Geotechnical Earthquake Engineering

Prof. Deepankar Choudhury
Department of Civil Engineering
Indian Institute of Technology, Bombay

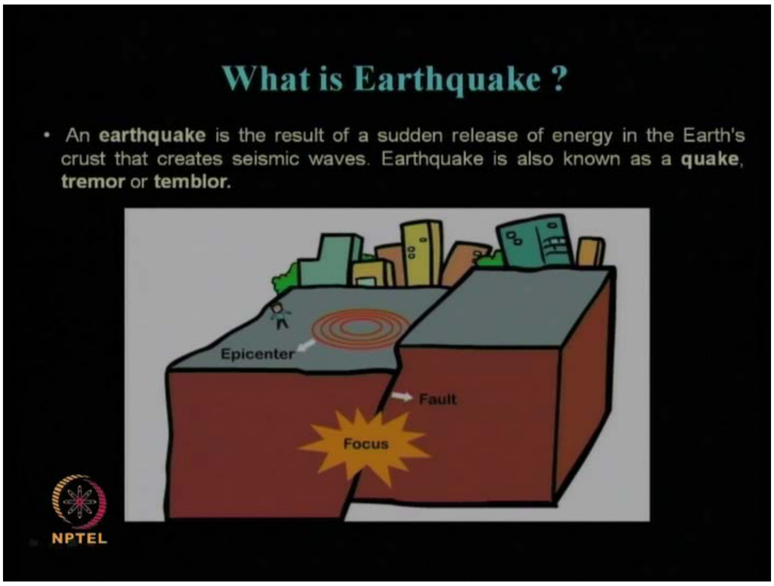
Module - 3

Lecture - 5

Engineering Seismology (Contd…)

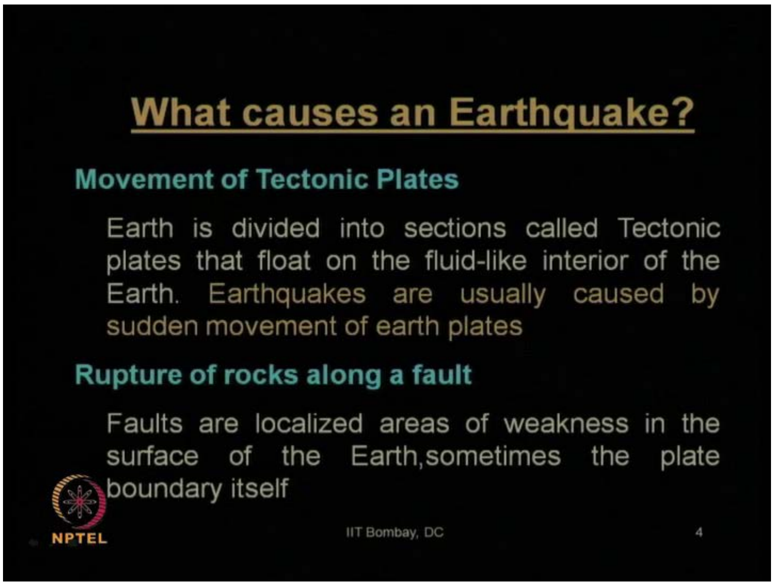
Let us start our today's lecture on geotechnical earthquake engineering. We can see here the slide on geotechnical earthquake engineering, our course. We were continuing with module three, that is engineering seismology. So, a quick recap what we have learnt in our previous lecture.

(Refer Slide Time: 00:44)



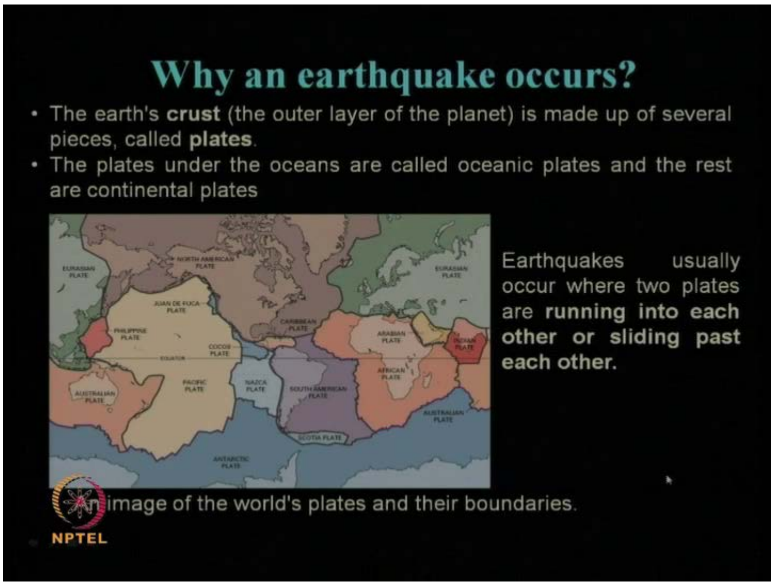
In this engineering seismology we have first studied what is an earthquake and how it gets generated through sudden release of energy in the earth's crust, which creates finally the seismic waves.

(Refer Slide Time: 00:59)



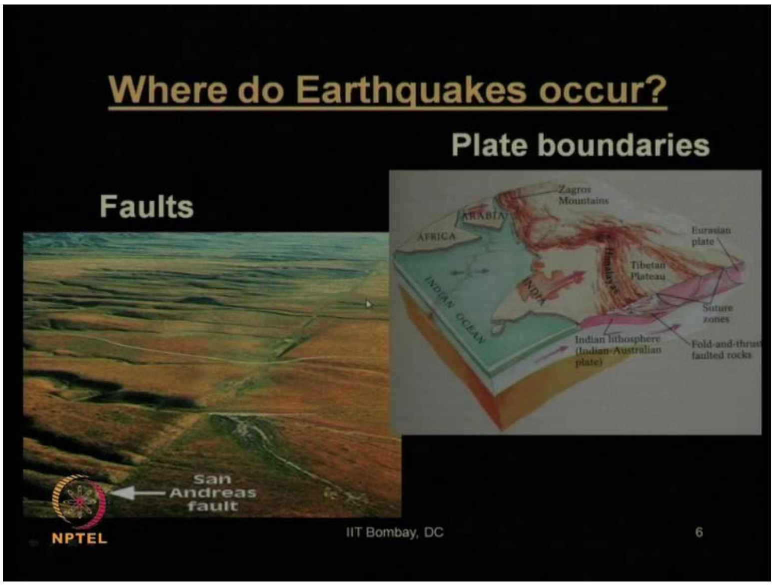
And what are the major causes of an earthquake? We have seen there can be two major reasons, one is movement of tectonic plates, and another is rupture of rocks along a fault.

(Refer Slide Time: 01:15)



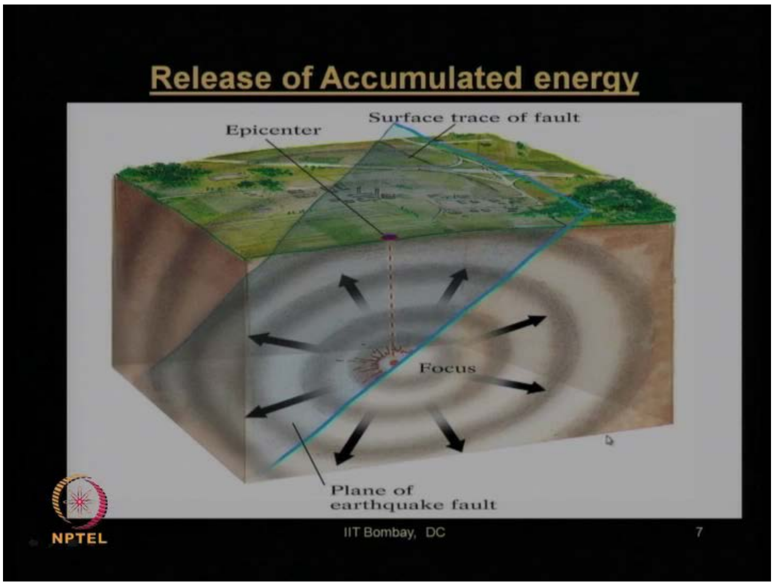
And as far as the tectonic plate movement is concerned, we have seen that earth's crust is made up of several pieces, which are called plates and there can be oceanic plate and continental plate. These are the two major types of plates the category, and these are various plates, which we have discussed in the previous lecture, which moves with respect to each other. So, two plates, when they are running into each other or sliding past each other, then usually the earthquakes occur.

(Refer Slide Time: 01:54)



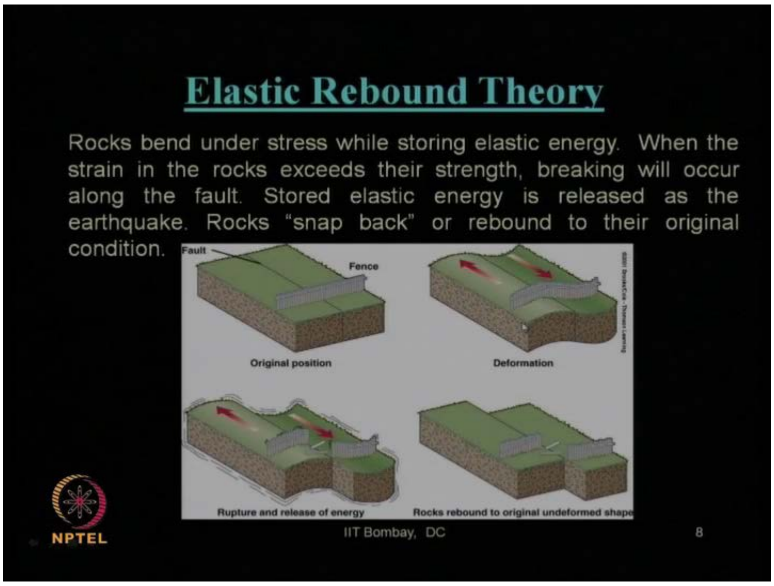
So, the pictorial view of two major reasons of earthquake we have seen, where do these earthquakes occur? One can be due to the plate boundaries between two plates, there are the possible locations of tectonic plate movement type earthquake, or another can be the fault rupture earthquake.

(Refer Slide Time: 02:20)



Then, we have discussed about the release of accumulated energy during an earthquake process at the point where the energy get released below the ground surface, that is, we call as focus or hypocenter of earthquake. And then the seismic waves travels in all the directions from that point of focus and we called earthquake epicenter is that point, which is nothing but the vertical projection of that focus point on the ground surface, least vertical projection on the earth surface, and we have seen what is the surface stress of a fault on the ground surface. So, let us list out our today's lecture with this small recap of what we have learnt in the previous lecture.

(Refer Slide Time: 03:05)



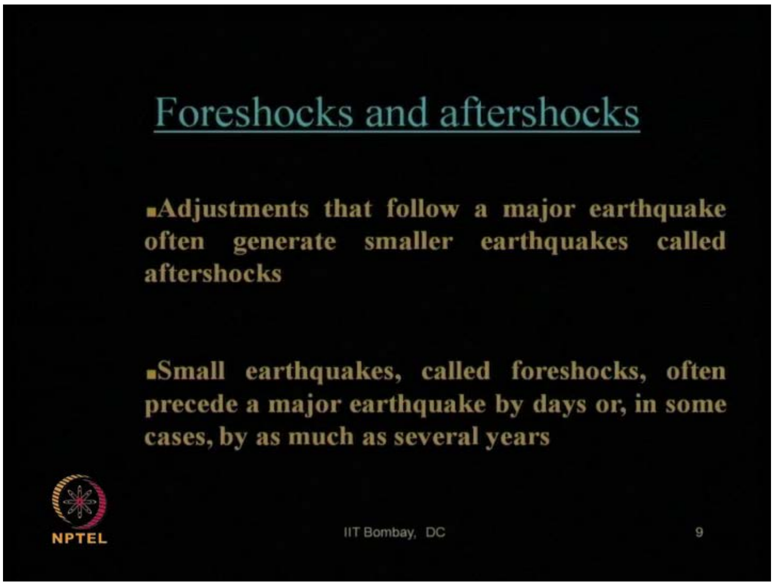
What is called elastic rebound theory? So, in elastic rebound theory, if we check over here, rocks, they bend under the stress while storing this elastic energy. So, how they bend, let us see. So, when the strain in the rocks exceeds the strength of the rock, that is, every rock is having a particular strain and when the strain inside the rock, due to the earth's interior energy, etcetera, is exceeds that value of the strength or capacity of that rock, then of course, the breaking will occur along the weaker part of the rock, which is nothing but a fault.

So, the stored elastic energy is released as the earthquake and rocks snap back. That is the terminology we typically use, that when rocks break we call snap back or rebound to their original condition. That is, if we see this as the initial condition or original condition of two rock blocks, basically it is a one rock block initially with, there is a weaker plane or weaker portion within that rock, which we have identified as a fault, let us say like this. And the structure constructed on that rock block is shown through this, say, this fence, which is constructed on the ground surface.

Now, what happens, when the stored elastic energy inside the bed of the earth exceeds the strength of that particular rock, they try to get deformed like this along that weaker plane and once that bending occurs due to the stresses, then finally, along that fault they get ruptured like this. Once they get ruptured, then energy stored inside the rock is getting released. Once it get released, the final position of the rock will be again another equilibrium condition or the, be it goes to the original condition of undeformed stress, the state of the stress.

So, here these are the deformed shape, deformed shape and again it goes back to another undeformed state or shape, but in that process you can see, there is a movement along that fault, which automatically creates the disturbance of the structure, which was constructed on the ground surface on this rock block. So, now, along that fault there is a breakage occurred or movement occurred, which essentially, causes the breaking of the structure constructed on the ground surface. This is known as elastic rebound theory, that is, rock block rebounds elastically and goes back to their original position form this position through the process of this bending under the stress or when the strain inside the earth's crust exceeds the strength of the rock.

(Refer Slide Time: 07:03)



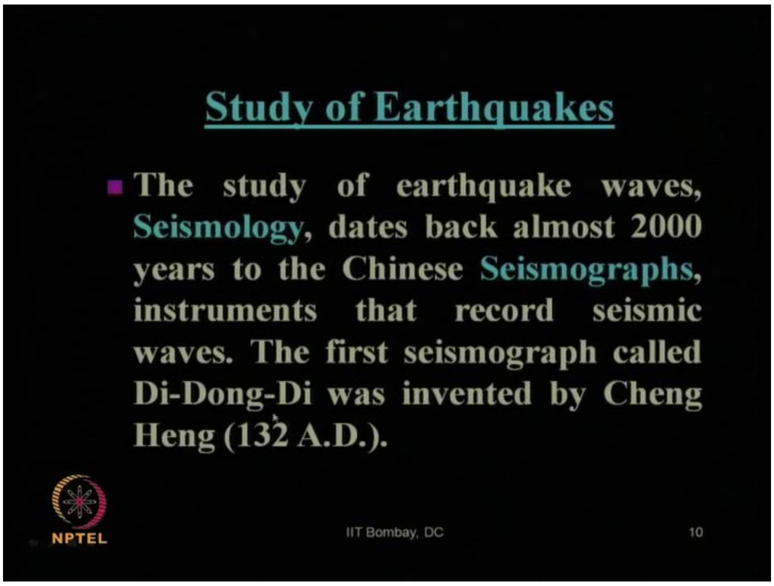
Now, let us see another few terminologies, which are commonly used in earthquake engineering like foreshocks and aftershocks. So, what are these things let us see. So, foreshocks, aftershocks, like whenever there is some adjustment, that follow a major earthquake often generate a smaller earthquake, these are called aftershocks. That means, many a times you will hear, that when a large magnitude or a major earthquake has occurred at a location, after certain time there is again few number of shocks coming or few number of earthquake motions are coming at that site or in the vicinity, which are known as aftershocks. That is, after that major earthquake incident whatever shocks or earthquake motions are coming, that is termed as aftershocks after that major event.

Whereas, there are small earthquakes, which are called as foreshocks, they often precede a major earthquake by even hours or days and in some cases even as much as several years. There is, many a times it is also possible, that say, small magnitude of earthquakes are keep on coming at a particular location or in a vicinity and after few hours or few months or few days at that location or in that vicinity a large magnitude or a major earthquake has occurred. So, that is called, that is, those small magnitude earthquake, which precede that major earthquake event are called as foreshocks.

So, we have to be careful not only about that major earthquake, but also the structure, whether it is a super structure or sub-structure, must be stable during this foreshocks and aftershocks also, like for example I can give, just about one and half year back or close to 2 years back, that is, in March 2011, there was a major earthquake in Japan in Tohoku. All of us are aware about that, that major earthquake event was followed by several numbers of small, small earthquakes, which are called as aftershocks. So, and during those aftershocks major damages has occurred because it got accumulated and also it created tsunami during that major earthquake. So, there were several numbers of combinations of disaster during that Tohoku earthquake of Japan in 2011 March.

So, that is why we say, aftershocks are very important to identify or to make sure, that our structure survive during this aftershocks, as well as, the foreshocks, that is, not only the major earthquake event. The major earthquake event may continue for only couple of seconds, but this aftershocks and foreshocks can be several in numbers and they can continue for several consecutive numbers of seconds, which gets accumulated and create severe damage to the structures because we will see later in this course, that structure also needs sometime to respond to this earthquake forces or earthquake shocks, so that response time required will be more if it is a very short duration. So, if you have a longer duration earthquake, then of course, that gives a quicker response of the structure and automatically for that reason, aftershocks, many numbers of aftershocks or many numbers of foreshocks of a major event is essential to study.

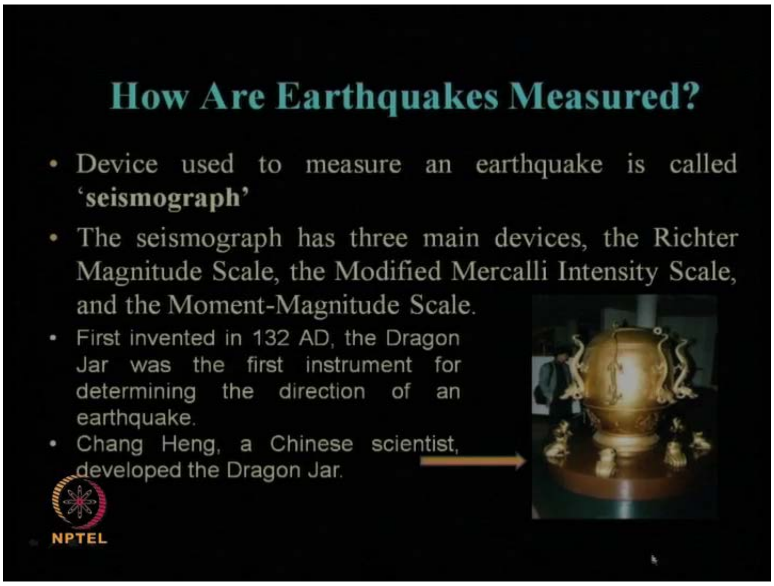
(Refer Slide Time: 11:28)



Coming to next point, that is study of earthquakes. We can see over here, when the study on earthquake started, it, the study on this earthquake waves, that is, what we call as seismology, that dates back almost 2000 years back, that is, about 2000 years back the study on this earthquake started.

The study on earthquake, that is, seismology started with Chinese seismographs. Seismographs are those instruments, which record the seismic waves or seismic characteristics, so that record the seismic waves. And first seismograph in the world is called Di-Dong-Di that was invented by Cheng Heng in China during 132 AD. So, that is why we said, that almost close to 2000 years back this study on earthquake had started or recorded.

(Refer Slide Time: 12:42)



Now, let us look at here how these earthquakes are measured. So, we have already seen, that the device, which is used to measure an earthquake is called a seismograph, that is, the instrument, which measures the earthquake is known as Seismograph. The Seismograph has three main devices, that is, in three different major scale, that is why, main, three major or three main scales are available, which are called Richter magnitude scale, modified Mercalli intensity scale and moment-magnitude scale. In addition to this three there are other scales as well, but these are most commonly used worldwide. We will see other scales also in subsequent lectures.

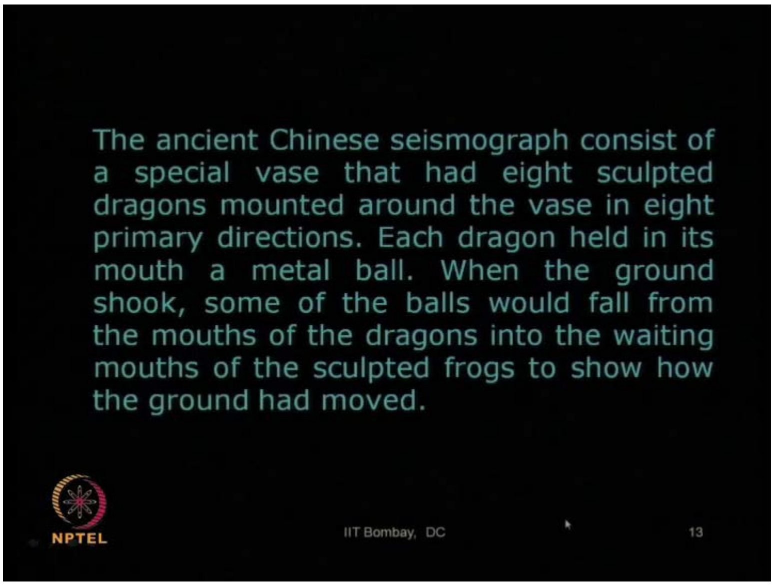
So, as I have mentioned, in 132 AD the first seismograph was invented, which is called as Dragon jar. So, that Dragon jar, it was the first instrument for determining the direction of an earthquake and Chang Heng, a Chinese scientist developed this Dragon jar.

(Refer Slide Time: 14:12)

Let us look at a close view of this dragon jar instrument or the seismograph, which can record the earthquake waves. So, this is the ancient Chinese seismograph, which is nothing but a Dragon jar. Why the name is Dragon jar? If you can look here this is nothing but a jar made of brass. There are dragons over here, you can see, these dragons are placed in eight major directions, that is, we have north, south direction, east, west direction and all the four corner directions, that is, north-east, south-west, again north-west, south-east. So, in these eight directions these dragons are placed. And in this open mouth of this dragon there are small brass balls, which are kept in the mouth of this dragon in such a way, that they are in place of a neutral equilibrium. That means, if you have any kind of small disturbance or shaking of the ground, these balls will fall out or come out of the mouth of these dragons. And you can see, in the same direction of these dragons, there are 8 frogs, and these 8 frogs are having open mouth.

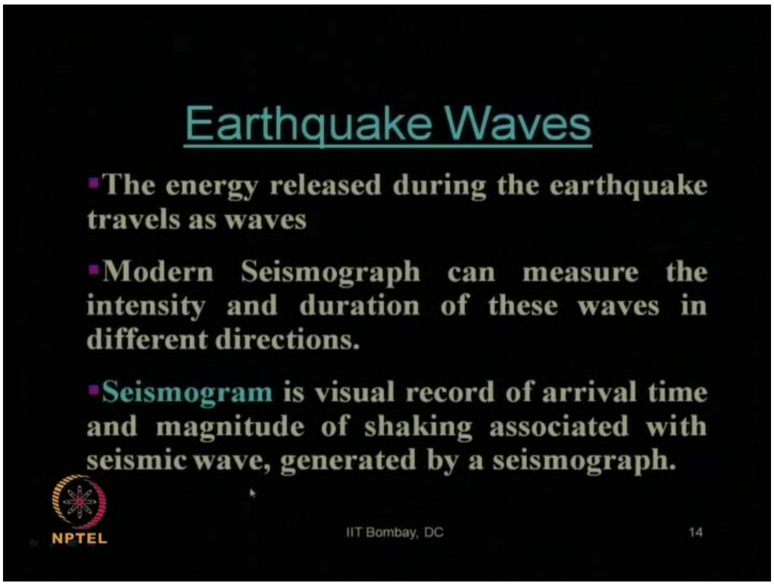
So, whenever these balls come out of this mouth of these dragons, they are catched by those open faces of these frogs sitting below this. So, whenever there is a shaking of ground in a particular direction, that gets automatically detected because these directions of the balls will come out and they follow a particular projection or projectile. So, that gives you the kind of a measurement and the direction in which the earthquake came. So, that gives us the idea or record of the seismic wave. So, this is the ancient seismograph, which was developed by Chinese about 2000 years back.

(Refer Slide Time: 16:39)



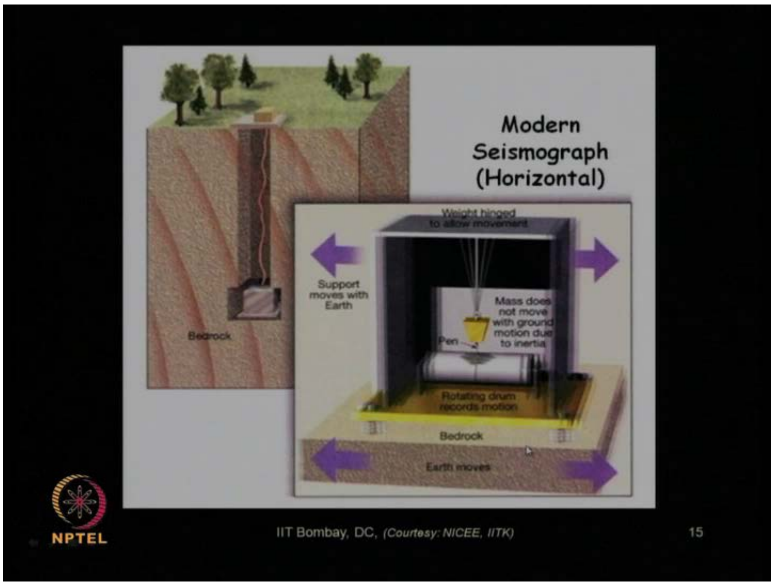
So, as I have said just now, this ancient seismic Chinese seismograph consist of a special vase, which we have seen, that had eight sculpted dragons mounted around the vase in 8 primary directions, as I said, north, south, east, west and all 4 corners. Each dragon held in its mouth a metal ball. When the ground shook some of the balls would fall from the mouths of these dragons into the waiting mouth of the sculpted frogs to show how the ground has moved. So, that is the principle, how, on which this dragon balls or dragon jar is working for measurement of the seismo, seismic waves.

(Refer Slide Time: 17:37)



Now, coming to earthquake waves, if we see over here, the energy, which is getting released during the earthquake, they travel as waves, as we have already mentioned earlier also. And the modern seismograph, that is, the seismograph of today's, today, whatever seismograph we use, those can measure the intensity, as well as, the duration of these waves in all the different directions. And the seismogram is the visual record of arrival time and magnitude of shaking associated with seismic wave, which are generated by a seismograph. So, the instrument which measured this seismic waves are called seismograph and the device or the paper or the page on which we get those recorded, that data sheet is known as seismogram.

(Refer Slide Time: 18:46)



So, this is the pictorial view of a modern seismograph. In bracket it is written as horizontal, that means, this seismograph, this modern seismograph, whatever is shown in this picture, can record any horizontal direction of the earthquake, that is, it can be in north, south direction, east, west direction or any corner directions, in the horizontal direction. But it cannot record the vertical accelerations or the vertical direction of the movement or vertical direction, whatever waves are coming, those it cannot record; so in this modern seismograph, horizontal.

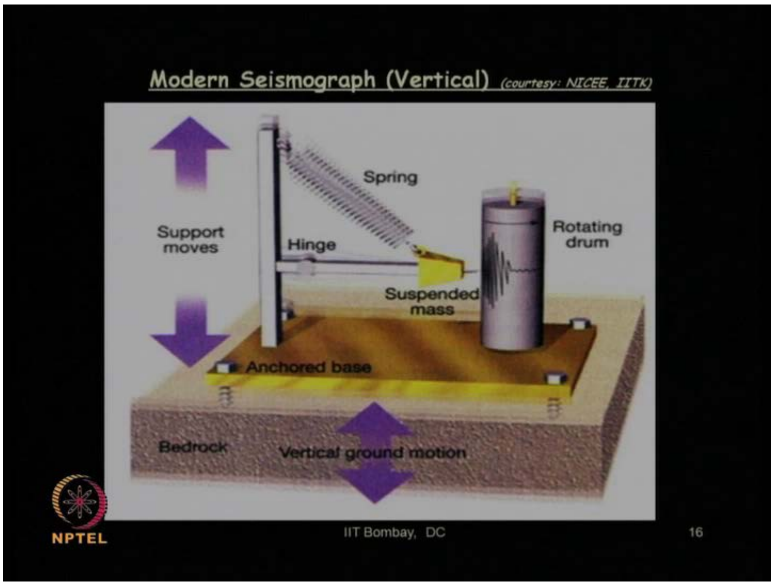
How this instrument is used, how this seismograph is used, this picture shows us clearly. So, it is placed below a certain depth, close to the bedrock, if possible; so this bedrock. And when the earth moves, you can see this cabinet, this support, it moves with the earth. And from this support there is a weight, which is hinged to allow the movement, that is, from this string a mass is hanging and on tip of this mass there is a pen or pencil kind of arrangement and along this there is a drum, you can see rotating drum, and throughout this drum there are white papers, which can rotate, this drum can rotate.

So, automatically when, what occurs? When earth moves in this direction, as the horizontal direction of movement like this, support also moves. So, automatically this hanging mass is moving and when it is moving it records through this tip of this pen or pencil on this plain paper the movement like this, is it clear. So, whenever there is no movement of the earth, that is, there is no earthquake, of course, it will remain strain or no record or very minimum record, that is due to the disturbance, local disturbance, instrumental disturbance, which will not be a major value or distinctly identifiable value. But whenever there is a shaking due to earthquake, it will be vigorous, so it will start capturing this movement or record.

So, whenever waves generated during an earthquake arrives at those point where we have kept this seismograph, then it will start recording through the movement of that support on that white sheet placed around that drum. So, that means, the seismic waves has to travel from the epicentral location or in particular, from that focus of the earthquake point to all the directions, and all over the world we can place this seismograph. So, each wave, it will take some time to travel to reach from that point of focus of earthquake to that point where this seismographs are located around the world. So, those depending on the travel time, etcetera, we will record on these seismograph different types of shaking and recorded data of different types of earthquake waves. So, we will see those things little later.

Let us see another type of modern seismograph, which can record the vertical movement, that is, the previous one could record the horizontal shaking in any direction, of course, as we have mentioned. Now, we want to see, whenever there is a vertical shaking of the ground how it can be measured, that is, how much vertical shaking is occurring during an earthquake? How we can measure using this modern seismograph?

(Refer Slide Time: 23:14)

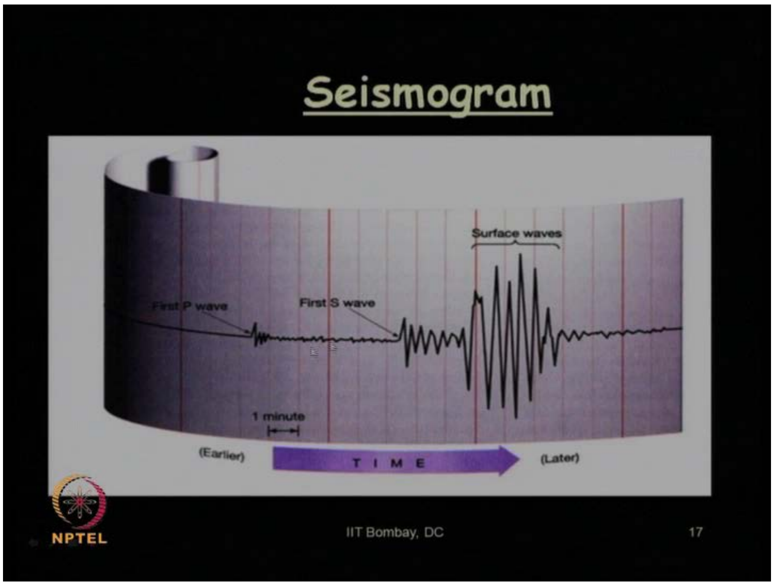


So, let us look at this picture. This shows modern seismograph in the vertical direction, that is, again we have a bedrock slab, on top of this we have an anchored base plate and a support system connected like this. Through a spring there is a suspended mass, you can see over here, and on tip of this mass there is a pen or pencil and this drum, again, is surrounded by white papers and this drum can, of course, rotate.

So, when there is an earthquake in the vertical direction, that is, in vertical direction it is moving, what will happen? This support also will move and as this support moves, so automatically the mass connected to this support also will move in the vertical direction like this, right. So, once it moves, this tip of the pen or pencil will record this kind of motion on this paper. And whenever there is no vertical movement, of course, it will be almost straight, little undulations because of, as I have mentioned, local disturbance or the instrument signaling. So, those we are calling them as noises, as we know.

Otherwise, when there is an earthquake, a proper or distinctive measurement of this excitation will occur, as we can see over here. This recording will be done on this piece of paper, which is surrounded through this rotating drum. So, this measures, automatically, the vertical motions of the earthquake due to the travel of various seismic waves at that station. So, in this way both, the horizontal motion, as well as, the vertical motion of any earthquake we can record by using this modern seismograph.

(Refer Slide Time: 25:49)



Now, as we have mentioned, instrument is called seismograph and the recorded data, we call it as seismogram. So, let us see how the seismogram will look like. So, this is the typical output of the seismogram, that is, what is getting recorded on that piece of paper through that rotating drum. We get, finally, that paper out from the drum and when we take a note of these excitations, which are getting recorded due to a particular earthquake; it will be something like this.

So, this horizontal access will give us the time scale, of course, and whenever there is a shaking, you can see, initially it will be straight when there is no earthquake, as we have already mentioned. Then when earthquake wave reaches to that station where that seismograph is located, it will start getting disturbed or excited and getting recorded and once, after sometime you will notice it has stabilized for couple of seconds or minutes even.

Then, we will find another excitation came, which is of larger magnitude of the previous one. Then we will see slowly, that also was about to get stabilized, but very soon a major shaking is getting recorded and after sometime we will see, even that shaking also getting stabilized or no shaking is occurred. So, that is the full picture, which we get recorded in through this seismograph and this recording we call as seismogram.

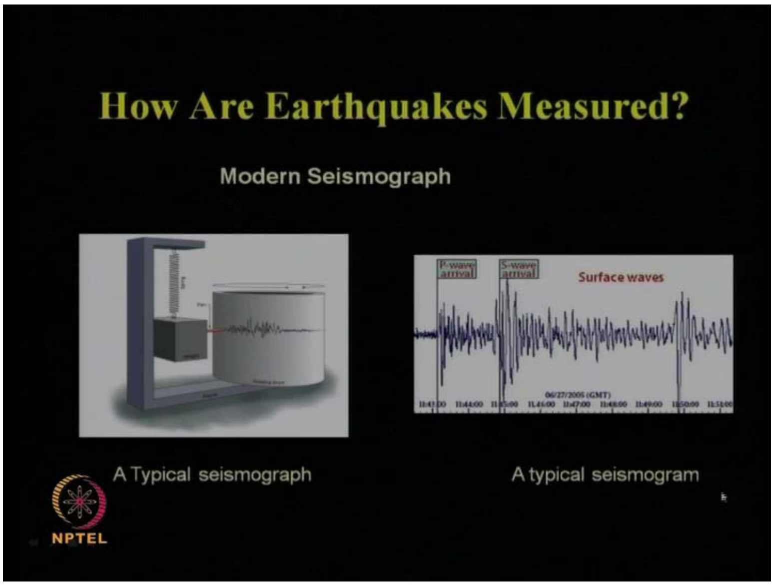
So, what are these waves? We can automatically see, that during an earthquake there are different types of waves are getting generated with different speed, that is, different waves are having different speed of travel, that is why their arrival at those points where those seismographs are located are different, and, or there is a time lag between two different waves, which reaches a particular seismograph from that earthquake focus point.

So, as we have seen over here, you can see, this is named as P wave, the next one is called S wave and this one is called surface wave. But it is not necessary that we will be able to record all these waves in each and every seismograph present all over the world due to an earthquake occurred at a particular place. We will see that reason in subsequent lectures. It may happen only P wave came, nothing after that came; it may happen P wave came, S wave came, surface waves also came; it may happen nothing came. So, these are the three possibilities, that is, any seismograph located at a particular location in the world can record a particular earthquake occurring at another place on the world.

That means, suppose in Japan an earthquake is occurring, in US there may be a possibility, that a seismograph station may record nothing, that is, they probably cannot sense any of this waves. So, that station will say no earthquake has occurred. It depends on several other aspects, which I will discuss little later. It may happen, another part of US may record only, say P wave, there is only one excitation and they have not recorded the higher excitations. So, they may say there is an earthquake, but probably we are located at such a geographical location compared to the occurrence place of the earthquake, that it reached only one wave, that is, P wave. And another station in another part of the world, other than Japan or even may be in Japan or may be in India, it may record all these waves as we have seen in this seismograph.

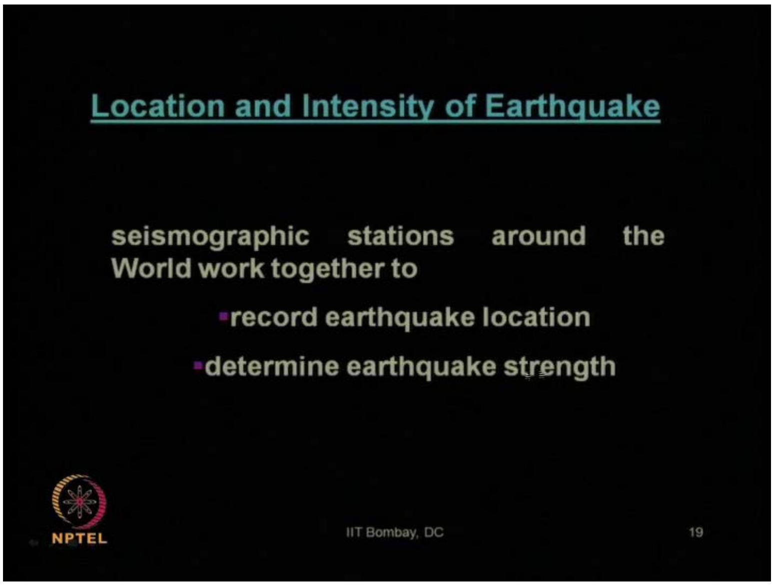
Then, it can mention, we have recorded some earthquake has occurred at some part of the world and how it can be understood, you can see over here. Obviously, these waves are having different speed, as I have mentioned, P wave is having different velocity, S wave is having different velocity, surface wave is having different velocity. So, obviously, their arrival from the focus to the instrument station will take some time and that time if the instrument location is much further away from that focus of the, focus of the earthquake point, obviously, this time gap also, etcetera, will change, it will vary. So, based on that we can identify the epicenter of an earthquake and that is how any recording, any numbers of recording stations together identify a particular earthquake, which has occurred at any part of the world. It need not be always on a continent, as I said, it can be in a deep ocean also, that also can get recorded in the seismograph located in some continent, so that we will see little later.

(Refer Slide Time: 32:25)



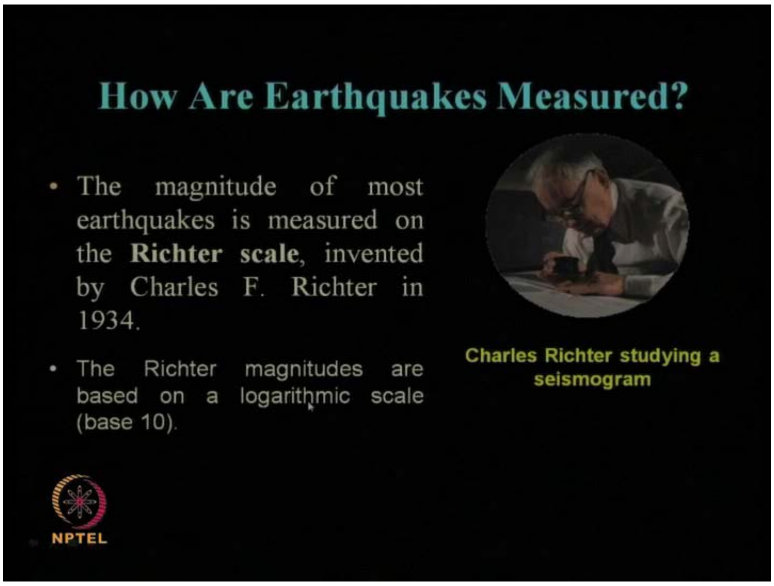
So, let us look at here how the earthquakes are measured. As I have mentioned already, this is the typical seismograph, modern seismograph, it is recording like this. So, what does it mean? What type of earthquake motion it is getting recorded? The vertical, you can see, it is recording the vertical because of this arrangement support system it shakes in this direction and a typical seismogram looks like. This is P wave arrival time, then this is S wave arrival time. You can see there is a time gap or time lag between this two arrival times of P wave and S wave because of their difference in velocities and remaining are surface waves. So, these are time scale, as you can see, a particular date, etcetera.

(Refer Slide Time: 33:18)



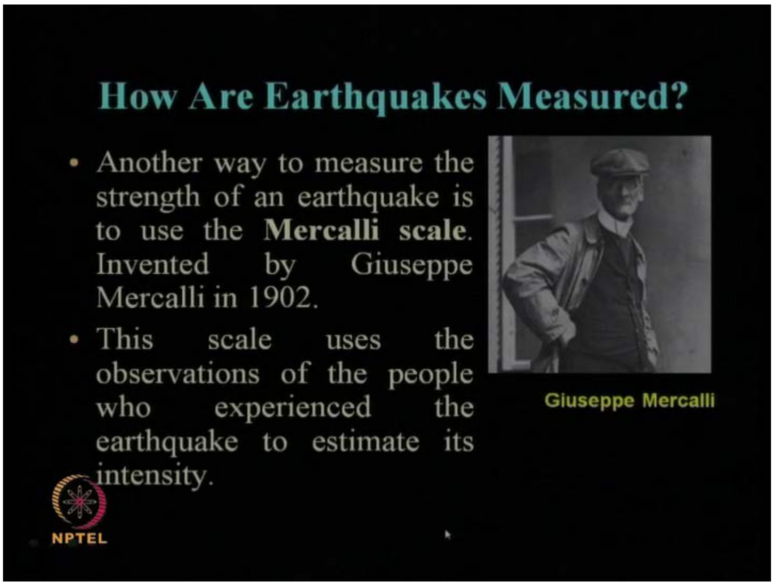
Now, location and intensity of earthquake is important and this seismographic station, all around the world they work together to identify or to record an earthquake location, also to determine the earthquake strength.

(Refer Slide Time: 33:51)



Now, how these earthquakes are measured all over the world, let us see. The magnitude of most of the earthquakes are measured on Richter scale, that is the most popular or one of the oldest method by which the magnitude of earthquakes is measured, which is invented by Charles F Richter in the year 1934. You can see, Professor Charles Richter is studying the seismogram and this Richter scale, typically this is based on a logarithmic scale, that is, log to the base 10 scale it is measured. We will discuss about this Richter scale in subsequent slides and lectures.

(Refer Slide Time: 34:48)



Now, another way to measure earthquake is based on the strength of the earthquake, which is known as Mercalli scale, which was invented by Mercalli in 1902. But you can see this is a measurement based on the observations of the people who experienced an earthquake to estimate its intensity. So, this is the picture of Mercalli.

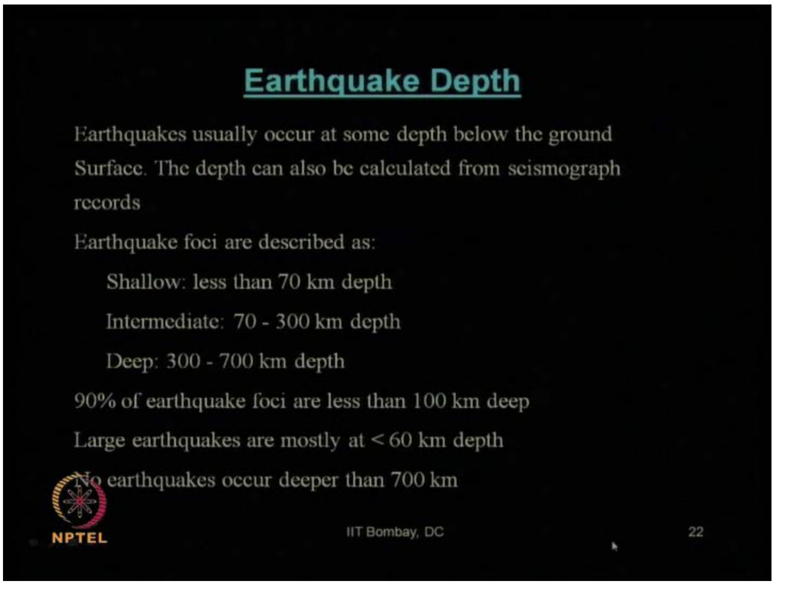
You can see the basic difference between this Richter scale and Mercalli scale is, that Richter scale measures the magnitude of earthquake based on the displacement of the ground on a mathematical scale or logarithmic scale, whereas the Mercalli scale is based on the intensity of earthquake, which is nothing but based on observations of the people who has experienced that earthquake. So, what does it mean?

Let me clarify it little more, like if an earthquake, say it has occurred in a deep sea or deep ocean, in the mid of an ocean or let us say, it has occurred in an open dessert area, say Sahara desert, where least number of or no people or no inhabitants are existing at those location, of course, for known reason. Now, if an earthquake occurs at those locations, then as we have mentioned just now, we can measure those earthquakes also using this our modern seismograph through this seismogram taking measurement all over the world and that we can put it in a measurement scale, which can be in the measurement scale unit, say Richter scale. We can identify that Richter scale magnitude of that earthquake. But as there are no people staying in those locations, either mid sea or dessert, obviously, there is nobody to experience that earthquake. So, you cannot get any feedback from the people, that is, how they experienced this earthquake when it came.

So, the Mercalli scale, which is based on the intensity or observations of the people what will be the value of that in those locations? It cannot be measured or unmeasured or 0 or not available, but still it may have a high magnitude of earthquake in the magnitude scale, in Richter scale. Whereas, another situation, let me tell you, as we have discussed in one of the previous lecture, say Haiti earthquake, which occurred in January 2010, a major devastating earthquake, but it was not the largest earthquake in 2010. The largest earthquake in 2010 was February 2010 Chile earthquake, but damages were more in Haiti earthquake in January 2010. So, if you ask people, those who experienced that earthquake in Haiti, they will give their observations, their feelings of an earthquake, which if we put in this Mercalli intensity scale, that will be very high because damages were more; people experienced more damages, more problems during that earthquake.

So, the magnitude, which is measured through that Richter scale may be of little lower than that Chile earthquake, but intensity of that earthquake may be higher even than the Chile earthquake, depends on how people experienced, how people observed that incident. So, that intensity scale is based on the personal experience of the people, those who face that event, whereas measurement is based on the purely mathematical scale based on the movement, travel of the waves, etcetera. So, is it clear, what is the basic difference between Mercalli intensity scale and the Richter magnitude scale? So, there are two basic scale, one is magnitude based scale, another is intensity based scale. Now, there are other magnitude based scales also, which we will discuss little later.

(Refer Slide Time: 40:11)



Now, let us come to the next sub heading, which is called earthquake depth. This is also another important parameter, which we should know from the seismologist, that is, earthquakes, they usually occur at some depth below the ground surface for obvious reason because the energy has to get released from the earth's interior. So, it has to occur at some particular depth below the ground surface; it cannot occur at the ground level mostly. So, the depth that can also be calculated from this seismograph records, there are ways to calculate the depth also. And that earthquake focus or the foci, there are many focus.

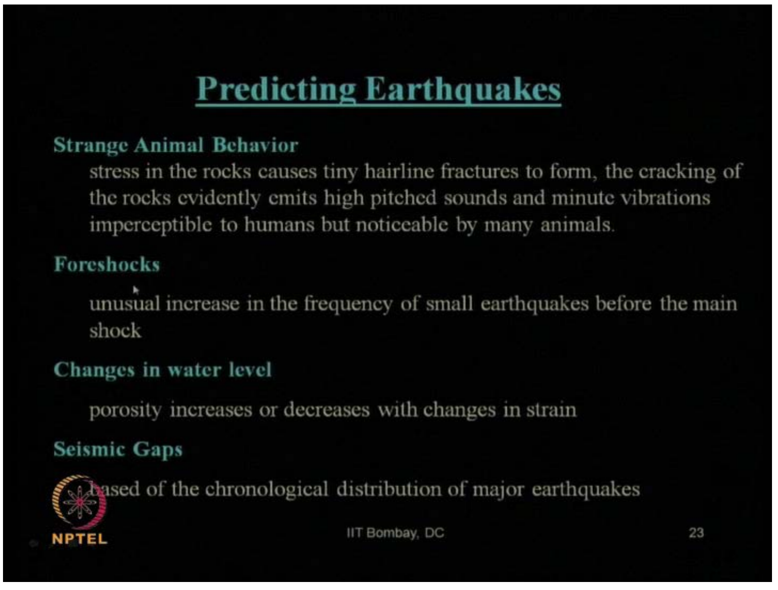
If we talk about several earthquakes, they can be described as in three major categories. One is called shallow earthquake, another is called intermediate earthquake and the third one is called deep earthquake. Now, what is called shallow earthquake? When that earthquake focus is within 70 kilometer depth from the ground surface is called shallow earthquake. Intermediate earthquakes are those earthquake where the earthquake foci are at the depth of between 70 to 300 kilometer from the ground surface and deep earthquakes are those earthquake where earthquake foci are located between 300 to about 700 kilometer depth below the ground surface.

So, that is how, based on the depth of earthquake, earthquakes are categorized based on the depth of earthquake focus. Earthquakes are categorized in three major classifications, one is called shallow earthquake, another is called intermediate earthquake and another is called deep earthquake.

Now, as a layman we can always say using the commonsense, that among these three earthquake, shallow, intermediate and deep, if we have the amount of energy released same in all these three earthquake, which one will be more destructive? Of course, the shallow earthquake, because it is occurring close to the ground surface, so it will have more effect, more devastating effect on the ground surface. So, that is why you can see over here.

And another historical record says that 90 percent of earthquake foci are within 100 kilometer depth below the ground surface and large earthquakes are mostly within 60 kilometer depth, that is, at shallow depth, which is for obvious reason, as I said. Because close to the ground surface when the foci is located, there is a chance of having a major earthquake or major devastation, that is why, large earthquake or major earthquake will be of shallow earthquake and no earthquakes occur deeper than 700 kilometer because then we will go to another level of earth's interior. So, that is why, no earthquakes occur deeper than 700 kilometer depth.

(Refer Slide Time: 44:08)



Now, coming to another important criteria, which many layman or common people they will ask, that is, whether we can predict earthquake, whether it is possible to predict earthquake? Now, if we want to give the answer in a single word to this, the scientific answer, we should say no, that is, so far we cannot predict earthquake exactly because prediction means, we should be able to tell, that after so many years at that location, that magnitude of earthquake of that duration is going to occur. And as we cannot do that scientifically, the answer is no that is, we cannot predict earthquake with this information.

But there are chances by which in a scientific way also we can give a range of possibilities of occurrence of earthquake based on the study on probability, that is, a mathematical study, what we can do. But that we should not say, that we can be able to predict earthquake that just give a probability of occurrence of an earthquake at a particular region over a timeframe. It cannot give an exact date and time, that at this date, at this time, that earthquake is going to occur.

So, let us look at here what are the common observations for predicting earthquake. There are some nontechnical or nonscientific observations also, which I am going to mention over here, like people say, through strange animal behavior one can be able to identify to some extent that maybe some earthquake is going to occur. That is, when stresses in the rocks causes tiny hairline fractures to form, that is, we have seen, that elastic rebound theory in the rock, so rocks are going to bend and fracture is going to occur. So, those tiny first breaking of those rocks, that creates stresses and the cracking of the rocks evidently, emits high pitched sound, that creates a high pitched sound when this rocks breaks and very minute vibrations, which are imperceptible to humans. But those high pitched range of sounds may be noticeable to few animals, that some people say, that those hairline fracture of the rocks may be audible by few animals, which is not in the range of the audibility of human ear. So, human cannot hear that hairline or tiny fracture of the rocks, but some animal may hear, so then they start behaving strangely.

Another thing you must have noticed, like whenever there is a solar eclipse, it will occur mostly during solar eclipse not in lunar eclipse. Solar eclipse, full solar eclipse, when it occurs, like during the daytime sun was there and on the process suddenly it become dark. Even you must have noticed, that birds, etcetera, start behaving, flying abruptly when that full solar eclipse occurs because suddenly the day become converted to similar to a night kind of environment, so they start behaving strangely. So, in the similar way people say when they hear that tiny hairline cracks they start feeling that something is going to occur, that people say it may be considered as some kind of prediction of earthquake.

But truly speaking, the birds and other animals, they can behave strangely for any kind of disturbance in the nature. It need not be due to earthquake, it can be due to a very long distance tsunami, which probably is coming, they can hear, which is not, again not audible in human ear up to a certain extent. It can be because of a storm, future storm, which is coming. It can be because of the eclipse, solar eclipse, as I said. See, it can be because of several other changes in the nature, it need not be due to only earthquake. So, obviously, the strange animal behavior cannot be correct way to predict earthquake. It can just give an idea and also, that idea is incomplete, as I have mentioned, it can be because of several reasons.

Another concept people say, like foreshocks, like when a major earthquake occurred, before that we mentioned unusual increase in the frequency of small earthquakes, before a main earthquake or main shock occurs, that is, small, small, several numbers of earthquake may come at the vicinity or in a locality, that may give an idea, that some big earthquake is going to occur. But they again, that is a qualitative basis not on quantitative. You cannot say, on that time, that day the main earthquake is going to come.

Change in the water level is another criterion, like porosity increases or decreases with changes in the strain, so that changed the water level. But again, that is not an exact quantitative prediction of earthquake. It can be because of other reasons also, like storm, like flood, there are several reasons for which water level changes. Another reason people say, seismic gaps based on chronological distribution of major earthquake, that is, the historical record of various earthquakes, they record chronologically and through that gap of different earthquakes they identify how the next gap will be probably be coming. So, again, that is on the probabilistic basis, not an exact answer. So, with this we will stop our lecture today. We will continue further in the next lecture.