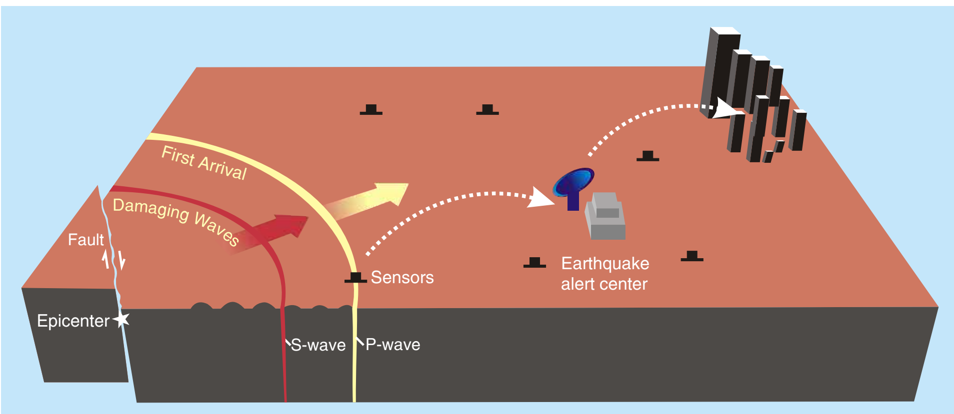


Figure 21: Schematic of an Earthquake Early Warning System

Earthquake early warning systems work because the warning message can be transmitted with the speed of light whereas the shake waves from the earthquake travel through the earth at speeds of only a few kilometers per second. Figure 21 shows how such a system would operate. When an earthquake occurs, both the compressional (P) waves and the transverse (S) waves radiate outward from the epicenter. The P wave, which travels fastest, trips the sensors deployed, causing alert signals to be sent ahead, giving people and the automated electronic systems a few seconds to minutes, to take precautionary actions before the arrival of the most damaging surface waves. The alert can be received on mobile phones or computer servers, with an automated programme directing the further course of action.

An earthquake early warning system provides a notification of earthquake occurrence at a certain location, it's likely magnitude and the fact that potentially damaging seismic waves are approaching. The warning times depend on the distance between the earthquake source and the receiver's location and may vary from a few seconds to over a minute if the source is quite distant. In the absence of a reliable earthquake prediction system, earthquake early warning provides a good alternative for which technology is currently available. The real benefit from an early warning system, however, depends on the quality of the available communication system, general public awareness and response readiness. This can be achieved only through proper training and preparedness of both the public and government agencies involved in disaster management. Some of the important applications of an Earthquake Early Warning System are:

- Public: Citizens, including schoolchildren, can go for safety cover, turn off stoves, safely stop vehicles, etc.
- Businesses: Personnel move to safe locations, automated systems ensure that elevator doors open, production lines are shut down and sensitive equipment is placed in a safe mode.
- Medical services: Doctors and Surgeons stop delicate procedures.
- Emergency responders: Shut down of nuclear power plants, stopping of high speed trains, open firehouse doors, personnel prepare and prioritize response decisions.

Tsunamis caused by earthquakes

A **tsunami** is a series of water waves caused by the displacement of a large volume of water generally in an ocean or a large lake. While the major cause of a tsunami is an under-water earthquake, other possible causes are volcanic eruptions, underwater explosions, landslides, caving in of glaciers, meteorite impacts and other disturbances in water bodies. A tsunami is different from a normal ocean wave generated by wind disturbance and also from tides generated by the gravitational pull of the moon and the sun on water bodies.

The tsunami waves are of unusually long wavelength of about 200-300 km and initially have a speed of up to 1000 km/h. The waves are generally not visible due to their very low amplitude or height of a few cm at the most. But as the waves approach the coast, they get squeezed, the wave lengths reduce and the wave heights increase, while the speeds reduce to below 100 km/h. Hence, the tsunami waves suddenly become visible as they approach the coast. The waves are very dangerous due to their heights which can reach several tens of meters and speeds capable of washing away people and vehicles and completely damaging buildings and structures.

The Indian Ocean tsunami of 26 December 2004 was the deadliest natural disaster in the history of mankind which followed the Sumatra-Andaman earthquake of magnitude 9.1. The earthquake and tsunami that followed killed at least 230,000 people in 14 countries bordering the Indian Ocean. After this event, a tsunami warning system was established in the Indian Ocean region by the Government of India.

Earthquake alert and Tsunami Warning in India

The Ministry of Earth Sciences (MoES), Government of India, has a network of several seismograph stations set-up all over the country. These stations are operational round the clock and record earthquakes near and far as and when they occur. These stations are linked up from their respective locations through a satellite connection to a computer server at the monitoring Center in New Delhi, where earthquake data recorded at each station is received in real time automatically. These data are processed by a special software that has the provision for automatic location of earthquakes, estimation of their magnitudes and other scientific parameters and the information is sent to officials and other users.

A center established by the Ministry of Earth Sciences called the Indian National Center for Ocean Information Service (INCOIS) is located in Hyderabad, which hosts the National Tsunami Warning System. This system uses the earthquake alert information in real time and based on the magnitude, location, focal depth, ocean floor bathymetry, etc, prepares an assessment for possible tsunami occurrence following an earthquake and issues a tsunami alert, if required. The Center also has several Deep ocean assessment and reporting of tsunamis (DART) systems comprising pressure sensors installed on the ocean bottom of the Indian Ocean which can detect tsunami waves when they move past the sensor. These sensors based on the principle of piezo-electricity transmit signals through satellite connection to the Center at INCOIS which uses this information to assess the situation and issues a tsunami warning including the expected arrival time and intensity of the tsunami at different points along the Indian coast.

Future Scope

Earthquakes have occurred for millions of years in the past and shall continue to occur for millions of years to come. Hence, there is no escape from them and one must learn to live with them. In spite of a lot of efforts for over a century now, earthquake prediction is still not possible anywhere in the world. Research is going on with the hope of cracking this extremely difficult yet important problem challenging mankind. In this situation it is very essential to have a good level of public awareness regarding earthquakes, at all levels - individuals, students, society, government and media. The general plan of mitigation should be very clear in the case of an emergency. Disaster management groups of the government along with non-governmental organizations and the media should be involved in such plans along with scientists and management experts. Regular drills at schools, colleges and for general public should be organized at regular intervals. At the level of scientists, further research should be continued to identify the best possible precursory phenomena that would precede an earthquake in different seismic zones. Also, detailed seismic hazard and microzonation studies should be carried out with government support for all major cities and towns in the country prone to earthquakes.

Finally, the maximum focus should be on the proper construction of buildings and other structures as per the prescribed norms and codes. It is a well known fact that the loss of life and property in the under-developed or developing countries is much higher than in developed countries for an earthquake of the same magnitude. For instance, more than 80,000 people were killed in the 2005 Muzaffarabad, Kashmir earthquake of magnitude 7.6 whereas for a similar earthquake in a developed country, the casualties are likely to be very few. Similarly, the 1993 Latur earthquake saw over 10,000 dead for only a 6.2 magnitude earthquake. In both these cases the quality of construction and material used was extremely poor leading to complete collapse of buildings and structures, a situation that could have been completely avoided. Guidelines for construction of earthquake-resistant houses and structures based on the seismic zones are already released by the Government of India through the Bureau of Indian Standards (BIS). These codes should be strictly followed during constructions, for the safety and security of people from future destructive earthquakes.

About the Author

Dr. Nemalikanti Purnachandra Rao

Dr. Rao was born in 1963 in the Guntur district of Andhra Pradesh. His basic school education was in Mumbai and Pune, and subsequently in Hyderabad where he got an M.Sc.(Tech.) and a Ph.D. degree in Geophysics from the Osmania University. Later he visited Japan and got a D.Sc. degree in Seismology from the University of Tokyo. He is currently a Chief Scientist (Scientist G) and a Project Leader at the CSIR-National Geophysical Research Institute, Hyderabad. Dr. Rao specializes in simulation of seismograms to study the physics of the earthquake source and structure of the earth's interior. He has worked on several problems related to earthquakes in the Himalaya, Andaman, Northeast India and the Indian Ocean region. He was involved in the Global Seismic hazard assessment program of the Indian region and the first Seismic Microzonation project of the country in Jabalpur, central India. Dr. Rao has about 70 published papers, reports and book chapters to his credit. He has been the project leader of several national and international projects, including the prestigious Koyna scientific drilling project where a deep borehole observatory is underway for study of earthquake genesis. He is also a Professor at the Academy of Scientific and Innovative Research of CSIR where he teaches Advanced Seismology and guides students for Ph.D.

Dr. Rao was the first recipient of the ONGC-AEG best Ph.D. award when it was instituted in 1997. He is also a recipient of the prestigious Alexander von Humboldt fellowship of Germany in 2003. He was a Visiting Professor at the University of Tokyo in 2008 and a Raman Research fellow at the University of California, San Diego, USA in 2009. He is a Fellow of the Geological Society of India, Andhra Pradesh Akademi of Sciences and the Telangana State Akademi of Sciences. He is a member of several important committees including the Earthquake Engineering sectional committee and the CED-39 working group of the Bureau of Indian Standards, Government of India, and the Department of Atomic Energy committee for Tsunami studies. He is an Editorial board member of the Journal of Asian Earth Sciences and a Guest Editor for a special issue on the 2005 Kashmir earthquake in the Journal of Seismology, and the 2015 Nepal earthquake in the Journal of Asian Earth Sciences. Additionally, Dr. Rao has been a spokesperson of NGRI dealing with the press and media for several years.

On the personal front, Dr. Purnachandra Rao is a classical singer, a writer and a cartoonist. He has a good flair for foreign languages which prompted him to learn French, German and Russian from the Osmania University, Hyderabad. He is a trained meditation teacher, and has lectured on this subject in several countries. He was involved in several extra-curricular activities and community services, and has organized several scientific and cultural events in the past.

Science Spectrum

An Official Journal of Andhra Pradesh Akademi of Sciences

About the ''Science Spectrum'' Journal

Andhra Pradesh Akademi of Sciences, the first state science Akademi established in the year 1963 has been engaged in the Publication activity as part of its objectives, towards advancement of Science in A.P. Over the years, the Akademi has been publishing journals on science containing Seminar Proceedings, research Articles & review articles. During 2015 the Akademi has initiated the proposal to bring out its official Journal ''Science Spectrum'' as the official Journal of AP Akademi of Sciences to publish research articles including review articles and short communications. Initially it is proposed to publish four issues (Quarterly) of the Journal per year. The first issue of the Journal ''Science Spectrum'' is proposed to be released during the AP Science Congress at Tirupati. The following are the details and guidelines for publication of articles in the Journal.

Research Articles: Research Articles are invited from researchers in Academic Institutions, Scientific laboratories and other institutions including industry pertaining to any of the following broad scientific fields including interdisciplinary areas :

- Physical Sciences
- IT & Computer Sciences
- Chemical Sciences
- Agricultural Sciences
- Earth including Ocean Sciences
- Mathematical Sciences
- Engineering Sciences
- Life Sciences
- Medical and Pharmaceutical Sciences
- Space and Atmospheric Sciences

Short Research Communications: These communications cover the preliminary research findings from the authors own research work. They are fast-tracked for immediate publications

Instructions/ Guidelines to Authors for Manuscript Preparation

Title: It should be bold, 14 point, centered to the page and brief in a maximum of two lines.

Authors: Names should be in bold, 12 point, in the order - family name, middle name and last name. The corresponding author(s) name should be marked with a '*' and provided with his/her email address.

Address: It should be normal, 10 point, with full postal details of department, institute.

Abstract: A short Abstract, 12 point, 10-15 lines (~100-150 words) describing the salient features.

Keywords: A list of 5-6 keywords to be presented below the abstract, in 10 point.

Text: The text, 12 point, should be divided into sub-headings, such as: Introduction, Results and Discussions, Conclusions, Acknowledgements, References.

References Should be provided in parenthesies with Author name & year in text of the MS (for example M. Siedlecka et al 2008; Hecht & Huc, 2007) The format of the references to be given in references is as follows:

M. Siedlecka, G. Goch, A. Ejchart, H. Sticht, A. Bierzynski, Proc. Natl. Acad. Sci. USA 1999, 96, 903-908. A. Patgiri, A. L. Jochim, P. S. Arora, Acc. Chem. Res. 2008, 41, 1289-1300.

S. Hecht, I. Huc, (Eds.), Foldamers: Structure, Properties and Applications, Wiley-VCH: Weinheim, Germany, 2007. C. Shellman, In Protein Folding; Jaenicke, R., Ed.; Elsevier: Amsterdam, 1980, pp 53-64.

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- The manuscript is submitted exclusively to APAS. The contents partially or totally were not submitted to any other journal simultaneously.
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Short Research Communications: These communications cover the preliminary research findings from the authors own research work. They are fast-tracked for immediate publications.

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Earthquakes

- Understanding earthquakes
- Plate tectonics
- Seismic waves
- Seismographs
- Location of earthquakes
- Earthquake hazard
- Do's and Don'ts of an earthquake
- Seismic zonation map of India
- Earthquake prediction
- Earthquake early warning system
- Tsunamis caused by earthquakes
- Seismic hazard mitigation
- Seismic microzonation