Earthquake Geology: A tool for Seismic Hazard Assessment
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Lecture # 16
Earthquake Forecasting and Prediction Model (Part I)

Welcome back. So, in previous lecture, we discussed about different types of seismic waves, body wave and surface waves and we also discuss briefly about the how the about the motion mainly.

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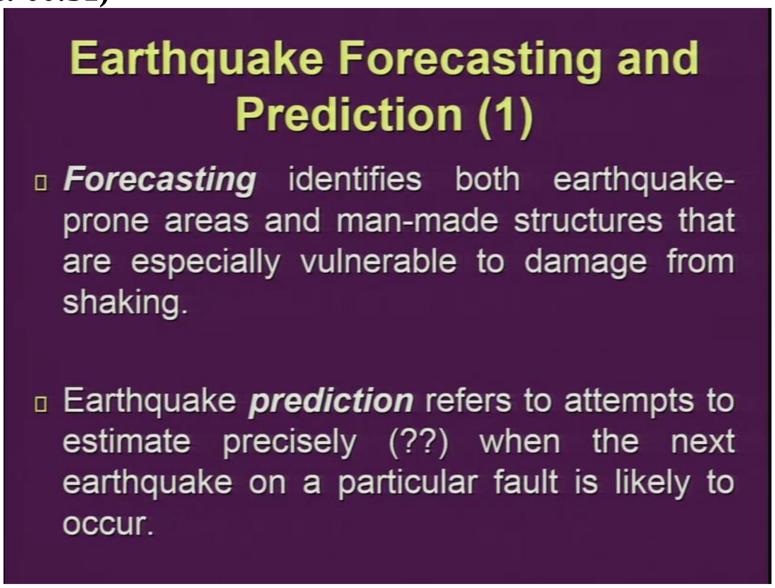

And coming to the last point, which we left out was the earthquake prediction and forecasting. And as I was mentioning that they forecasting mainly identifies both earthquake prone areas and man-made structure because mostly we are concerned about that what will be the damage which will take place because of the ground shaking. Now, earthquake prediction basically yes modify can precisely estimate the event, but in the complex nature of the earth is crust.

And the heterogeneity which exists within the rocks and all that, it is sometimes difficult that whether the earthquake will occur at the same interval or not. So, that is 1 of the limitation and other limitation is of the dating the earthquakes are the events that we will talk when we are discussing exponential part. Now, the idea is that, if we do the prediction then on which particular fault the earthquake will occur, that is the important part.

So, the previous lecture we saw some figures which were I was trying to show you that there are different fault lines within the fault zone and those fault lines slips at different rate.

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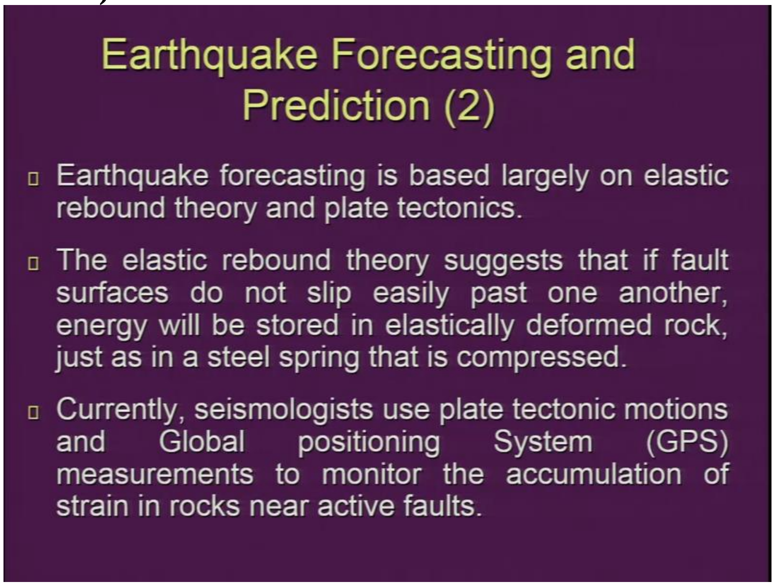

Now, coming to the other part of the earthquake prediction and forecast. So, earthquake forecasting is based largely on elastic rebound theory and plate tectonics. So, the elastic rebound theory suggests that if fault surfaces does not slip easily past one another energy will be stored in elastically deformed rocks just as a steel spring that is compressed. So, what basically this means, so, it is not if the fault plane is locked or the 2 blocks which are adjacent to one another along the particular fall plane.

Then they are not sleeping but at the same time because of the continuous ongoing deformation, it will keep storing the energy and that energy has been stored in elastically deformed rocks. So, after the ratio limit, they will slip and result into the earthquake. So, if you use this the formation that is elastically deform rocks and the energy that is getting stored which can be measured with the help of the GPS station.

So, continuous GPS stations if you are having so, that can help you in understanding that which portion of the along the fault line is getting compressed or is storing the energy and so, along with the value seismic studies, GPS measurements is extremely important because they will help us in monitoring the accumulation of strain in rocks near the active faults. So, in most of the countries even like now, we have started in India also, since last couple of decades I would say that most like past 10 to 15 years, the GPS installation has been intensified.

And that has been done under the flagship project of Ministry of Science and many stations have been installed, which are doing 24, 7 recording of the coordinates in Andaman. And that was done after 2004 and even after 2001 Bhuj earthquake administrations we have been put in Kashmir region by Institute of seismological research, and mostly in Andaman Survey of India and other regencies like NGRI national Geophysical Research Institute has are installed.

the station is GPS stations in Andaman also and in coming to the Himalayan part, many stations have been installed in the central Himalayan zone and we but I did cannot we have installed almost like 15 stations and we are going to install more and these are all permanent GPS station. So, it will keep on recording the coordinates 24, 7 and the any movement or any information which is taking up in the crust will be recorded because the coordinates keep changing and based on that one can easily make out.

That which area is performing with a higher rate and which area is performing with a lesser rate and that will help us in understanding the pattern of stream accumulation in different blocks in the act tectonically active regions. So, what we did there was that we have taken into consideration the active faults because these are the areas where you will expect the next earthquake.

So, the aim was to tap such features on the surface and the GPS stations will be installed accordingly. So, based on this recording also one can understand that for which area is going to trigger the future earthquake.

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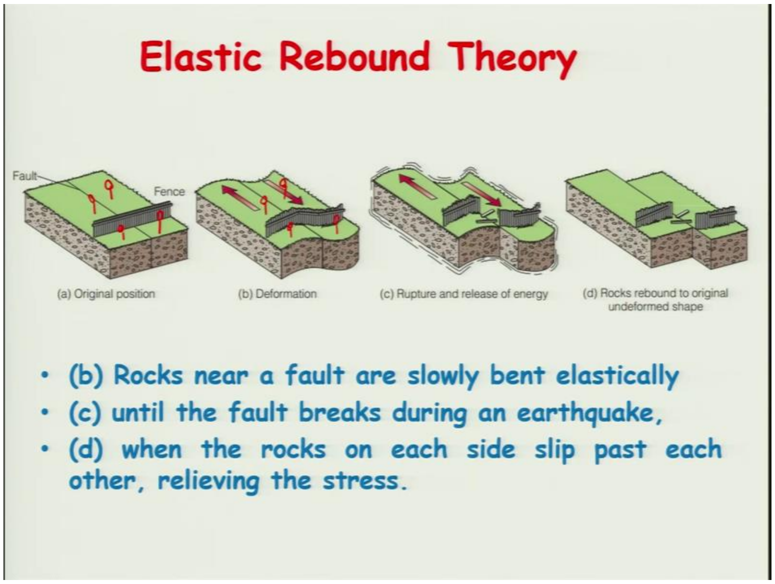

Particularly in seismically active zone regions. So, how it works? So, if you look at the sketches which are when are the diagrams? Schematic diagrams which are given here it shows that there is a fault line here. So, this is a plant view and any management structures and as I was showing you in the previous lecture even the landforms the naturally formed features on the Earth is surface like drainage or the surfaces, they will get deformed because of the ongoing deformation.

So, this is an original position of defense and the fault line and since the formation is ongoing before it finally slip it will get deformed and depending on the what is the moment along default, so, this it shows the right lateral where this block is moving towards right towards us and this is away from us. So, this is a right lateral one so, fence will be deformed like this again but this process is very slow. So, you cannot make out easily by a naked eye so, GPS if they are for example if they are installed for example 1 is GPS has been installed here.

And another one has been installed here. As well as here, then this GPS stations will be able to will help you and understanding because the position of the GPS will keep changing. So, if you are having 1 is here another one was here and third one is for example, here, you can have one more here also basically what we have done in harmonic is not a we have taken into consideration the fault lines and across the fault lines we have tried to install the GPS station.

So, this coordinates will tell you changing the coordinates will tell you that how much amount of slip has been accumulated or what is the pattern of deformation and how much strain is getting accumulated along this fall time and finally, what we see is the rupture. So, this is the process of the deformation which may take 100 years or more than that, because in Himalaya, what we have seen us not the recurrence of the earthquake is almost like 500 to 600 years.

So, the ongoing deformation can be easily picked up based on th is and whatever the deformation will occur like this slip final slip or rupture would be release of the energy this is release of the energies here earthquake at that time, you will also get things recording the GPS as well as they will be also a manifestation on the surface will be seen in terms of the displacement of the landforms and any man made structure.

So, it shows that there is a deformation which is elastically deformed, then there is a rupture and then the rebounds because the material having some elasticity, so, they will try to rebound to original undeformed shape, but then this slip which has occurred. So, we will see that is beloved and this deformation will get preserved on the surface. So rocks near a fault as slowly bent elastically that has been shown here until the fall breaks during an earthquake and when the rock on each side slip past each other revealing the stresses.

So, this is what has happened here in the d. So, this process remains very much similar in any type of deformation regime, either it is compressional or it is normal or extensional or unstack stiff regime.

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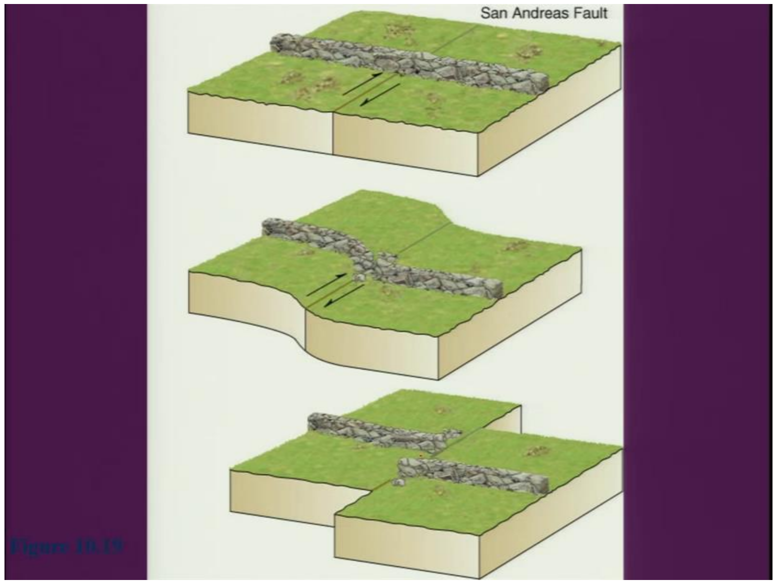

There is another example of San Andreas Fault system which has been shown here so, you have some management structure which will get elastically deformed and finally it will break along the fault.

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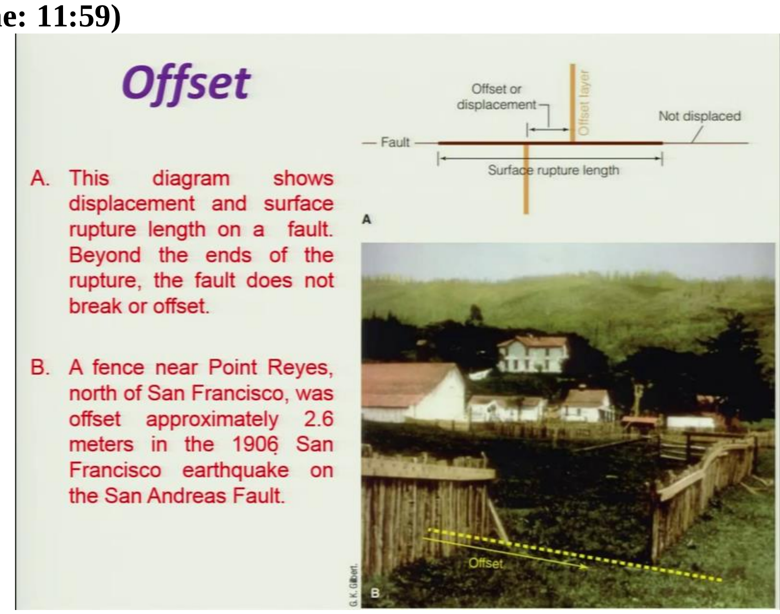

Now then this was observed in 1906, San Francisco earthquake along San Andreas Fault system, where the big difference spot offset along the unfaltering 1906 San Francisco earthquake.

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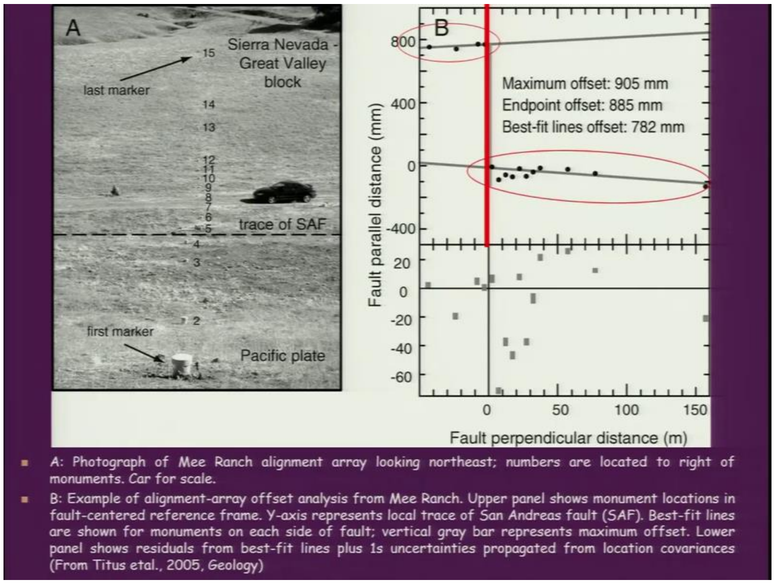

So, how GPS can help and this has been shown here again, now, along the or across we can see across the San Andreas Fault system. So, what they have done is they have put number of GPS stations along the way across the fault line along this same the same transit here. And you can see the, that this is the fault line which is, which was been marked, and the same pattern, mode methodology we are also following in Himalayas.

That we have the fault trace we want to monitor that what is the amount of strain which is been getting accumulated along the particular fault region. So, now then if you see there from 1 to 15 GPS stations which have been installed here and which shows different moment. So, this is what you are having the maximum offset has been seen along between this one and this is the fault line here.

So, the photograph which shows the aligned deployment of the GPS station a number of numbers are located on there. So, these are the numbers which have been given here 1234 and you can see the car for scale here. So, the B example, this is after the measurements what they have it sphere observed is the alignment array offset analysis along the Mee Ranch area. So the upper panel which has been shown here, shows the monument located in the in fault centered reference frame.

So these are the this is the fault here and these are the this stations which you can see here, so these are all it shows the offset so initially there is all stations with in and the same line, so this was a transit but now after the formation what they are able to see is the displacement. So the maximum offset they were able to pick up was almost like 905 millimeters between this one so there is an offset along this line.

So this shows the default plain, fault parallel displacement are the distance. So, along which these this 2 array of GPS is shown here. So, maximum displacement was the almost like 905 millimeter whereas, the endpoints are the offsets so, what it says suggest is that the displacement or the deformation is slightly variable but of course, with the help of this event can make out, but what is the amount of strain which is getting accumulated along the fault lines.

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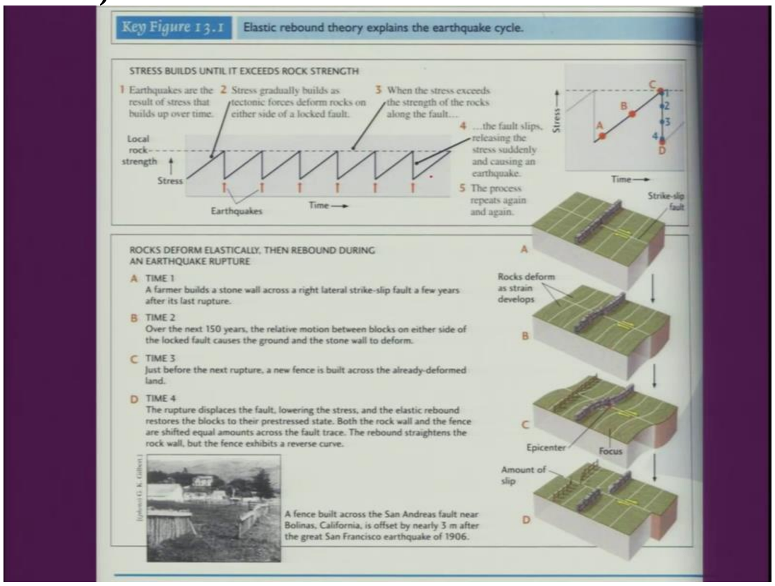

So, in 1 of the slide we also discussed that, if the sun the rock strength remains the same, the material which is under deformation remains the same can we will have a very typical like strain lag between the 2 events. So, this will be the time of the strain accumulation and this is the event is the strain accumulation this the event. So, this will be very systematic, but this never remains the same because of the heterogeneity of the material, as well as the, the rock strength, we will see change over the strain because of the fracturing or the displacement which has been taken up by those rock blocks along the fault zone.

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So, this we already discussed now, I will show a couple of pictures if possible in the next slide, that how this different faults are behaving. And particularly we will talk about some signatures of this fault, Hayward Fault, which is creeping basically.

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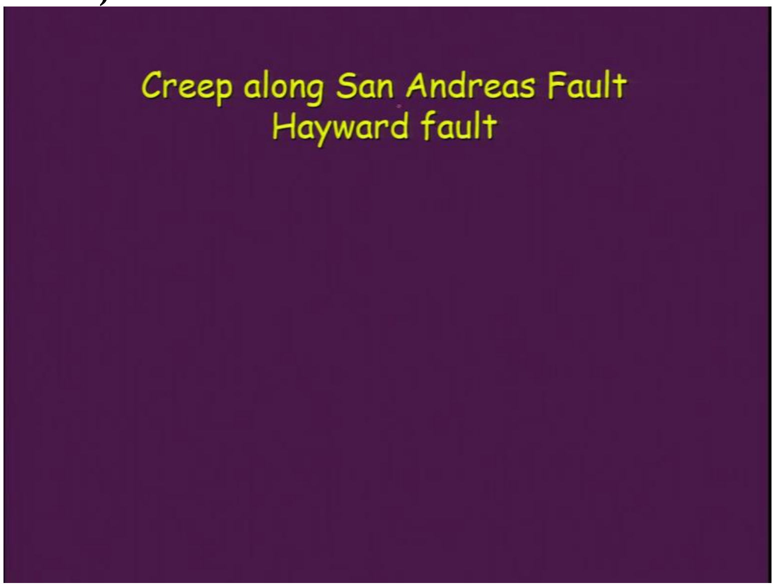

So creep along the San Andreas Fault system that is along the Hayward Fault, which is a part of the larger fault system that is San Andreas.

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So people stay here in this region and the fault goes along this line and but now since they have confirmed and this is an active fault no construction has been allowed here, but those who are staying here they understand the hazard long this fault there is Hayward Fault and since it is creeping one can easily pick up the deformation which is either seen in the displace walls or either seen on the payments as well as the pedestrian pathways which are getting deformed over time.

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So, the pedestrian path, if you can see this is completely getting folded here or offset it here, along this 1 is fault line somewhere along this line here. So if you if we put the fault here long this one this is what the boundary it comes again this was an offset. So, this block has moved in this direction and this fault is creeping Hayward Fault is creeping. So, one can make out not how much and the deformation has been consumed by this.

So, local people who are staying here are facing problems and but this with the understanding they are trying to cope up that how they can fulfill and make their structures more stable or safe because of this ongoing creeping. So, the utilities like pipelines of the gas pipelines for the sewer lines or maybe you can say the water pipelines, they have kept it something in an very elastic nature of the pipes we are been installed. So that this can be this creep is has been consumed because of the displacement along the Hayward Fault system.

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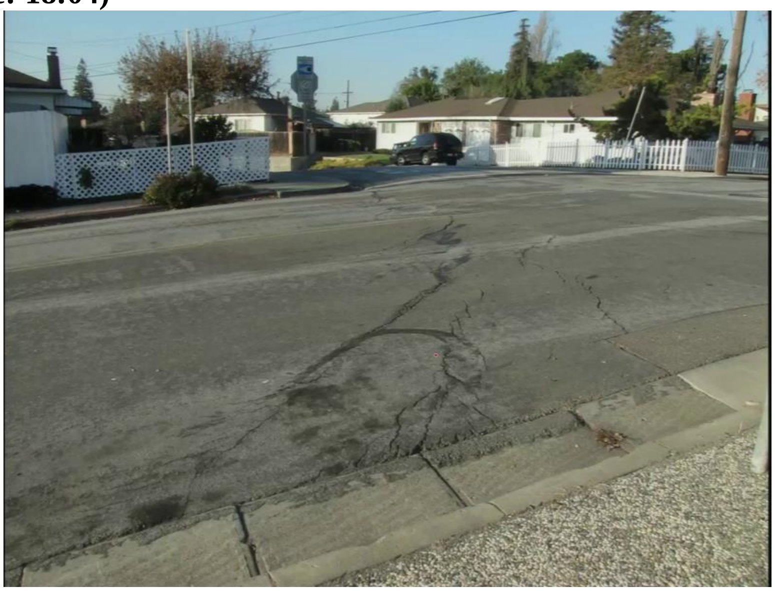

So, this is another example of the same region which shows the displacement and the fall strains somewhere over here, this is 1 portion and another one is coming over here. So, they keep on repairing this I will show the close up of this one. And you can see the shear fractures which have been deformed because of the displacement which is occurring along the Hayward Fault.

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So, this is the close up of that payment over here, this is the portion and the next slide. So, this of course this was not horizontal or straight feature we can see which was going like this but now it has got displaced as my so this is displacement amount of displacement which is occurred over the time.

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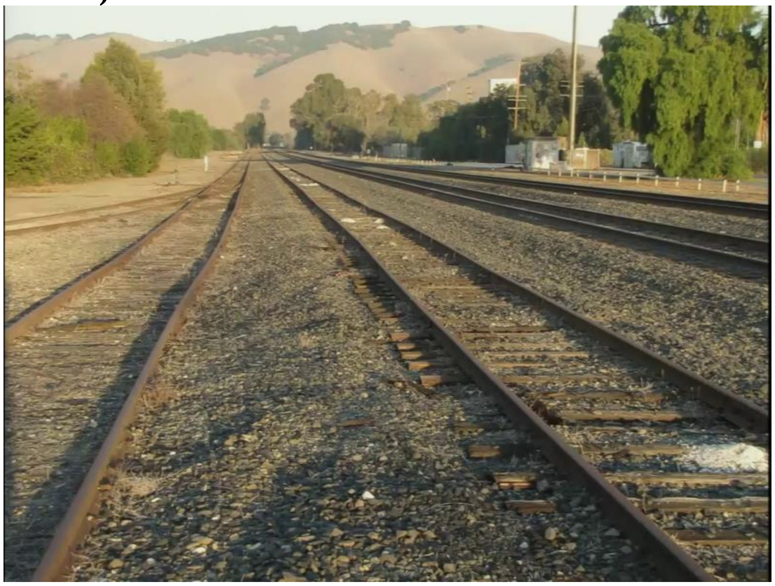

Similarly, because they are having the understanding of the ongoing deformation along this fault what they keep doing is because then it cannot like fly over the default but you will have to survive along with default only. So, if you see the offset here of this rail track, these are the oldest rail tracks and they are been replaced by the newer one. So, by the time this will get deformed they will replace another new one along this one. So that the transportation is on every time.

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There is a close up of that so, if the offset you can see the fault and somewhere over here like this until you have an offset of the so, this is because of the creepy now, this since the creeping is comparatively faster. So, energy is not getting stored along this fault, but it is in slipping. So, this is very fast in terms of the overall the formation. So, of course, the overall slip if we take is around 9 millimeter only. So, the overall fault is not sleeping so fast but the creep what we see is been manifested around the surface and that has helped in understanding the ongoing deformation pattern in this region.

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So, this is another example of a displacement offset in 2004 and then offset in 2006.

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This one is another example where the water pathway or the train way is been offset it along the San Andreas Fault systems.

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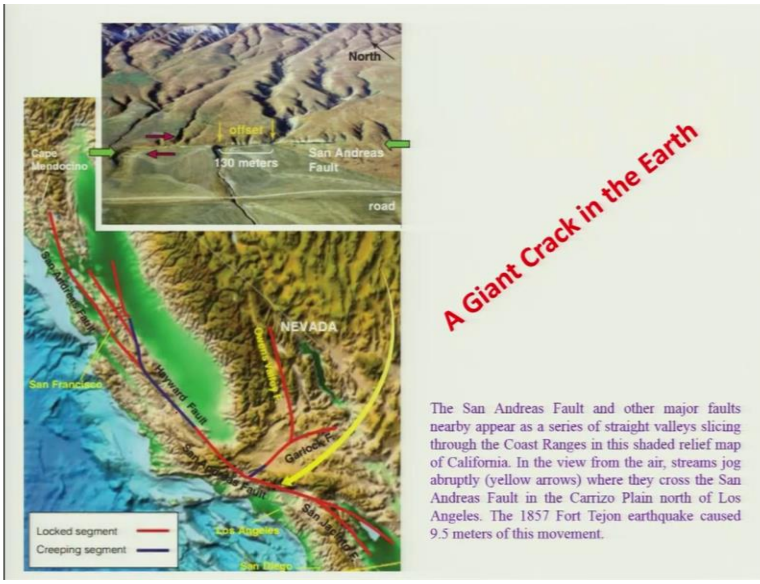

The Hayward Fault so, in many region like San Francisco as well as the Hayward Fault here, they know that were exactly the fault lines are passing through and they also know that what is the amount of stuff has been taken up along the respective fall. So, this is what they see a giant crack in the earth that is your San Andreas Fault system is crossing beneath many of the cities.

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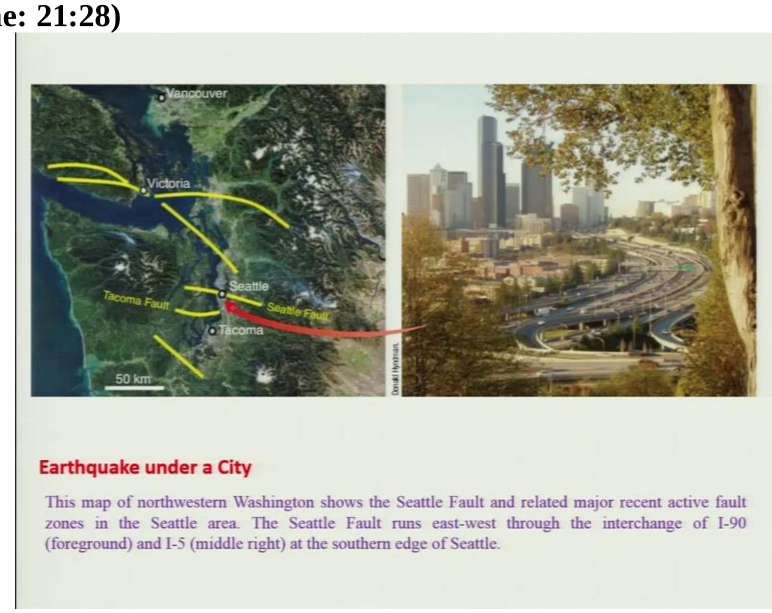

So, this is an example from the Seattle where the major fault of Seattle fault which passes through so they also know and then the construction has been done accordingly keeping in mind that what will be the magnitude, if the when the next earthquake will be triggered along that particular fault.

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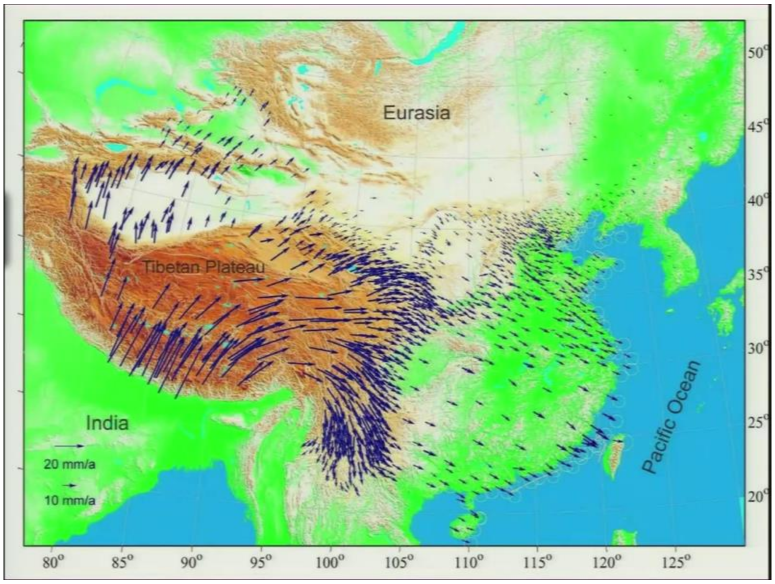

Now, looking to the GPS part, this is what it can help, it can also make us understand that what is the well city of at different points and if you are having unclosed array of the GPS networks and then you can also make out that how individual faults are behaving. Now, if you carefully look at then most of the away part which is sitting in India is not having, many GPS stations. So, this figure is of course, bit old, which does not show the location of the GPS in this region which are already been installed.

This is Nepal part so, in Nepal, we have many look GPS stations, which are recording the ongoing deformation in Himalayas, but now, we are covering this part and then some agencies the institutions have taken up putting the GPS stations in Kashmir region also.

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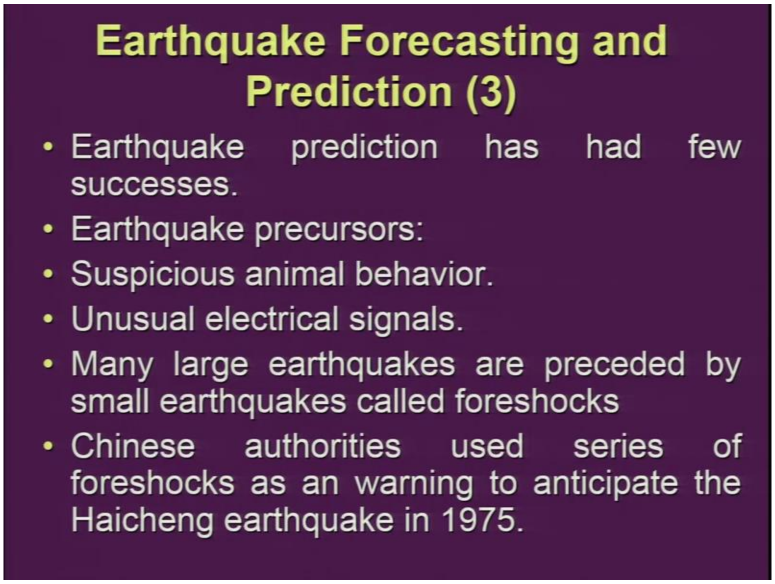

So, the strain accumulation can help in predicting and forecasting the earthquake if we take the GPS measurements, so, we have like, 2 type of information with us so, one is we are doing the Paleo seismology now, this will give us long term deformation and then second one is your GPS. So GPS will give you short term because in Paleo seismology basically we are going to look at the deformed landforms.

So, this deformed landforms are definitely the during the previous earthquake, so, more than 500 600 years old or at least what we have been talking about since beginning that at least that deformation goes back up to if it goes back to 10,000 years. So, in that sense we are talking about the long term deformation whereas, this we are saying we have started recording since last 50 to 60 years.

So, this 2 type of deform deformation we can gather and with this and both of them complement each other activity. So, we understand with the bio based on deform the paleo seismology we understand the long term deformation and with the GPS to present deformation ongoing deformation which can be picked up as what we call the short term deformation. So, this 2 part goes side by side along with this we also will get and like we can use the seismic networks also to understand the distribution of earthquakes.

And all that and that can also take be taken into consideration when we are talking about the overall a hazard assessment. So, long term we are having from the paleo seismology studies because we are going to studies the landforms and short term is the GPS measurements we do. So, these are the 2 important pillars, which can helps us in identifying the pattern of the formation. So, earthquake prediction has had a few successes and one of the best was from China, which will just immediately talk but mainly what the successes is been achieved until now is based on the precursor regiment events.

So and then one can also look at the suspicious animal behavior, then unusual electric signals. Many large earthquakes are preceded by small earthquakes called foreshocks. So if you do continuous monitoring of the foreshocks or because you does not know that whether this the desire the foreshocks or now the main shock will come so, there is no like you cannot conclude it, but at least you keep on monitoring the micro seismicity.

And if there is some unusual pattern which has been observed during the recording, then you can try to predict the future, or forecast the earthquake. And these are all short term predictions. So many large earthquakes are preceded by small earthquakes called foreshocks. Chinese authorities used series of foreshocks as a warning to anticipate the heightened earthquake in 1975. And they were extremely successful in this are they have ever been able to predict this and they forecasted this.

And that was been done based on the analysis of the small magnitude earthquakes, which because there was a main earthquake, which was triggered as they can they, categorize those small earthquakes as in portion.

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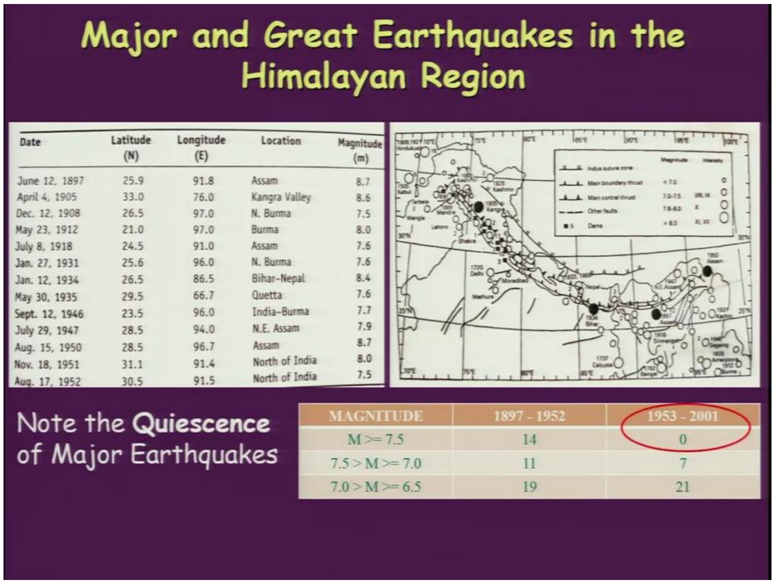

Majors and great earthquakes in Himalaya, so another study, which also highlight that there was successfully they were unable to identify and predict of the earthquake major earthquake in Himalayas. So, if we have looked at the information, which is available, other than what we have been talking about, and few of them are listed here, but, we discussed about some historical data also. But if you take the good record in the sense we have having the latitude, longitude of those earthquakes and the magnitude also then we have like from 1897 it goes back into the 1952.

So, those are the locations of those earthquakes large earthquake So, I was talking about that we had like in 20th century if you list down this 1 from here, from since 1905. We are having many earthquake pictures have occurred within magnitude greater than 7. And some of the earthquakes have been assigned like magnitude above 8.5. This was been resized that is Kangra Valley fault earthquake, which was resize 7.8.

But anyway, if you see those, this listed earthquakes and they are about 7.5 all are about 7.5 and most of the earthquakes which are recorded are from the 20th century. And so, we if we have more data from the paleo seismic investigation, we can easily have the somewhat complete data set of the seismic events can help in better prediction. So, these are the 3 major 1 which has been shown by black dot see as along the Himalayan arc and this is slightly away from the Himalaya that is 1897 shall long earthquake.

So, what it was been observed considering this available later that there was a period of Quiescence where the 7.5 magnitude above or equal to 7.5 almost 14 events have occurred between 1897 and 1952. So, almost 14 events but from 1953 onwards until 2001 no earthquake has occurred. And of course, if you try to incorporate more data than we have after 2001 the magnitude about 7.5 we have 2005 Kashmir earthquake or Mozmabad earthquake.

And then another one is 2015 Gorkha earthquake we are having so, those too will be added here and then but the with the magnitude ranging from 7.5 that is greater than and less than equal to 7, a 11 events have occurred in during this period and 7 events have occurred during this period, but, and similarly goes for the delay is greater than equal to 6.5 we have 19 events and then we have 21 events.

Now, the occurrence of number of occurrence of this earthquakes with magnitude in around 6.5 is not going to suffice the amount of energy which is going to be released during this magnitude earthquake. So, many earthquakes will be required in terms of number to supplies this one so, this still remains they the gap here. So, this is what has been told that the presence of major earthquakes since 1953 and 2001 so I will stop here, and we will continue in the next lecture. Thank you so much.