Introduction to Engineering Seismology
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Lecture – 58
Seismicity Hazard Analysis-Seismic Study Area and Seismotectonic Map

So vanakkam. So we will continue our lecture on Engineering Seismology. So last class, we have introduced about the seismic hazard analysis is why it is important? What are the parameters we are expecting to estimate? Okay from the seismic hazard we have discussed. So we have seen that, the seismic hazard analysis is the first and foremost step after any zonation, okay. So this hazard analysis are carried out basically for the design of new buildings as well as to know the seismic status of the any particular region, okay.

So this has to give the input further infrastructure design, so that the failure of these structures, okay infrastructures can be reduced are minimized, okay, so due to any future unexpected earthquakes. So generally this is done by considering the past earthquake data based analysis, okay. So with the continuation of the introduction to the seismic hazard analysis, so today we are going to talk about the seismic study area and the preparation of seismotectonic map.

So this seismotectonic map preparation is the very basic information. This map decides your hazard at a particular place. So it should be done with a very careful thought as well as the input data and necessary models and then collect all the information. As we have discussed seismotectonics of India, we have seen that a different parts of the India behave differently because of the different seismotectonic force associated with that.

For example, east and west we have seen that the boundaries of east and west basically transformed nature and thrust faults are that are not completely thrust fault, but still there is subduction earthquakes which can also take place and very deep, so about more than 200, 300 kilometer deep and then the presently continent to continent, okay, so convergence is contributing to the most of the rupture and fault in the northern India which causes many shallow earthquake.

Apart from that we also seen that central and south, okay there were the curtain regions has undergone a several deformation and caused considerably damaging earthquake particularly after 1950. So there we have also seen why those curtains are creating earthquake. We also understand the geology, okay of those; all these regions and then the fault mechanics beach balls**,** okay. The VpVs ratios, Poisson ratios, okay the depth of the earthquake.

So these are all their seismotectonic information. So the fault type, okay focal mechanism type. So these are all the data fault seismotectonic details of that particular region which has to be compiled. So even though we are discussing the India level like it is like a global or bigger scale macro scale we discussed. But when you want to do the seismic hazard analysis on a particular site, okay you should narrow down to the particular place and try to understand what is the seismotectonic details in the particular region and try to prepare your seismotectonic map, okay.

So that is what we are going to discuss. Before starting preparation of the seismotectonic map, first of all, we need to identify the seismic study area. So what is the seismic study area? We know study area. Study area means, where you are keen and interested to collect some data or interpret some result or analysis and result is the study area. So seismic study area means actually so generally most of the project or any kind of report the concentrate study area means only that area, okay.

So for example somebody want to do some analysis in Bangalore, they consider Bangalore. They do not look at what has happened in the Mysore, okay. What has happened in the Tumkur? What has happened in the Chennai? So they do not look at it. But seismic; with respect to seismic action, as we have seen that the earthquake originate and propagate waves, okay emit the energy in the form of seismic waves.

That waves can reach throughout the world, okay. So that means, it is not only the earthquake happening in Bangalore will affect Bangalore but anywhere earthquake occurring in and around Bangalore also will affect. The around means, what is that around, okay? What is the radius we have to decide? How much area we should consider? That is the seismotectonic, okay. So the map preparation it will help so that the area is called as a seismic study area.

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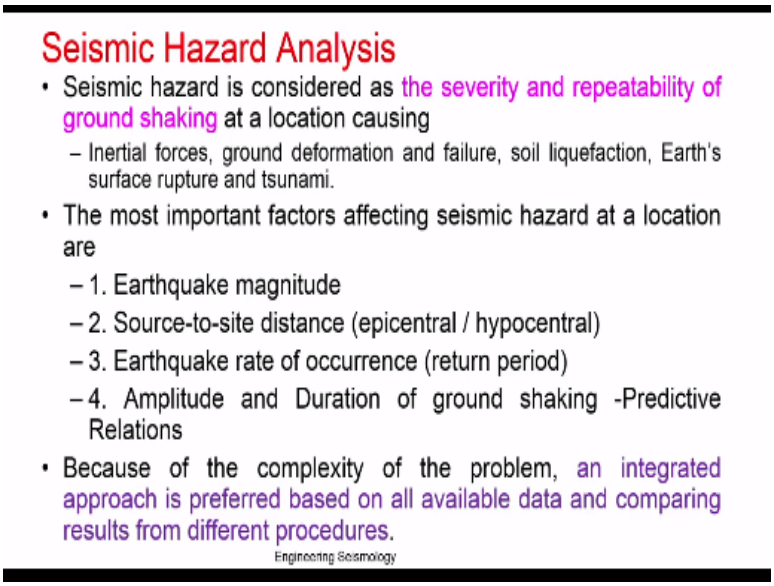

So the seismic study area, basically okay so helps to compile the record information for the seismic hazard analysis, okay to represent your hazard in the form of severity and repeatability of ground shaking. So what are the information which can compiled in this region actually as we have seen that the earthquake magnitude the distance, okay epicentral/hypocentral distance and the earthquake rate okay the recurrence model or written model, then amplitude duration ground shaking predictive equations.

So these are all the information we need to account in the seismic study area which will result in the your hazard prediction, okay. Like a PGA PGV are intensity which will helpful to estimate the inertial force and ground deformation failure, soil liquefaction possibility, landslide possibility, surface rupture possibility, tsunami possibility all those things are we have to estimate. These are all the seismic hazard, okay which can expected which is the function of your seismic study area what you are considering.

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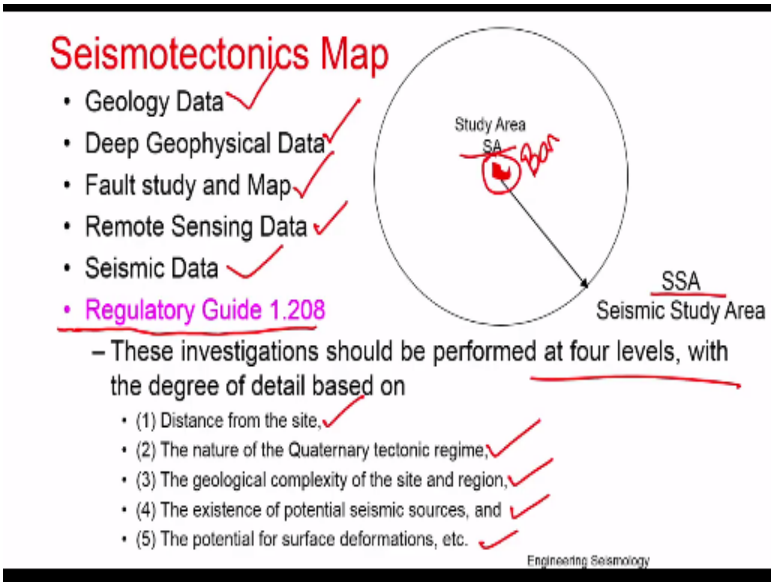

So, if you look at the map this one. So the study area is actually the region where you are looking at your hazard estimation, okay. So the Bangalore City I want to estimate the hazard. The Bangalore BBMP area, okay is a study area, okay. That is the study area. That may be in any shape. So depends upon the place-to-place some place we will have the proper circular, some place we will have the irregular shape, some place you have even linear shape, okay.

So it does not matter, okay. So the study area is where you are trying to predict hazard is the study area, okay. So the seismic study area is, the area where you need to consider, okay whatever parameter we discussed the previous slide, all those parameters need to be considered, okay within that radius is a seismic study area. So generally the seismic study area will be the several times of your study area diameter.

So for example, this is the; I say it is Bangalore, okay. If this is the Bangalore, okay. So my study area will be this much radius. So how I will decide this much radius that is what we are going to discuss. What is the practice we do? So what are the (()) (07:12) in that, okay? What way we can select more representative study area, okay? So in the study area, okay. So in the study area and seismic study area you have to identify.

So then after identification of the seismic study area, basically we call it as a SSA, okay. So the SA is a study area SSA is a seismic study area. You need to understand geology, okay. Deep

geophysical data, fault study and map, remote sensing seismic data. So these are all the information which is a part of your small tectonic details. That is what we are seeing that now. So those details should be compiled, okay and the geo referenced and plotted in the seismic study area. So let us see how the seismic study area is generally selected.

So I mean as per the literature in India concern, okay. So the hazard analysis particularly when they talk about the systematic hazard analysis. I understand that the first work was done by the RN Iyengar, okay his group and his team Professor Raghukanth right now he is faculty at IIT, Chennai, okay. So IIT Madras he is the faculty. So they have done, okay. So they referred a seismic study area. So that is what I come to know what is the seismic study area.

So they consider a seismic study area some X radius based on the regulatory guide, okay. The regulator guide 1.082. What is this regulatory guide? This is actually a regulatory guide actually released by the US Nuclear agencies, okay for doing any seismic hazard studies, okay. One has to consider as per regulatory guide, this is the seismic study area, okay. Which says that; so the investigation should be performed at four level, okay with the degree of detail based on the distance from the site, okay, this is a distance from the site, nature of the Quaternary tectonic regime.

So based on the tectonic regime, the geologic complexity of the site and region so, the site geology and complexity also need to be accounted. The existence of potential seismic source and potential surface deformation. So they say that, you should do a four level of study, okay to identify starting from there your seismic study area.

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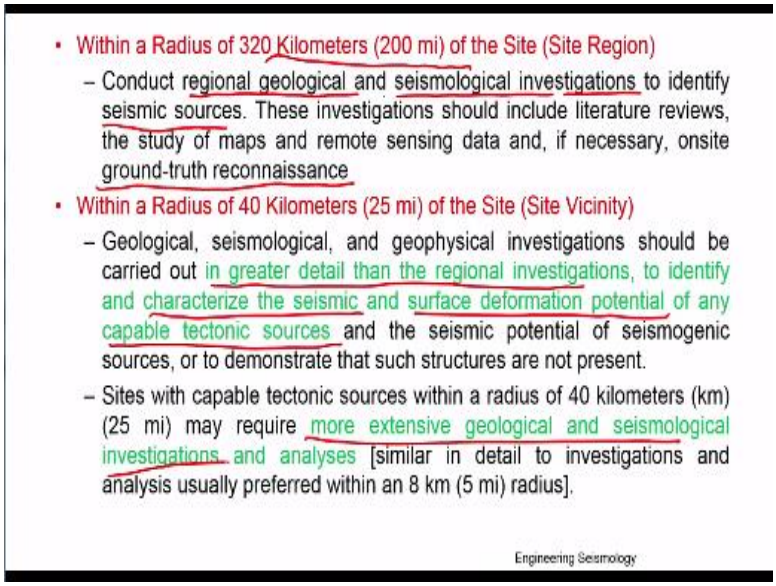

So what is that four level? So within the radius of 320 kilometer which is equal to 200 mile? They have given that any seismic study area you should take as 320 kilometer or 200 miles, which is basically given us 200 miles, okay. If I convert the US system they use miles. So if we convert that into the kilometer, it comes to roughly 320 kilometer. So one has to conduct regional geological, seismological investigation to identify the seismic source.

So people has to go through a literature and identify seismological and geological investigation and identify the different seismic source in the; in this radius region. This investigation should include literature review, study of map, remote sensing data if necessary onsite ground-truth reconnaissance. So they say what are the detailed study you should do? So within the radius of; so that is a first level they say for this one.

So within the radius of 40 kilometer like 25 miles of the site, okay Site Vicinity, the geological seismological, geophysical investigation should be carried out greater details you can see greater detail means you should go; do the field studies, okay regional investigation, identify and characterize all the seismic and surface deformation potential of any capable source in the area, okay. That is what you should do in the 40 kilometer radius.

The seismic potential of the seismogenic source and demonstration of such a sector are not present. So you have to do the detailed study and the demark it**,** which are the potential

seismogenic source? Which are the not potential seismogenic source that we have to demark by doing this detailed analysis.

So site with the capable of tectonic source within the radius of 40 kilometer, maybe require a more extensive geological and seismological study. If you found that there is your potential seismic source, okay then you have to take a further detailed investigation, okay. So that should be done again another scale, okay.

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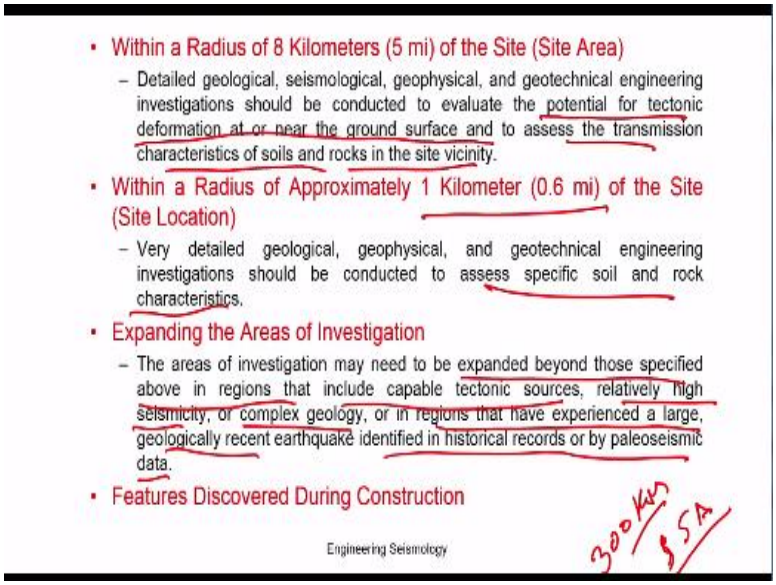

That is like 5 miles or within the radius of 8 kilometers, okay. So the detailed geological, geophysical studies and then geotechnical investigations should be conducted to evaluate potential tectonic deformation in the near ground surface to assess the transmission characteristics of the soil and rock, if there is a potential seismic source. So this will be the level; three level.

So within the radius of approximately 1 kilometer from the site which is like roughly 0.6 mile of the site very detailed geotechnical, geophysical geo; and then geotechnical, geology, geophysical geotechnical engineering investigation should be conducted to assess specific soil and rock characteristics. So that you understand how the wave propagation going to change when earthquake comes, so that is the whole idea this.

So they also given, okay after giving this minor discussion the details they also suggested that the area of investigation may be need to be expanded beyond the specified above in the region include capable of tectonic source relative to the high seismicity, complex geology and regions of that experienced large geological recent earthquake identify historical record or by paleoseismic data. So this is what they have given.

So this was basically a guideline given by the US Atomic Regulatory Guide, okay. So they have given this guideline to basically do seismic hazard analysis of nuclear power plant located in the eastern north; Northeastern America, okay. So, because the western side they do not have much nuclear power plant. So then eastern side they place a lot of nuclear power plant that power plant seismic hazard analysis, this is the guideline given.

So Raghukanth actually one of his paper, he quoted this regulatory guide and used 300 kilometer, okay as a seismic study area for the analysis in the some I think Mumbai City or Delhi City somewhere. So this was the first work where they considered the seismic study area officially to account, okay. So when I was start doing working on this research area, as I told you that I not only adopt a procedure, I also try to understand why we adopt that procedure by doing the research area. I initially adopted a like a 350 kilometer for the Bangalore, okay.

So because the 320 was written in the regulatory guide, 300 was followed by the Raghukanth then we take 350. Further I try to investigate why that seismic study area is very important. So, that investigation and findings only helped me to demark get how to estimate a seismic study area at a particular place. So, what I did actually let look at how the damage pattern in the Northeastern USA. So, Northeastern USA is actually also called as your stable continent region, okay.

So there the earthquake occurrence similar to Peninsular India, but they did not have experienced any big earthquake, okay before release of that regulatory guide, even after release of the regulatory guide until now. So can we adopt a similar procedure a similar concept in the Peninsular India? So when I am discussing with the seismotectonic details, I told you that our crust formation, okay the crust formation in Peninsular India particularly the curtain region are

thin about 39 35 kilometer thick up crust when it goes to Himalaya it is thicker about 70 to 80 kilometer that is what we are seeing.

This thickness is lowest among the world over anywhere in the intraplate slab crust thickness, okay. That is what we understand. So that means we are taking up similar kind of recommendation even though it is a similar tectonics both of them are intraplate in nature, can it be right or wrong? So that is the question I posed myself? And try to understand whatever available recorded, okay are the earthquake which is experienced very recently and how the area, okay the felt area like intensity, okay because the measured data are very limited.

So the intensity indicates that how much distance people are feeling similar kind of intensity values, okay. So that I tried to study by taking two typical earthquake and then decided that whatever we are doing seismic study area right or wrong how we should decide. So let look at; because I started my research on the Bangalore region. So then further I did actually for the Coimbatore. So I take South India as a example for demonstrate how the seismic study area has to be selected.

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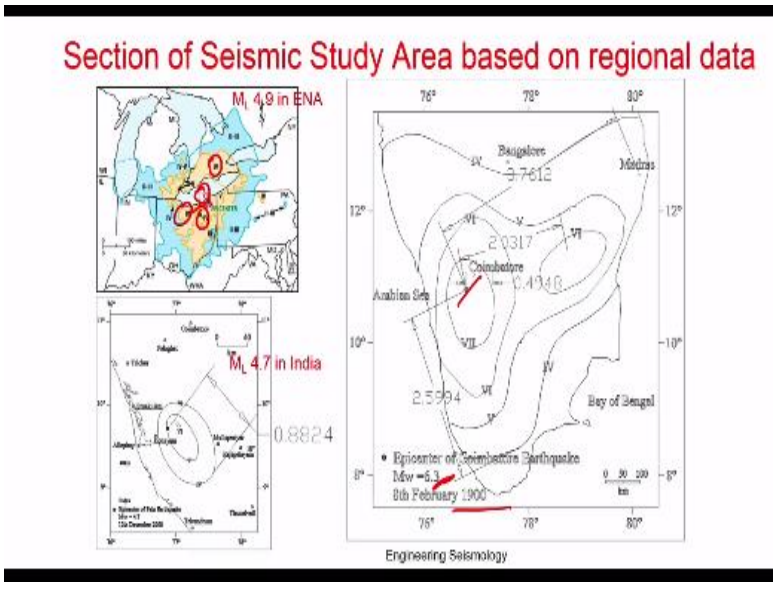

So let us see the US map, okay. This is actually the 4.9 magnitude, okay local magnitude in eastern North America, you can see the intensity map, okay. You can see that intensity map

okay. The 4 the 6, okay, 4, 4 very closely, you can see the intensity map, okay. So this is the distribution of the isoseismal map.

Let us see the same kind of map here, okay like you can see here, okay. So it very clearly indicates that, okay the distribution of this and this are completely different. So we have basically a longer distance that similar kind of intensities are reported, okay. This also a magnitude of 4.7 occurred on 2004 in the Pala region, okay. This is called as a Pala earthquake, okay. So, here you can see that there is a considerable variation in the intensity where here this was actually a smaller distance here it is bigger distance.

So which indicates that the wave propagation in the Peninsular India may be different than the wave propagation in the Northeast America, even though regions are similar. So that means, the damage level since the wave propagation or intensity indicate the damage level are felt. So similarly the bigger earthquake may cause a larger damage than the US. So then I look at what are the isoseismal maps are present are prepared in India for the past earthquake.

So when I was talking about the isoseismal map, I told you what is the importance of that. So now you realize that where it is important? Because since we do not have the recorded data, the alternate only available data is a damaged map or the isoseismal map or intensity map that map I tried to study. So this is the typical isoseismal map which is published by the Geological Survey of India for Coimbatore earthquake, there was a Coimbatore, okay, so earthquake during 1900, okay 8th February there was a earthquake with the magnitude of 6.3 or 6 to 6.3.

You can see that okay, the 4 intensity like 4 to 5 is the intensity which is interesting for the civil engineers where your structure get e cracks or its get start vibrating and then the dribbling and all those things will happen. So that intensity value we should look at. You can see the distribution of the isoseismal map. So these are controlled by your local geology. So that means taking up seismic study area considering the local data is more appropriate than using a universal approach, okay not universal procedure.

Because nobody telling us to take we are only whatever literature available we just going through and taking that. So instead of taking a some literature which is elsewhere which may or may not applicable to us, let us see understand our own earthquake that is why we discuss here seismic event sorry earthquakes reported in the India. I have given a few classical examples no. So that isoseismal map understanding of that damage will help you to identify your seismic study area, okay. So, now you understand why is the importance of that?

So by looking at this one can decide what intensity the building damage or the human felt uncomfortable that intensity they can decide. Based on that they measure how much distance it is from the isoseismal map and take that distance as a minimum distance for the seismic study area. So that means, taking up seismic study area may not be uniform throughout the India as we have seen that the southern part behave differently, western part behave differently, central part behave differently and eastern; western part behave differently, northern part behave differently.

If we recall all the isoseismal map what we discuss, some of the map even it goes up to like 1,000 kilometer with the intensity of 4 and 5 we have seen. So those kind of places if you do basically you have to consider your seismic steady area so much and this case particularly the shows a maximum distance of close to 3.76 degree which is multiply by 110 if you do, it goes to 450 or 500 kilometer radius you will get. So this is how you can select the seismic study area.

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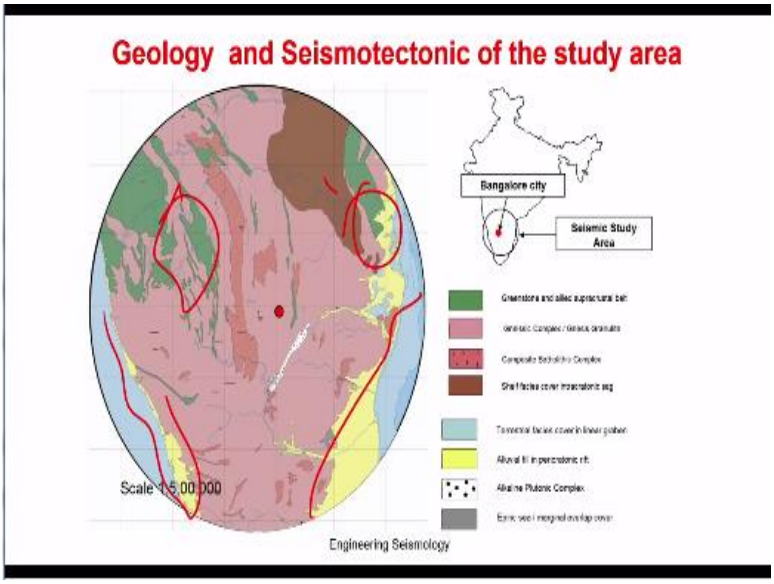

So, now we understand the study area under seismic study area. Once you select a seismic study area, then you try to see what are the geological formation? So when I talk about the South Indian geology, I told you no. So understanding of geology will indicate how more the complex is geology, you indicate you can expect more and more seismic activity in this region. So similarly, this is your Bangalore as I told you that study area.

So this is my seismicity area. This is the radius where I tried to collect all the geological and seismotectonic features. Here you can see that this is basically a Cuddapah this one and then the nice granitic terrain, okay. So all the geological formation you can see, okay. So these are the similar type, similar type more complex geology, okay. So these are other place more complex geology, okay. So this is the way you should compile. So this geology and seismotectonic details is already may be published.

So as I told you that, during 2004 only available data was the seismotectonic map published by Geological Survey of India. But now there are a lot of studies are available even for Bangalore, okay. So those kind of studies based on the recorded data in the region should be consider.

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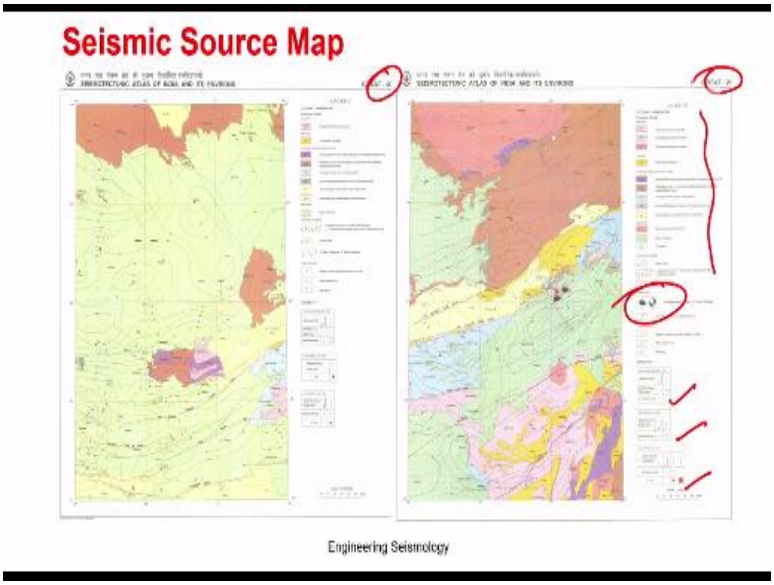

So while you compile a geology and seismotectonic data and try to do**;** as I told you that, the seismotectonic map published by the Geological Survey of India, it consists of a lot of seismotectonic details, okay like location of the fault, lineaments, okay shear zone, geological

boundary, the earthquakes, heat flow, magnetic flow, depth of the earthquake all those information is compiled for the whole India and published as a seismotectonic map that map is actually available for the cost.

So you can look at this is a typical map it has actually 43 sheet of this kind of map and each; India is divided as a different grid, each grid this kind of details are provided. You can see even the beach ball there are given you can see the beach ball, okay the depth the size of the earthquake depth of; see it is here. So they are all the geological features. Then the fault heat flow map.

So this is a typical sheet 21 sheet 20, 20, okay. So like that the Bangalore comes four sheet. So you have to take that sheet now it is available as a soft copy when I was doing actually we have completely digitalize all of them and try to merge and create this map actually, okay by removing the; by creating different layers in the AutoCAD.

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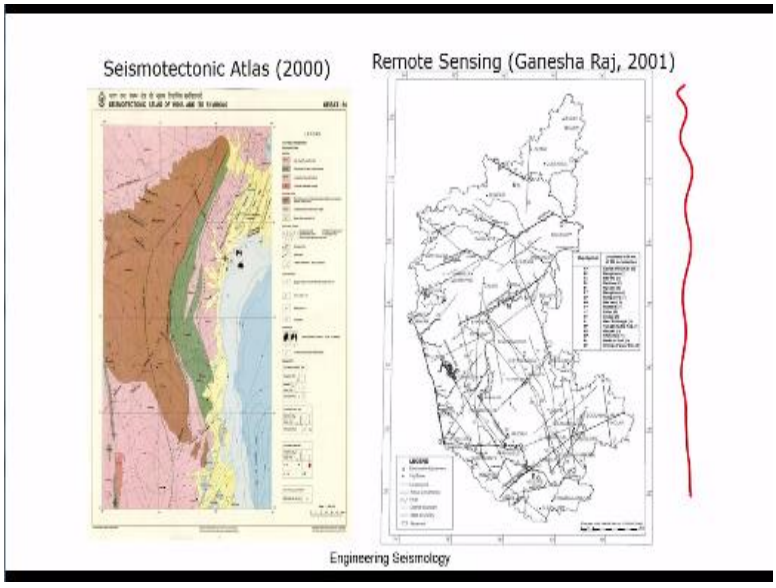

So sometime this maps may be very low, okay, very old, okay. But it is example I said 2004, I did my analysis. So 2000 map is actually quite new, but the same map if I do now, okay, it is completely old. So I have to look at what was any updated studies done on this region? So there was a; updated study means generally geologist and geophysics and remote sensing people they do the studies what we discussed in the seismotectonic of South India.

We discussed based on the data to do a lot of analysis, no. So they do that kind of studies and try to publish a map which shows a active seismic sources, okay so the; dead the seismic sources lineaments, okay earthquakes all those; so this is a such study carried out for the Karnataka where authors are used remote sensing image okay he is Dr. Ganesh Raj from ISRO scientist we had actually interacted with him.

We have used his map 2001 map in the 2004 analysis, where he has also said our publication along with us for the Bangalore micro zonation work in the hazard analysis. So there they plotted identify the all the lineament and the super impose the earthquake data minor earthquake data, try to identify the active lineament and the comment about that how this lineaments are active. Why it has to be included in the seismic hazard analysis, okay.

They carried out the study part of his PhD. So this paper has published a Ganesh Raj and Nanjundiah's guide. So that information also we need to consider. Any remote sensing data in the region, okay.

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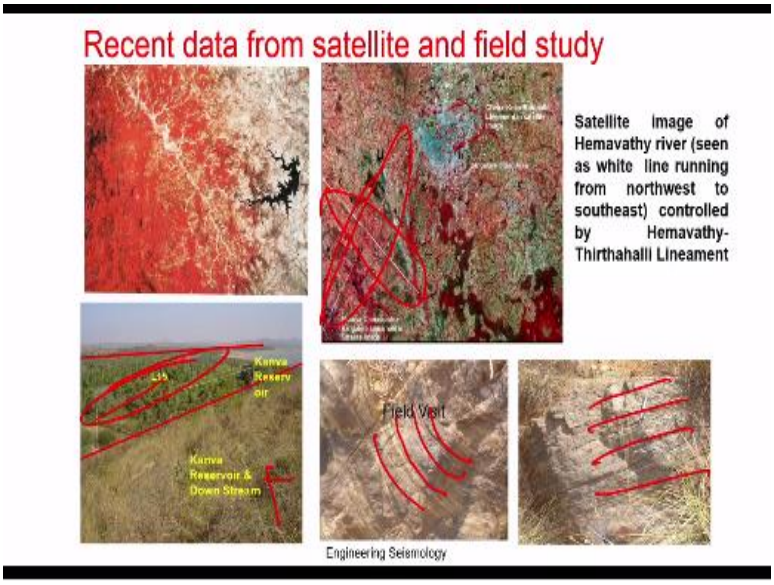

So then so remote sensing data as I told you that so remote sensing data you can also collect and verify when your data old analysis are available. You have to look at that. So if you see the remote sensing data generally you can able to get the linear future lineaments, okay. The seismic

activity the fault or lineaments, okay you can easily get from the satellite. This is a typical satellite data which shows here some of the lineament, okay.

You should not get confused with lineament and road. So you should always approach a expert on remote sensing to process your satellite data. Here also we have taken Ganesh Raj and his group for the Bangalore analysis where we have been seen this lineament and this lineament as a new this is called as Mandya Channapatna Bangalore lineament, okay. So, this is basically IISc, this is the roughly a Bangalore City, okay.

So apart from identifying these kind of sources, you should also go and physically verify how it is geological. So these we have also done that. So this is actually the Kanva Reservoir people who are in and around Bangalore will be familiar with that. So you can see that this is actually the reservoir where this is the part of the lineament. This is a downstream and upstream side of the Kanva Reservoir.

So you can see that we are saying active based on the some earthquake data and the satellite data, how field it is varies. So we went and then we have taken a geological studies on that with the help of Ganesh Raj and talking to the people so and then what is their experience on earthquake how; so they are all given even said that when Bhuj earthquake was there people living in this part of the area felt that vibration more than people living here, okay or other side.

So and even the Sumatra earthquake, they said they felt, okay. So that means this zone whatever we are talking as a lineament, this is a deformation zone in the crust, okay. That is what you can take. So then we will have to see the geological sample we have collected a geological sample on the left side and right side you can see the rock formation orientation. See you can see. So this is how the rock is oriented on the one particular direction.

In the other direction you can see the rock how it is oriented. Same type of rock its orient. So that means once this rocks may be similar, there may be breakage in the geological period which we have not seen like several thousand years or million years old, then these rocks are get turnaround because of this breakage and the movement of the taken place in that region. So, this

kind of field studies need to be carried out, okay to identify whatever information you are getting right or wrong, okay.

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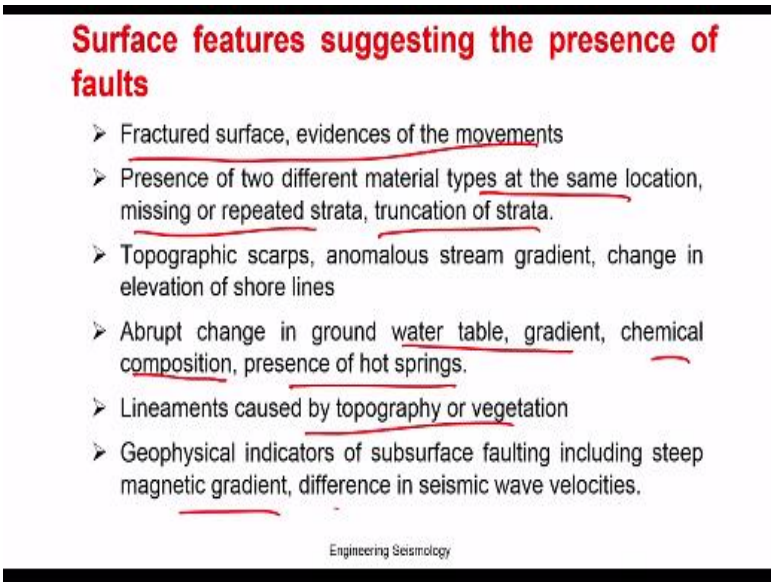

So you can also look at some of the futures, okay subsurface futures okay so and this one. The fractured surface evidence and movement of the ground, okay by looking at the geological rock sample, soil samples also those things. Presence of two different material type of same location that is what we have seen missing and repeated and truncated strata. So which indicates that there was some kind of moment taken place in the long.

So topography scrap anomalous stream gradient changes in the elevation of the shore lines that I will show in the next slide. Abrupt changes in the groundwater table gradient, okay chemical composition and the presence of hot spring within a short distance if you see all these irregularities, it is indicates that so, there are some kind of geological disturbances happening in that area. So lineament caused by the topography or vegetation.

Geophysical indicates subsurface faulting, including the steep magnetic gradient difference in the seismic velocity. So all those data also you can do if there is a possibility. So you can see that the fault scrap is actually topography expression faulting attributed to the displacement of the land surface by the moment along the fault.

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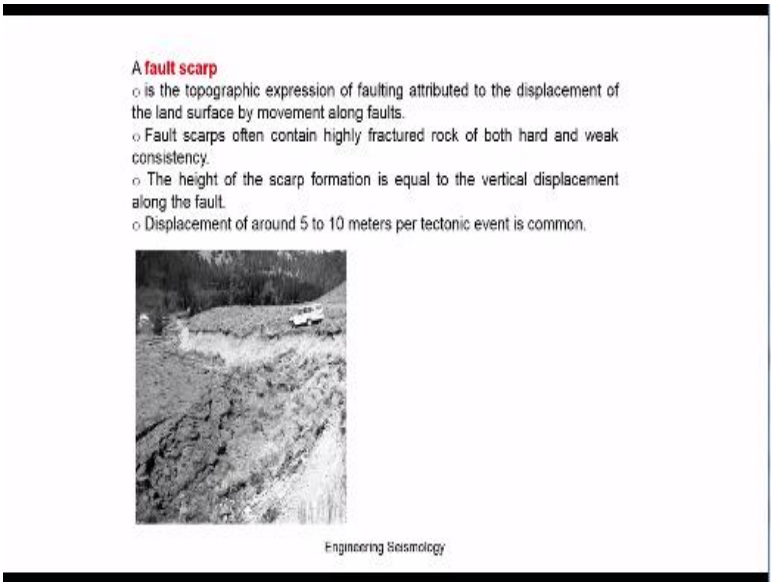

Fault scrap often contain a highly fractured rock on both hard and weak consistency. The height of the scrap generally, so formation equal to the vertical displacement, so you can get here this kind of geological features you can see, so same land down due to that this kind of seismic activity. So you can also see here see this one okay, so you can see here. So this is a raised up, okay, so same soil here same soil here. So, this kind of geological, land formation and it is called as fault scrap, this gives the evidence, okay.

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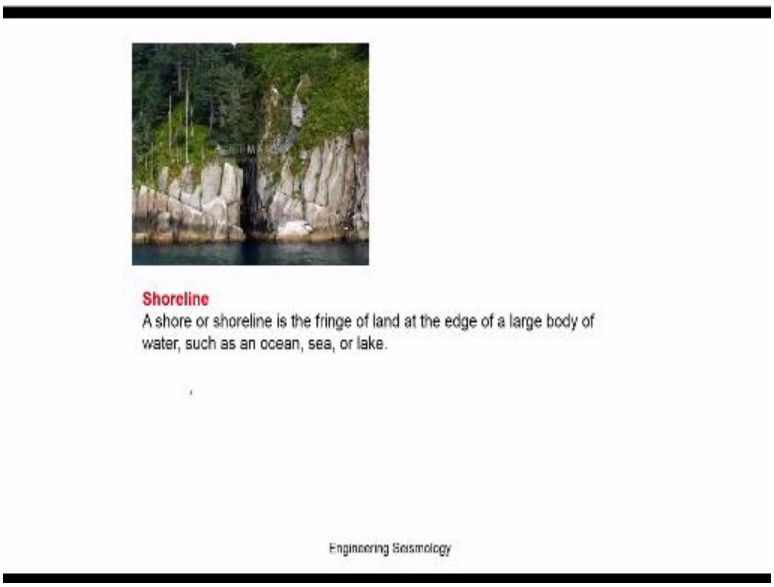

So this data's okay we have to basically collect it and use it in this one. Then identification of the shore line in the sea area, there will be shore line changes, okay. So in the water bodies and you all can see here how the rocks are, okay. So you can see how the; okay. So see that is here. So

these are all the features you can study basically and by doing a geological investigation in the site, okay.

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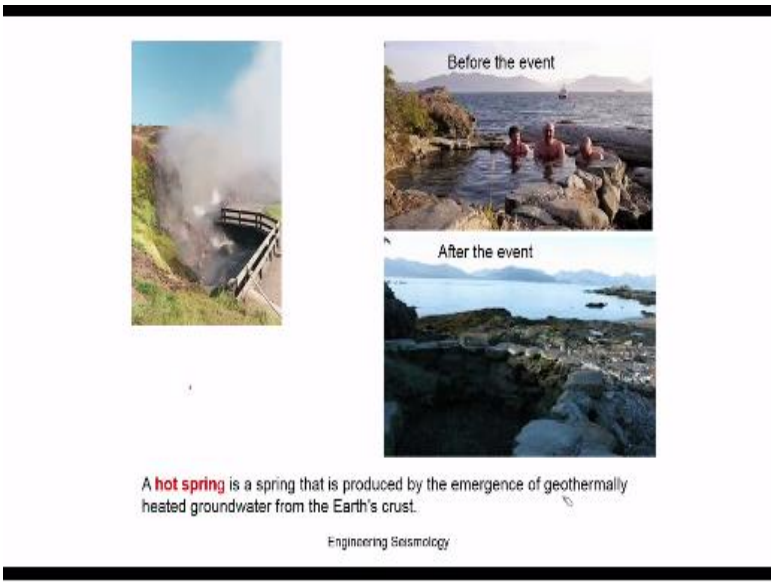

So abrupt changes in the groundwater elevation due to the increasing the pore water pressure also causes liquefaction in the hot spring okay produce this one. So these hot spring where generally hot spring comes because of the magma eruption in that particular area. So somewhere suddenly we have the hot spring in the ground, it indicates that there is geological activity is taking place.

So this is the; so before event how the hot spring was after the event you can see. So before the earthquake after the earthquake where you can see that activity physically. So if you have this kind of hot spring one as to be very careful. There may be chances of seismic activity in that region.

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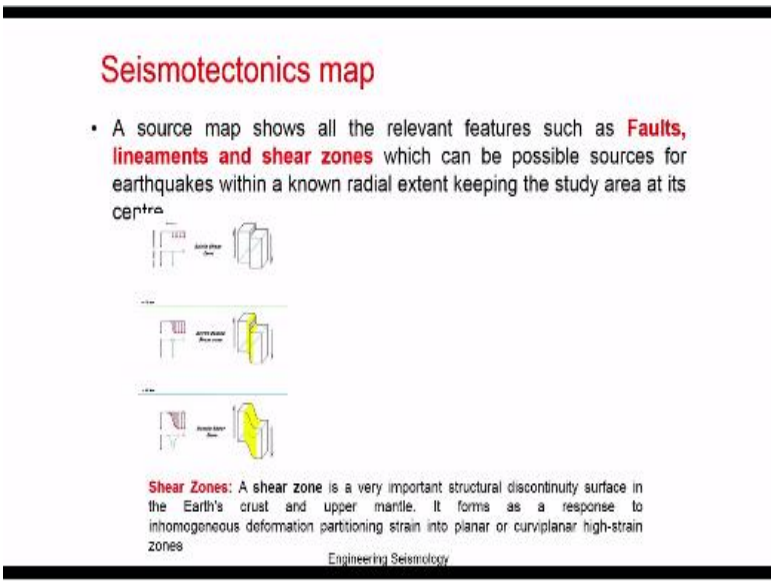

So the seismotectonic map, okay should include all this geological and futures parameters and try to compile them, okay by doing a detailed analysis. This is like lineament identification the satellite image again. So you have to include that and where you can try to even understand what type of fault how the movement taking place in that particular location by looking at a geological deformation, okay.

The shear zone activity happening at a particular place will be visible as a shear zone where you will have the very fertile land in between you will have the rock terrain and suddenly you will have a very fertile land for several kilometer width. So like we have seen in the previous slide no. So here you can see that this so, here, so basically this region is very fertile but this is very hard rock. So this kind of geological differences will give you the; your indication of the seismic activity in this.

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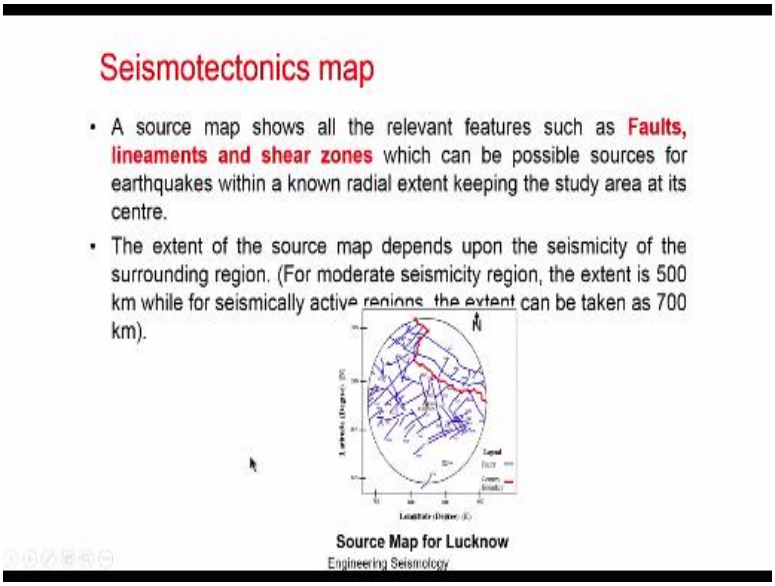

So all this information needs to be compiled and prepared as seismic source map, okay which is called as a seismic source map. Which has to indicate all the fault in the region active fault in the region from the remote sensing, field observation, photo studies, literature as on date when you are doing the hazard analysis. You should not take 10 years back map published by somebody X and do the hazard analysis.

If you do that you will end up in the trouble, okay by deciding your seismic study area. So this will help you to estimate a more reliable hazard values as we try to map all the possible seismic sources due to this kind of detailed analysis, okay.

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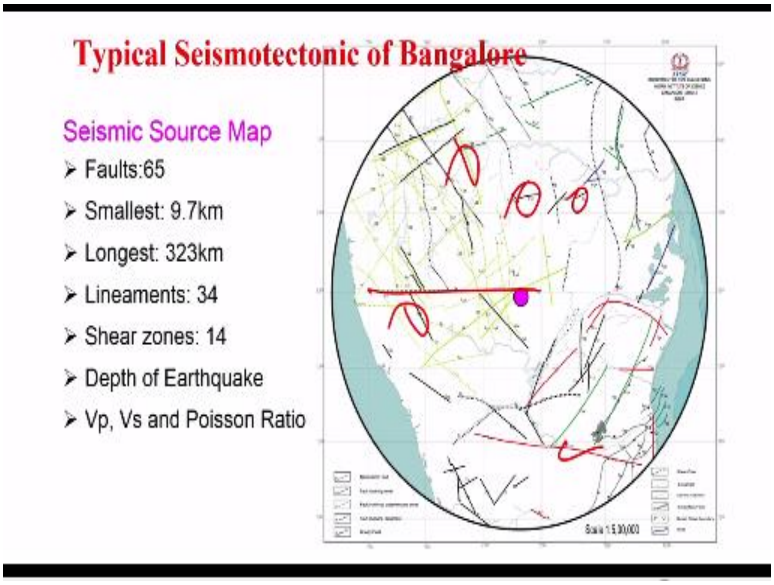

So this is actually a typical seismotectonic map source map you can see again for the Bangalore. So where you can see, we have used like a neotectonic fault, okay. So this one the fault involving the cover, okay so the some fault where it is not hidden fault involved in the basement cover, okay so the green one, okay. So then the fault involving the basement so other types. So like that different type shear zones, okay so the shear zone. So shear zone, okay lineaments.

So all those information has to be compiled, okay and then made a data okay like how many sources are there each source has to be systematically numbered. You can see here you are systematically number by assigning a fault 001 fault 002 something like that. And then highest part and lowest part what is the; how many lineaments are there? How many shear zones are there? What is the depth of the earthquake this area experienced?

What is the Vp value Vs value Poisson ratio of this region from the previous literature, if it is not available your to do detailed study depends upon the project, okay. If you are doing for the important project like nuclear power plant, dam and multi stories it is time investing on that, so that you are reliable hazard estimation will happen because of these maps. So, this is how you can prepare your hazard analysis process of preparing seismotectonic map, okay.

So the seismotectonic map is the base information source about the seismotectonic character of the region which includes the seismic source, deep geophysical data, okay. So its VpVs and Poisson ratio, crust thickness, depth of the earthquake a number of fault lineament active sources, all those information should be compiled for seismic study area. So where a seismic study areas to be arrived based on the intensity experienced in the region intensity map our isoseismal map or if you have the business earthquake recorded data that also can be taken as a reference to this as a seismic study area.

So as on now, so we; I do not recommend any seismic study area for any particular location. You have to do your own homework and try to arrive a seismic study area. So if you want to check the; how to arrive that you can refer some of my publications done for Coimbatore, okay the KSR dam and other regions where we have given you a systematic approach how to arrive a seismic study area radius, okay. Then how to prepare a seismotectonic map, okay.

So, this is the base map, where we identified all the active fault sources and mapped them. So with this we will move to the next step of the hazard analysis, okay. So, that is a seismic data collection and then seismic data homogenization, so that we will discuss in the next class. Thank you very much for watching this video. So, I will meet you in the next class. Thank you.