Geotechnical Earthquake Engineering
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Module - 4
Lecture - 10
Strong Ground Motion

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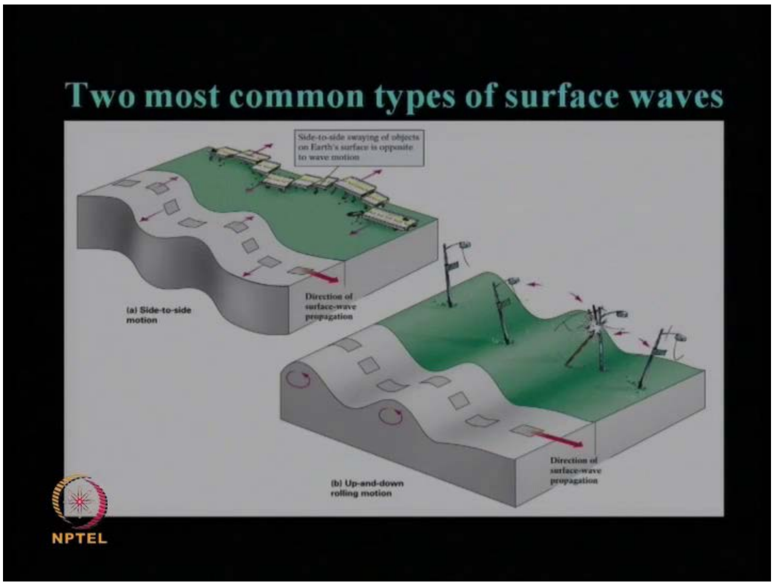

Let us start our today's lecture on geotechnical earthquake engineering. We were going through the module three of our course and that is engineering seismology. In the previous lecture, in a quick recap, let us see what we have learnt. We have seen various types of seismic waves and we discussed mainly in the previous lecture about the surface waves and also the body waves. Body waves we have discussed earlier. For the surface waves, we have seen two most common behaviors. One is side to side motion like this and another one is up and down rolling motion like this. So, these two waves, we have identified this as love wave type surface wave and this as Rayleigh type surface wave.

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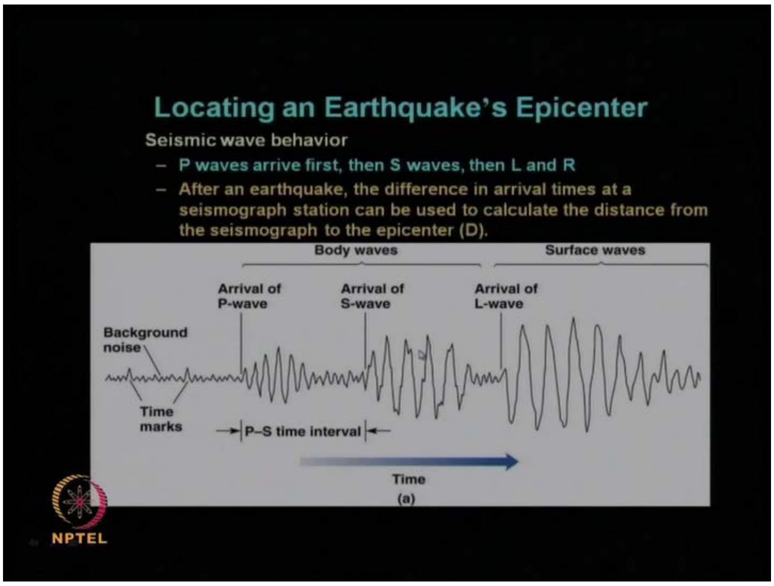

When we talked about the arrival time of all these waves, we have seen on a typical seismogram, where both P wave and S wave will arrive. That means that seismograph station is not located in a shadow zone of P or S wave. There we will find that there is a particular arrival time which can be observed for the P wave and then there will be another particular arrival time for the S wave and then the surface wave will continue. But, from the typical velocity of this P wave and S wave, S wave crustal velocity is about half of that P wave. P wave typical crustal velocity about 6 kilometres per second. For S wave, it is typically 3 kilometres per second. Due to this large difference between their crustal velocities, their arrival time can be obtained distinctly on a seismogram. But, the surface wave, their typical velocity is about 90 percent to 95 percent of that S wave.

So, unless the seismograph station is far away from the epicentre, you will hardly be able to identify this distinct arrival time of this surface wave like love wave and Rayleigh wave. So, anyway we are going to use this available information of arrival time difference between S wave and P wave for locating the earthquake's epicentre.

So, in the previous lecture, we have seen how to calculate and how to use this difference of arrival time to calculate the distance of epicenter from this seismograph station, where these values of arrival time of different waves have been recorded to identify the earthquake's epicenter knowing their crustal velocity.

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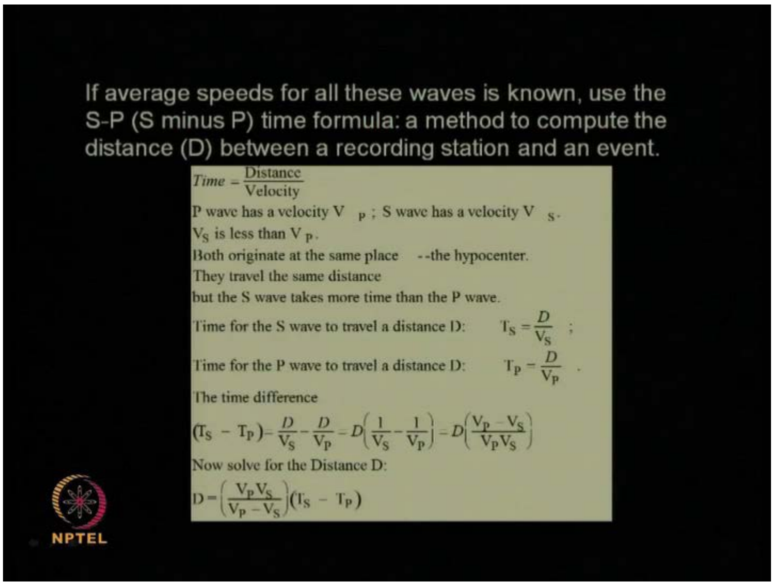

In that case, we have seen various methods. One is to use the average wave speed of this S and P using the S minus P time formula, which is very simple like time equals to distance by velocity equation. Corresponding to the time for shear wave velocity it takes and the primary wave velocity it takes time and the difference which we are observing at the seismogram can be obtained, can be used to obtain the value of the epicentral distance D by knowing or assuming the crustal velocity of V P and V S and this known value of T S minus T P.

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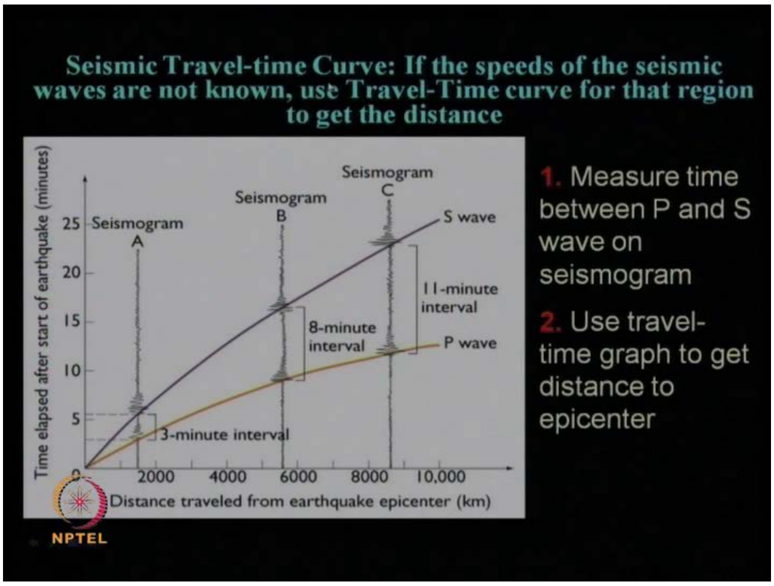

But, where we do not have the information whether it is a shallow earthquake or the V S and V P values are not known, in those cases, what we should do is we can use this seismic travel time curve method. In this case, where speeds of the seismic waves are not known but with various seismograms located all around the world, if we have collected the information between the arrival time between S and P wave, say the time difference is 3 minute, 8 minute, 11 minute and accordingly, we can easily find out that this 3 minute is closest to the epicenter and 8 minute, one is little farther and 11 minute is more farther than the point of epicenter to this measuring station. Accordingly, we can move this on this chart of time elapsed in minutes versus the epicentral distance from the recording station and where we give a smooth band that gives us the actual location of the earthquake epicenter at a particular distance from this seismograph stations.

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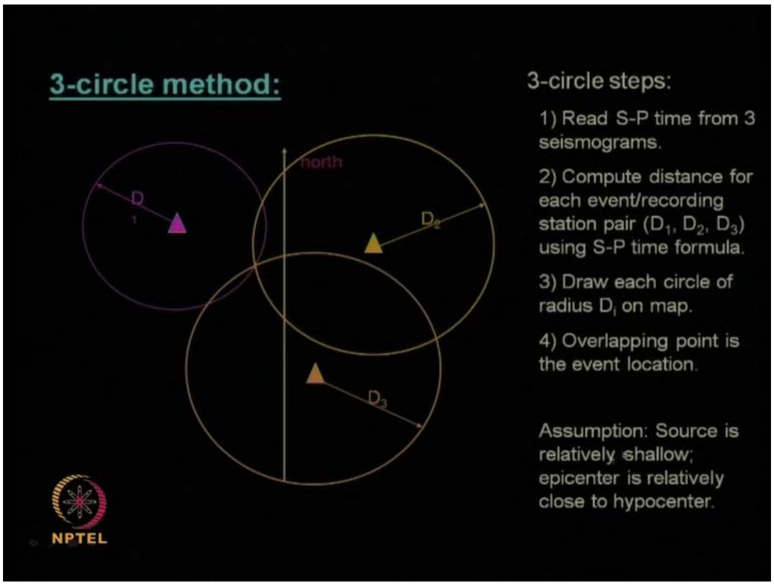

Then, we have seen the most popular method in the world, which is known as 3 circle method. So, in the 3 circle method, what we have seen is the same S minus P time formula we have to use for minimum three seismogram stations or seismograph stations. So, minimum three seismograph stations, so that we can find out three values of the distances. That is, station 1 corresponds to distance D 1, station 2 corresponds to distance D 2 and station 3 corresponds to distance D 3. Let us draw the circle considering their seismograph stations as the center and where those three circles will meet that is the point which is nothing but the earthquake epicenter. So, this way we can find out the earthquake epicenter.

But assumption is; obviously, source is relatively shallow and epicenter is relatively close to the hypocenter. So, if source is a shallow earthquake, obviously the epicenter will be close to the hypocenter. Otherwise, that consideration or assumption of the shear wave velocity and primary wave velocity in the crustal plate will not be applicable in this 3 circle method. Then in the previous class, we have gone through one example problem also, through which we have identified how to calculate the earthquake's epicenter from seismograph station, data of arrival time of S wave and P wave and their latitudes and longitude. So, we are now pretty familiar how to estimate or calculate the earthquakes latitude and longitude epicentral location.

So, with this we have come to the end of our module 3 that is on engineering seismology. Now, we will start module 4 of our geotechnical earthquake engineering video course. Module 4 is on Strong Ground Motion. So, under this module 4, there will be several sub topics as we know. So, the first subtopic I am going to cover is size of earthquakes. How to determine the size of an earthquake is an important issue for the earthquake engineering. So, let us learn how we estimate or determine the size of an earthquake.

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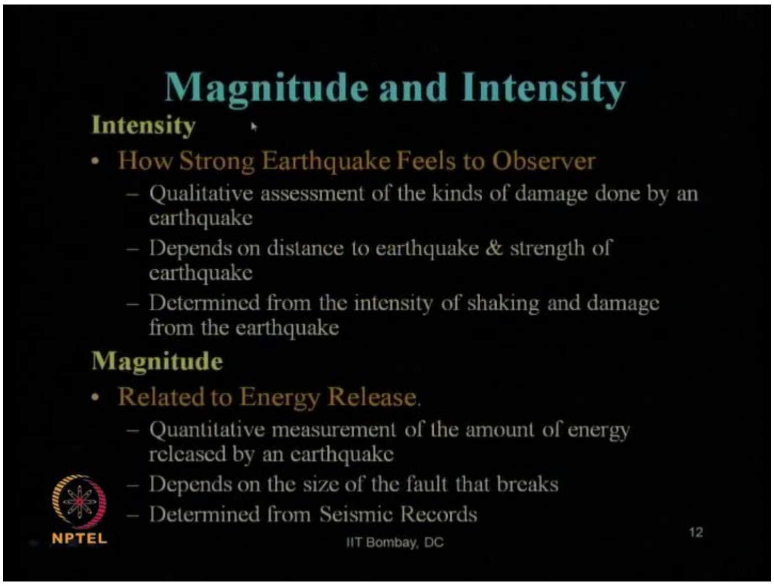

When we talk about the size of an earthquake, there are two scales possible. Those are, one is called magnitude scale and another is called intensity scale of earthquake. Intensity is nothing but it is a qualitative assessment. Why qualitative is because it depends on how strong the earthquake is felt by an observer. That is, if some person has experienced a particular earthquake, how much he felt during the earthquake is nothing but a qualitative estimate.

That is, he can mention, “Oh, it was a very big earthquake. The shaking was too much.” Or he can say, “It was a very mild earthquake. I could not feel the earthquake much.” Or he can say, “It was a moderate kind of earthquake. It shook the ground, but not that vigorously or not that mild also. I could observe it, but it was not that huge amount”. So, that kind of qualitative statement or qualitative assessment by an observer of an earthquake gives us the intensity scale of an earthquake.

So, as I said, it is qualitative assessment of the kinds of damage done by an earthquake. So, from an observer as well as looking at various damages of the structures etcetera, we can say this earthquake caused only surficial damage to the structure. So, not a big earthquake, but if it causes structural damage, then yes, it is a big earthquake. So, like that a qualitative assessment on the damage detection also can be used to identify or to obtain the intensity scale of an earthquake. Obviously, this measurement of the intensity depends on the distance to the earthquake and strength of the earthquake.

That means, how far that site is located from the hypocenter or epicentral distance of an earthquake. That determines whether this feeling of an earthquake by an observer or the structural damages etcetera, whether it is small or big depends on how far from that epicentral location to the site of your concern is located. Also, it depends on how strong was the earthquake. So, that is determined from the intensity of shaking and damage from the earthquake. So, this intensity scale is once again a qualitative scale and depends on the observer’s assessment and the damage assessment.

Whereas, the magnitude scale of an earthquake is purely based on quantitative assessment. So, quantitative means it is related to the energy released. That is, during an earthquake process, how much energy gets released and that gives us the estimation of the energy. We quantitatively measure it as to how much energy gets released during an earthquake and that gives us the idea that this much energy has been released. So, the magnitude of earthquake can be calculated using various scales etcetera like this magnitude.

So, it is fully based on the quantitative assessment. It is not on qualitative basis. So that means, even if there is no observer, as I said earlier, if the earthquake occurs in deep sea or deep ocean or in the mid of a desert where no observer is there and no buildings are there which are going to get damaged, but still, that can be a large magnitude earthquake if the energy release amount says so or the computation or estimation of that or the quantitative assessment of that says so. So, this magnitude scale is independent of the observer's feeling or reading or observations. So, it is not qualitative at all. It is fully quantitative.

So, quantitative measurement of the amount of energy released by an earthquake depends on the size of the fault that breaks. So, it is fully dependent on the fault size. That is, their length, area, depth etcetera will be considered to estimate the amount of energy and it is determined from the seismic records, whereas your intensity scale was measured by interviewing the observer and by looking at the damage of the structures. But, whereas this magnitude scale, if you can see over here, it is determined from the seismic record. So, whatever records in the various stations, the ground motion determines the magnitude of an earthquake.

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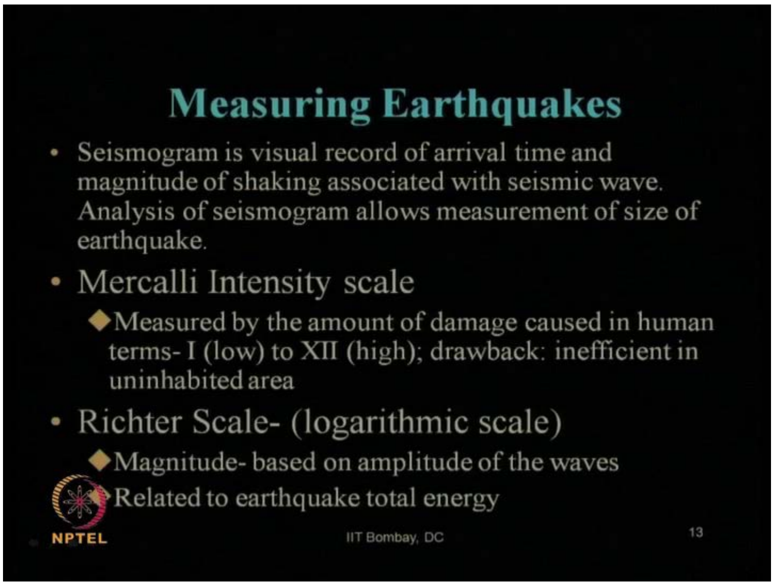

So, in measuring earthquakes like seismogram, which we have discussed in detail is a visual record of the arrival time and magnitude of shaking which is associated with seismic wave. So, we have talked a lot about the arrival time. Now, we will come to the magnitude of that shaking, that is that spikes or speaks, what we have observed in the seismogram. So, that analysis of that seismogram allows us to measure that size of the earthquake. So, that is the way quantitatively we can measure an earthquake.

Now, coming to the very commonly worldwide used scale for the size of earthquake is the intensity based scale known as Mercalli intensity scale. So, Mercalli intensity scale is measured by the amount of damage which is caused in human terms. Human terms means by taking the interview of the person who faced it, they have to express whether it was big damage or large damage or small damage or moderate damage like that and looking at the structures.

So, they have classified it into 12 sub divisions. Mercalli intensity scale 1 corresponds to low or lowest and 12 corresponds to highest. So, 1 to 12. These 12 sub classifications are available to identify the Mercalli intensity scale. So, what is the drawback? It is inefficient in uninhabited area. As already we know because where there is no habitation or no people or no society is living. How you can estimate this because there is no observer or no human being who can report you the amount of damage and because there is nothing to get damaged in those locations.

Whereas, the Magnitude scale, very commonly used worldwide is Richter scale which is based on a logarithmic scale. Richter scale is based on logarithmic scale. It is magnitude based on the amplitude of the wave which we record in this seismogram and it is related to the total energy which is getting released during an earthquake. So, it is fully magnitude based scale. This is intensity based scale and this is magnitude based scale.

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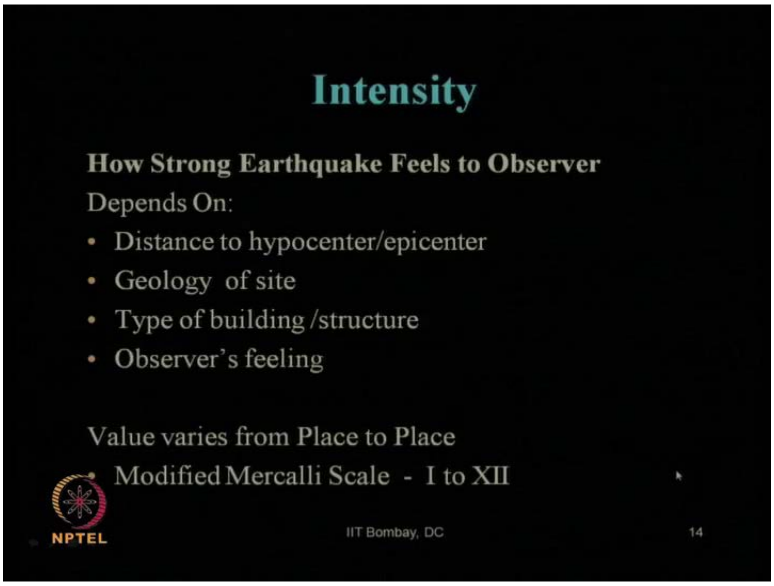

So intensity, as I already mentioned how strong the earthquake is felt by an observer, depends on distance to the hypocenter or epicenter of an earthquake and geology of the site. That is, different geology obviously will create different types of feeling to an observer. Like, even a small magnitude earthquake at a rock level can be felt very big due to amplification or some other reason in a soft soil. So, that geology of that site is very important for an observer to report it as a high intensity earthquake or low intensity earthquake.

Then, type of building or structure. Suppose, if we have masonry structure or mud structure or non engineered structure, which is not designed in an engineered way or in a proper way using total provisions etcetera, those structures obviously are going to collapse very soon even at moderate level of earthquake. So, that damage etcetera will get related to a person where there is a very good RCC structure, reinforce concrete structure or still structure, probably they may not get damaged as compared to at the same earthquake magnitude if they were masonry structure or mud structure or hard etcetera. So, the amount of damage depends on the type of building which the observer is reporting to you or which you are observing at the site after the earthquake. And also, the observer's feeling as to how they felt during the earthquake. As I said, the value varies from place to place and the modified Mercalli scale that is called MMI, where I is intensity modified. Mercalli intensity scale or the MMI scale is ranging from 1 to 12.

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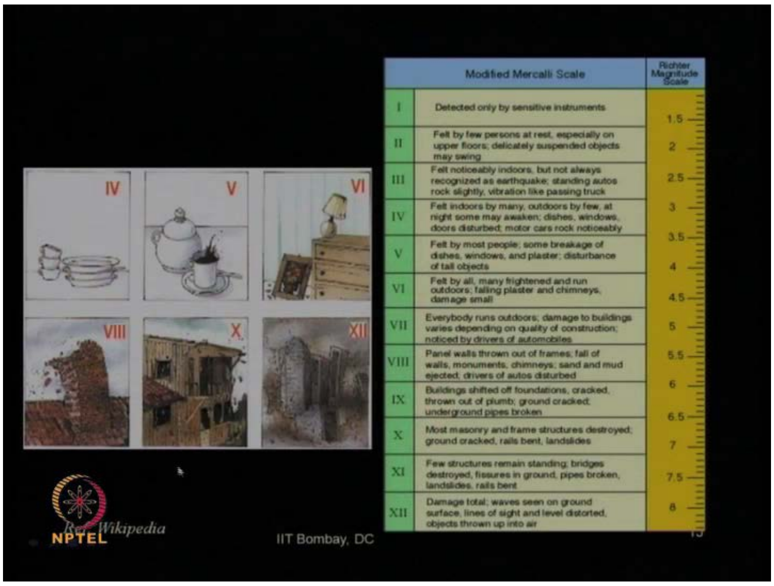

So, this is a typical representation of a modified Mercalli scale. You can see over here from the modified Mercalli scale, an intensity of 4 to 12 is shown in this picture because below 4, it is almost not felt by the observer. So, 4 5 6 and then 8 10 and 12 are shown in this slide.

You can see about the various types of damages which are mentioned in this table corresponding to MMI scale of 1 2 3 4 5 6 7 8 9 10 11 12 and a corresponding correlation with the Richter magnitude scale. So, this is the intensity scale. So, intensity scale corresponds typically to how much of Richter magnitude scale can be correlated. So, this is the typical correlation. Obviously, that does not mean that where the earthquake Richter magnitude of 7 is occurring at a desert will have the MMI scale of intensity 10, because there is no observer. So, this correlation relates the other way round. That is, where we will say the earthquake intensity scale of say 9 has been measured or observed by an observer qualitatively, that may correspond to typical magnitude scale of 6 to 6.5. So, we can go from this to this scale, but not from this to this scale. So, this is the correlation which we can obtain from this chart.

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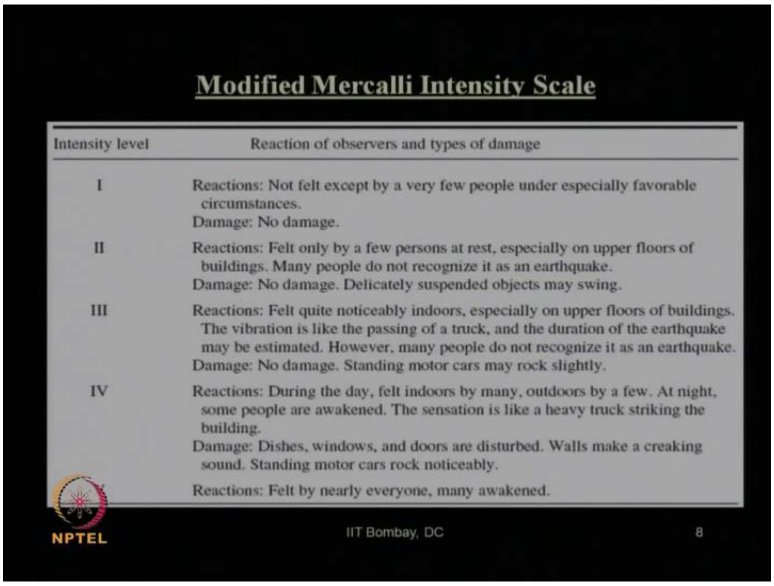

So, in this modified Mercalli intensity scale or MMI scale, for each intensity level, we can identify what could be the reaction of the observer and the type of damage. Since, these two are the main observations which we notice and on that basis, we identify what is the intensity level of a seismic event. So, intensity level 1 means reactions will be not felt except by a very few people under specially favourable circumstances. That is, at very top floor of a very high raised building or may be a little swing in the ceiling fan, which is located at the top floor of a very high raised building. In terms of damage, if we look at the slide over here, there is no damage.

Coming to the intensity level 2, the reactions to the observer or people will be felt only by very few persons at rest. Those who are moving, they cannot feel it. Only those who are at stationary may feel it, especially on the upper floors of the buildings. Many people do not recognize it as an earthquake. They probably will think that some vehicle probably has passed by or some train some must have passed by or something like that or even minor to that. What could be the damage? In this case also there is no damage and delicately suspended objects may swing. So, what I was mentioning in the case of 1, similar thing will occur in intensity level 2. That is, ceiling fans etcetera which are hanging from a certain height may start swinging.

At intensity level 3, the reactions will be felt quite noticeably indoors. That is, people in outdoors probably may not feel it, but people staying inside the house may feel it especially on upper floors of the buildings. That is in tall towers etcetera and the vibration is like the passing of a truck. So, this is again people will start feeling like some truck probably has passed near the building and the duration of the earthquake may be estimated in this case. However, many people do not recognize it as an earthquake like the intensity level 2. They will feel that probably it is due to the vibration caused by a passing vehicle. In this case also, no damage. Only standing motor cars may rock slightly.

Whereas for intensity level 4, the reactions are during the day it is felt indoors by many, but outdoors by a very few number of people. At night, some people are awakened because of this intensity level of shaking. The sensation is like a heavy truck striking the buildings. That is, as if a heavy truck is going to hit or come close to the building. Damage means, in this intensity level of 4 is that dishes, windows and doors are disturbed. They will make certain kind of sound and vibrations etcetera. Walls make a cracking sound and standing motor cars rock noticeably. They start rocking.

At the intensity level of 5, reactions will be felt by nearly everyone and many awaken. So, almost everybody will start feeling the MMI intensity scale of 5 and what can be the damage. Let us look at here. In this case, some dishes, windows etcetera are broken. In case of intensity level 4, we have seen that they are disturbed and they are shaken. But at intensity level of 5, they are broken. A few instances of cracked plaster and unstable objects are overturned and they may topple, etcetera. So, disturbances of trees, poles and other tall objects are sometimes noticed and pendulum clocks may stop functioning during this intensity level of 5.

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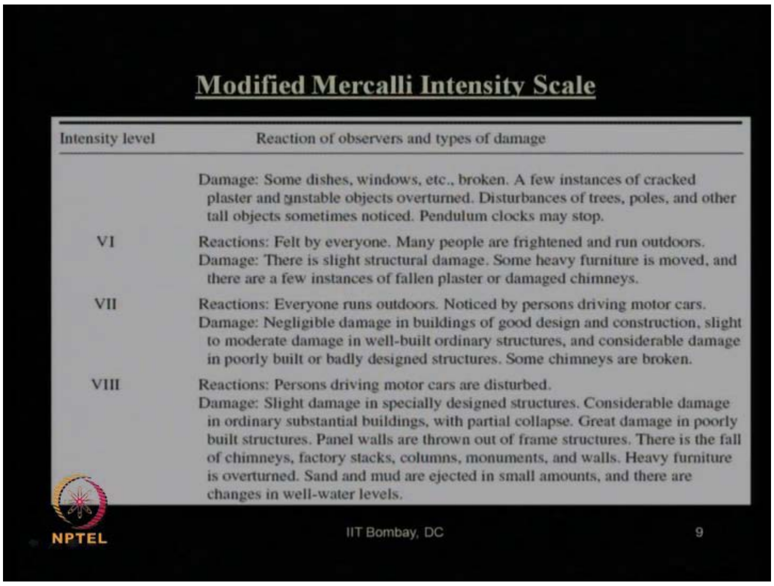

Now, next intensity level of 6. The reactions will be felt by everyone. All people must feel this intensity level of 6. That is, if everybody at a place reports after an earthquake that they have felt the earthquake, the minimum intensity level will be 6. That is what it means. So, many people are frightened and run outdoors during this intensity level and damages, slight structural damage. So earlier, all the damages were only external or non structural for which we civil engineers are not that concerned about. But of course, we have to be very careful because these falling objects should not create problem to the human beings staying inside the houses. But, anyway the major damage on what we civil engineers are concerned about is the structural damage. That will start appearing from this intensity level of 6.

So, some heavy furniture is moved and there are a few instances of fallen plaster or damaged chimneys. So, that is the intensity level. Now, if I want to correlate this intensity level of 6 with our Indian condition like for our city Mumbai, as per our Indian seismic design code IS 1893, it says that Mumbai will be in zone 3 which may face an intensity level of around 6 or 6.5 in MMI scale. So, what does it mean? We can expect slight structural damage appearing during an earthquake which may occur in this region. That is what it means.

So, let us come back to this slide. So, next intensity level is 7. Here reactions means everyone runs outdoors. That is, they felt it and of course very rigorously. That is why due to panicking they run outdoors. It is also noticed by persons who are driving the motor cars. That is, those who are in motion, they also can feel this earthquake. Because obviously, when people are in motion, it is sometimes very difficult for them to feel or identify it as an earthquake unless it is a large magnitude or large intensity. So, that is what it says from 7 onwards, even the moving people or moving in the car, they also can feel this magnitude of earthquake or this intensity of earthquake.

Damage is negligible damage in buildings of very good design and construction. That is where proper engineering concept of design and proper construction following all the by-laws etcetera have been adopted. There will be negligible or no damage to such buildings. But, slight to moderate damage in well built ordinary structures may be noticed and considerable damage or large damage can be found in poorly built or badly designed structures. That is, the structures which are not at all designed by an engineer. Just it is constructed like that by some mason or somebody without any proper design or guideline. So, those are getting considerably damaged even at intensity level of 7 and some chimneys are broken.

So, intensity level 8 refers to the reactions of persons driving motor cars are also completely disturbed. So, obvious reason is other people are automatically feeling it very vigorously and damage can be slight damage in specially designed structures and considerable damage in ordinary substantial buildings with partial collapse of these buildings. So, collapse of the buildings starts from 8 intensity scale onwards. Great damage in poorly built structures, panel walls are thrown out of the frame structures and there is fall of chimneys and factory stacks, columns, monuments, walls, etcetera.

Heavy furniture is over turned, like big almirah’s etcetera, can be over turned. Sand and mud are ejected in small amounts from the ground surface and there are changes in the well water levels. That is, if there is a bore well through which you can see their water level, at intensity level 8 onwards that water level keeps changing. Either it may rise or it may go down depending on the situations etcetera.

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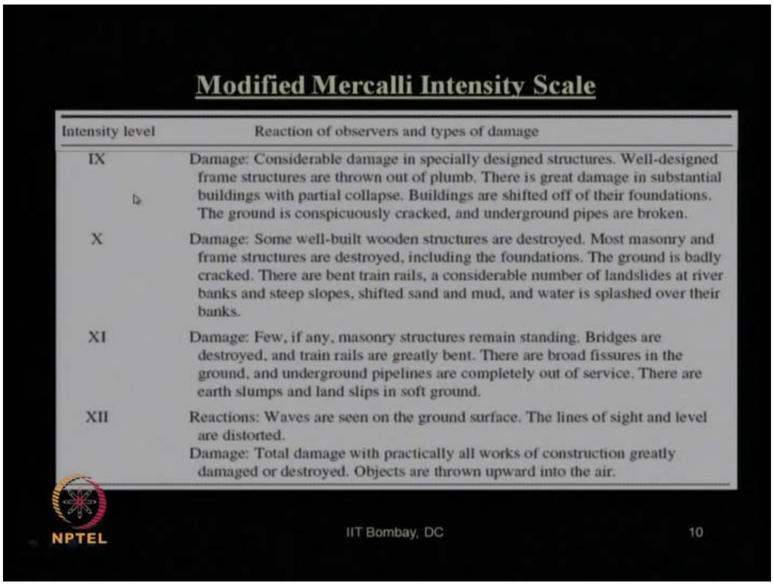

So, next intensity level is intensity level of 9, in this MMI scale. The damage is considerable damage. So now, of course, reaction does not matter. Reaction means everybody is now feeling from previous two intensity level onwards. So, we are talking about now damage level, which will help us to identify different intensity level. So, damage is considerable damage in specially designed structures. That is, even if you have engineered design structure, that also will be going through considerable amount of damage. Well designed frame structures are thrown out of the plumb and there is great damage in substantial building with partial collapse. Buildings are shifted off their foundations. That is, you will see that probably this super structure or the top building are uprooted out or taken out from the foundations during this intensity level of 9. The ground is conspicuously cracked and underground pipes are broken completely.

Intensity level 10 shows the damage will be some well built wooden structures are also destroyed. As we know that wooden structures are typically good structures in the earthquake prone region. But, even those wooden structures start getting destroyed at intensity level of 10. Most masonry and frame structures are totally destroyed including their foundations and the ground is badly cracked. There are bent train rails, considerable number of landslides at river banks and steep slopes, shifted sand and mud and water is splashed over their banks.

Next intensity level is 11. Damage means, if any few et all masonry structures remain standing, that means, at intensity level of 11 all masonry building will supposed to get fully collapsed. They cannot stand at the intensity level of 11. Now bridges are destroyed and train rails are greatly bent. There are broad fissures in the ground or cracks in the ground. These are large cracks and underground pipelines are completely out of service. There are earth slumps and land slips in the soft ground. Earth slumps means there will be sudden depression in the earth ground.

The highest MMI intensity scale is 12 as we have mentioned already. So, this 12 intensity scale, what does it mean, the highest intensity? The reactions will be that you can see even the waves on the ground surface. That is, the seismic waves which are travelling, even that you can see on the ground surface. They are getting formed through these waves. That is, wavy motion of the ground surface, even that you can notice. The lines of site and level are totally distorted. That is, whatever is line of site etcetera will completely change. Damage will be, if we look at here in this slide, damage shows the total damage with practically all works of construction will be greatly damaged or destroyed. So, nothing can survive at this intensity level of 12. Objects are thrown upward into the air. So, even heavy objects etcetera will be just thrown out in the air at this highest intensity level of 12.

So, that is various intensity levels. How an observer should fill and what could be the rate of damage or amount of damage. So, knowing all these details, now once we go for a site investigation soon after an earthquake by interviewing people and also by looking at various levels of damage of the adjacent structures and area, we can say that this earthquake was having a MMI scale of this much. So, that is the way people find out what is the MMI scale of an earthquake by taking this qualitative assessment. Now, let us come to the next form of determination of size of earthquake through magnitude or quantitatively.

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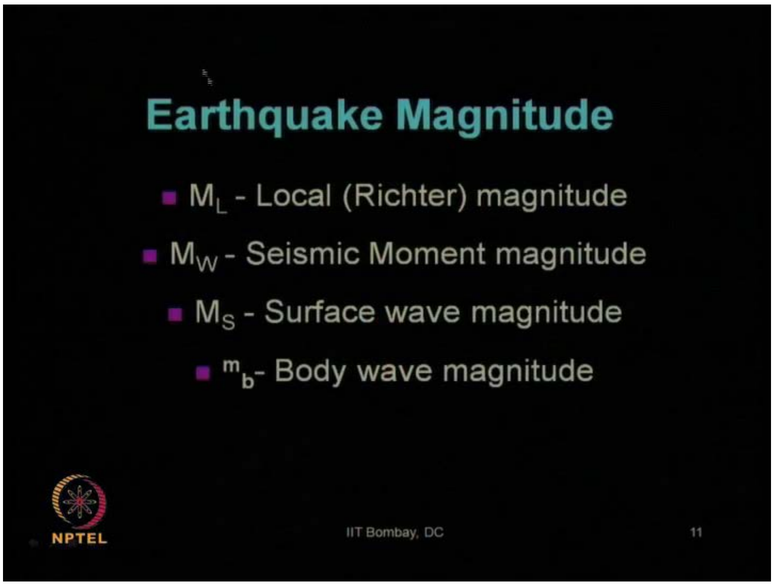

So, let us talk about earthquake magnitude. Earlier we talked about intensity. Now, we are talking about magnitude, which is quantitative in nature. This is not qualitative. This is fully based on how much energy gets released during an earthquake. Based on that, it is magnitude based or quantitative based determination of the size of an earthquake. Typically, the major four scales are used. There are other scales also to estimate the magnitude of an earthquake. The most commonly used one is called M L, that is local magnitude. Another name of this is called Richter magnitude scale or local magnitude scale M L.

The next important or I will say, according to engineering calculation wise or engineering design wise this is the most important magnitude and that is M W, which is called seismic moment magnitude scale M W. The next another important magnitude scale which is commonly used is called M S, which is nothing but surface wave magnitude scale. Another important magnitude scale is called M B. It is called body wave magnitude scale. So, these are four major magnitude scales. Other than that also we have several few more magnitude scales used locally. Japan metrological agency use their own separate magnitude scale J M A. So, like that there are few other magnitude scales, but worldwide these four are commonly used. Among those, the most popular one is local magnitude. When we talk about engineering design and any technical consideration of earthquake, then we talk about M W or moment magnitude.

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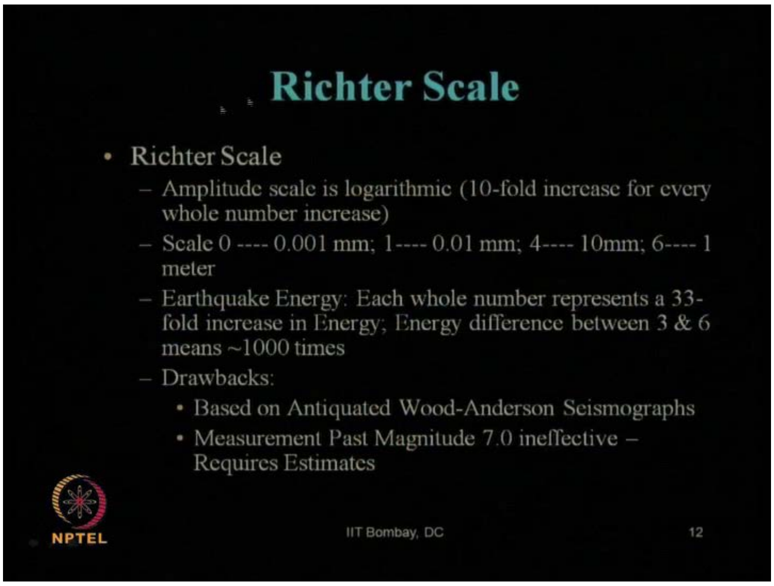

Now, let us go through each of this magnitude scale with their details, etcetera. So, first let us start with local magnitude or Richter scale. So, what is Richter scale of magnitude? It is the amplitude of the earthquake magnitude which is determined using a scale in logarithmic scale. That is log to the base 10 and tenfold increase for every whole number increase which is quite obvious. That means, Richter magnitude 3 to 4 means it is a 10 times increase because it is in the logarithmic scale. So, scale 0 corresponds to 0.001 millimeter of displacement of the ground 1 and scale 1 corresponds to 0.01 millimeter. These are typical values. Scale 4 in Richter scale corresponds to 10 millimeter and scale 6 corresponds to 1 meter of ground deformation.

So remember, when we are talking about this ground deformation, this can be either the eve on the ground or the settlement in the ground. So, when we are talking about this movement of the ground, this vertical movement of the ground that we are talking about, it can be eve or it can be settlement of the ground by this amount.

Typically, for a better understanding by a lay man, if we want to visualize what is earthquake Richter scale, then let me give you one simple example. That is, if suppose at the ground, 1 millimeter of ground particle deformation has occurred after an earthquake. Then what should be the magnitude scale as per the Richter scale or local magnitude for that magnitude which has caused that 1 millimeter of ground movement either by giving vertically up or by depression vertically down. So, if it is 1 millimeter, then we have to multiply this with the number 10 to the power 3.

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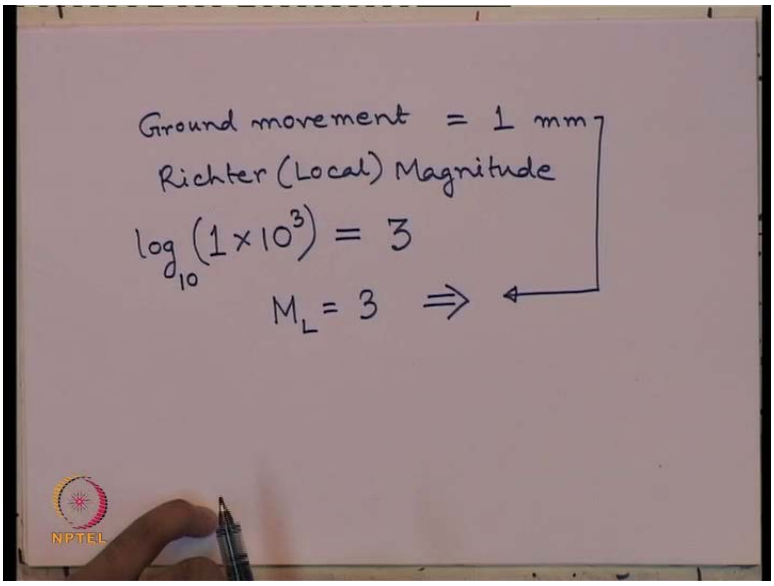

So, I will show it over here through calculation. Suppose, ground movement say this is 1 millimeter. Now, what we need to do for this earthquake is we have to find out what is the Richter or it is also called local magnitude. This is the simplest way to remember or to understand how Richter magnitude is calculated. So, this value of 1 millimeter, we need to multiply it with respect to 10 to the power 3 and then we have to take a log of this value to the base 10. If we do that operation, then the value we are getting is 3. So, that means, M L of 3 means it will cause equivalent ground movement of this 1 millimeter. Is it clear?

So, this is the simplest way to understand how Richter magnitude scale is computed and that is what we see after any earthquake. Several technical and newspaper articles etcetera, various websites they will record or they will mention about what is the Richter or local magnitude of the earthquake.

So, this is the simplest way how one can estimate this Richter magnitude of earthquake. There is of course detailed values etcetera which we will come very soon in the subsequent slides. So, that is what is shown in this slide. You can see each scale, each whole number rise in the Richter magnitude denotes to tenfold increase. That is why 4 to 6, 2 whole number rise and there is 10 millimeter to 1 meter, if we talk about in terms of earthquake energy, because this magnitude scale is always related to earthquake energy that is getting released during that earthquake.

So, each whole number of Richter scale will represent a 33 times increase in the energy that means, Richter magnitude of 3 to Richter magnitude of 4 will differ by 33 percent increase in the release of earthquake energy. So, automatically energy difference between an earthquake of Richter magnitude scale of 3 and 6 will mean that there is an energy release of 1000 times when there is an increase in the earthquake scale of 3 to 6 in Richter magnitude. Clear?

Now, what are the drawbacks of this Richter scale? How this Richter scale is used. This Richter scale is estimated based on Wood Anderson seismograph. This is the typical seismograph which was proposed by Wood and Anderson. So, that Wood Anderson seismograph is used. So, it is based on that antiquated Wood Anderson seismograph and measurement past magnitude 7 is ineffective and that requires estimate. What does it mean?

The drawback of this Richter scale shows that at higher magnitude, that is when the magnitude is more than 7, then the Richter magnitude estimation through this seismograph is not correct.

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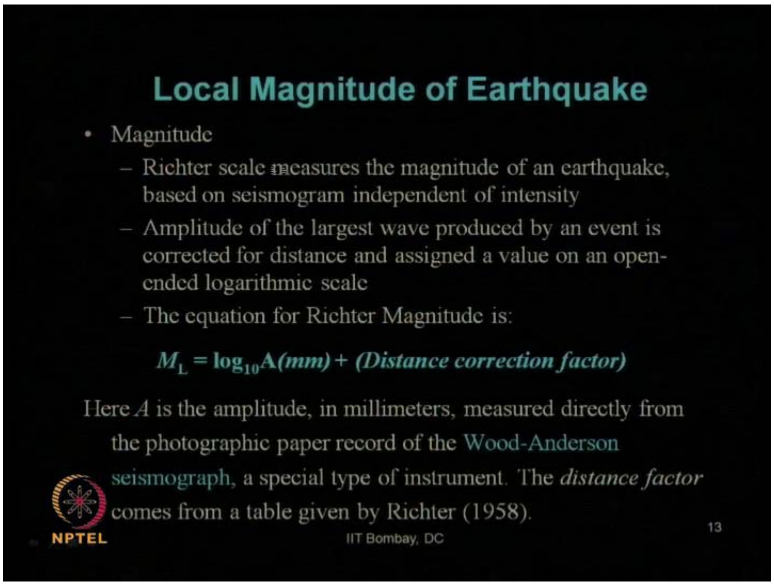

So, if we talk about this local magnitude further or Richter magnitude further, Richter scale measures the magnitude of an earthquake based on seismogram independent of the intensity. As I said, it does not matter whether some people has felt it or not. Even this magnitude can be in the deep ocean or it can be in desert where there is no human being or there is no such damage. So, it is independent of the intensity.

Amplitude of the largest wave produced by an event is corrected for the distance and assigned a value on an open ended logarithmic scale. So, that is how it is estimated. So, whatever in the seismogram we have estimated, that value, that is the largest value or the maximum value of the amplitude, we have to take to compute the Richter scale of earthquake magnitude. So, the equation for the Richter magnitude which is used is given by this expression M L local magnitude or Richter magnitude is log to the base 10 a in terms of millimeter. That is what I have shown you just now through the example. But, there needs to be some distance correction factor. This correction factor comes into picture when your seismograph location is far away from the earthquake epicenter.

So, in this equation you can see over here, A is the amplitude in millimeter unit. It is already given over here. This is the displacement amplitude of the ground in millimeter unit and maximum amplitude is what you have to take and measure directly from the photographic paper record of that Wood Anderson seismograph. So, that is the typical seismograph as I said revised by Wood and Anderson. That seismograph has to be used. So, direct reading of that amplitude we have to take in millimeter unit and we can put it here. The distance correction factor comes through a table which was proposed by Richter in the year 1958.

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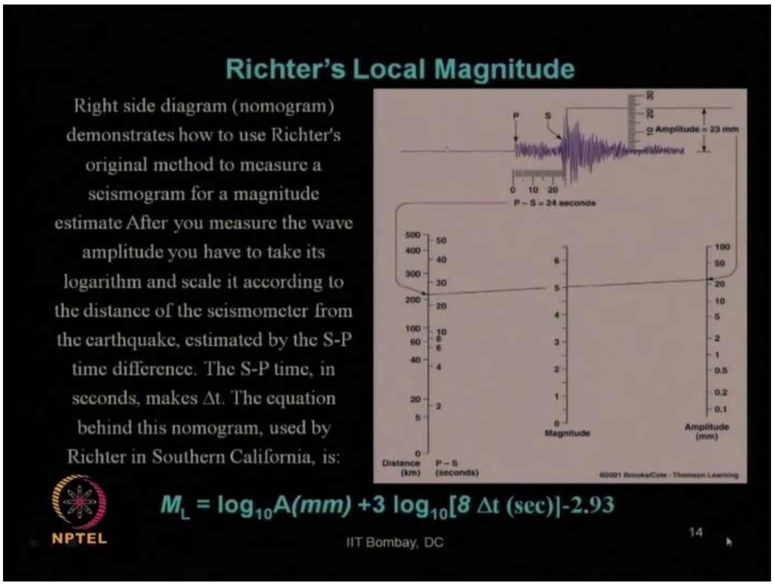

So, this is how this Richter local magnitude is calculated. You can see this right hand side nomogram, which demonstrates how to use this Richter's original method to measure the seismogram for a magnitude estimate. After one measures the wave amplitude, you have to take its logarithm and scale it according to the distance of the seismometer. That is, how far it is located from the epicenter and estimate that S minus P time difference, which already we have learnt. S minus P time in seconds makes it delta t. That is, the time difference delta t in second unit. The equation behind this nomogram used by Richter in the southern Californian region of US is these are empirical relations. So, these are basically location specific. This is based on southern Californian earthquake. This is the expression which Richter had proposed by considering the distance correction factor.

So, this comes as a distance correction factor. That is, 3 log to the base 10 8 delta t in second unit. That is the time difference between arrival of S wave and P wave minus 2.93. So, how best you can use this nomogram? You see this is the basic record you are getting this top part, which I am highlighting over here in the seismograph of Wood and Anderson.

Typical Wood Anderson seismograph will give you arrival time of P wave and arrival time of S wave from which, suppose we get the time difference say 24 seconds. What is the amplitude? Maximum amplitude, we have to take from this. The maximum value is this one. Let us say in amplitude scale, it is measured as 23 millimeter. It has to be in millimeter unit. So, it says you can take the distance in kilometer which is correlated with respect to P minus S in second using that epicentral distance and time travel distance method. This is the magnitude which we have to find out, Richter magnitude or local magnitude and this is the amplitude which is measured in this Wood Anderson seismograph. So, let us put here 23, we can get from the seismograph. Put the value 23 here and this 24 second also you can get from the seismograph, put 24 second over here.

Now, join these two lines by a straight line using a scale. Wherever it cuts, that is the value of your Richter magnitude. So, here it is coming little above 5. So, 5.1 or even 5 you can say. So, that is the use of this nomogram as given by Richter using this distance correction factor for southern California. So, with this we have come to the end of this lecture. We will continue further in the next class.