Introduction to Engineering Seismology

Prof. Anbazhagan P
Department of Civil Engineering
Indian Institute of Science-Bangalore

Lecture - 07
Seismic Sources and Faults

So vanakkam. So today we due to continue our understanding of the earthquake so from the last class. So last class we have seen what is meant by earthquake, where the earthquakes are highly occurring. And we also discussed that the plate tectonics okay where and all the major earthquakes are reported in the throughout the world. So it has been brought to your attention that the joint okay or the boundary of the plates okay.

So the more earthquakes are occurring when compared to the interior of the plates. We also given some of the example. And then there are earthquakes also in the interior. So that also we seen. So we also understand from the elastic rebound theory that none of the place in the world is free from earthquake. Only the frequency. Some places it is very frequent, some places it will be less frequent, okay.

So with continuation with the plate tectonic, we also studied about the different type of plate boundaries okay. So like the convergent boundary, divergent boundary, okay. So transform boundary kind of things. So these are all applicable directly to the plate edges or plate joints okay. So but if you want to really understand that not only the earthquakes are occurring on the edge of the plate, it also occurring on the so interior of the plates.

So the places where the earthquakes are occurring is called as a seismic source, okay. So which is also called as a faults. So today class we are going to discuss about the seismic sources and fault, which is responsible to cause a earthquake or which is the place where one can expect a earthquakes, okay. So today class we are going to see about the seismic sources and fault.

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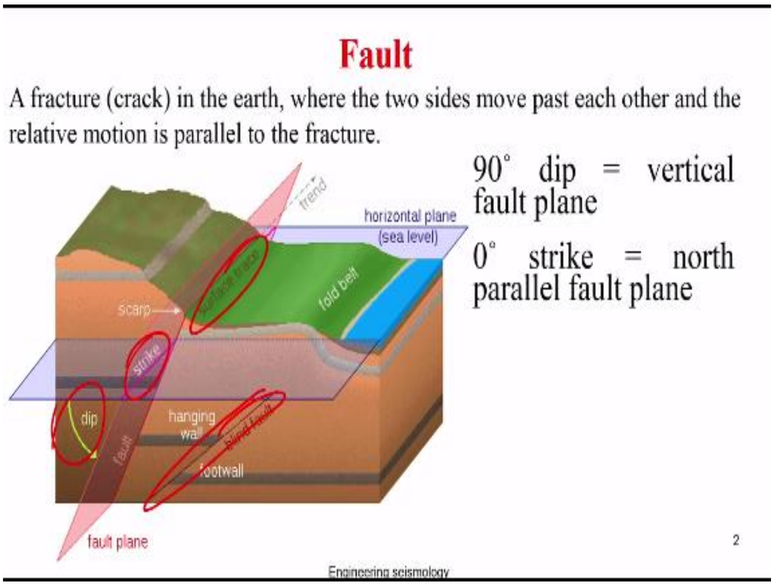

So if we look at, so the seismic source and fault. So basically the fault is a fracture or crack in the earth where two side move past each other and then the relative motion is parallel to the fracture. So like last time we have seen that there is a fault where the two geological rocks are joining together or two plates are joined together at the deeper level it is called as a fault.

So that fault basically in this sketch, so this is the fault. So even though it is a line in this diagram, but in the earth scale this will be having several meters width okay so starting from like a 5 meter, 10 meter width to the 1.5 kilometer and then a 15 meter width of the fault. Then the length again it extend to the horizontally towards maybe several hundreds of kilometers okay.

So this fault okay is actually a seismic source. So it can be the joints of the two plate or it may be the middle. It has been created due to the geological formation, okay. Due to the movement of the plate and bending action and then all those things whatever we discussed plate tectonics will cause this kind of weak zones or fracture. So the upper part of the fault is called as hanging wall.

The down part of the fault is called as a footwall okay. So the fault which basically makes angle with the horizontal section is called as a dip, okay. So this is a dip. The fault which makes angle with the north is called as a strike, okay. The fault which is projected on the surface is called as a surface fault. The identification of that is called as a surface trace. So this is basically a surface trace.

So this is basically horizontal plane. So you can see that the vertical fault plane will have the 90 degree dip. So the zero degree strike for the north parallel fault plane. That means, the fault is oriented towards a north. You will not have any angle. So that is basically zero degree of strike. So similarly the fault is perfectly vertical you will have the dip as a 90 degree.

So from this we can understand what is the dip and strike and what is the fault and hanging wall and footwall, okay.

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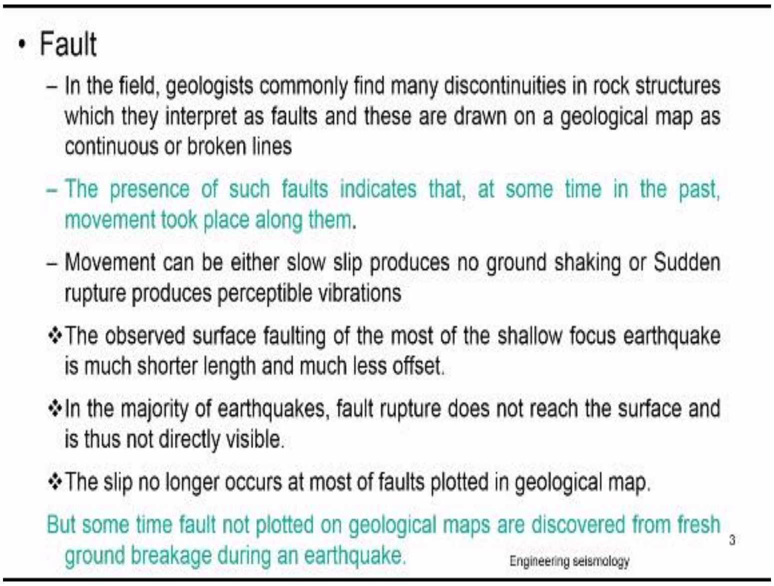

The fault in the field geologists commonly find many discontinuity in the rock structure, which they interpret as a fault as these are all drawn as a geological map as continuous and broken lines. So basically the geological when they do a field investigation at the geological deposit or they go for the field visit they find there is a discontinuities in the geological formation or the rocks or the cracks.

So those area they call it as a fault. So in the presence of such fault indicate that at once one point of time, there was a movement taken place. As you know that, if there is no movement is taking place at one place, you will have the uniform material. If there is something happening and then you will have the different material in the same place. That is why they call it as a geologically variation of the geological deposits in the form of soil and rock which is causes a called as a fault.

So the fault can be either slow slip procedures, no ground motion shakings are occur or sudden rupture produces perceptible vibration. So the fault may have the movement or may not have the movement. So all the fault may not be having the movement at a time or sometime it might have been had. So the observed surface faulting most of the shallow focus earthquake much shorter length and much less effect.

So generally you can see the surface observation of the fault in the shallow earthquakes. So shallow earthquakes means the earthquake which is occurring on the less than 70 kilometer, 30 kilometer kind of things where you can call it as a shallow earthquake. Even sometime it occurs on the 5 kilometer. So where you can see the great surface features.

I will show you some of this one. So those kind of fault can create a surface rupture. So the surface faulting of the most shallow focus earthquake much shorter length and less offset. So majority of the earthquake fault rupture does not reach to the surface and does not directly visible. So most of the earthquake you can see the earthquake vibration or you can feel the earthquake vibration.

But fault may not be projected to the surface, okay. So because of the when the rock breaks, even though rock breaks the top of that will have the soil deposit, so that soil deposit will adjust that such that the crack or breaks does not come to the surface or the breakage is happening at very deep level. It may not reach to the surface by the time the displacement will become a negligible okay.

So no slip longer occurs at most of the fault plotted in geology. So generally geologists what they do they map this discontinuity, geological discontinuity, and then they also observe there is any movement is taking place. And then they mark that in the geological map saying that this is the fault, this is how it is moving. This is how it is slipping. So all those information.

So this is kind of like a geologist will be more involved in the mapping of this kind of fault or people who have the geological knowledge can do this kind of things.

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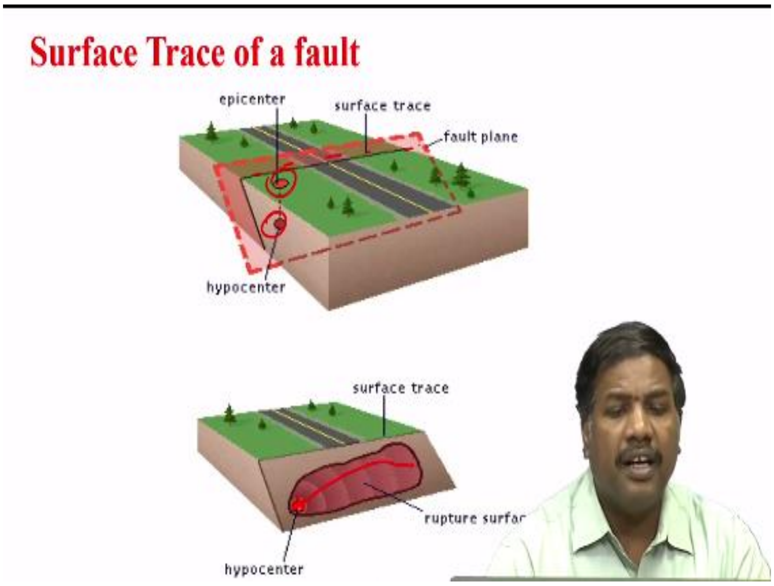

So this is how the fault for example, the down one is actually the hidden fault where you can see that this is basically your focus, okay. So where then the earthquake originated and went to up to this level. So this entire area is ruptured. So since it is rupture within the below the ground surface there is no surface projection or surface trace you can see, okay. So when you see this in the complete section you can it will be visible like this.

The hypocentral, so this is the epicenter. So the fault projection you can see a line in the surface, which is maybe a geological. But the rupture may not be visible, okay. The geological features you can see. So what are the geological features as I said that there is a difference in the geological formation of the material.

So same place we can find two kind of rock formation or different materials like one soil will have the highly weathered in nature and one soil is less weathered in nature. So that kind of fracture and then heterogeneity and shear properties of that particular regions are can be used to trace this kind of fault in the ground, okay.

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So this fault can be characterized three major category, okay. So three major category when we say this also similar to your plate boundary classification. So this is basically how the fault moves with respect to its original position. So one of them is actually a normal fault. So when the rock on the that side of the fault hanging over the fracture slip downward below the other side.

So dip vary from 0 to 90 degree. Faulting is midoceanic ridge, example where this occurs. So those kind of fault is called as a normal fault.

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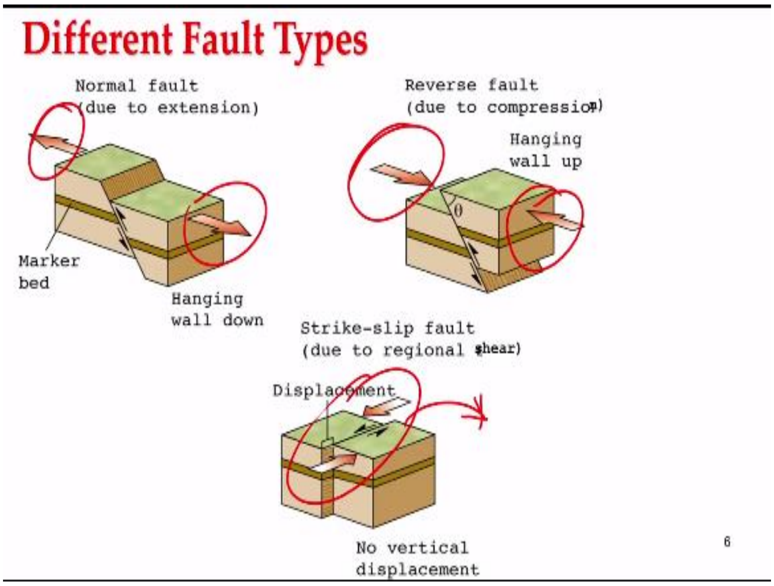

So you can see that if this is the two geological block, when earthquakes are occurring, okay so you can see that this block actually moves a down okay. And the force which is caused this kind of fault movement is basically a tensile force. You can see the. So this kind of fault is called as a normal fault, okay. So this generally happens in the convergent boundary kind of things, okay.

So convergent or as convergent or divergent boundary kind of things you can expect this okay kind of movement. So the next one is actually the reverse fault. So in the reverse fault the hanging wall of the fault moves upward in relation to the bottom of the footwall okay. So special type of reverse fault is stress fault. Dip is very small. Mountain zones are formed on this kind of thing. So this is the one.

So where you can see that here a compressive kind of natural of force is applied, okay. So this is the reverse where the hanging wall is going. So the another type of fault is basically a strike-slip fault. So that strike-slip fault causes only the horizontal displacement, no vertical displacement is taking place, okay. So the first two you will get a vertical displacement. Normal and reverse fault you will get a vertical displacement.

Strike-slip fault you do not get a vertical displacement. You can see it is only a horizontal displacement. So this is what actually in the San Francisco fault. So this you can equate to the Himalayan kind of zone or something like that. So this you can equate to the places where there is a divergent kind of plate boundary action. So this is basically divergent. Sometime even a convergent also you can expect.

So this is basically most of the time on the convergent. This is a strike-slip fault or transform plate boundary kind of things you can expect.

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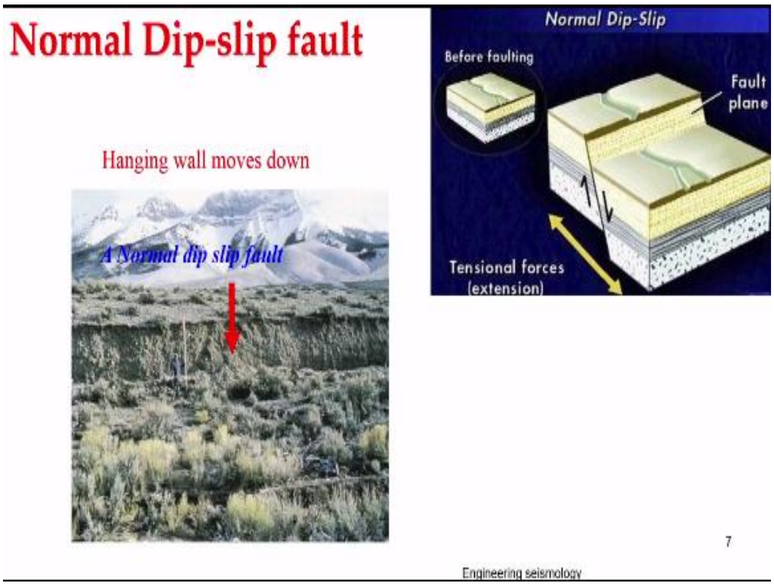

So you can see how this really in the visible okay how the geologist this kind of thing studied soon after the earthquake. So soon after the earthquake people go and observe wherever I told you that there is a surface features of the fault is available. Then you can see these things. So this is the typical example of the normal okay dip-slip fault where hangingwalls moves down, you can see here. So this is the person who is standing and you can see how much down it is.

So this is the typically, example where the. This is the before faulting, so this is the after faulting, okay. So these are before faulting and after faulting. So you can see that this is the before faulting and after fault this is what has happened, okay.

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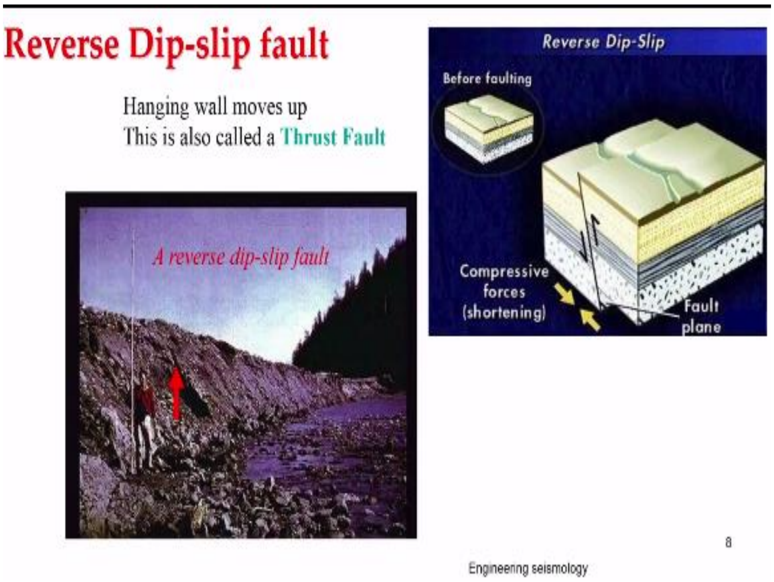

So similarly, you can also understand for the reverse, okay dip-slip fault where this is the one. This moved like this. So this is a classical example where the land was moved up due to the earthquake okay.

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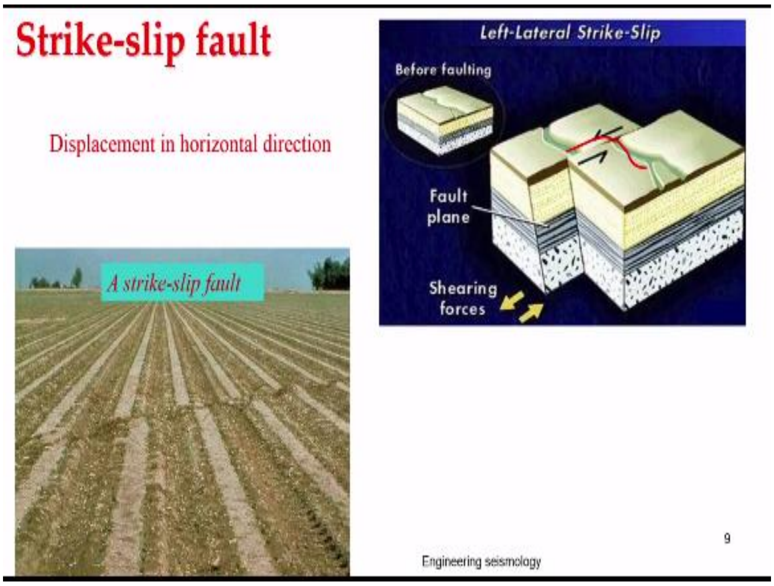

So similarly, the transformed boundary. So strike-slip fault or this one. You can see, this was actually the kind of agriculture land which you can see from the satellite image. So after the earthquake you can see that this was moved here. So there is not much vertical displacement is happening. So the same thing here, so when it occurs it moved. So this kind of change in the river orientation in the same level okay.

The river now it comes like this. So these are the indicate that this was the once created by the earthquake, okay. So this kind of things are indicative this one.

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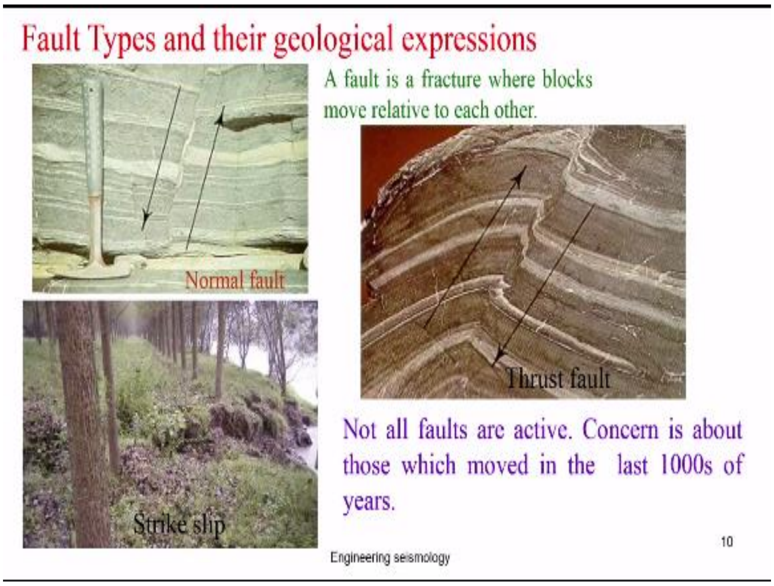

So similarly when you cut a rock formation also these things are not only happen in the very large scale, this kind of phenomena also happens in the very smaller scale. You can see that this is actually a normal fault. You can see how the both the edges are moving. This is the thrust fault where you can see both things are moving.

So this is a strike-slip fault where you can see the trees are moved from its original position to some position without much ground displacement, okay. So not all the faults are always active, okay. There are fault which is active only we are been very concerned okay. So generally the fault if has a so movement in the last thousand years we have to be very concerned, okay.

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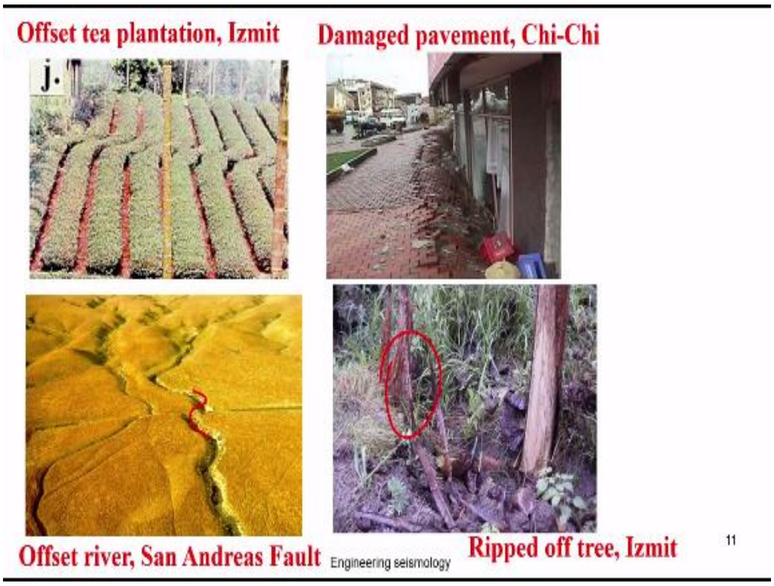

So this is the typical again the photos of the fault movement after the earthquake you can see here. See this is a transformed so boundary or you can see this is actually basically a strike-slip fault. So this is again the where there is a raise in the ground, okay. So which may be a hanging wall and footwall kind of things.

Again the tree okay where this was the original position of the tree so which moved after the earthquake so much with ground okay. So then again this is the river. So where you can see there is a displacement. So this is the way you can geologically identify a type of fault.

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So in case these faults are not visible in the surface. So you can do a geophysical study and try to understand how the materials on different locations are varies, okay. Then based on that you can define what type of fault mechanism by the geological studies. Or even if you have the recorded data by comparing the recorded earthquake data at different direction you can make a tension and compression of the force observed.

Then based on that one can draw a source characterization or find out what type of fault it is. So this is a similarly a typical raise of ground due to the earthquake. This is actually the surface faulting from 1957 Mongolia earthquake where the magnitude was 8.3. The left lateral strike-slip was accompanied by a vertical compound of slip 4.1. So then similarly, this is actually the down figure is Mm was 7.6.

This is actually a Bhuj earthquake so where some of our Indian scientists went to the source and then they have seen how the this there was actually this was the things which is created in the after Bhuj that source location the projection of the ground in the agricultural land. It is actually in between the India and Pakistan border okay. So which is part of the Gujarat regions, okay.

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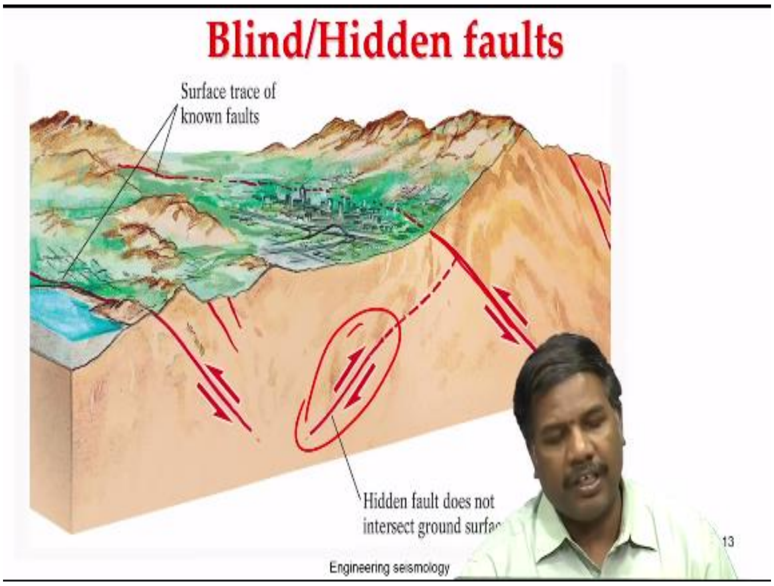

So these are all the place. So apart from this fault so you can also have the hidden fault where you may not see the fault at any time. Only you can see the recorded of earthquake or vibration, but the fault never project into the ground because the orientation is such that which has to travel a very long distance to reach a surface which never happens. For example, this fault.

So there is a horizontal alignment here. And this fault is even if it tried to rupture, it will be stopped because of alignment of this fault okay. So these are all the fault is called as a hidden fault, does not intersect the ground surface at any point of time okay.

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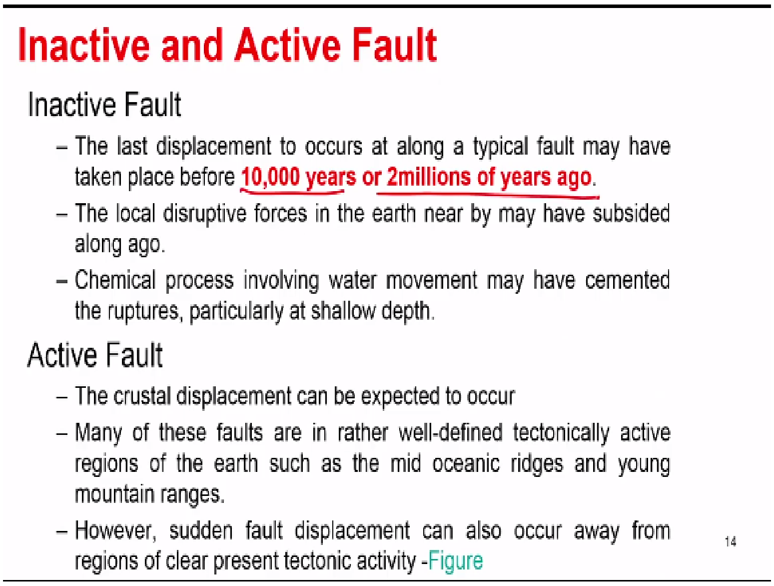

So now we have seen that so we need to go understand about that fault then the faults are active or not. So when I discuss the fault as a three major category. So actually this is a very broader classification. So sometime in the site what happen you have the vertical displacement as well as horizontal displacement. So in that case you should say that the fault is actually the normal strike-slip fault okay.

So reverse strike-slip fault, reverse thrust fault. So something like that a combined name will be used depends upon the vertical displacement, horizontal displacement and the dip and the strike angle which creates after the earthquake, okay. So now so as we discussed that all the faults are not active then it is necessary to understand what is the active fault and inactive fault.

So the inactive fault what the seismologist or the literature they define that the last displacement to occur along a typical fault may be taken place before 10,000 years or 2 million years ago. So those kind of faults are the inactive fault. The local disruptive force in the earth nearby may have subsided long ago. The chemical process involving the water movement may have cemented rupture and particularly at a shallow depth.

So this kind of faults are like called as inactive fault. So you have to carbon date those fault material and see that there is no variation of the material which like all the material in the fault will have the very long period carbon dating years. So then that is a inactive fault. So then the active fault is, the crust displacement can be expected to occur.

Many of these fault are in the rather well-defined tectonically active region of the earth such as a mid-oceanic ridge or young mountain ridge. However, the sudden fault displacement can occur away from the region of clear present tectonic activities.

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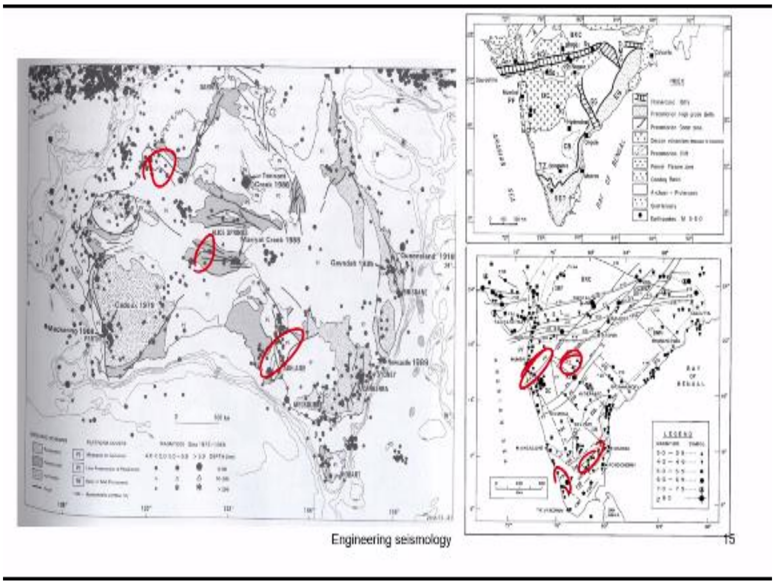

So when you see the tectonic maps and then the earthquakes, so where you can see there is a identified fault. There is a frequent seismic events recorded by the earthquake. So which indicates that these faults are active fault. So where you can see this kind of datas okay. So these are all the indicate that there is a active fault. So as far India concerned, so this is basically the peninsular India geological map.

So we have heterogeneous geological formation in peninsular India. So if we superimpose a different earthquake occurred in the peninsular India in the past you can try to see that there are few earthquakes are so aligned with the some particular fault. So those are all the fault you can take it as a very active fault. But here I should also interesting to note that in India, many of the faults are identified after the earthquake not before the earthquake.

Why because right now, the seismic source available for India is actually prepared by the Geological Survey of India. So which was done before 2000. Then they officially released a seismic atlas of the fault and source map at 2000. So after that there is not much study has been done and they have also as you know that the geologist also may not go inch by inch in the ground and study.

So based on the experience and some major geological features which they can see. So they will basically identify that as a source and map it, okay. So it does not mean that the maps whatever they are given is always true. It may earthquake may not occur. Because there are many earthquakes for example, Killari earthquake, the where the source was not known before, but after earthquake there was a source has been identified.

Similarly a Jabalpur earthquake, so something like that there are many earthquakes where you can see the source has been identified after the earthquake. So in that case, the linear or fault based source identification one has to be very careful when you are considering that for the seismic hazard assessment or estimating the seismic.

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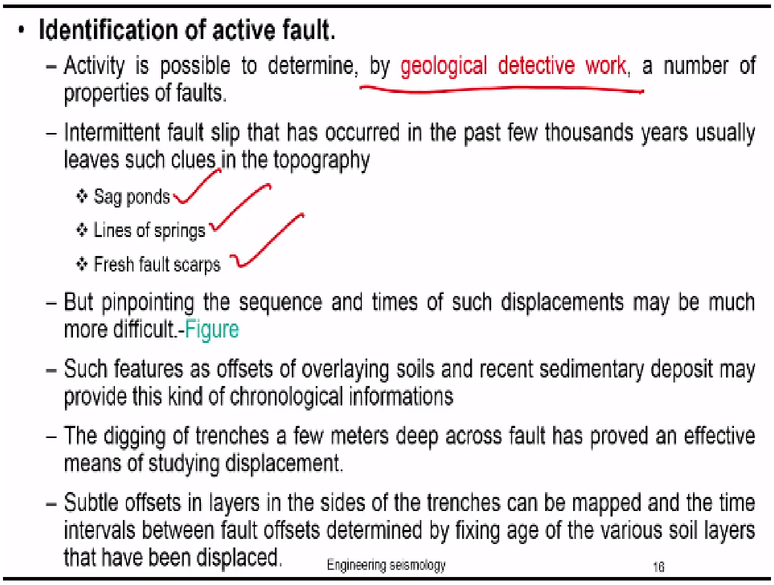

So how do you identify a active fault? So the active fault is possible to determine by the geological detective work. So you can identify the fault by the geological detective work. So what is the geological detective. The intermediate fault slip that occurred in the past few thousand years usually, so leaves such clues on topography. What is that? Sag point, line of spring, and fresh fault scraps. So these things are the evidence that there was a fault in that region.

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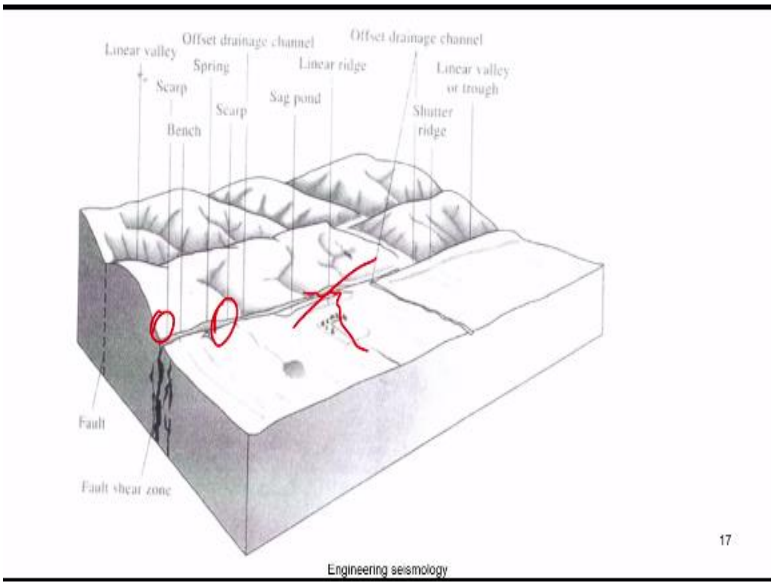

So what is that, so basically if there is a fault in the particular region I told you that there is a the surface fracture will be visible and surface geological features will change. So for example, this is the scrap where you can see there is a surface problem okay. So here also you can see. So similarly the unusual water storage okay. So change in the river pattern okay.

So the rivers are completely like it is flowing like this, suddenly it changes. So that breakage okay will indicate a there was a geological difference or settlement or cracks happened earlier which might be due to the geological formation of the fault in this region.

So these are all the identification you can do in the field by physical survey in that particular location or taking a very high resolution satellite image and try to identify how the different level of elevation changes. So for example, there is a technology called LiDAR survey where you can measure the 5 mm accuracy displacement in the ground. So if you have such kind of maps it is very easy to identify the upper and lower level of the ground.

So but pinpointing of this sequence time such displacement may be much more difficult. It has to be done very carefully. Such features are offset overlaying soil. Recent sediment deposits may provided this kind of chronological information. So sometime what happen this kind of data will be destroyed by the local activities.

For example, somebody want to do some kind of a big meeting in the open ground, where the mother ground they will level it and then they will fill it with fresh soil and then they do some activity. So the original formation whatever happens, it may disappear, okay. So those kind of things also we have to consider.

And then, in case if you have the doubt there was a earthquake frequently on those region but there is no surface features, you can basically cut a trench and then see how the materials are varies in that particular location. Then you can carbon date those materials and try to identify how this place is seismically active or but these are all very expensive process where need to cut for several kilometer trench a deeper height, which needs a money.

But some of the geologists say they do these kind of studies and try to map activity of the fault using this kind of. So this is how you can identify the active fault.

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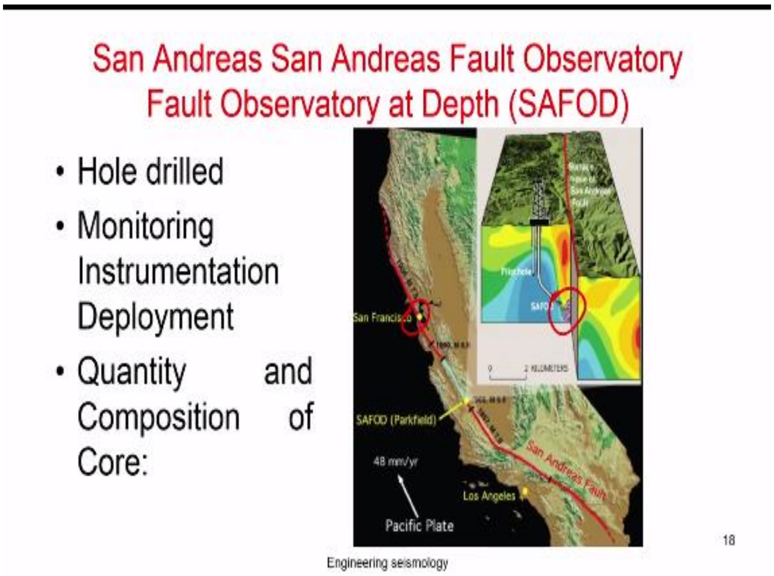

So in case so if you have the great amount of the funding, you can also do a very deep drilling and try to identify activity of the fault for the known fault location. So as I told you that the San Francisco was one of the classical earthquake where the San Andreas fault was created. They did lot of scientific study to understand that.

So such fault basically they had a very deep drilling okay in that fault location and try to install a seismometer and displacement gauges and try to understand how the seismic energy is built on those places. How we can predict a earthquake. So that is what they did. Basically, this is the San Francisco City. This is a San Francisco City. So there you can see the San Andreas Fault.

So where they taken a project called San Andreas Fault observatory fault observatory at depth, okay. So where they had made observatory. So they drilled a very deep bore hole, okay. Then they deployed a all the monitoring instrument and then they tried to monitor that and tried to identify how much displacement is taking place at that place, when we can expect a next earthquake.

That is what their agenda was that. In that they spent lot of money. So this kind of studies also can be taken up to map a active fault if you have the money. Some of the important project they advise for example, locating a nuclear power plant. So where the site if you find there was a fault running by the in the site. But there is a plant you have to locate.

Then you can take this kind of detailed study and monitor and decide there may be a big earthquake going to happen in that area or not. Then you can go ahead with the construction or not. Those kind of activity help.

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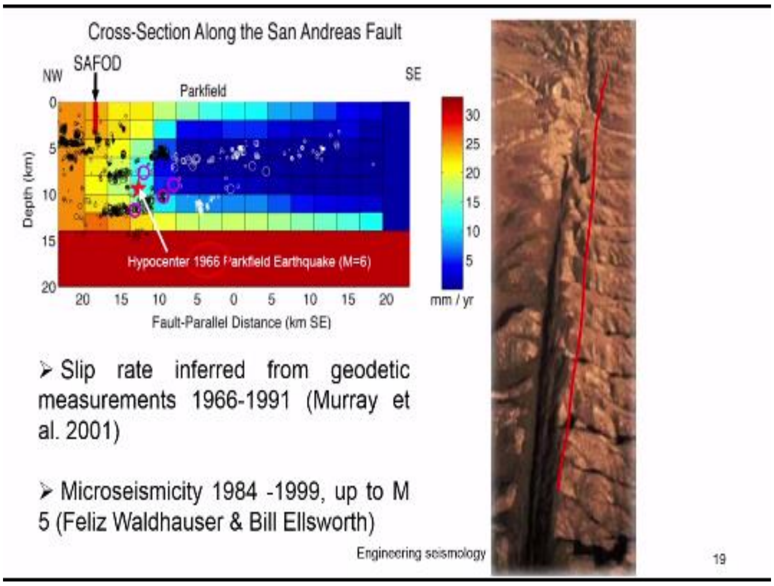

So this is actually the surface image of the San Andreas Fault. So where you can see basically the displacement say mm per year with depth you can see from 0 to 20 kilometer and then the fault distance from this side. So 20 kilometer that side 20 kilometer and where the far field earthquake reported and where the drilling is taken place, okay. So you can see how the displacement has been mapped very accurately.

The slip rate inferred from the geodetic measurement 1961 to 61. So they mapped and the microseismicity is 84 to 99 up to M 5 has been reported on from this study.

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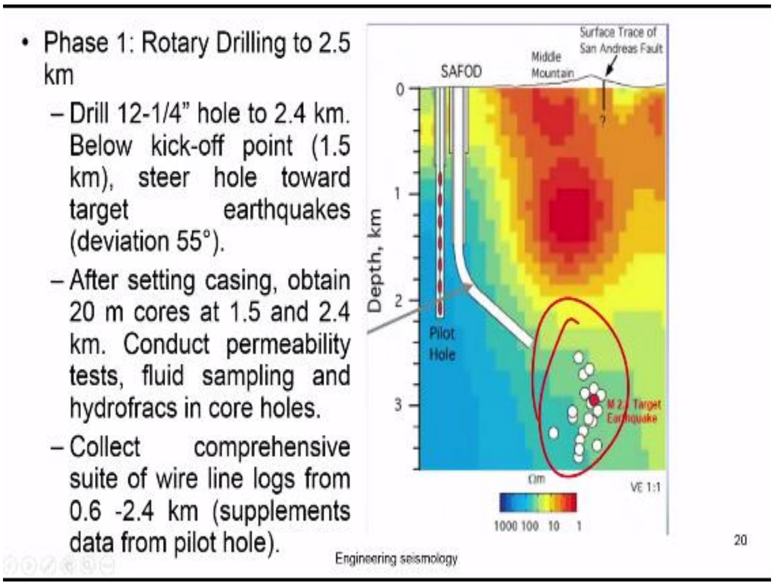

This was a very expensive study and taken by the San Francisco geological US geology, USGS okay geological office. So they have done. So basically they drill a very big hole vertically and then they found so it is not vertical. They found it is a deviation. Then they deviate and tried to drill and tried to measure those thing.

This is actually the resistivity imaging of the same area where you can see there is a huge difference of the resistivity values in the places where because of the heterogeneity in the fault plane area, okay.

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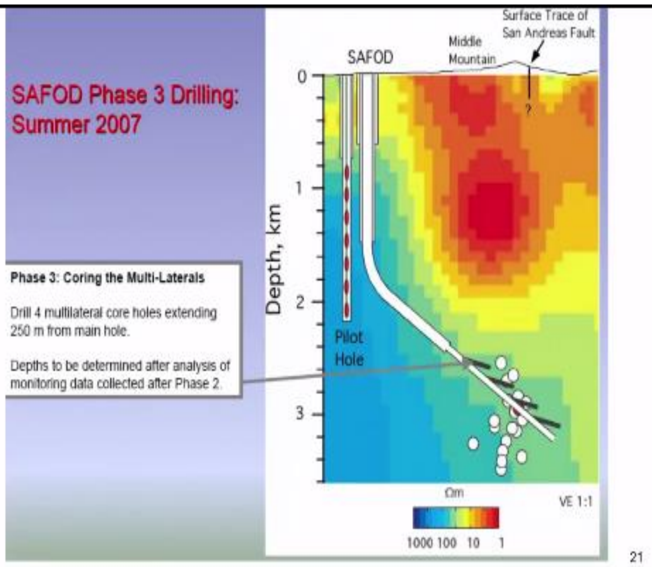

So this is again they installed like the inclined hole and then necessary instrumentation. Even their drill like this and tried to monitor. So the similar kind of basically observation of this drilling a deep bore hole and try to observe these kind of things is happening in India also. So if you look at a ministry of earth science website, basically the Koyna region, okay where they tried to understand how the Koyna earthquake regions are having this kind of behavior.

So they are drilling a hole and collecting the sample and tried to measure all those things. But it could be also noted that the Koyna earthquake is actually reservoir induced earthquake. We will discuss what is the reservoir induced earthquake when we are talking about the type of earthquake after this class okay.

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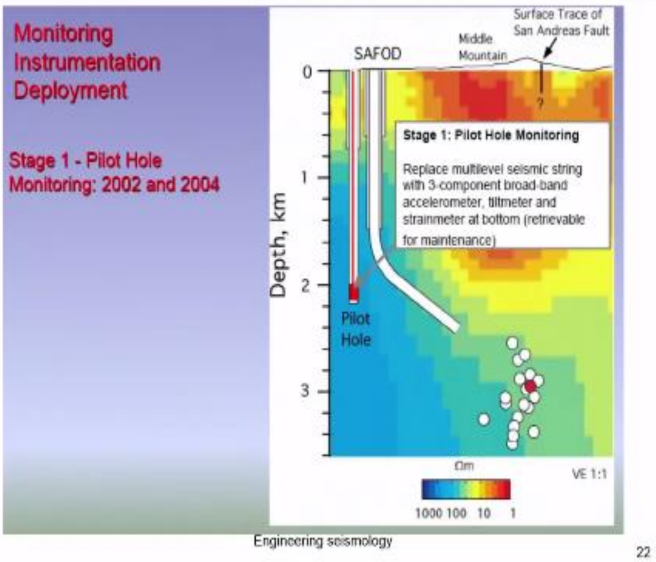

So this is a plane so where you can see that they have the like different set of multi size string equipment placed on the hole. They tried to monitor the observations whatever is happening. And then what is happening below some depth. So since it is a shallow earthquake it is very possible to get all this data.

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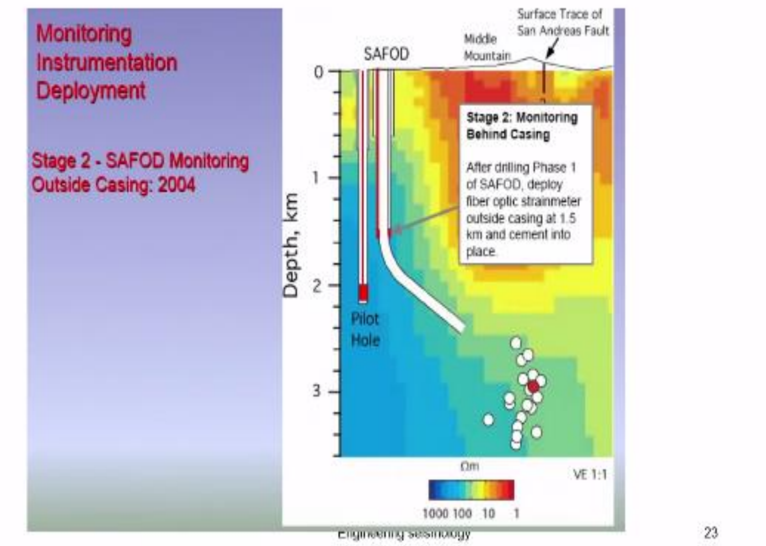

But if the earthquakes in these locations are very deep in nature, it may be difficult to drill as I said that drilling is not possible beyond some depth. For example, two to three kilometer you can drill depends upon the where you are drilling. Beyond that it may be very difficult to drill. You have to invest huge amount of money. Even there may not be technology to drill because you need a very hard material to drill which may not be possible.

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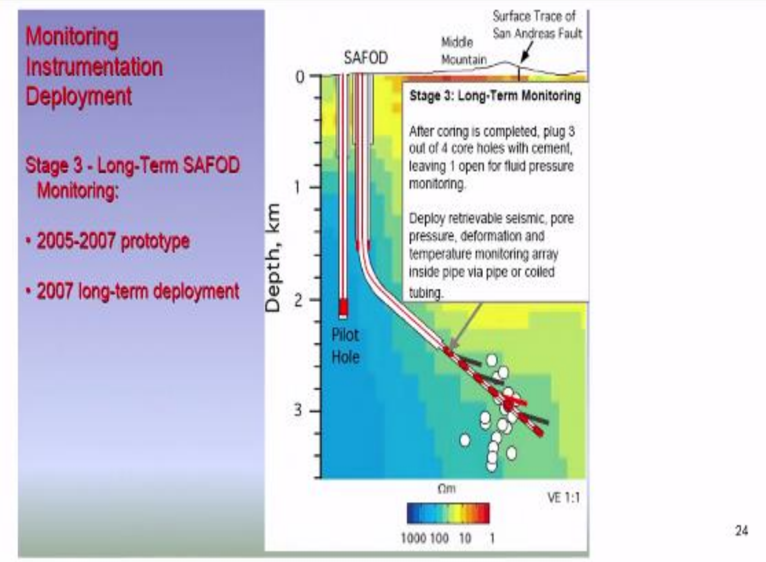

So these are all the things will help this kind of studies to understand all those things. But as I said that these kind of studies only taken up if you have the huge amount of the financial support and at the end of the day so even after monitoring all these things, so even this committee they found that the earthquake does not follow any sequence of the time to predict accurately, okay.

So only thing they could dig this and then find out that was the this one. So but the mapping up active default and cutting all those things technologies are available.

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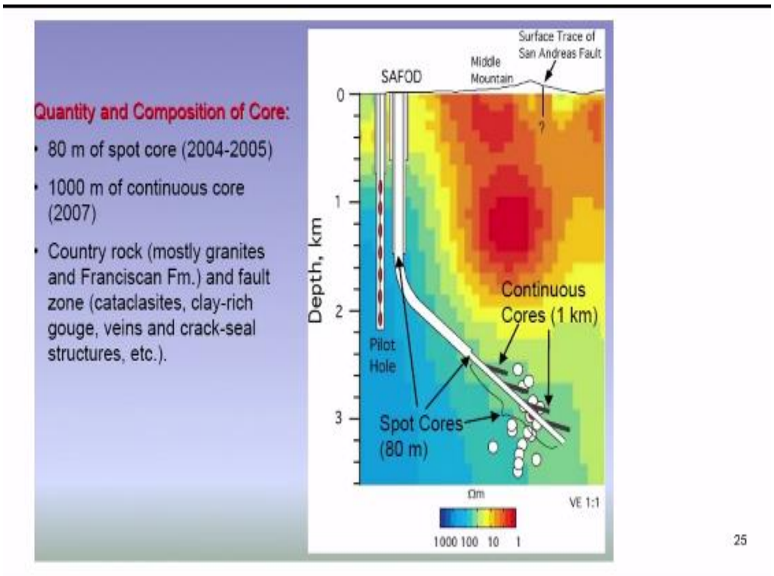

But as such it is very expensive and it is not advisable to invest so much money country like us, because the crores of rupees has to be spent okay for getting this data finally. So you will be this study highlighted that the earthquake sequence what is predicted okay. So basically is not following any specific interval. So that means the six magnitude not happening every 40 years, okay.

It happens sometime 25 years, sometime 40 years. So you cannot really predict how the earthquake going to happen. So that was the lesson which was learned from this. So but they could able to get a proper core samples okay. So core samples which will tell you that what was the material here, how this material behaves and some geological studies they have done and invested with lot of money on this, okay.

So like this so you can characterize the seismic source, type, and then identify it is active or inactive. And if it is active, what are the geological study you can see and what are the detailed drilling you can take place to do that. So apart from this, the fault can be also mapped using the aerial images. Basically, that is a separate topic of subject. So people use remote sensing as a tool to identify the surface geological features which is called as a lineament.

So that lineament they map first. Then based on the available earthquake data in the region they try to identify the earthquake and superimpose and which are the lineament which is experiencing a earthquake they call it as a active lineament, okay. That active lineament need to be accounted. So there was one PhD thesis by the Ganesh Raj who was a ISRO RESPOND manager right now.

So he did study on this kind of things. How the satellite image can be used to identify the active lineaments, okay. So the lineament mapping and then the study of lineament actually remote sensing and GIS related subject okay. So this is about the seismic source and fault, which causes a earthquake. So we will be discussing the type of earthquakes in the next class. So with this I close this class and thank you.