Earth Sciences for Civi l Engineering
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Module 4
Lecture No 16
Seismology and the internal structure of the Earth (Part-04)

Welcome back. So we last lecture, we talked about the seismic waves and most important part which we discussed was the frequency of seismic waves.

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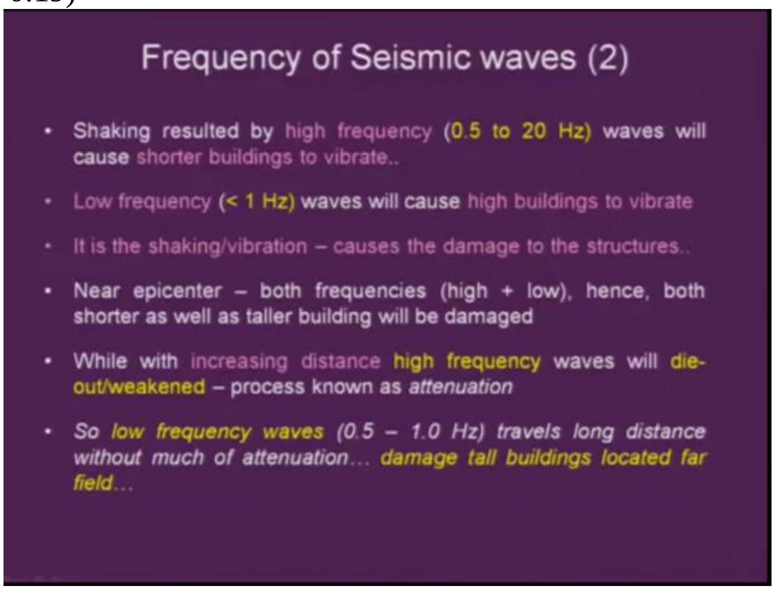

Different type of frequencies are generated during an earthquake. So basically the body waves have the higher frequency waves ranging from 0.5 to 20 Hz whereas the surface waves are low-frequency waves having the frequencies which are less than 1.0 Hz. So the higher frequency waves dies out very faster. And the low-frequency waves will travel far distance. So that what we were talking about that the shaking will result by high-frequency waves if you are having will cause shorter buildings to vibrate and the low-frequency waves will cause higher buildings to vibrate.

So if it if it is this shaking, vibration caused, that usually is been important because that will cause the damage to the main civil structures and all that. So this is important that near epicentre, both of the frequency because high and low frequencies will be generated and both types of buildings like taller and shorter buildings will be are expected to will be expected to damage.

Whereas the increase in distance, the high-frequency waves as we were talking about that they will die out. So it will not affect the shorter buildings. But taller buildings because the low-frequency waves will have tendency to travel far distance will damage the taller buildings also. So this was the last part which we discussed. Now the another part which is important of the seismic interior or the earthquake related portion is the magnitude.

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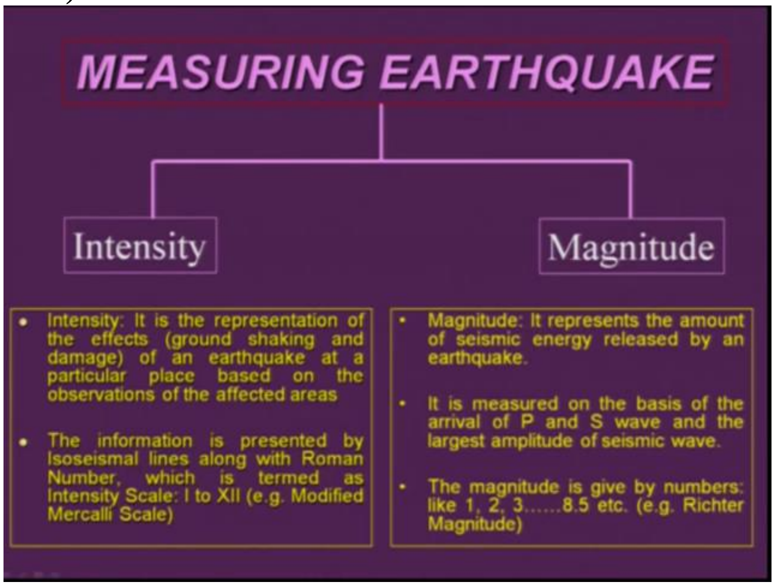

So we will talk about very quickly about the different types of magnitude scales and all that. And what are the other methods which are available to measure the earthquake. So in short, we have 2 types of methods which are available. And the intensity scale and then we are having so basically intensity is the representation of the ground shaking and the related damage at the particular area.

So during an earthquake, you will have the damage which will be seen or experienced by an area. So depending on the damage how it varies from the epicentral if you move away from the epicentral area depending on that this intensity maps are generated. And they are represented mainly in form of like intensity scale in Roman letters mainly from 1 to 12.

So this is what this is one of the scale which is known as modified mercalli scale or MMS scale is there. So here, everything is based on the effects, the nature of damage and all that. Whereas the magnitude where, is representation of the amount of seismic energy released during an earthquake.

And this has an representation again we have very briefly we discuss about this that how we can measure the earthquake if you are having the arrival of P and S waves and the amplitude of P and S waves. If you are having that, so based on that, you can talk about the magnitude, what is the magnitude of that. The representation of this is given in numbers from 1 to like up to 9.5.

The largest magnitude earthquake recorded after having the instrumentation and all that or recorded until now in the history of Earth is 9.5 magnitude. Beyond that, we have not recorded such a large magnitude earthquake. And that 9.5 magnitude earthquake was the Chilean earthquake of 1960. So the main difference if you look at, so the intensity is representation of the effect, that is the ground shaking and damage related.

And magnitude is the representation of the amount of seismic energy released by an earthquake. And the other point which is the difference between the intensity and the magnitude scale is that the intensity scale is represented in Roman letters from 1 to 12 and again the magnitude scale is also from 1 to 10. But this is in numbers. This is 1, 2, 3, 4, like that.

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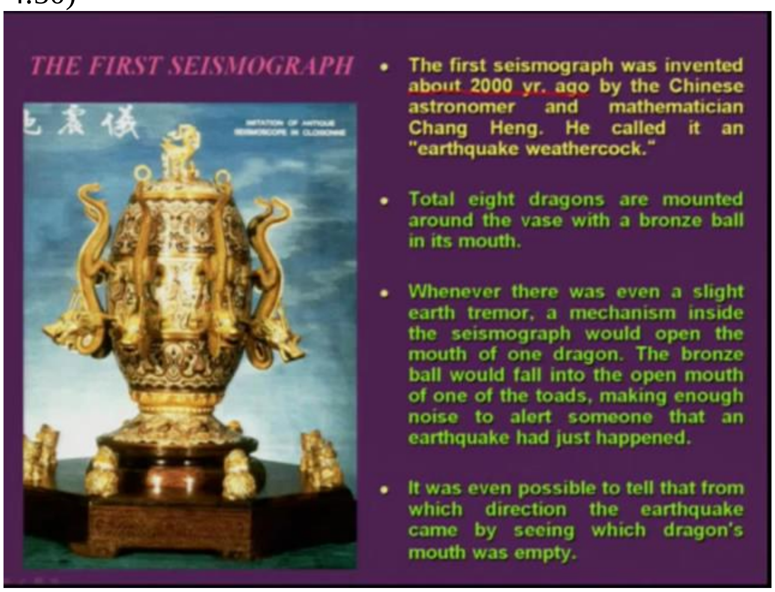

So if you go back into the history of the development because earlier we never had instruments to measure the energy which was being released at the time of an earthquake, so the 1st seismograph which came in was been invented by Chinese almost like 2000 years back and that was been termed as earthquake weathercock.

So what it comprise of was that it was an very beautiful you can see here it is a very beautiful vase and then you are having some 8 toads which are sitting at the base of the vase. So total like 8 Dragons. These are the Dragons here and you are having at the same time you are having also the toads which are sitting down. So you are having almost like 8 Dragons are mounted around the vase and with a bronze ball in the mouth of the Dragon.

So each Dragon will have a bronze ball in its mouth. And then whenever there is a shaking of the ground then the bronze ball will fell into the mouth of the toads which are sitting here with an open mouth. So that will help.

So whenever there is there was even a slight shaking or the earth tremors, a mechanism inside this seismograph this is what they call the weathercock would open the mouth of one of the Dragon and the bronze ball would fall into the open mouth of the toads which are sitting down here making enough noise.

So when the ball passes through the mouth of the Dragon and fall it will make a very typical noise to alert someone that the earthquake had happened. So this is one of the very typical way to identify the earthquake that weather the earthquake has occurred or not in that area. So this was invented almost like 2000 years back. So later on, a lot many other scales came up and we will see the chronology of intensity scale and all that 1st and then get into the magnitude scale .

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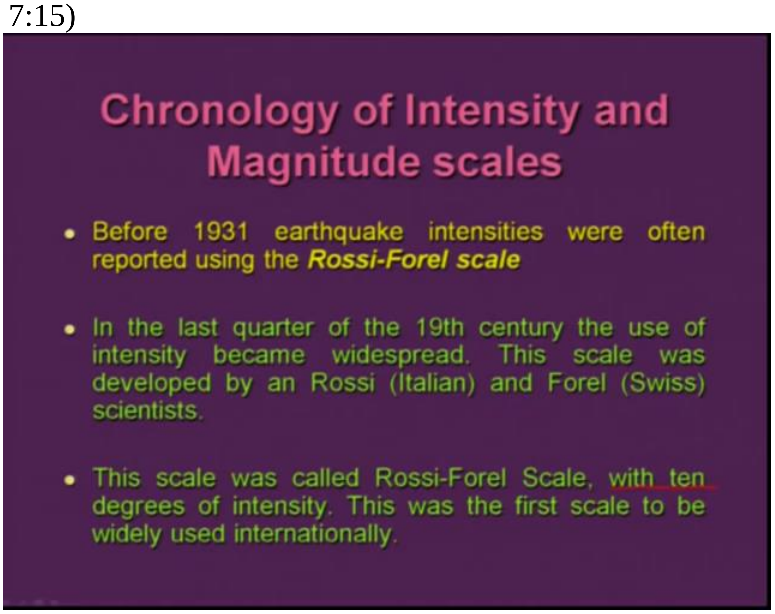

So before 1931 earthquake intensity were often reported using the Rossi-Forel scale. And this scale was like and the last quarter again it was in the 19^{th} century, the use of the intensity scale became very widespread. And this was basically dependent on the damage part and all that. This scale was been known as because it was been modified by both developed and modified later on.

Then it was been known as the Rossi-Forel scale. Now the most important part was that this came with the with the ten folds so 10 degree of intensity scale was given. So if you take this, that was 1 to 10 it was been given. So this was until or or you can say before 1931, the earth quake intensity scale was there

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Then it was so this is if you look at what it says, I will not go into the detail of this. You can read out later on but I said like for example, the intensity 1 means the micro shock recorded by either it is recorded by single seismograph. If you have the instrument, still because still you can use and still we are using the intensity scale even though we are having the magnitude scale. So it says that it will be recorded by a single seismograph or of the same model the shock felt by an experienced observer.

So if you are extremely experienced to understand that whether the shaking was related to some earthquake or something else, then you will be able to make out that this was an earthquake with an intensity of 1. Intensity 2 is saysis a extremely feelable shock and then intensity very very feelable shock. So, few people will be able to judge that there was some ground shaking. Then 4 is feelable shock.

Then you can say shock of moderate intensity of 5. So felt by everyone. So so intensity 5 earthquake will be felt by everyone and you will have disturbance of the furniture, breads and all that and ringing of some bells. Ringing of bells is like either we in India we say, the bells in the temple and all that or in the church we are having the bells. So those bells will ring because there will be a motion of the surface.

Fairly strong, that is 6, so on. So we are having like up to you can say it goes up to 10. So you are having 10 intensity shock of extreme intensity it says. Great disaster, ruins. So most of the total damage will take place and it says the fissures in ground. So land will have cracks which will be developed and in the hilly areas, there will be a massive rock falls and all that.

So this is how the intensity is been described. So you you have this set of intensity scale. So locally you people visit or the seismologists visit the to collect the ground truth and then they assign that which area had what particular intensity during the time of an earthquake.

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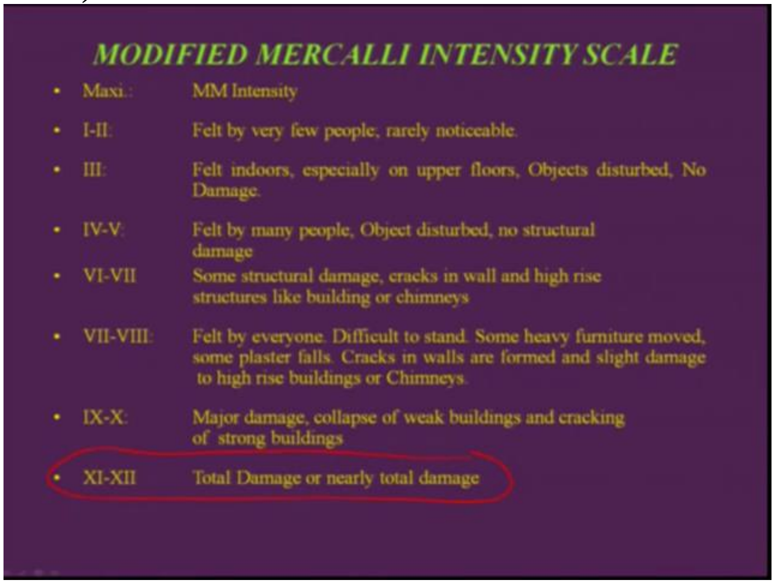

Further next phase came in, the scale was improved by Mercalli who published a modified version still with the ten folds. So still we got the intensity scale of ten fold. However, even this ten degree were insufficient for expressing the whole range of effects. So the extension of scale came up within twelve degrees. So earlier it was ten. Now it was been given by Cancani.

This he he they suggested that they the more refined scale and the reason was to express the whole range of damage. So that was been given with a twelve scale. Then this scale was been named as modified Mercalli. So the 1st was Rossi-Forel. Then came the Mercalli scale and the Mercalli scale was been modified by him and then this was being termed as modified Mercalli scale with twelve degrees of the twelve degrees scale it came.

So intensity as we were talking about that it measures the it is the representation of the effects of the damage in a particular area.

So modified Mercalli scale if you look at, it is also like mm scale. So it has been bracketed 1 to 2 intensity felt by very few people, rarely noticeable, 3 felt indoor. Objects were disturbed, no damage. Then 4 to 5 we are having like 4 to 5 we are having felt by many people, object were disturbed but still no structural damage will be seen. And then some structural damage that is from 6 to 7 we are having damage little bit will be seen.

And here if you carefully look at, then it says that the cracks involved high-rise structures like buildings and chimneys. So this will be seen mostly. Then 7 to 8, felt by everyone, difficult to stand. So even so how you basically we have we try to know that whether this was whether this happened or not. So the seismologists or the geologists when visit the area affected area after the earthquake, they will also interview the people, the survivors.

And they try to understand that what type of shaking they felt and what type of damage they will record, the damage that occurred during an earthquake. So based on this, they will prepare an intensity map. I will come to that how the intensity maps are been prepared. Then you come to 9 to 10, major damage. Collapse of weak buildings and cracks of strong buildings.

So this is one and then coming to 11 to 12, total damage or nearly total damage. So this will finish most of the area in terms of the damage. So this is an very probably related to large magnitude earthquakes we talk about.

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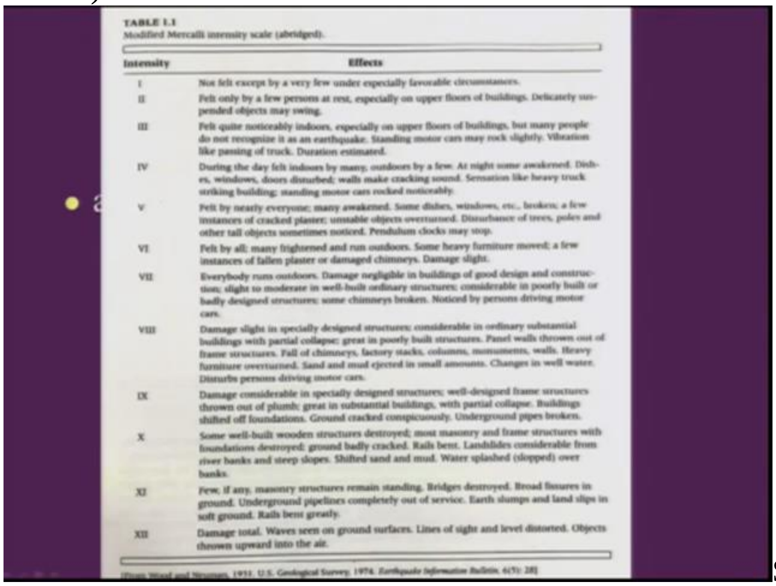

TABLE 1.1
Modified Mercalli intensity scale (abridged).

Intensity	Effects
I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
IV	During the day felt indoors by many, outdoors by a few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building; standing motor cars rocked noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbs persons driving motor cars.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures with foundations destroyed; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
XI	Few, if any, masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

[illegible] 1931. U.S. Geological Survey, 1974. *Earthquake Information Bulletin*, 6(5): 28]

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So these are the intensity scales and this is another like with the greater description given by USGS and it was been given in 1974 this scale which is again it shows up to twelve and with greater description you are having. So you can go through this and then try to understand that what type of descriptions are given. Of course it is a bit difficult to remember everything but you can look and look at the different type of descriptions which are then given related to the respective intensity.

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Now that this is an example of the 1905. This is one of the massive earthquakes in India. 20,000 people were been killed at that time in 1905. And this earthquake was of magnitude 7.8 and termed as or known as Kangra earthquake. This occurred in Kangra Valley and it killed almost like 20,000 people during that period. Now if similar magnitude earthquake occurs in present conditions, then maybe more than 1 lakh or 1, 50,000 people will be killed in the Valley because the population has gone so up.

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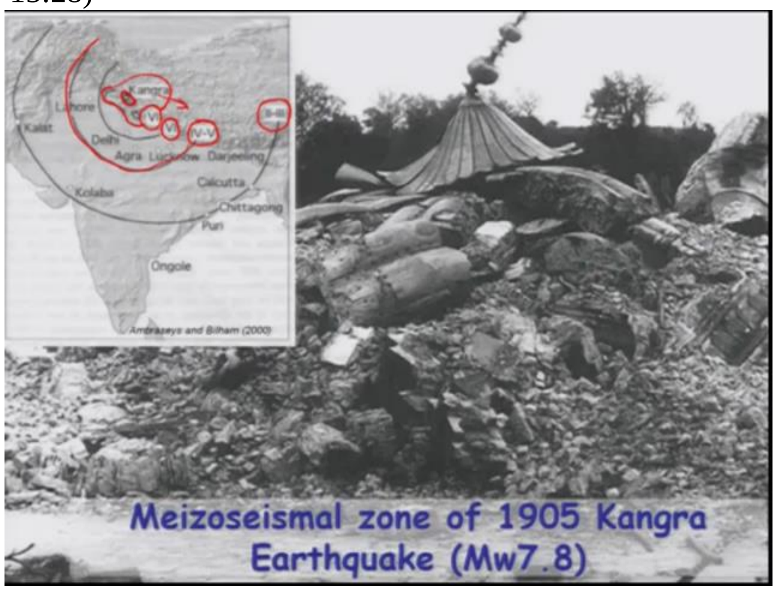

So this was what it shows here if you can look at carefully, these all lines are are having the some some numbers which are given here in Roman letters. So you have this one here and this corresponds to this one here you have. And then you are having higher intensity at Kangra. And then it goes to like so this was again it was 6. Then you are having around it reduces to 4 to 5 and then further it reduces to 2 to 3.

So as you are moving away, this is the this was the epicentral area. So as you are moving away from the epicentral area, you see that this intensity reduces. That means the damage also reduces away from that. So if you look at this one, this earthquake was felt almost in half of the Indian subcontinent region.

So this is what is the intensity scale and then this what we are looking are termed as isoseismals. So this indicates that all this region along this one had almost similar type of damage which they experience. So you can see that. So these are termed as isoseismals. This is very much similar to the conduits which we see the topography topographical heights but this is not the topographic height but these are the based on the similar pattern of damage which was experienced along this region.

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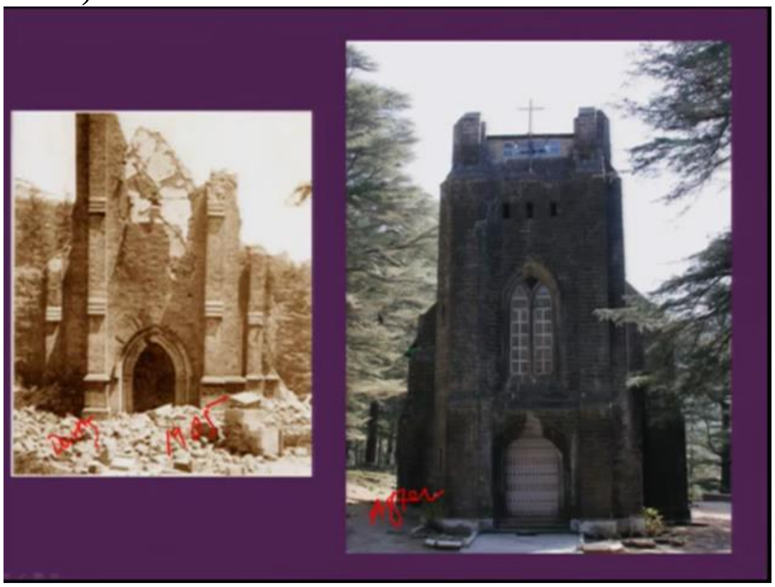

So this is an example the photograph which has been shown. So this was the damage to the church by 1905 Kangra event. And this is so this is during the earthquake and this is after. So after it has been constructed, you can compare these both the pictures which (inaudible 17:43). This is in Kangra area close to Dharamshala.

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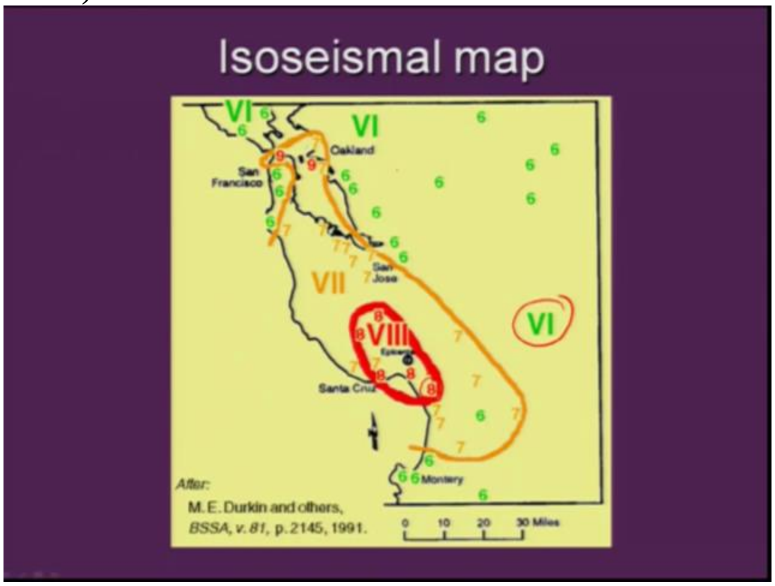

So isoseismal map as we discussed in this the previous slide, so you have like these are the numbers which have been given but when final map is been represented, it will be given with the with the Roman letters. So this is the epicentral area which has been marked here with the red. So it has an intensity of 8 but as you move away from this, it has an intensity which reduces to 7 and 7 to 6. So this is what happened.

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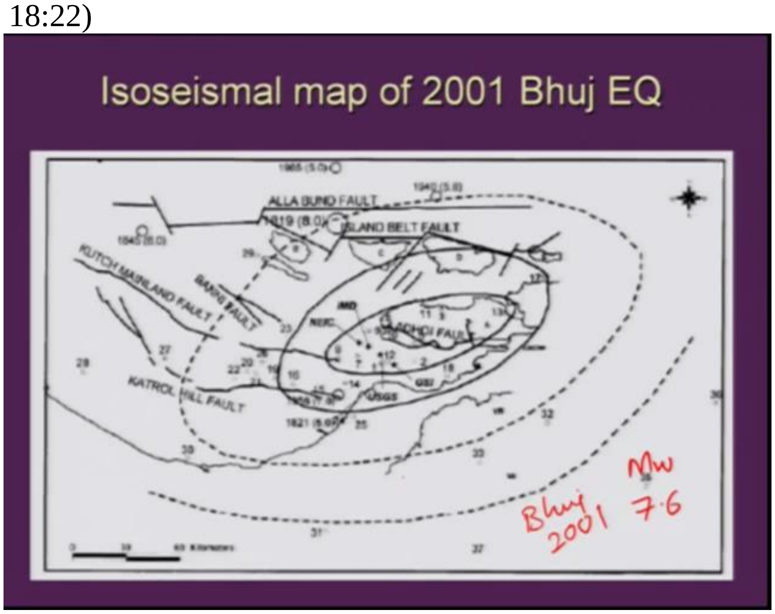

And this is the intensity map, we are looking at the isoseismals of Bhuj earthquake. Bhuj 2001 earthquake. This again, it was 7.6 MW 7.6. So you can look at the maximum intensity was here and then it slowly if you move away from this it reduced. So this is an isoseismal of 2001 Bhuj earthquake.

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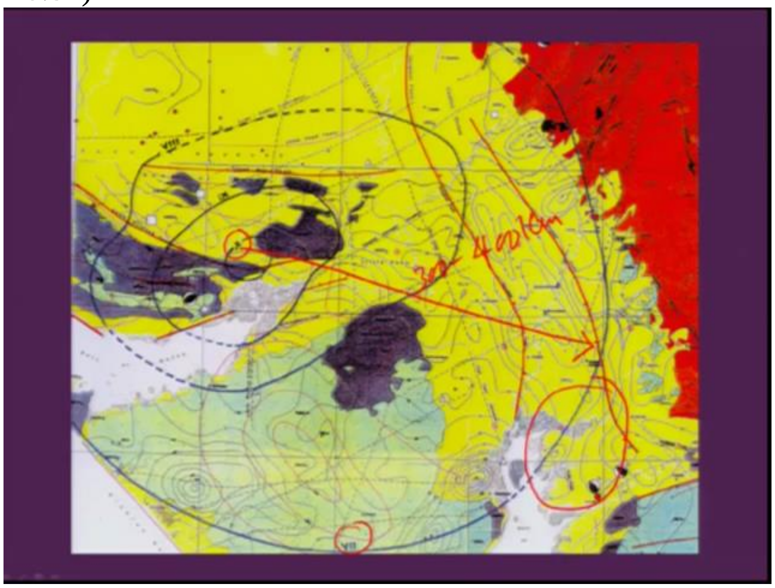

This is the same again. So this was an epicentral area which shows that the intensity was almost like 10 and then it reduced to 8 and further away, faraway almost like this the distance from here to this was almost like 300 to 300 to 400 km. So the intensity here was almost like 7 which is comparatively very high. So 7, definitely it affected and it resulted into a massive damage in this region.

That is in Ahmedabad region also they experienced and in Surat also they experienced but Ahmedabad was been affected much more as compared to the other areas in this alluvial plain of Gujarat. So 300 to 400 km away also it affected the region. So the intensity of 2001 Bhuj earthquake was almost 10 in the epicentral area.

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This is an epicentral, the isoseismal map or or the contours, isoseismal contours which are been shown for 2005, Muzaffarabad earthquake of 2005 your Kashmir earthquake. So again the intensity which came up to Patiala, Ambala or Amritsar was or close to Delhi was around 4. So the intensity was slowly it reduced like that.

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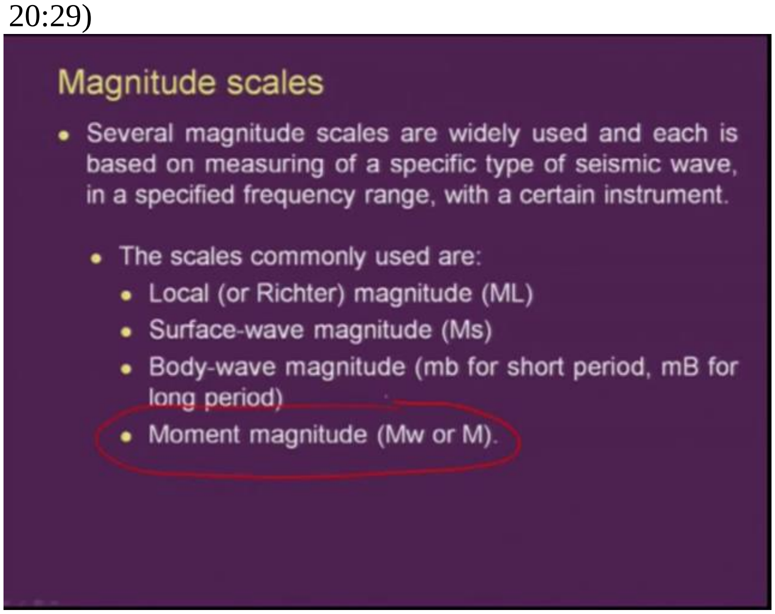

So magnitude scale if you look at, then several magnitude scales are widely used and each is based on the measuring of specific type of seismic waves. So either you are because if you remember, we have different type of seismic waves. We have body waves, P and S waves. We have the surface waves, love and rayleigh waves. So depending on that what type of seismic waves are been measured, the different magnitude scales were been generated and used.

Now the 1st scale which was been extensively used earlier was the Richter scale, Richter magnitude scale which is also termed as local magnitude. And it is denoted as ML. And then came the surface wave magnitude which is given as Ms. then body wave magnitude, MB and then you are having the moment magnitude, MW. So this moment magnitude is now the most widely used scale amongst the magnitude scales.

But still to some extent, people have been using the Richter magnitude also. But this is very effective only up to 100 km. Beyond 100 km, that is if the seismograph is located or the earthquake occurs within the within that region where the seismograph is located within 100 km, then this is more effective. Otherwise it will not be effective as compared to the other other scales.

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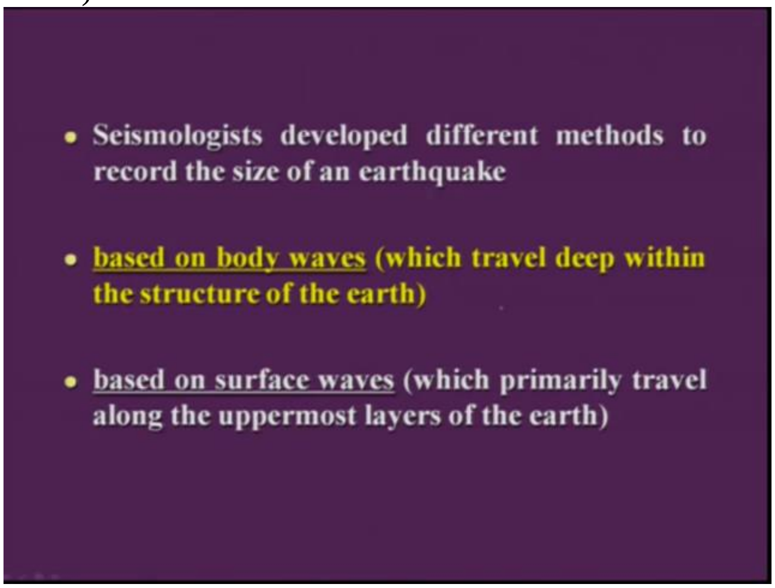

Then seismologists developed different methods to record the size of an earthquake and based on the body waves which travels deeper within the Earth’s structure, he came up with the body wave magnitude. And based on the surface wave they which primarily travels along the uppermost part of the Earth and they developed on the scales.

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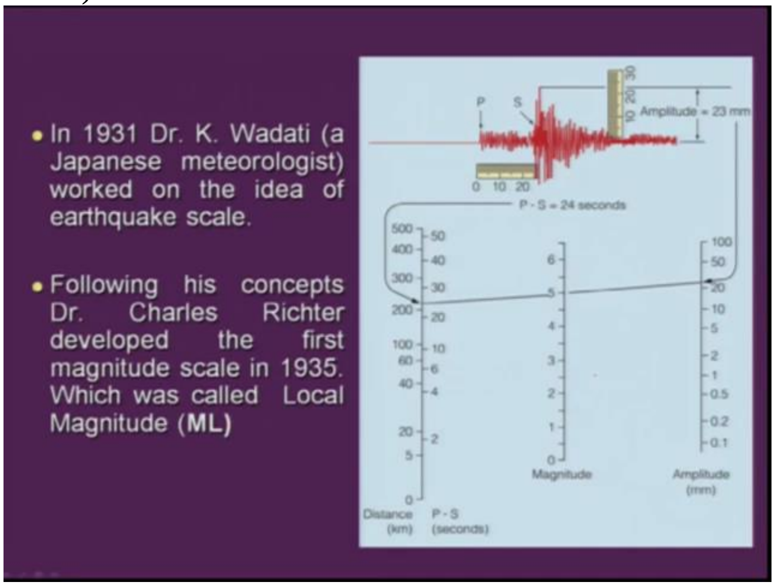

Now this is just to show that we have already discussed this part. This is the ML, local magnitude scale. How in the previous lecture also we were talking about that if you are having the amplitude here and then from this 0 line you are having the amplitude and then you are having the arrival of the P and S waves. On the logarithmic scale you can have the what is the magnitude you can make out.

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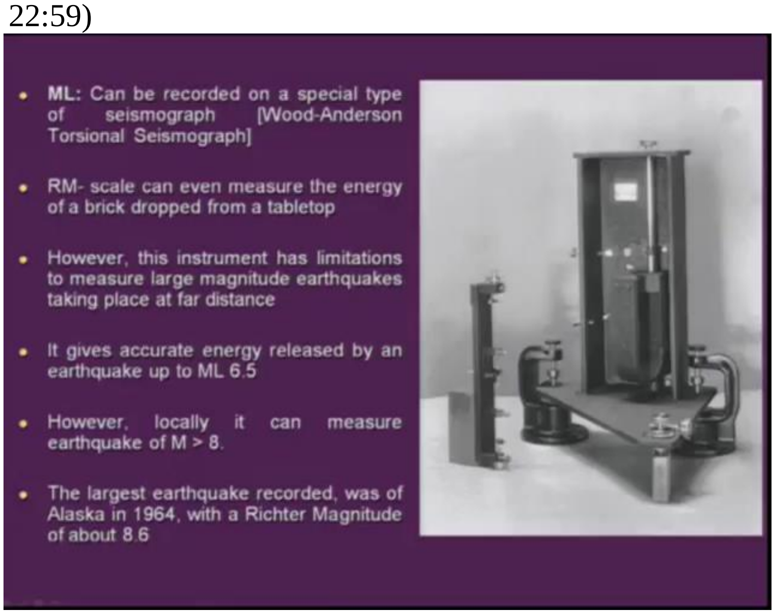

So local magnitude can be recorded using the instrument which is known as or or or was known as Wood Anderson torsional seismograph. So this instrument has limitations. This is what we are talking about that it can only measure the local magnitude are occurring up to 100 km. So it has a limitation to measure the large magnitude earthquakes. And large magnitude earthquakes when we are talking about, greater than 6.5 or greater than 7.5 or so.

So when large magnitude earthquakes taking place at far distance. So if they are distant earthquakes, then this instrument has limitation to record it. It gives very precise or accurate energy released by an earthquake up to 6.5 magnitude. However locally it can measure the earthquake of greater than 8 magnitude. But if the distance is more than 100 km or so it will underestimate the magnitude.

So the largest earthquake recorded was of 1964 Alaska. On Richter scale, it was measured as 8.1 but it is greater than 9 magnitude earthquake.

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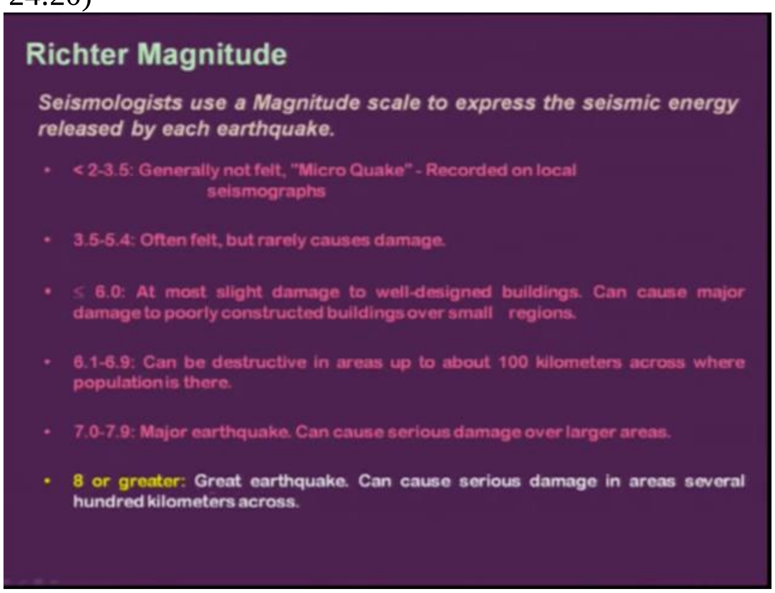

So this is what we have then the Richter magnitude scale. Seismologists use magnitude scale to express the seismic energy released by each earthquake. So if you look at the Richter magnitude, it says less than 1 less than sorry 2 to 3.5 then it is generally what we consider this as an micro earthquake. So it will be recorded by the local seismographs and then you are having the magnitude ranging 3.5 to 5.4 or so than often felt but rarely cause any damage.

So it is very much similar to that the scale which we are talking about the intensity. But this is in terms of the magnitude. So less than or equal to 6 most slight damage and the most slight damage will be seen to well-designed buildings. Then 6 to 6.9 can be destructive in the area up to about 100 km or so. And then 7 to 7.9, major earthquake, can cause serious damage over the large areas.

And then 8 or greater, then we can we term that as great earthquakes. So in Himalaya basically what we see the earthquake or we observed the earthquake in 20th-century were all great earthquakes.

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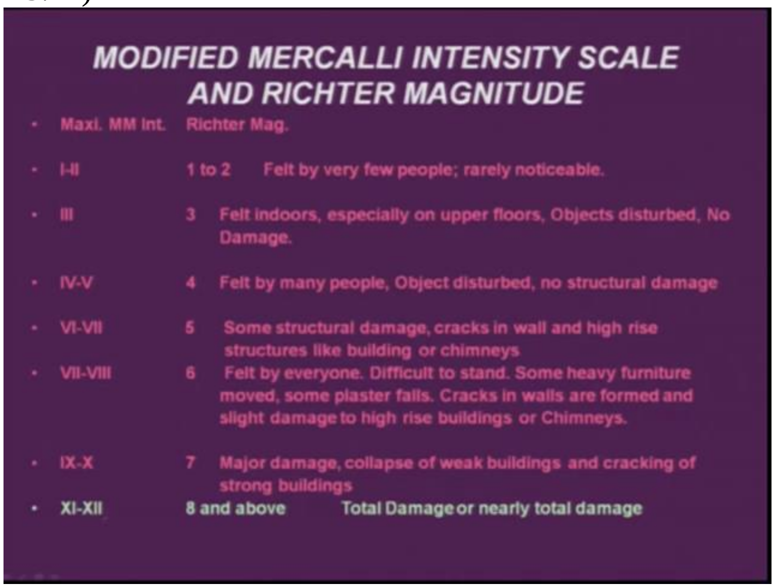

So Modified Mercalli intensity scale and the comparison I will just quickly more head here and then you can look at and compare that there is an intensity scale here and the and the magnitude scale here which has been given and then comparative descriptions are been given for respective bracketing intensity and the magnitude here. So this is what if you have an intensity of 11 to 12, then you are having total damage or nearly total damage area.

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So these are the seismographs which are been shown at USGS where you can see this these marks, small small marks here, they are all the events which are been recorded. So this is the seismogram which keeps on recording the events. So even the smaller events were been are been recorded here. So continuous monitoring is done of the earthquakes which are occurring. So this is the same close up picture of that one.

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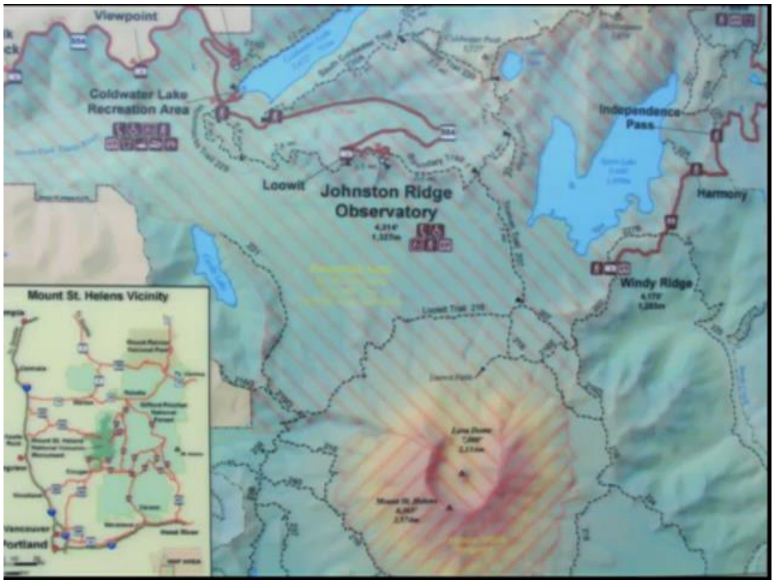

And as we discussed during when we were talking about the igneous rocks, this is an the seismogram which is (())(26:52) from the Johnston Ridge Observatory at Mount St St Mount Helens.

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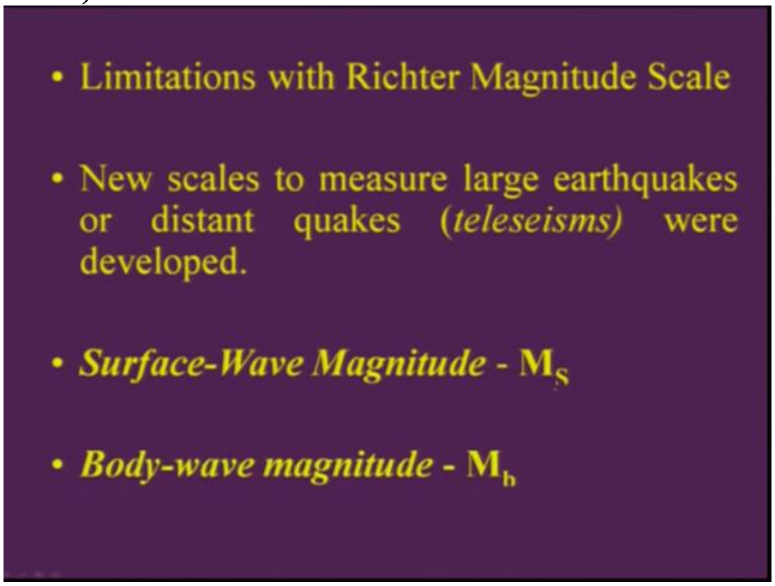

Now limitations with the Richter scale were there and then that was the reason that new scales to measure large magnitude earthquake because if you have large magnitude distant earthquake, then the Richter scale will get saturated or the instant which is measuring, the Richter scale magnitude was not enough. So new scales to measure the large magnitude earthquake or the distant earthquake teleseismic what we call the far distant earthquake were developed. And the 1st which the magnitude scale which came up after the Richter scale was the surface-wave magnitude denoted by MS. And then the body wave magnitude, MB.

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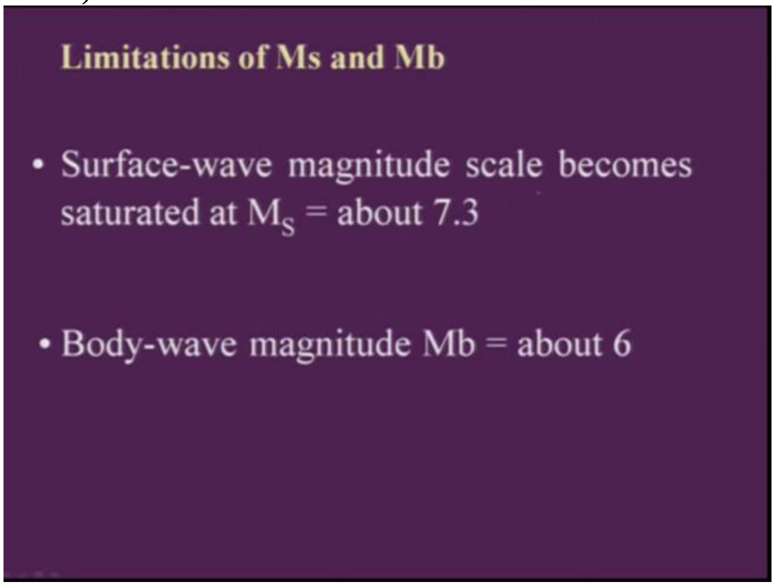

Now limitation again was there which was been observed with MS and MB scale. So surface wave magnitude like if you local may magnitude we were talking about that it became saturated but 6.5 but this was the surface wave magnitude scale will become saturated at around M is almost like equal to 7.3 or so. And the body wave again about 6. So this again had limitations, both of the scales.

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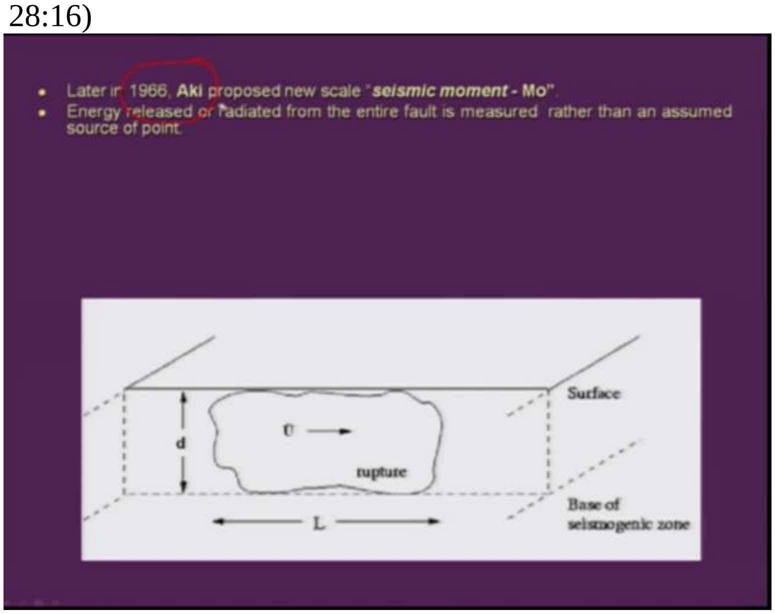

So so the new scale which was been developed and it was thought that why not to take the overall deformation pattern or the energy which is been released along the fault plane completely. And if you remember, we were talking about that along with the main shock, there will be small magnitude or micro earthquakes which will occur after the event which are termed as after-shocks and those after-shocks are also taken into consideration to calculate the magnitude or calculate the rupture area also.

So that is been given here. So you are having the length of the rupture, you are having the depth of the rupture. And then in short, you are having the slip of of of of of the rupture. So how much slip occurred along the fault? How much what was the length and what was the depth? So if you are having these parameters one can easily calculate the magnitude which was newly developed.

So Aki in 1966, he proposed a new scale which was been termed as seismic moment. And then energy released what exactly you look at here is the energy released or radiated from the entire fault is measured rather than assumed source. So anyways, we will discuss this in the next lecture. I will stop here. Thank you so much.