Geotechnical Earthquake Engineering

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

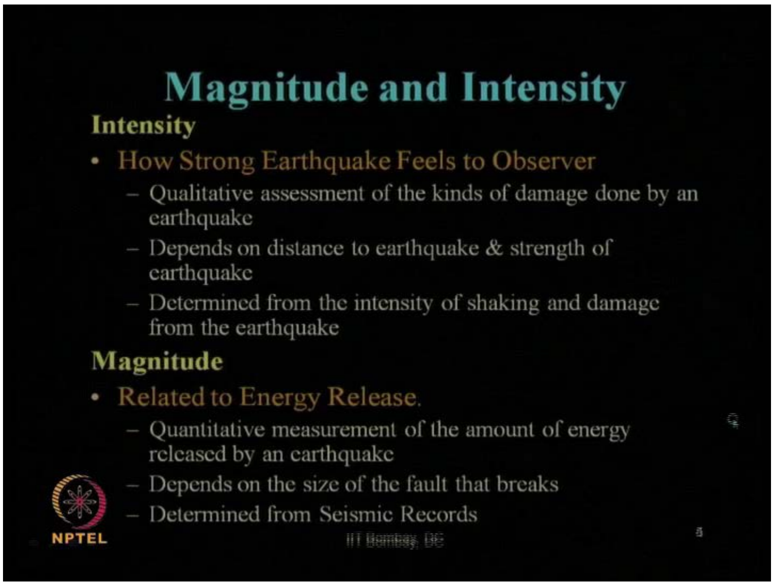
Module - 4

Lecture - 11

Strong Ground Motion (Contd…)

Let us start our today's lecture on geotechnical earthquake engineering video course for NPTEL. In this geotechnical earthquake engineering course, we can see in this slide, we were going through module four of this course which is on strong ground motion, and within that we were discussing the subtopic of size of various earthquakes.

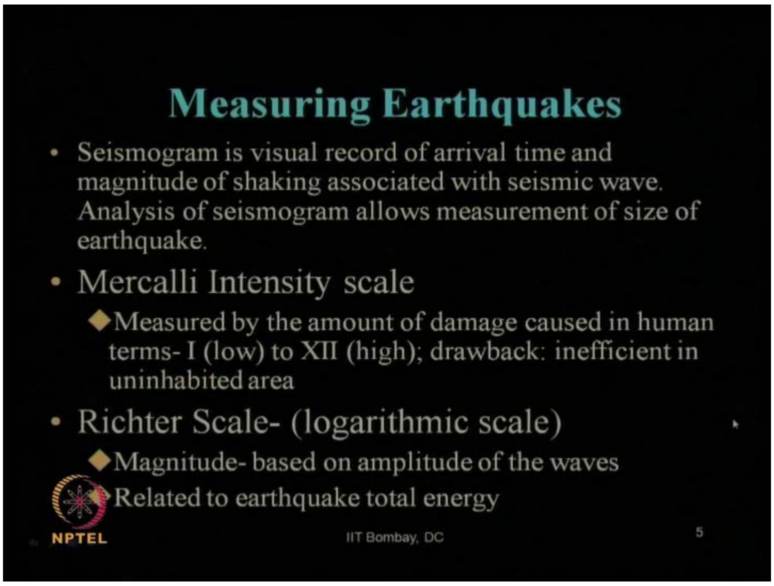
(Refer Slide Time: 00:49)



A very quick recap what we have learnt in the previous lecture. Like size of an earthquake can be estimated either by magnitude or by intensity or both. And intensity is mostly qualitative in nature; that is how strong an earthquake is felt by an observer or how much damage has an occurred after an earthquake.

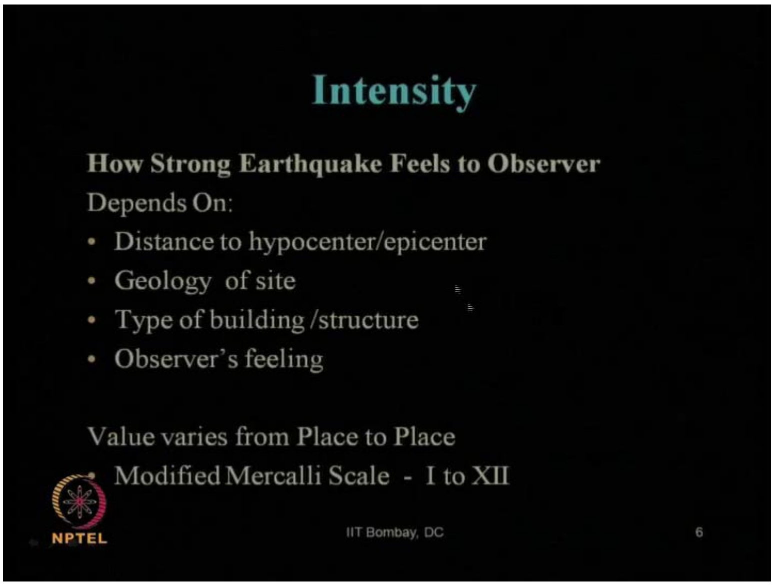
So, this intensity is mostly a qualitative assessment whereas, magnitude is fully quantitative assessment of the size of an earthquake. And it is related to the amount of energy which is getting released during an earthquake.

(Refer Slide Time: 01:36)



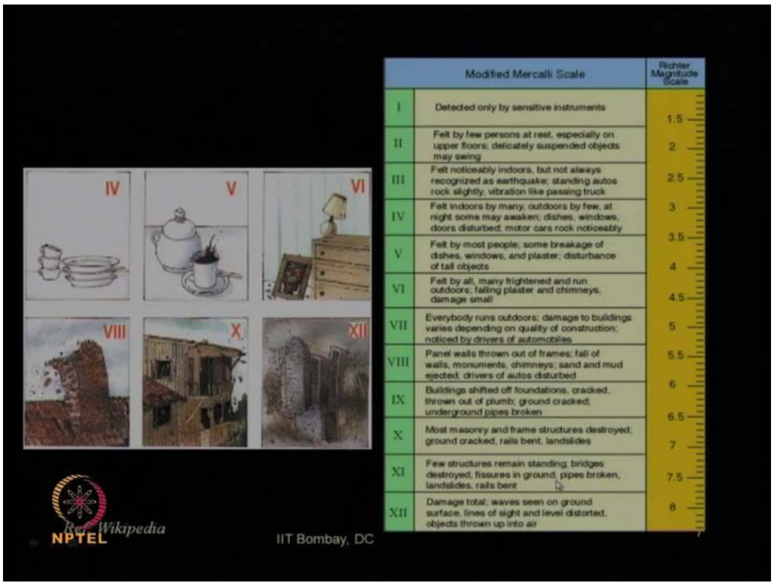
And the basic measuring scale for this different intensity and magnitude scale we have seen for intensity, it is Mercalli intensity scale. Later on it has been modified. So, which is named as modified Mercalli intensity or MM I scale and another is Richter scale.

(Refer Slide Time: 01:59)



So, as I already mentioned intensity of an earthquake depends on how the observer felt it qualitative, and distance from the hypocenter to that point of observation, geology of the site, type of the building and the observer's personal criteria of feeling. So, that MM I scale varies from scale one to twelve. Scale one denotes the least amount of earthquake or intense earthquake or MM I scale of twelve denotes the maximum or worst amount of earthquake, which is felt by an observer, and also depending on the damage to the structures.

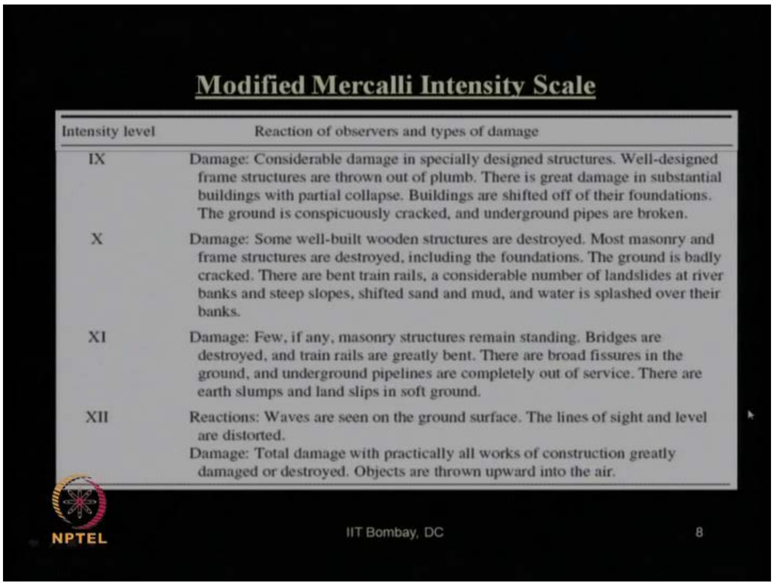
(Refer Slide Time: 02:52)



So, this picture we have seen earlier. The various MM I intensity scales are noted over here from 4, 5, 6 then 8, 10, 12 showing the different levels of damages to the structures and the various articles, which is, we just correlated with respect to Richter magnitude scale on this side as I said. We can go from modified Mercalli intensity scale to Richter magnitude scale, but we cannot do the reverse one. That is, from Richter magnitude scale we cannot come back to modified intensity scale, because it may happen that earthquake may have occurred in an locality where there is no habitant. So, there is nobody who felt it or there is no observer or no damage at all.

So, intensity scale in that case may be 0 or very little or very low, but Richter magnitude or actual energy released may be pretty high. So, that is why I said conversion from Richter to MM I is not correct, but once somebody faced the damage and felt a large earthquake; obviously, you can go to the magnitude scale which is based on the quantitative assessment of the energy released.

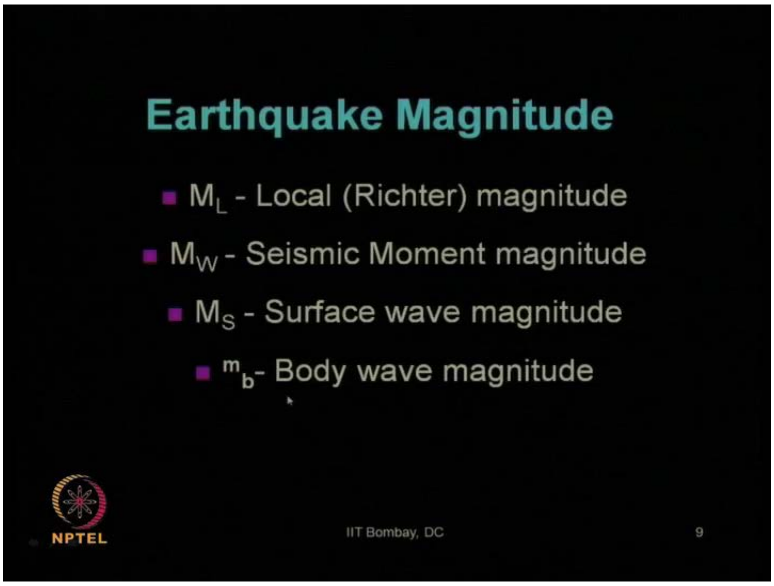
(Refer Slide Time: 04:10)



Intensity level	Reaction of observers and types of damage
IX	Damage: Considerable damage in specially designed structures. Well-designed frame structures are thrown out of plumb. There is great damage in substantial buildings with partial collapse. Buildings are shifted off of their foundations. The ground is conspicuously cracked, and underground pipes are broken.
X	Damage: Some well-built wooden structures are destroyed. Most masonry and frame structures are destroyed, including the foundations. The ground is badly cracked. There are bent train rails, a considerable number of landslides at river banks and steep slopes, shifted sand and mud, and water is splashed over their banks.
XI	Damage: Few, if any, masonry structures remain standing. Bridges are destroyed, and train rails are greatly bent. There are broad fissures in the ground, and underground pipelines are completely out of service. There are earth slumps and land slips in soft ground.
XII	Reactions: Waves are seen on the ground surface. The lines of sight and level are distorted. Damage: Total damage with practically all works of construction greatly damaged or destroyed. Objects are thrown upward into the air.

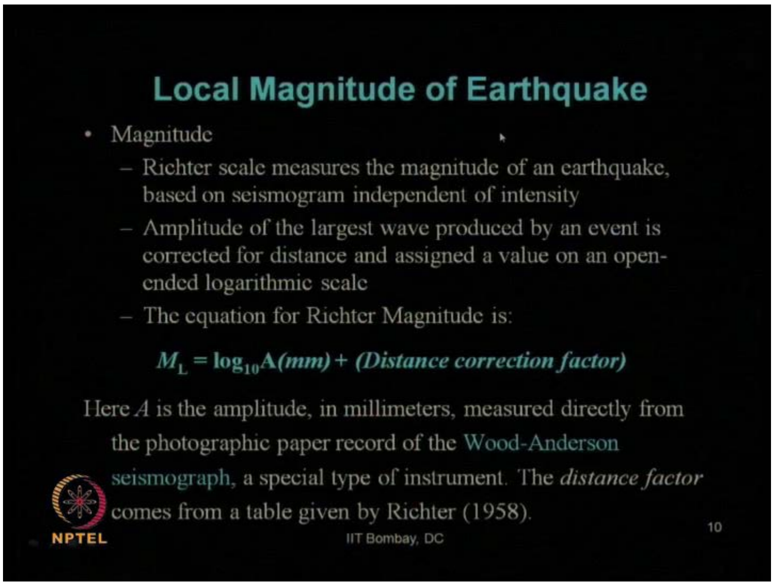
Then we have seen how this intensity level of MM I is actually reported after an earthquake looking at the various damage level, and the reactions of the observer's.

(Refer Slide Time: 04:23)



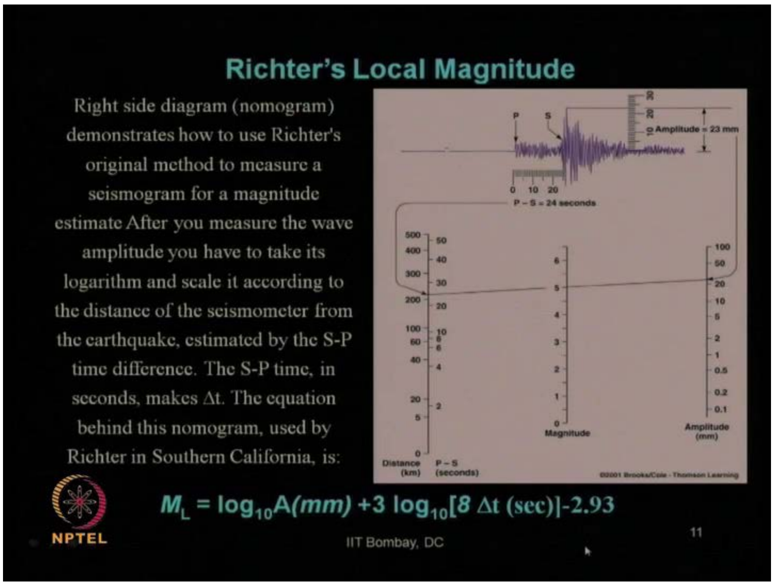
Then we discussed about major four scales of earthquake magnitude which are quantitative in nature like M L local magnitude scale or Richter magnitude scale, M W seismic moment magnitude scale, M S surface wave magnitude scale and M b body wave magnitude scale.

(Refer Slide Time: 04:48)



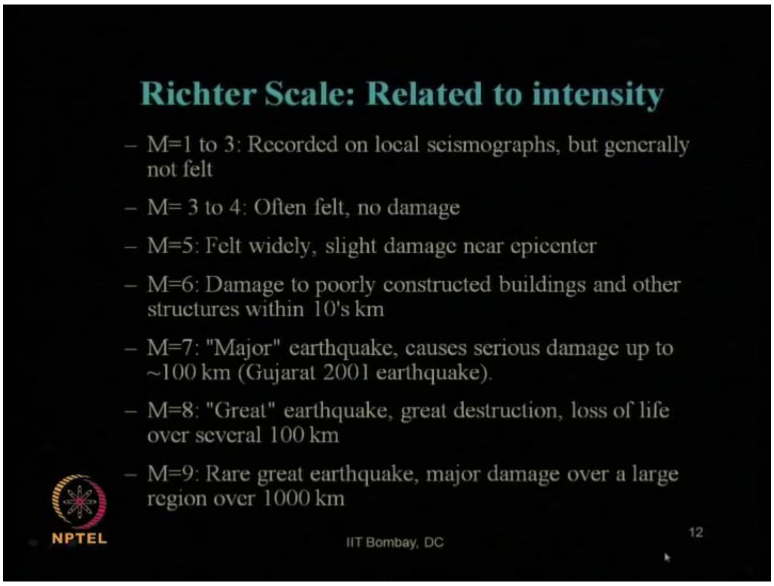
Now, we have also discussed the local magnitude scale or Richter magnitude scale in detail that the basic equation is M l log to the base ten. A is nothing, but the amplitude in the millimeter unit which is measured directly from Wood-Anderson seismograph and there should be a distance correction factor which is proposed by Richter the in 1958 through a nomogram.

(Refer Slide Time: 05:11)



So, this is the nomogram which we have seen. This is the direct output on the paper from the Wood-Anderson seismograph. You can get the maximum amplitude which you can compute from this scale and you can also compute the arrival time difference between S wave and P wave in second unit. So, coming to this scale of P minus S in second unit and the amplitude in millimeter unit, you join these 2 points by a straight line where it cuts it is magnitude scale in this nomogram of Richter. You will get the value of Richter scale magnitude. So, Richter used or proposed this nomogram using the earthquakes of southern California in USA.

(Refer Slide Time: 05:57)



So, how this Richter scale is related to intensity? Let us start our today's lecture in detail. As I said just now that in the recap of our previous lecture that magnitude from Richter to intensity is not a good one, but it gives certain amount of idea that how much devastating it should be, but other way it is possible. So, Richter magnitude or local magnitude of one to three means recorded on local seismograph and assuming that the site is occupied by human means. So, there are observers we can say that it is not generally felt by anybody that magnitude of one to three of Richter magnitude where as magnitude 3 to 4 Richter scale is often felt, but there is no substantial amount of damage.

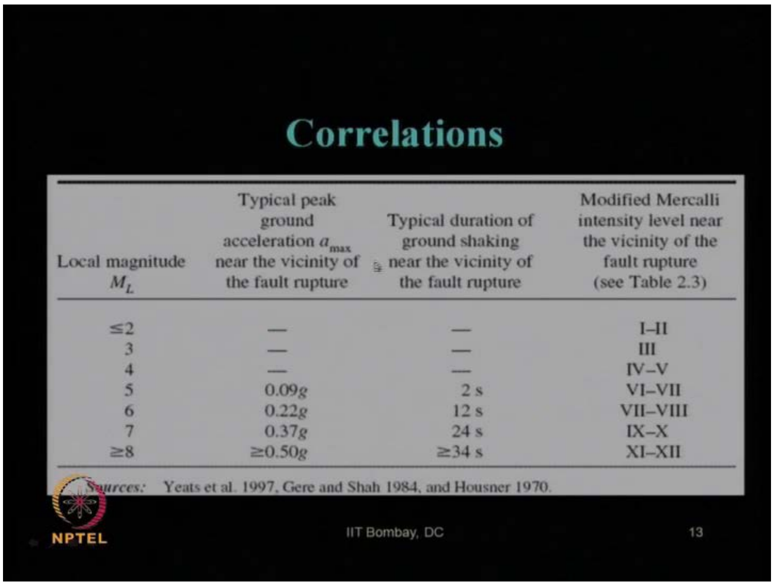
If magnitude 5; it is felt widely that is, observers can feel it easily this Richter magnitude of 5 and there can be slight damage near the epicenter. If the earthquake is close to the epicenter, there can be slight damage to your utensils or buildings or other things.

Magnitude 6 means damage to poorly constructed buildings or non engineered or which are not constructed properly those buildings or other structures within some 10s of kilometers. Say, 10 kilometer, 20 kilometer, 30 kilometer like that. 10s of kilometers in the units of 10; not goes to 100 of kilometers. That is what it means.

M 7, Richter magnitude of 7 refers as major earthquake which causes serious damage up to a distance of about 100 kilometers. That is if a site is located within about 100 kilometers from the epicenter; this magnitude of 7 major earthquake may cause our Gujarat earthquake of 2001 is falling under that category. The local magnitude of was about 7. Magnitude of 8 in Richter scale or local scale is called as great earthquake. There will be great destruction, loss of life over several of 100’s of kilometers. And Richter magnitude of nine this is a rare great earthquake major damage over a large region over 1000 of kilometers of distance.

So, that is the various scales of Richter magnitude and their correlations to the damages to the structures and how the observers feel it. So, you can automatically feel or locate over here for our engineering analysis mostly Richter magnitude above 5 or so we consider for our technical study or details in the earthquake engineering. Because 5 onwards you can see it is felt widely and slight damage starts occurring. Some people will say that they want to consider 4 as the limiting or the lower most value which should be considered for further analysis. So, anyway the magnitude either 4 or 5 can be the threshold magnitude above which always we should consider the proper analysis and design.

(Refer Slide Time: 09:38)



Local magnitude M_L	Typical peak ground acceleration a_{max} near the vicinity of the fault rupture	Typical duration of ground shaking near the vicinity of the fault rupture	Modified Mercalli intensity level near the vicinity of the fault rupture (see Table 2.3)
≤2	—	—	I–II
3	—	—	III
4	—	—	IV–V
5	0.09g	2 s	VI–VII
6	0.22g	12 s	VII–VIII
7	0.37g	24 s	IX–X
≥8	≥0.50g	≥34 s	XI–XII

Sources: Yeats et al. 1997, Gere and Shah 1984, and Housner 1970.

So, this is a correlation which I have just talked to you. These correlations were suggested by, initially, Housner in 1870 then modified by Gere and Shah in 1984, then again further modified by Yeats et al in 1979. This is the local magnitude or Richter magnitude values are given over here. Corresponding to that typical peak ground acceleration; that is a max value near the vicinity of the fault rupture those values are given. Here, typical duration of the ground shaking near the vicinity of that fault rupture is given and this is MM I scale values corresponding to this magnitude.

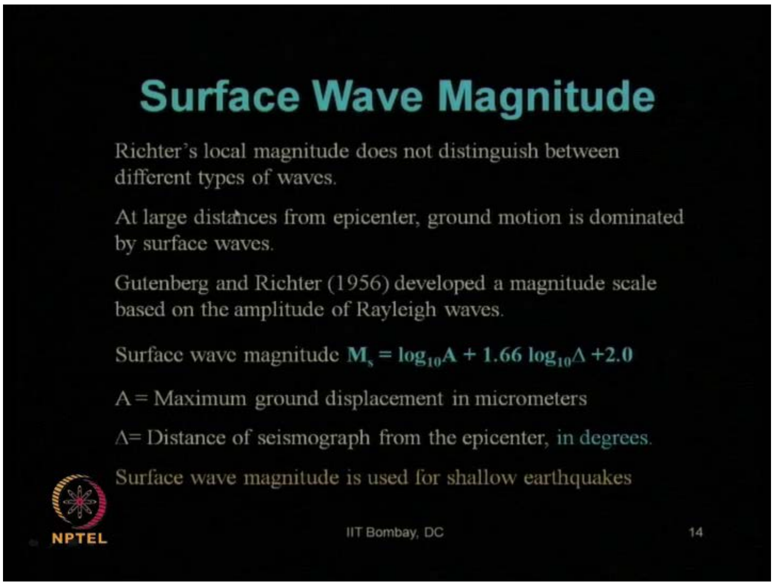
So, you can see over here less than two or nothing is important. 3 no, 4 no, even a max and duration does not matter to us for the engineering design and other things. So, 5 onwards it is noticeable as well as it is important, because 5 Richter magnitude or local magnitude typically, these are typical remember, these are not exact values. So, never use this as an exact value. This you can use just as a guideline to understand what can be the range of your A max.

Then, you can use sophisticated techniques to calculate the exact value of a max and the duration for an particular earthquake. And that should fall in the typical range of this. That is what it is a cross check. Or if somebody asks you what can be a typical maximum acceleration during an earthquake of Richter magnitude of 5 that you can always tell; it is about 0.1 g. That is what it means 0.09 g or 0.1 g and typical duration will be about two seconds and this corresponds to MM I scale of between 6 to 7. Then magnitude, local magnitude of 6 corresponds to typical a max value of about 0.2 or 0.22 g, typical duration is 12 seconds and intensity scale can be 7 to 8.

Then, local magnitude 7 corresponds to typical Amax value of 0.37 g and duration is about 24 seconds and intensity scale MM I scale can be about 9 to 10, where as local magnitude or Richter magnitude more than or equals to 8 refers to the typical values of Amax will be more than or equals to 0.5 g, and typical duration is more than equal to 34 seconds and MM I scale is 11 to 12.

So, if you look at these values it will be easy to remember corresponding to each scale. I will further simplify it in this fashion 0.1g, 0.2g, 0.3g and point or 0.35g or 0.4g to 0.5g. So, that can be kind of a correlations between local magnitude scale and the A max value and then MM I scale also you can see a jump from within the bracket of 6 to 7, 7 to 8, 9 to 10 and 11 to 12.

(Refer Slide Time: 13:25)



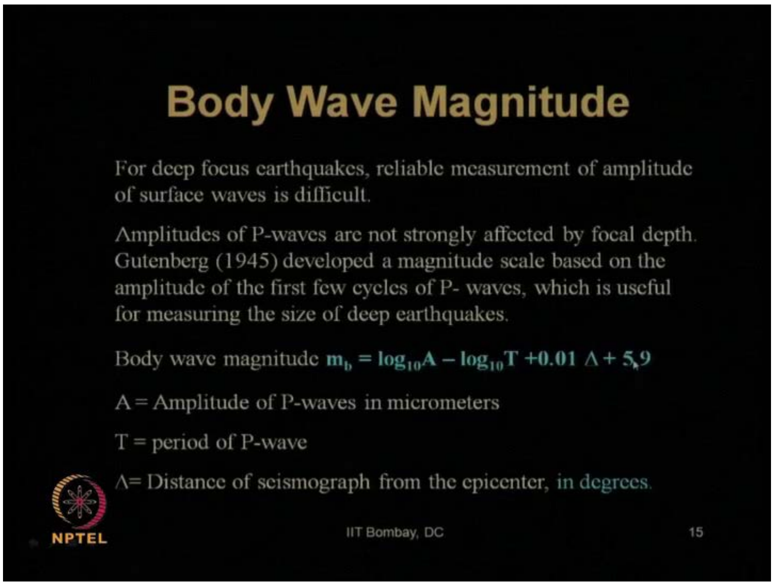
Now, let us discuss about other magnitude scales which are also commonly used. Next one is surface wave magnitude. So, surface wave magnitude, Richter's local magnitude does not distinguish between different types of waves though in the Wood and Anderson seismograph, you get actually all the waves are coming and recorded their arrival time, but it does not distinguish between your shear wave and surface wave. Because as I have already mentioned in previous lecture; it is very difficult to differentiate between shear wave as a body wave and other surface wave like Rayleigh wave and love wave, because there is hardly any difference between the arrival time of these earthquakes, because of their typical crystal velocity. We discussed already.

So, at large distance from epicenter, ground motion is dominated by surface waves because waves have to travel a quite far distance. If the site of your interest or where your seismograph is located or the site of your concern is far away from epicenter; obviously, the surface wave is going to dominate or guide. So, that is why Gutenberg and Richter in 1956 developed a magnitude scale based on the amplitude of this Rayleigh type surface wave. So, that is the reason why it is called surface wave magnitude because it is based on the estimation from the amplitude of Rayleigh wave only.

So, surface wave magnitude as per Gutenberg Richter equation is given by M S equals to log to the base 10 a plus 1.66 log to the base 10 delta plus 2.0; a numeric number 2.0. So, what this empirical relation says? What are the various units and components? This A is nothing but maximum ground displacement in the unit of micrometers. Remember here there is a change it is not in millimeter, it is in micrometer unit. This A value is the maximum ground displacement in micrometer and this delta is the distance of the seismograph from the earthquake epicenter in the unit of degree. This delta is what is the distance of your seismograph from the epicenter in the degree unit? How we can find it out in degree unit,, because Earth's circumference distance we know this is typically we can say about 40076 kilometers.

So, if on an earth's surface your distance between the seismograph and the epicenter is known which we can calculate. Already we have discussed through an example problem earlier. So, that distance you have to convert it into equivalent degree. So, that is why it says distance of seismograph from the epicenter in degrees and surface wave magnitude is generally used for shallow earthquake. Why? Because of quite obvious shallow earthquake only will have the major amount of surface wave which will surface out on the earth's crust, right?

(Refer Slide Time: 16:51)

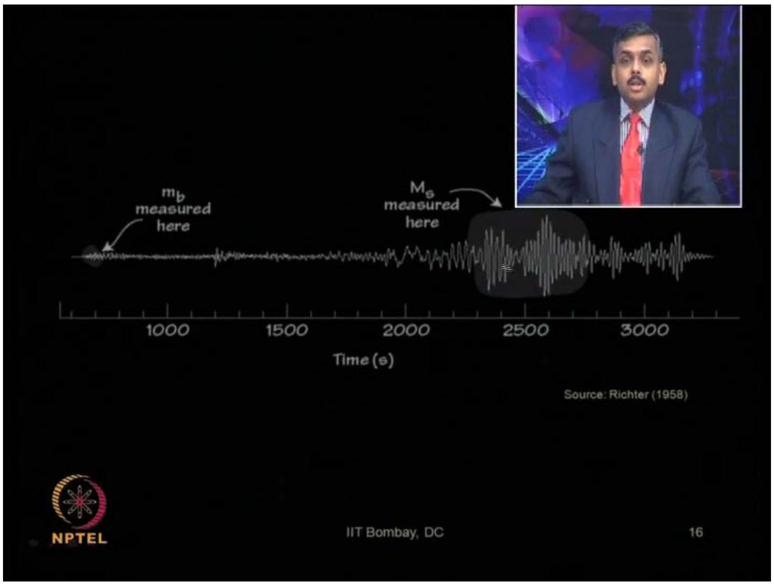


Next scale; another important scale is body wave magnitude. So, for deep focus earthquake, that is, the previous one surface wave magnitude was for shallow earthquake. Now, if we have a deep earthquake which is occurring at a deep straighter crustal distance, then reliable measurement of the amplitude of surface wave is very difficult.. Because in many a times your surface wave may not appear or even if it appears it will be distorted and it will pass through several layers etcetera right, if it is an deep earthquake or intermediate earthquake even.

So, the amplitude of the P-waves are not strongly affected by the focal depth. Hence this concept of body wave were magnitude scale was developed by Gutenberg in 1945 which is a magnitude scale based on the amplitude of first few cycles of the P-waves which is useful for measuring the size of an deep earthquake. So, for deep earthquake this scale is utilized. So, you should know which scale is suitable for which type of earthquake. We should not blindly use any scale for any type of earthquake.

So, body wave magnitude the empirical relation given by Gutenberg in 1945 is MB equals to log to the base 10 a log to the base 10 t plus 0.01 delta plus numeric value of 5.9 So, what is A? A is amplitude of the P-wave only in micrometers unit. So, here also the unit is micrometer and T is the period of p-wave. This is the time period of p-wave and this delta is the distance of seismograph from the epicenter in degrees as we have used for earlier also. So, you knowing these parameters one can easily estimate the body wave magnitude.

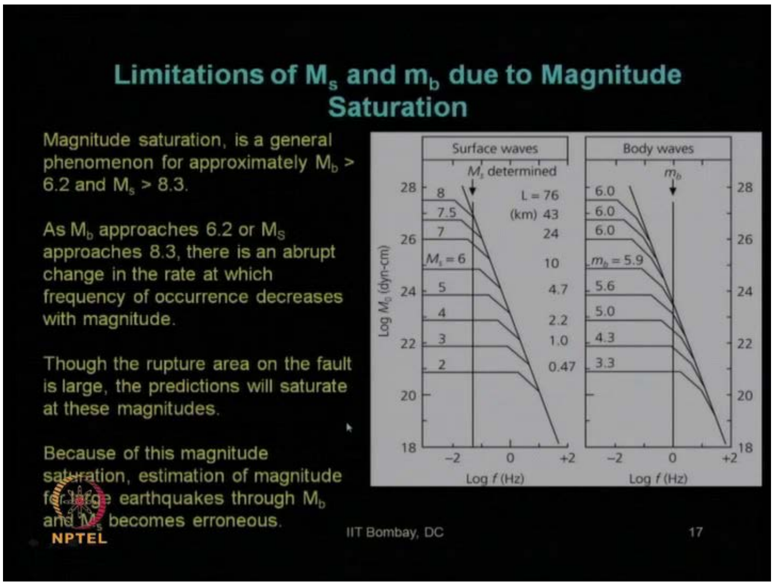
(Refer Slide Time: 18:59)



So, this is the Richter's estimation you can see from this scale. This is measured time in second unit. You have MB if you want to calculate the earthquake magnitude in MB scale. That is the body wave magnitude scale, you should use this region right were P-wave is arriving and P-wave amplitude and etcetera you have to use.

And if you are interested to compute the surface wave magnitude then this MS has to be measured and that has to be obtained. So, this is for the shallow earthquake were MS will be pre-dominant or surface waves will be pre-dominant and MB is for deep earthquake were body waves obviously, will exist properly.

(Refer Slide Time: 19:55)

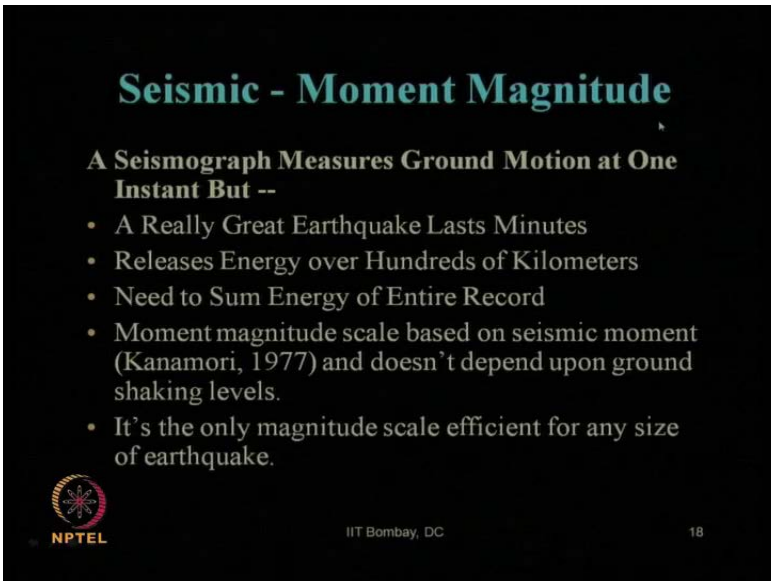


Now, there are few limitations of this two scales that is surface wave as well as body wave which is called magnitude saturation. So, what is magnitude saturation? Let us see. Magnitude saturation is a general phenomenon for approximately body wave magnitude M b greater than 6.2 and surface wave magnitude greater than 8.3. Above this value the value of the earthquake magnitudes tend to saturate. What does it mean? We will see very soon through this picture. Let us first understand what is written. As this body wave magnitude M b approaches this value of 6.2 or M s value approaches the value of 8.3 there is an abrupt change in the rate at which frequency of occurrence decreases with magnitude. Though the rupture area on the fault is large the predictions will saturate at this magnitude and because of this magnitude saturation problem estimation of this magnitude for large earthquake using this body wave magnitude scale or the surface wave magnitude scale becomes erroneous.

One should not use this scale beyond these values. So, if we look at this picture now; the x axis shows the log of the frequency of an earthquake. During an earthquake we can have various frequency in hertz unit and this is showing the earthquake moment. I will come very soon about the estimation of this earthquake moment or seismic moment in the dyne centimeter unit in the log scale.

So, it is a log scale you have. Here the various values of surface wave scale. If you see at higher frequency all of them are going to get collapsed or nullified beyond the value of this 8 or 8.3. So, that is the reason it says, beyond 8.3 it is not correct. Similarly, for body wave magnitude they try to become ineffective or they go to a saturation. That is all of them merge to a single response at higher values of frequency beyond the value of earthquake magnitude of 6 in the case of body wave from this picture. So, exact values 6.2. So, beyond these two values, we should not use these two scales reliably because they are not giving the correct estimate.

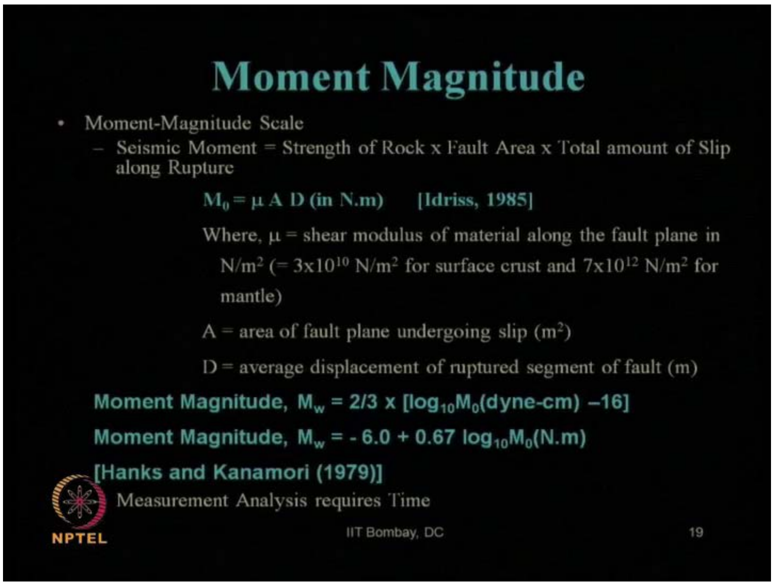
(Refer Slide Time: 22:54)



So, that is another limitation about the use of this M s and M b scale. Now, coming to the best magnitude scale which is called seismic moment magnitude scale, so a seismograph measures ground motion at one instant, but a really great earthquake it lasts for several minutes also even. So, releases energy over hundreds of kilometers. So, we need to sum up this entire energy for the entire record period. So, that can actually estimate what is the magnitude scale if we estimate the total energy which is getting released for over a couple of seconds or even minutes. Am I right?

So, the moment magnitude scale has been developed or proposed on the basics of seismic moment concept which was proposed by Kanamori in 1977 in Japan. So, that was the first time when seismic moment magnitude was proposed and it does not depend on the ground shaking level. That is, it can be irrespective of your ground shaking measurements etcetera. So, it is the only magnitude scale which is efficient for any size of earthquake and for any type of earthquake. Whether it is shallow earthquake, intermediate earthquake or deep earthquake or whether it is a small magnitude earthquake or large magnitude earthquake, this is the best scale because it is independent of all these variations of these parameters. They do not have that limitation of that magnitude saturation like the other two scales.

(Refer Slide Time: 24:37)



Now, how this moment magnitude is estimated? As I have mentioned the first step for moment magnitude scale is to calculate the seismic moment. We have to remember as in engineering or in the engineering mechanics, we understand the concept of moment is nothing but the force multiplied with the with the leverer right that gives us the moment. So, in the concept of the seismology or geology this concept of seismic moment is little different. Little different is in the sense here also we talk about the force, but the leverer in our concept of mechanics, it should be always perpendicular to the direction of the force. So, that is when we multiply force with the leverer, we get the moment. But in this case it need not be a perpendicular one to the force which is getting developed during release of an earthquake through the energy release.

So, seismic moment is computed by this way; strength of the rock that is how much strength of a rock is initially having multiplied with the fault area. That multiplied with total amount of slip along a rupture surface. That gives us the estimation of seismic moment. So, what does it mean? Strength of the rock multiplied with fault area will give the force or capacity of the rock, right? So, that gives us the force. Now when two surface through a fault they rupture or move there will be a certain amount of displacement. So, how much is the amount of that displacement or distortion that rupture gives the amount of slip. So, that is giving us the, in other words if we want to correlate kind of a leverer to estimate the moment. But obviously, that is not in the perpendicular direction of the force of the rock or the capacity of rock. So, this is the geologist way or the seismologist way to compute this seismic moment.

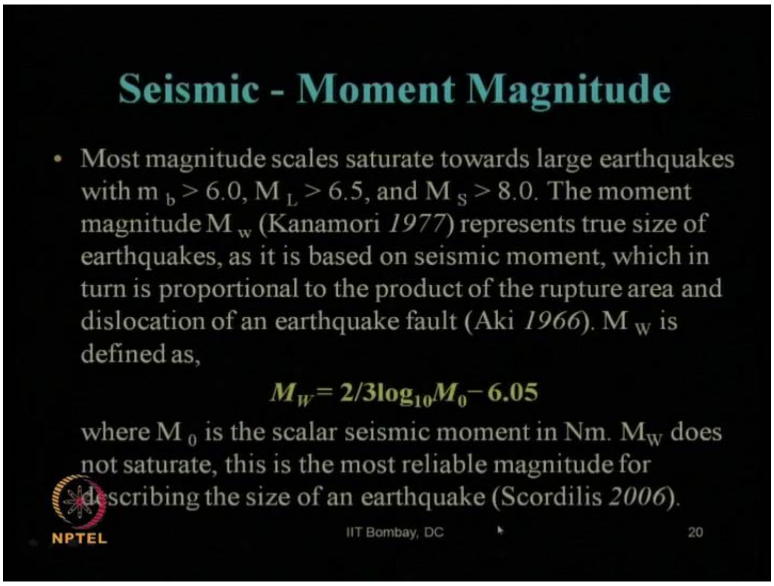
So, if you look at this equation; this is given by Idriss in 1985, when we want to estimate seismic moment in the unit of Newton meter, unit is given by mu. Mu is nothing but strength of the rock multiplied with fault area a, multiplied with total amount of slip along the rupture surface d. So, mu is the shear modulus of the material along the fault plane in the unit of Newton per meter square. The unit of this has to be in Newton per meter square and what is known to us, the typical strength or the shear modulus for crust, surface crust it is 3 into 10 to the power 10 Newton per meter square and for mantle it is about 7 into 10 to the power 12 Newton per meter square. That means, suppose if it is a shallow earthquake you are estimating you have to use this value of mu to compute the seismic moment.

If you are handling the deep earthquake you have to use this value of mu to put it here for the estimation of seismic moment. Now, A is the area of the fault plane which is undergoing through the slip in the unit of meter square. Unit of a, should be meter square. That is we talked about in the previous lecture the fault plane we can identify. So, that cross sectional area of the fault plane which is actually getting exposed or you can find out during the release of an earthquake energy. That area of the fault area needs to be used in this expression and this capital d is average displacement of that ruptured segment. That is the through which it has been slide or slipped of the fault in the unit of meter.

So, then only it will give you us the unit in Newton meter of course. So, this moment magnitude then is calculated using this seismic moment expression in this fashion. So, moment magnitude Mw can be estimated by this expression; two third times log to the base ten M naught when M naught is in the unit of dyne centimeter. Remember here it is in Newton meter minus 16, another expression the same expression actually when you are using the unit of seismic moment in the Newton meter unit then the equation takes the form of this. M w equals to minus 6.0 plus 0.67 or the 2 3 times log to the base ten M naught when M naught is in the unit of Newton meter.

So, this equation was proposed by Hans and Kanamori in 1979 and this measurement analysis, it requires time. You cannot quickly measure soon after an earthquake. The moment magnitude it requires time to estimate. Why it requires time? Because after an earthquake you need to find out how much area of the fault plane undergone through the slip and how much is the average displacement of that ruptured fault. So, that estimation requires your time and you have to wait for all aftershocks etcetera, etcetera. So, after accumulating everything you can find out these parameters and once you are getting this parameter, then you can estimate M naught and then you can use that M naught to compute M w. So, it requires time. It is not as quick as Richter scale magnitude estimation.

(Refer Slide Time: 31:00)

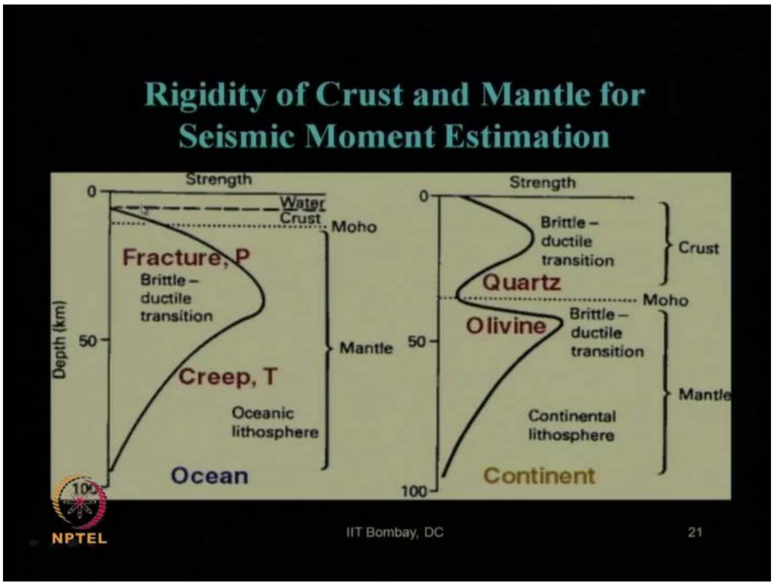


So, we you have understood soon after an earthquake whenever we see any estimation reported anywhere technically or publicly that there is a high probability that or actually it will be a Richter magnitude or local magnitude. The moment magnitude actually will be reported little later once this calculations etc are done properly.

Now, let us discuss further about the seismic moment magnitude. Most magnitude scales, they saturate towards large magnitudes with Mb value of greater than 6. Even M l local magnitude also above 6.7 they start saturating. So, local magnitude of above 6.5 also we have to use it very carefully.

Ms more than eight, the moment magnitude M w which is originally proposed by Kanamori in 1977 represents the true size of that earthquake because it is independent of any kind of magnitude saturation. And it is based on that seismic moment which is in turn proportional to the product of the rupture area and dislocation of an earthquake fault which is actually discussed in detail by Aki in 1966 and Mw is defined using this expression which just now we have seen, actually. This is the same expression that minus 6 or minus 6.05 plus 2 3 of log to the base 10 M naught when M naught is in the unit of Newton meter and M w does not saturate. So, this is the most reliable magnitude for describing the size of an earthquake as also proposed by Scordilis in 2006.

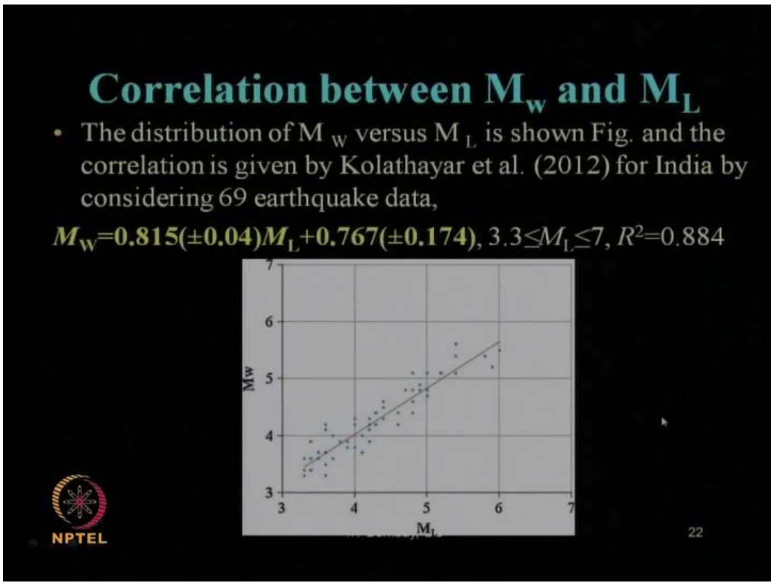
(Refer Slide Time: 33:04)



Now, what we have estimated about the strength of a rock in the crust level and mantle level. So, this shows, this picture shows the rigidity of the crust a d the mantle for that seismic moment estimation for that new value of estimation which is already given a number. So, you can see this is the oceanic crust and this is the continental crust. So, for oceanic crust we have few kilometers of water. Then the oceanic crust then we have the boundary between crust and mantle which is mohorovicic discontinuity then this is the strength variation of the rock. So, in the crust you can have some average value for that estimation and for mantle also you can take average value or even if you know the depth of an earthquake that is the best thing. You can take the exact value of the strength from this picture. That is what I wanted to show.

Even for continental earth crust this is the crustal depth. It varies. You can take an average value and mohorovicic boundary then mantle starts. You can take an average value if the exact depth of an earthquake is not known, but you if you know whether it is a shallow earthquake or deep earthquake.

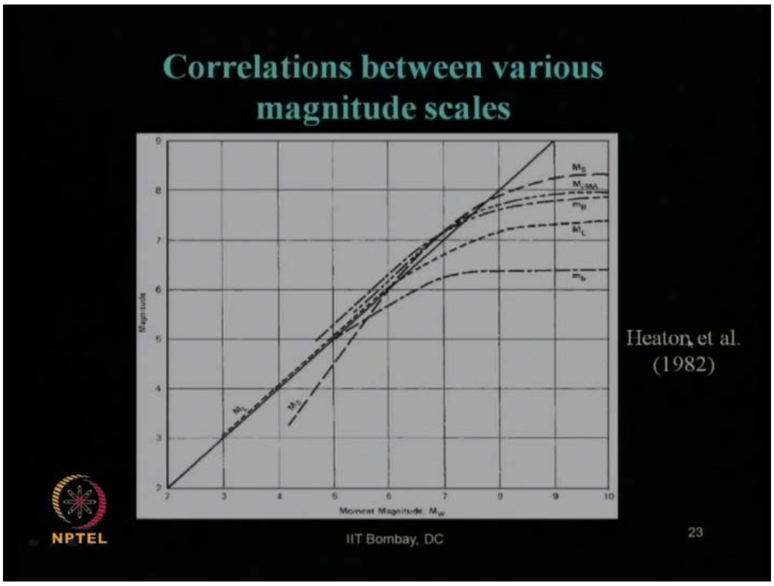
(Refer Slide Time: 34:23)



And a very recent correlation between this Mw that is seismic moment magnitude and the local Richter magnitude Ml is given. The distribution of this Mw versus this Ml is shown in this figure and this correlation is proposed by Kolathayar et al in 2012 for Indian earthquakes. Like they have used 69 earthquake data for all over India so far and proposed this equation or relationship between seismic moment magnitude with respect to the local magnitude.

That means; suppose if we know the local magnitude at a particular location you can calculate the seismic moment magnitude, if you do not have that rigorous information of the seismologic data like value of a d etc. But this is of course, with certain level of confidence. It is not exact. This is an empirical. We have to always remember that with a correlation this coefficient is 0.884 r square value is 0.884. You can see the scatter of the data as they have used between Mw and Ml. And these numbers also can vary within a certain standard deviation. You can see over the variation of the standard deviation of these values and this is applicable when your local magnitude lies between these 2 range 3.3 and 7. That means, beyond 7 and below 3.3 you should not use this equation.

(Refer Slide Time: 36:09)

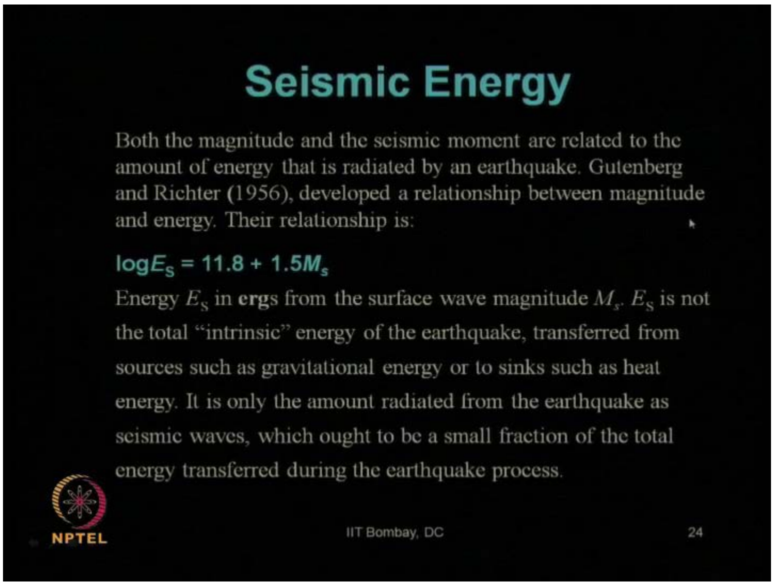


Clear like that many other researchers had proposed various correlations and the best correlation used worldwide is proposed by Heaton et al in 1982. You can see this is showing correlations between various magnitude scales the y axis is in the natural scale of magnitude. That is various magnitudes and x axis is again natural scale in moment magnitude M W. So, with respect to M W why we are so concerned about M w, because later on all our technical calculations engineering calculations will be based on this M W value only if we have any other scale we need to convert those scale to M W that is what it means. So, this dark line shows line of equality.

You can see 2 2 3 3 4 4 5 5 right here 9 9. Now you can see this dotted line shows the local magnitude or Richter magnitude M l which goes here goes here and then saturate you can see over a value of about beyond this 7 or so it tends to saturate right. But once you know this relationship as proposed in this chart; in absence of your computed value of M W you can use this correlation very well for your design purpose. What does it mean? Suppose at a site, say the local earthquake magnitude is reported as 7 that is Richter magnitude is 7. So, now, for your engineering calculation if you have to use Mw what you should do? You should use this curve.

Look at Ml equals to seven. M l equals to 7, is here this is the line 7 right and that corresponds to M w value of typically say about 7.6 or so right little beyond 7.5 as we can see so 7.6 or so. So that is the way you can calculate or use the value of M w for your further engineering calculation. Similarly this is the curve for M s that is M s scale surface wave magnitude scale this is the curve for M v scale. So, M s scale goes like this this large dashes, this goes from here then goes here. This M b goes here this M j may other scales are also reported over here.

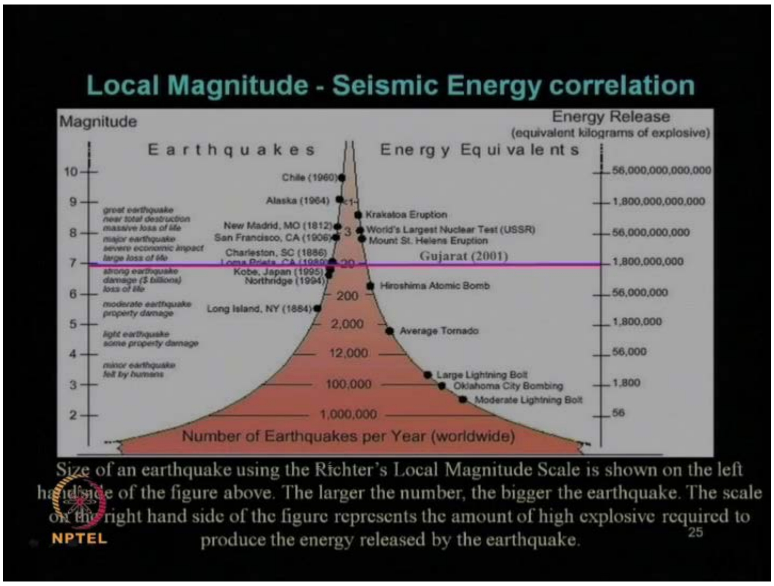
(Refer Slide Time: 38:52)



Coming to seismic energy; how much energy is getting released during that earthquake that also we should estimate. So, both the magnitude and the seismic moment they are related to the amount of energy which is radiated during an earthquake and Gutenberg and Richter in 1956, they developed a relationship between the magnitude and the energy. Their relationship was given by log s equals to 11.8 plus 1.5 M s. M s is surface wave magnitude and Es is the amount of energy released in the unit of r. So, e s is not the total intrinsic energy of the earthquake. It is transferred from sources such as gravitational energy or to sinks such as heat energy. It is only the amount radiated from the earthquake as seismic waves which ought to be a small fraction of the total energy transferred during an earthquake process.

So, what Gutenberg Richter mentioned; if you're using this equation to estimate the energy let us look at the slide. It will show that your energy estimated using this expression is giving only related to the amount of seismic wave or more precisely amount of surface wave only. It is not related to the energy which is lost during the transfer and through the heat energy or sound energy all these losses. So, you are not able to get exact amount of energy which is getting released. You can estimate only a portion of that energy which is getting released during an earthquake. But that is also a good enough estimation which we can now compare through a slide that how much energy released during an earthquake can be comparable with respect to say which is known say blasting activity or bombing activity. How much energy is getting released? Let us try to see this correlation.

(Refer Slide Time: 41:02)



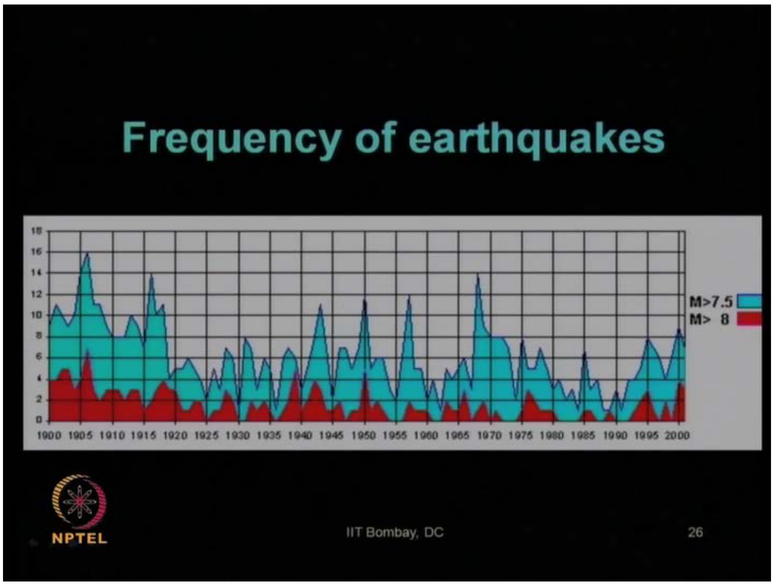
So, this picture shows local magnitude and seismic energy correlation. Size of an earthquake using the Richter's or local magnitude scale is shown on the left hand side. So, this is the magnitude scale in Richter magnitude or local magnitude. And the larger the number the bigger is the earthquake quite obvious. The scale on the right hand side this one shows the figures through which it shows the amount of high explosives which are required to produce same amount of energy which is getting released during that magnitude of earth. That means, if you want to equal amount of energy, you want to equalize, these are the amount of so much of equivalent kilogram of explosive you require to get such a magnitude of earthquake.

So, you can see the numbers, huge numbers and this is the x axis is showing number of earthquakes per year worldwide. So, obviously, large magnitude there will be several thousand’s or hundreds of numbers of earthquake. But very large magnitude say, more than 7 it will be very few number of earthquakes which is obvious result. So, our Gujarat earthquake of 2001 falls here which is equivalent to so much of millions of kilograms of explosives you need to burn to get that much energy released which will give you an earthquake shaking of a magnitude of about 7. So, you can realize how much energy is getting actually released during an earthquake. It is so huge, so devastating that is the reason. So, here people have compared with other known events like Hiroshima atomic bomb or during the second world war, it gives that atomic bomb which totally destructed an entire city that corresponds to earthquake magnitude of little above 6 or above 6.

Then average tornado how much energy is released that is just above little less than even 5 magnitude of earthquake. Anyway, their natures of destructions are different, but this is in terms of energy equivalence when we are talking about. Then various other earthquakes are also informed over here. Northridge earthquake, Kobe earthquake, Loma Prieta earthquake, Chile earthquake of 1960, then Alaska earthquake even the two thousand eleven earthquake of Tohoku Japan, will come at this location which is just about one nine point one or so.

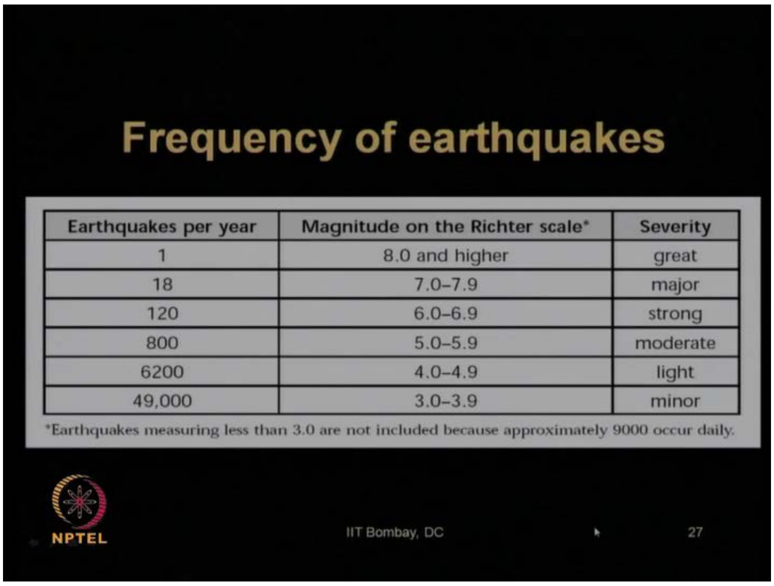
So, these a great earthquake near total destruction of massive life and these are major earthquake with severe loss of life. These are strong earthquakes damage in billions of dollars and loss of life. This 5 to 6 is moderate earthquake with minor property damage and between 4 to 5 is slight earthquake with some property damage. And three to four minor earthquakes which is may be felt by human being. So, that is why as I have already mentioned typically above 4 magnitude of Richter scale probably we should be using for our engineering design or engineering constructions etc. But even that if you see four magnitude of earthquake how much energy is getting released? That is equivalent to like 56,000 of kg of explosive you need to burn to get that amount of energy.

(Refer Slide Time: 45:07)



This shows the frequency of that earthquake worldwide, this red colors are magnitude more than 8, this is from 100 years record 1900 to 2000. So, this red color is the number of this y axes strength frequency means number of earthquakes. So, how many number of earthquake of more than 8 occurred. So, beyond 2000 if we plot up to this 2012 again you see there are many more such red color number of earthquake which has occurred during the last ten, thirteen years and more than 7.5 there are so many of course, So, these are the very major earthquake or strong earthquake which can cause easily severe damage to the mankind and property loss.

(Refer Slide Time: 46:04)



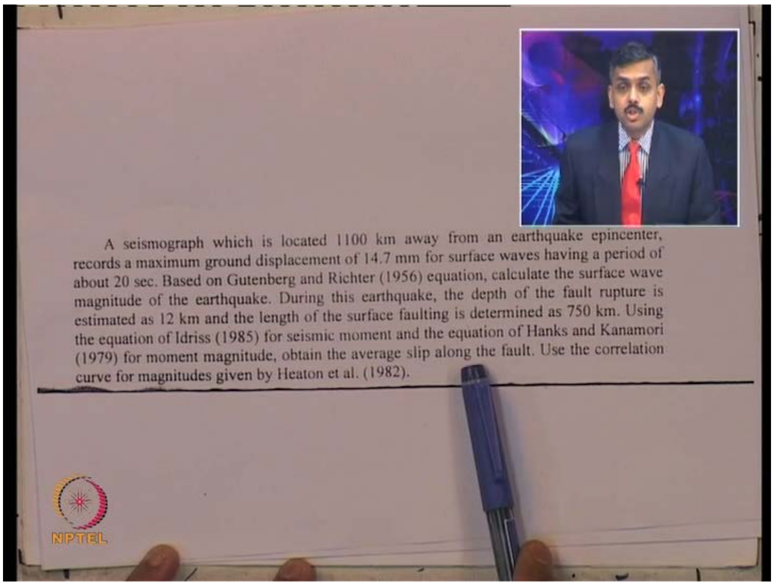
Earthquakes per year	Magnitude on the Richter scale*	Severity
1	8.0 and higher	great
18	7.0–7.9	major
120	6.0–6.9	strong
800	5.0–5.9	moderate
6200	4.0–4.9	light
49,000	3.0–3.9	minor

*Earthquakes measuring less than 3.0 are not included because approximately 9000 occur daily.

And this shows the frequency of earthquake like earthquakes typically. These are typical values of course, per year about one worldwide will occur which is having a magnitude of Richter scale of 8 and higher and severity can be considered as great earthquake. About 18 or so between 7 to 7.9 major earthquake. Above 120 or so between 6 to 6.9 strong earthquakes, above 800 or so between 5 to 5.9, which are called moderate earthquakes? Above 6200 or so between 4 to 4 point which are light earthquakes and above 49,000 or 50,000 or so between 3 to 3.9 which are minor earthquakes and below 3 there are several 10’s of 1000’s of which occur worldwide.

That means, if you take an average every now and then and everyday some part of the earth they might be having on an average some earthquake which are having magnitude less than 3 which we do not bother about.

(Refer Slide Time: 47:31)

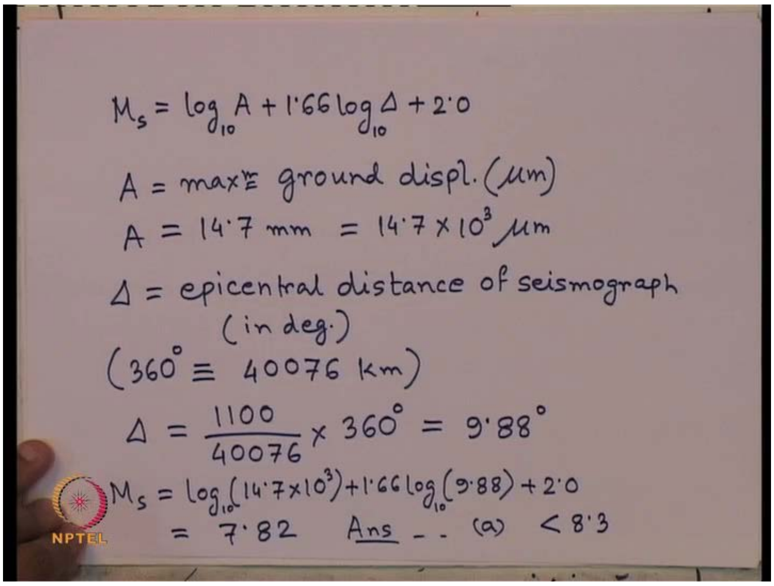


Now, let us do one example problem on this size of magnitude, on this, see the problem statement over here. This problem says a seismograph which is located 1100 kilometers away from an earthquake epicenter. It records a maximum ground displacement of 14.7 millimeters for surface waves having a period of about 20 seconds. So, based on Gutenberg and Richter 1956 equation; which we have discussed just now calculate the surface wave magnitude of the earthquake. It is asking to calculate the surface wave magnitude using Gutenberg Richter equation for the given data. Now, what is the next part?

It says during this earthquake the depth of the fault rupture is estimated as 12 kilometer and the length of the surface of the faulting is determined as 750 kilometer. So, these are the fault dimensions after earthquake which is measured length and surface faulting using the equation of Idriss 1985 for seismic moment and the equation of the hanks and Kanamori of 1979 for moment magnitude obtain the average amount of slip by which the fault has moved or the fault has experienced. That is this is the other way round. See it is asking how much will be the amount of fault slip or movement which should be recorded or will be experienced for an earthquake of such magnitude.

So, use the correlation curve for magnitude given by Heaton et al in 1982. So, let us see how we solve this problem. So, the first statement or first equation which we have to use the Gutenberg Richter equation for surface wave magnitude.

(Refer Slide Time: 49:44)



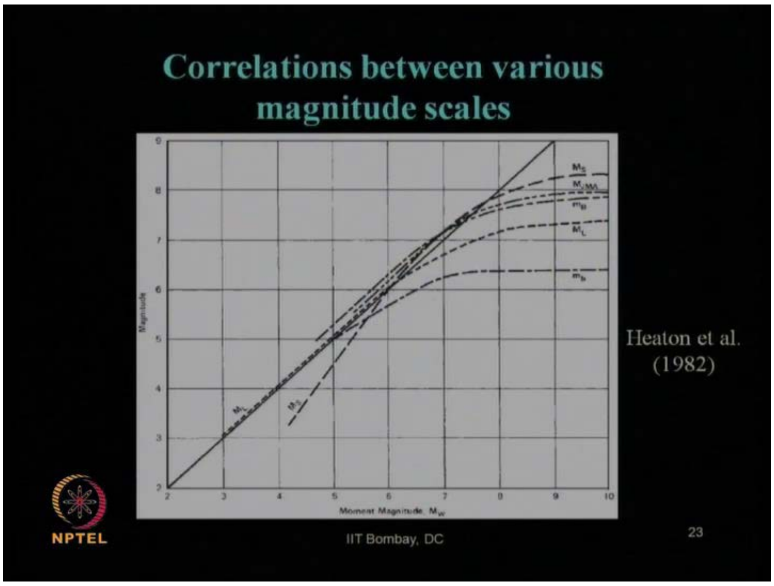
So, that equation as we have seen let us go back to the slide here. If we go back to the slide here for the surface wave magnitude this Gutenberg Richter equation of 1956; this is the equation which we should use. M is log to the base ten a plus 1.66 log to the base 10 delta plus the numeric value 2. Now, in this case what is the value of A? A is the maximum maximum ground displacement ground displacement in the unit of micrometer not millimeter. So, this value is given to us as a is given as fourteen point seven millimeter which is nothing but 14.7 into 10 to the power 3 micrometer and what is delta?

Delta is epicentral distance of the seismograph. So, this is in degree unit. Now, we know 360 degree of earth equivalent to the distance of 40076. So, much of kilometer for us that is those who are from IIT Mumbai or IIT Bombay it is easy to remember it is similar to our pin code except 1 0. So, for our IIT Bombay pin code is Powai pin code 40076 Mumbai. Say it is 40076.

Now, delta will be for our given case what is the distance given it is 1100 kilometer. So, that kilometer is equivalent to how much degree we need to find out. So, this into 360 degree; So, it is coming about 9.88 degree. So, that should be in degree unit. We have converted it into degree unit. Now, let us use this equation Ms. You put all these values log of fourteen point seven into ten to the power three plus 1.66 log of 9.88 plus 2.

So, this is to the base 10, to the base 10. This value if you compute it gives us the value of 7.82. So, that is the answer of first part of the question. That is what the surface wave magnitude of this earthquake? So, this is the surface wave magnitude of this earthquake 7.82. And remember it is below that value of 8.3. So, we can easily convert it to another scale there is absolutely no problem because that magnitude saturation problem or limitation is not valid for this range.

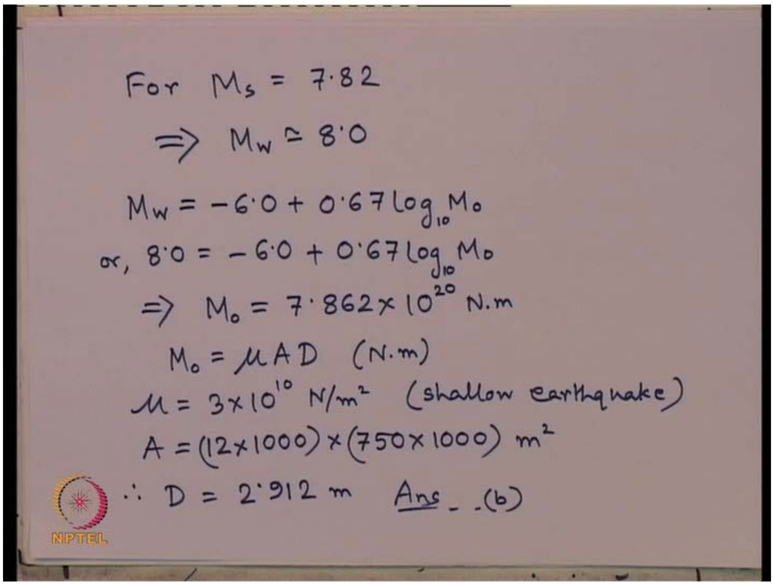
(Refer Slide Time: 53:56)



So, let us see what we can do further. So, for this conversion I need to go to the slide over here. Let us look at the slide here which is given by Heaton et al. That is what it is asked. Use this slide to convert your Ms scale to Mw scale because then only we can estimate the moment seismic moment. Am I right?

So, using this chart what we can say Ms value of 7.82. So, let us follow this line from this curve 7.82 is somewhere here right, somewhere here. So, we can say 7.82 of Ms can be taken as Mw value of equals to 8. Am I right? From this correlation look at here this is little below 8. So, 7.82 can be here is it clear any doubt, so this equivalent to Mw of 8. Clear?

(Refer Slide Time: 55:07)



So, using this relation for M s value of 7.82, we can infer that M w can be at about equals to 8.0. Now, if somebody wants to calculate this exactly; either you can use a scale to estimate it properly or you can use some other correlations between Ms and Mw, as I have discussed in the lecture in the similar way.

Now, what is the expression next we need to use? The hanks and Kanamori's expression of 1979. So, let us go back in this slide now. So, this is Hanks and Kanamori's expression of 1979 for M w with respect to M naught in Newton meter unit. So, Mw equals to minus 6.0 plus 0.67 log to the base 10 M naught.

M naught will be in Newton meter unit. So, we can put this value of 8 minus 6.0 plus 0.67 log to the base 10 M naught will give us, the value of seismic moment M naught as 7.862 into 10 to the power 20, so much of Newton meter because that is the unit in this equation right. So, if that is the unit; now what is the expression for M naught as given by seed and Idriss? Let us look at the slide once again. So, M naught equals to mu A D in Newton meter and value of mu is shear modulus in Newton per meter square 3 into 10 to the power 10 for surface crust and this is the shallow earthquake. It is mentioned in the problem statement. So, M naught is mu A D.

Let us calculate over here. Let us calculate in this page. So, this is in Newton meter unit. Mu naught M naught equals to mu A D, where mu is known to be 3 into 10 to the power 10 Newton per meter square for shallow earthquake, and A is the fault area in meter square. So, what is the fault area in meter square? Let us see A, we can compute from the given data was 12 kilometer, we have to convert it into meter and 750 kilometer we have to again convert it into meter. So, so much of meter square is the area fine; that the length and rupture distance of the fault.

Now, we have to calculate this D that amount of slip. So, therefore, putting this value in this equation you can get D is coming out to be 2.912 meter. That is the answer of part b or the last part. That is this is the amount of slip by which the fault will rupture or two plates of the fault will move with respect to each other 2.912 meter fine. So, with this we have come to the end of today's lecture, we will continue further in the next lecture.