Introduction to Engineering Seismology
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Lecture – 39
Seismic Gap

So, vanakkam, so we will continue our lecture on engineering seismology, so we have been discussing about the prediction of the earthquake, so we have seen that the earthquake can be effectively predict, so if you observe some of the precursors, what are the precursors we have discussed basically, we discuss the unusual animal behaviour which is very success in predicting Chinese 1975 earthquake of magnitude 7.3.

So, apart from that, so the Chinese people also related the other unusual other behaviours such as a raise in the water level, hydro chemical process okay, raise in oil wells okay, raise in the temperature in the region okay, chemical concentration in the water, so all those phenomena they clubbed together along with foreshock, they effectively predicted magnitude of 7.3 before 6 hours where they could save a life of millions of people okay that was one of the very best classical example of the earthquake prediction success, okay.

So, which we have seen that all this prediction okay, the animal behaviour as well as the well level variation, temperature all ring linked with the crust. So, if you have the crust; earth crust projected to the ground, the wells are drilled in those crust okay because this deformation will be well represented in the raise in the water level as well as raise in the oil level and also the temperature variation.

Because the crust going to twist okay because of that there is a change in the pressure and temperature of the crust material which reflect in the region okay, which has been sensed by the animal as well as a instrumented wells and as well as the data recording in that region. So, which is very classical example that when there is a crust close to the surface, you can very well predict these parameters accurately thereby you can also predict an earthquake in that region, that period depends upon the different observation.

We have seen that there are about 2, 3 hours early to the 72 hours early people are observed on different phenomena, so this is basically works well when the crust rock projected to the basically in the region. But in case, okay the crust rock below some level, so that is the some of the places like if you want to see the rock level at Indo Gangetic Basin, so particularly the Uttar Pradesh.

So, if have to see you have to go at least 100 meter to 4 kilometre, 6 kilometre below the surface, so those kind of region even this kind of things are maybe very difficult, okay so that we have to keep it in mind. So, the similar way of other this one there is a data based earthquake prediction which is explained in the coming few prediction methods. One of them is basically, theory of seismic gap okay, so what is mean by seismic gap?

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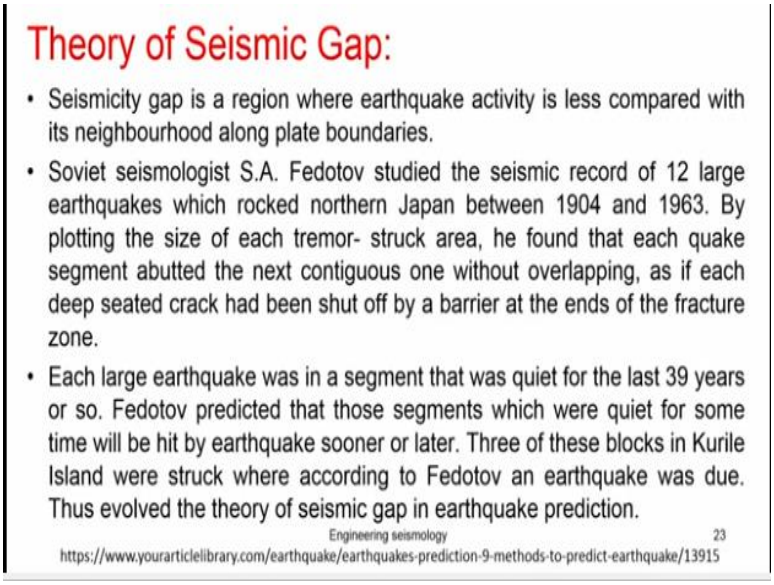

The seismic gap is a region where the earthquake activities less compared to the its neighbourhood along the plate boundaries, so this seismic gap basically concept which is applicable in the closed to the plate boundary. The Soviet seismologist S.A. Fedotov studied a seismic record of 12 large earthquake which rocked northern Japan between 1904 to 1963 by plotting the size of each tremor- struck area.

He found that each quake segment abutted the next contiguous one with overlapping, so this deep seated crack have been shut off the barrier end of the fracture zone, so each large

earthquake was segmented that was quite for a large 39 years, at least last for 39 years, Fedotov predicted those segments which were quite for some time will be hit the earthquake sooner or later, three these blocks are Kurile Island where struck were according to the Fedotov an earthquake was due, so thus endowed the theory of seismic gap in the earthquake prediction.

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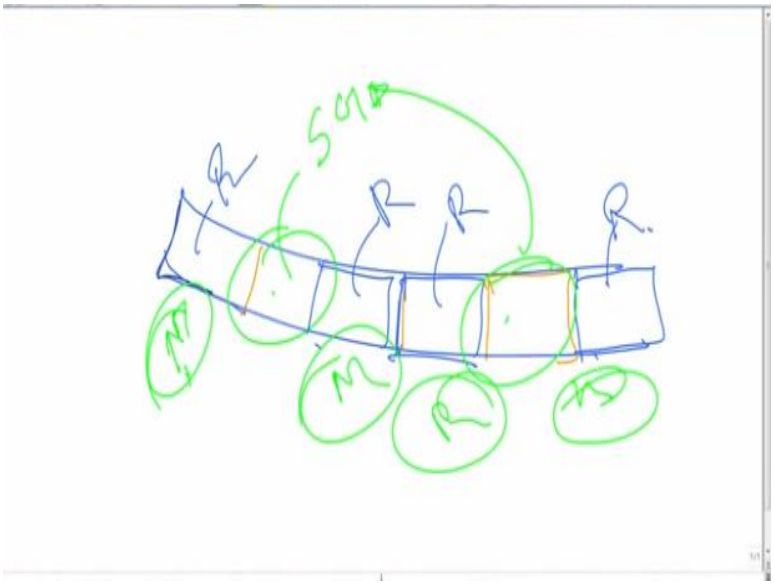

So, what it means basically, the seismic gap means, so basically the seismic gap okay, so this is a basically a plate section, you assume this is the plate section okay, this segment ruptured, okay so this segment ruptured, so this is the segment which is not ruptured, this segment, so this segment ruptured, so this segment ruptured, so this is a segment not rupture, again this segment rupture, so this is the ruptured, ruptured, ruptured, ruptured, so this is the area where there is no rupturing, so this is called as a seismic gap, this is called as a seismic gap.

Since this you know that what is the M and happen, this is a M happen, M happen, M happen, this place there is no M is happen, so that means this area potential for the future big earthquake similar to this range, so that phenomena is called as a seismic gap, so where people can say that this big earthquake can be expected on this area okay, so such kind of statement can be made from the seismic gap kind of theory, okay.

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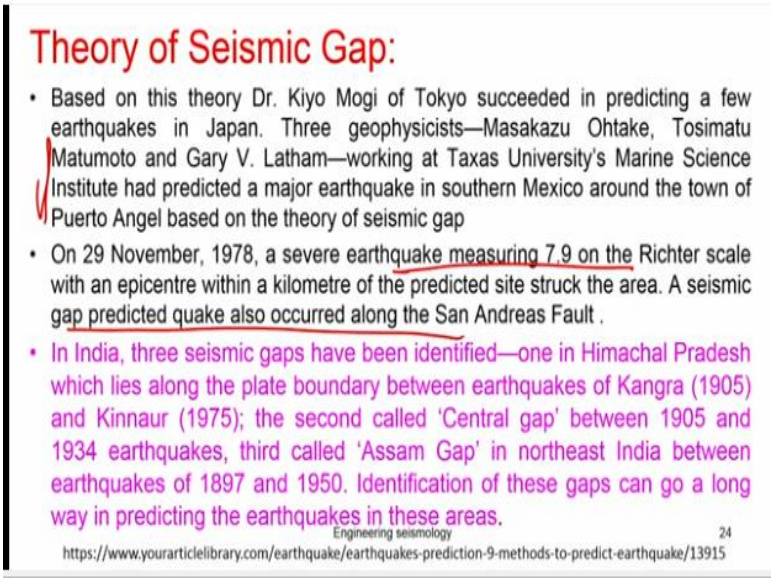

So, the seismic gap concept has been extended okay, so based on this theory, Dr. Kiyo Mogi of Tokyo succeed in predicting a few earthquakes in Japan, 3 geophysicist; Masakazu, Ohtake and then Tosimatu, Matumoto and Gary V. Latham working at Texas University, marine science Institute had predicted a major earthquake in southern Mexico around the town of Puerto Angel based on the theory of seismic gap.

So, this theory has been used and many people predict the earthquake, on November 29th okay, so on 29th November 1978, severe earthquake measuring 7.9 at Richter scale with epicentre with kilometres of the predicted site struck an area, a seismic gap predicted quake also occurred along the San Andreas Fault. So, this is where the predictions are basically success, so you should have the complete knowledge of the segment earthquake produce in the particular region, then you could be able to predict an earthquake there, so that was the one of the beauty.

This seismic gap not only exist in those areas, this seismic gap also exist in India, so in India 3 seismic gaps are being identified; one in Himachal Pradesh, which is lies along the plate boundary between earthquakes of Kangra okay 1905 to the Kinnaur 1975, the second called central seismic gap between 1905 to 1935 earthquake, third called Assam gap in the north east India between the earthquake of 1899 to 1850.

Identification of this seismic gap can go long way predicting the earthquake in this region, so that is why many seismologist okay, so the Bilham is actually, the origin of predicting seismic gaps in Himalayan region, many seismologist believe who follow a Bilham literature and all including I also accept a Bilham theory on seismic gap at Himalayan region, so there may be a big earthquake due at plate boundary at Himalaya, northern Himalaya particularly.

This earthquake occurs, there will be a huge infrastructure's failure and many people will die in the northern part of India but I do not know when it occurs as the sequence of the earthquake occurred in Himalayan plate boundary is not well define okay. We have only few earthquakes not all, so because of that the time prediction of the future earthquake is problem but it is believed that there is a seismic gap in Himalayan belt.

It is theoretically and experimentally also people believed that there is a seismic gap in Himalayan belt, that gap releases an energy that may cause a magnitude of 8 and above okay, 8 and above can be expected which will affect basically the entire Indo Gangetic basin and Nepal. So, even in 2015 Nepal earthquake believed to be a not part of the seismic gap but it is a the interaction or initiation of the seismic gap in the region, the resolves are people are believe.

So, there is a paper related to this, those who want to study about the Himalayan earthquake, work on this region (()) (09:30), so it is always advised to consider this for the particularly very important projects like a nuclear power plant, dam construction, okay, so the multi-level hazard record for the infrastructure development need to consider this as a probable future earthquake location in the Himalayan region for the design purpose okay.

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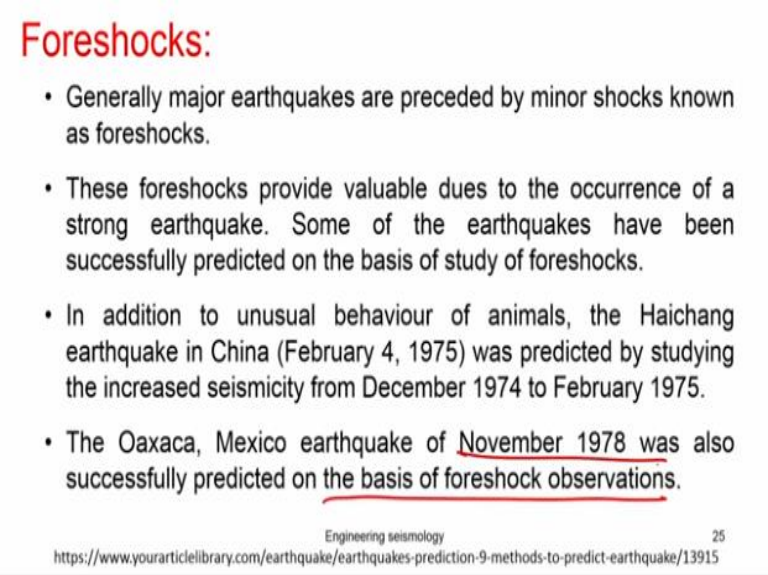

So, this is a seismic gap theory and earthquake prediction, so the next one is actually the foreshocks okay, the foreshocks as we have seen that the foreshocks are the earthquake which is occurring before a main earth shock okay generally, the major earthquakes are preceded by the minor shocks as we called as a foreshocks, this foreshocks provide valuable dues to the occurrence of the strong earthquake.

Some of the earthquakes have been successfully predicted on basis of the study of foreshock in addition to unusual behaviour of animal okay, so Haichang in China earthquake are the classical example where the foreshock and unusual behaviour clubbed together, then the Oaxaca, Mexico earthquake November 78 was also successfully predicted based on the foreshock observation okay, so these are all the classical example where other precursors are linked with the foreshock and then the earthquakes are predicted.

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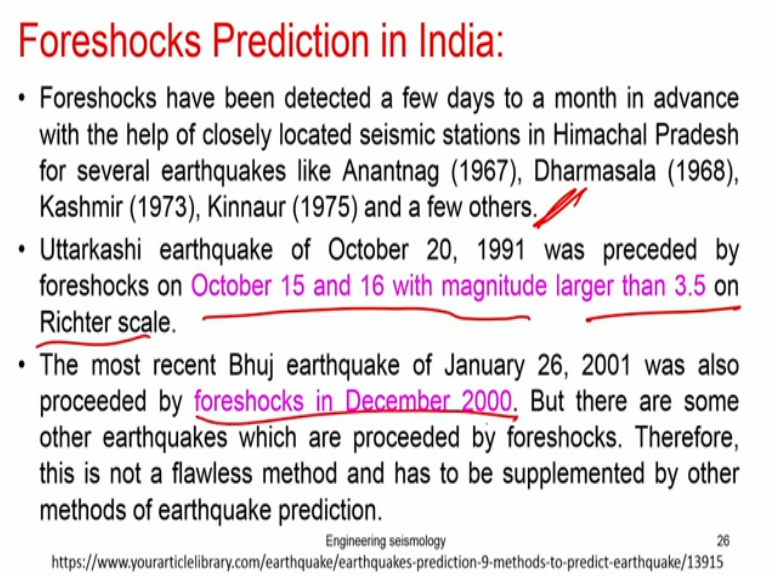

The foreshocks have been detected even in India, so the foreshocks have been detected at a few days to a month in advance with the help of closely located seismic station in Himachal Pradesh of for several earthquake like Anantnag, Dharmasala, Kashmir and the Kinnaur, and few others but these are all data's are reported, okay people said that this is the foreshock but this mainshock not warning system issued.

So, the Uttarkashi earthquake of October 20th okay, 1991 was preceded by the foreshock of October 15, 16th magnitude larger than 3.5 Richter scale, the most recent project Bhuj earthquake January was also preceded by the foreshock of December 2000 okay but these are all some other earthquakes with were preceded by the foreshock, therefore it is not flawless method to supplement by the other method of earthquake.

So, the foreshocks is and related with the animal behaviour one can say that the earthquake predictions are more or less accurately possible but if there is a risk here some location, the foreshocks are few days before some location, the foreshocks are few months before some location the foreshocks are few years before as we have discussed in the some of the classes in the previous, I told you that there is a foreshocks being frequently reported in the NCR region of Delhi okay.

So, this NCR region, the foreshocks are reported, if there is an unusual animal behaviour on the same area, epicentre area, there may be a big earthquake within the 24 hours, so somebody monitors that there will be definitely say okay that can be used but the people should work in that region should aware both of them okay, like there is a foreshock, this epicenter region people always should monitor the burrow animal particularly snake, rat kind of behaviour in that.

So, then see that unusual behaviour, they could easily predict a bigger earthquake it going to happen in that region whenever okay, so that is a phenomenon, the foreshocks are more helpful for the forecasting the earthquake.

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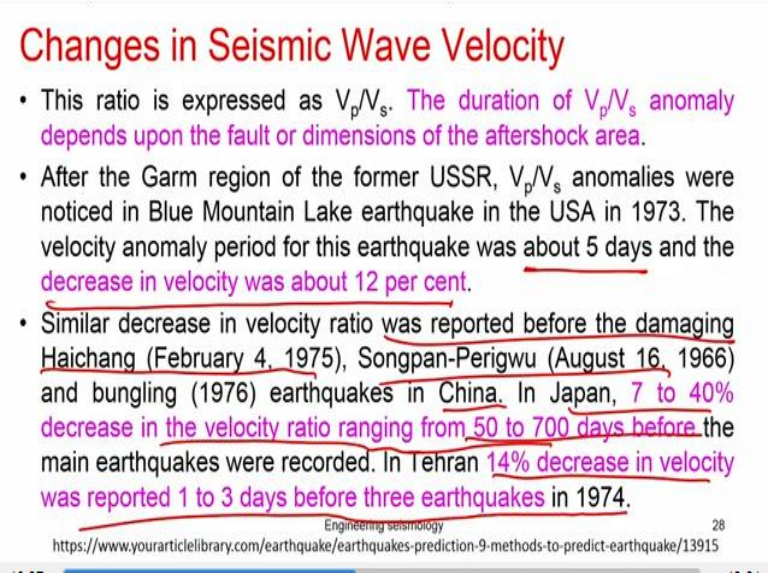

So, the another phenomena scientist also observed that changes in the seismic wave velocity, so as we know that P, S and L waves are originate from the earthquake focus and propagates and reaches to a particular site based on the site where the site and epicenter is located. As we know the P wave comes first and S wave next and L wave, then later valley wave. So, this is the sequence of the wave which we have seen by studying a theory of wave propagation, wave character and all.

So, the time log between the arrival of P and S wave is called as a lead time that is called as a lead time, thus Russian seismologist found that the lead time begin to decrease okay significantly for a days and weeks and even a month before an earthquake. So, the lead time for example, the

P wave and arrival there is a ratio, you can get constant for a particular region, this value goes below that constant value okay, then there may be a big earthquake going to occur okay.

So, before a quake, the area lead time was back to normal, so there is a decrease and again back to the normal, the longer period abundantly in the wave velocity presaged to a larger quake in the region. So, if somebody monitored this lead time effectively, one can predict basically earthquake in that location. So, taking a cue from the Russian and then the Lynn Sykes, Scholz and Agarwal conducted laboratory okay, so experiment on rock samples in 1973.

So, this experiment showed that abnormal change of ratio of the P and S wave velocity before the earthquake, so if this observations are made very accurately okay, so the ratio of the Vp and Vs, the duration of Vp and Vs anomaly depends upon the fault and dimension of the aftershock area. After the Garm region of the former USSR Vp/Vs; Vp versus Vs anomalies were noticed in blue Mountain Lake earthquake in US in 1973.

The velocity anomaly period of this earthquake was about 5 days okay, so decrease the velocity was about 12%, so this lead time decrease okay for the before earthquake, it will be very accurately noticed and reported okay, so that will help you to predict an earthquake in the region. Similar decrease in the velocity ratio also reported by the damage Haichang earthquake and then the other earthquakes in China and Japan even 4 to 40% decrease in the velocity ratio, 50 to 700 days before earthquake, you see the number of days.

So, the main earthquake were recorded in Tehran 40% decrease in the velocity was reported, 1 to 3 days earthquake in 1974. So, the lead time variation and decrease somebody observes that will help you to predict an earthquake in the region, okay.

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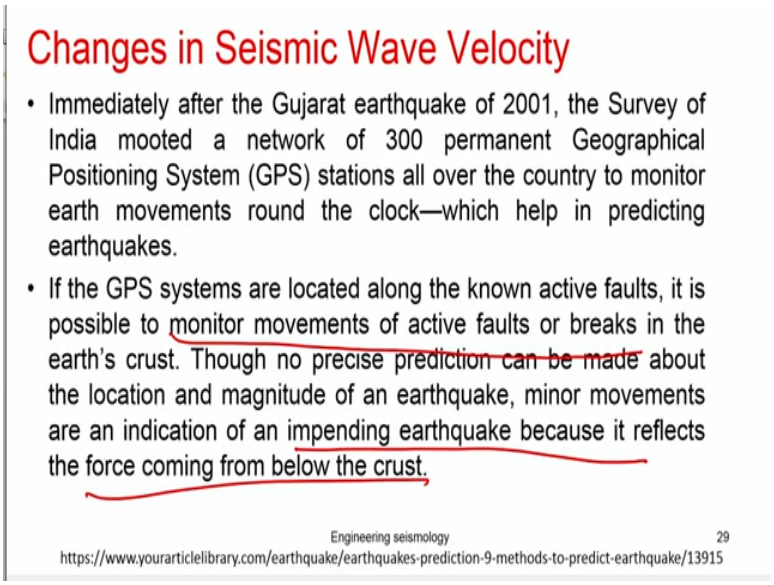

So, the immediately after the Gujarat earthquake of 2001 in the survey of India mooted a network of 300 permanent GPS station all over the country to monitor the earth movement round the clock which help to predicting the earthquake. So, if the GPS system are located along the known active fault, it is possible to monitor the movement of the active fault break in the earth's crust, though no precise prediction can be made about the location and the magnitude of earthquake, minor movement are in the indication of the implementing the seismic earthquake, impending the earthquake because of the reflection of the force coming from below.

So, basically after a Bhuj earthquake, so the survey of India deployed the global geographical positioning system throughout the country and try to monitor the movement of the plates okay, the fault or rock, so as we know that we studied that if there is a movement at particular place, movement happening at the particular place, that movement indicates a seismic activity. The seismic activity indicates that there is an earthquake going to occur.

But again, the when and how much is a question, so that is also has to be addressed path of the prediction but the change in the velocity overall observed in the earthquake region before a big earthquake that was a message which you can get from the this one.

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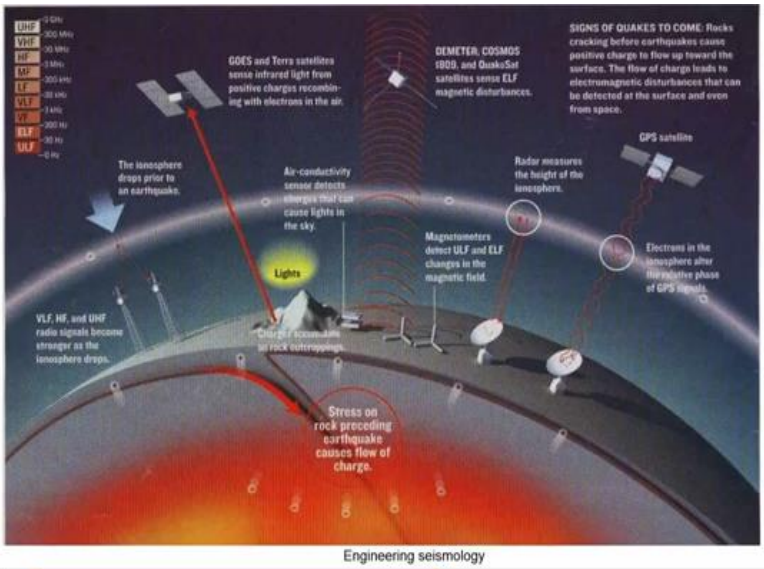

Engineering seismology

So, if you look at this theory, whatever we have discussing, the 9 approach to predict an earthquake, so it is very clear that there are many method is basically related to the mechanics and theory of the plate tectonics okay or the elastic rebound theory okay. So, the elastic rebound theory its behaviour in the region will help to identify and predict an earthquake at particular location, so which is a well-established and well understandable okay, so where the earthquake can be predicted in the plate tectonics concept.

So, if the crust are very close if you monitor some of the crustal deformation like if you have the seismic instrument and it record a waveform, so the foreshock okay the Vp and Vs ratio okay, so those are all the recorded information will help you to identify the unusual earth signalling, we can say it is a earth signalling which will help you to identify a big earthquake due in the that region okay that is the one of the classical way we can look at it.

So, apart from that the well and oil well and then the water well linked or drilled in the crust where it is going to break, there is an unusual raise in the temperature, level of water, level of oil and then the water composition as we have seen that the breakage okay, basically tried to release the minerals in the area or the minerals undergo a change or conversion or increase or decrease the concentration before breakage that will seen in the evidence in the wells okay.

So that concentration hydro chemical process or precursor constant, so these 2 if we link with the animal behaviour, animal unusual behaviour in the region, you can pinpoint epicentre location precisely okay. So, if not a 1 meter, 1 meter at least by a kilometre you can pinpoint, so as we have seen that the animal behaviours are related with the size of the earthquake magnitude, so we can also predict size with that okay.

So, the other methods actually will tell you only roughly the days okay sometime it is very short, sometime it is very long. But overall linking up any of these methods will help you to predict a earthquake as much as close to the actual event okay, so that is a one message.

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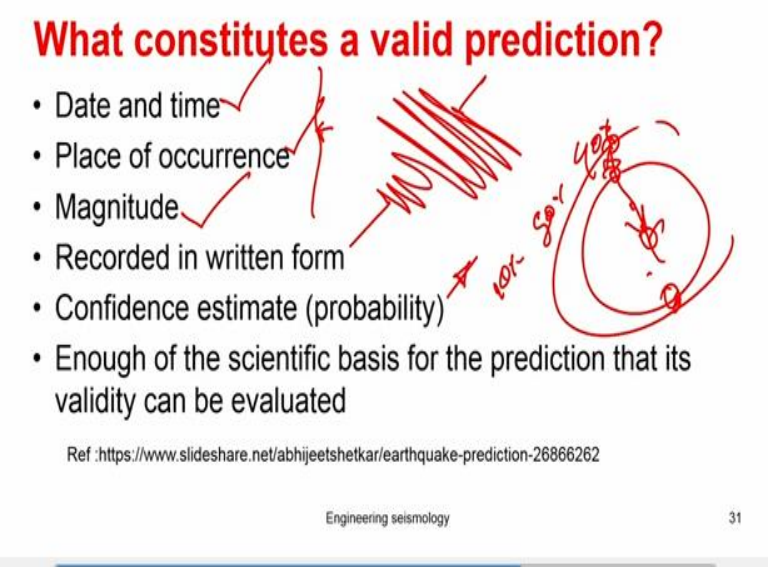

So, what constitutes a valid prediction okay, so the valid prediction basically should be the date and time okay, I should say that it going to occur on such a date, such a time okay, then the place okay with variation of small level not 1000 kilometre, 100 kilometre variation, it may be the few metres variation or 1 or 2 kilometre, single digit kilometre variation is accepted. Second; the size of the magnitude, as we have seen that the damage of the earthquake is a function of energy carried by the seismic waves that is a function of amplitude of the seismic wave that is a function of magnitude or size of the record.

So, the record in written form, so not only predicting this, if you predict this basically we should get at least synthetic ground motion data which is possible or expected in the region, then only

people do analysis using this and say that this is the expected damage at this place, this is the expected failure you can get okay. Then the probability of confidence of estimation, so say that 10% confident, 50% confident, 90% confidence about this prediction that also is basically the constitutes a part of valid prediction.

Enough of a scientific basis for the prediction that is valid can be evolved okay, so basically you can get all this materials from the Internet, I also taken for the teaching as I do not work on the earthquake prediction right now, so there was a case also basically, I also told that we did not discuss here that method explicitly. So, there are theory of like the planet position for prediction of earthquake.

So, as you know that the sea waves controlled by the Moon position and earth position correct, the similar kind of concept has been extended by the astrophysics okay where they position the different time, what is the planet position, then they say that when these planets are coming in a particular alignment okay, then there is an imbalance created between the attraction between the planets which can cause an earthquake in the earth okay.

So that kind of predictions are all well known, many people are there but we did not explicitly discuss that there is a ambiguity and also that theory itself a separate topic of research okay, so that so what I did actually, there was a some geologist from Chennai who are working this kind of area, so you was suspicious that there may be such kind of coincidence going to happen close to Coimbatore where there was a 6.3 magnitude reported, 1900 okay.

So, then since it is a very near to the Bangalore, I also thought that let us see what happens, what we did actually, so based on his input and he has interaction with the astrophysics who predict all over world these kind of phenomena, so then I deployed a seismic station at wherever you said nearby but it was not happen okay, so we have written even paper and submitted before the earthquake but unfortunately, fortunately earthquake was not happen, and so unfortunately the time what I spent to writing the paper and doing that analysis was become a waste.

So because of that the prediction method which is not having enough scientific basis okay, cannot be considered as a valid and method for prediction, so one of them is this planet position basically, what they say as you know that this is the earth, this is the moon, then there is another planet rotates on a; they say that these are all comes on alignment, so there will be an imbalance force happens, so this causes an earthquake in the earth okay that is what they say.

But one of the cases where it has been predicted but it is not happen which believed that this is not the good direction I should work, so even if you predict the science what I work actually needed for save the people, so prediction of earthquake alone will not save the people, you should know the predicted earthquake, how waves will propagate, how it will affects, what are the failure it causes okay.

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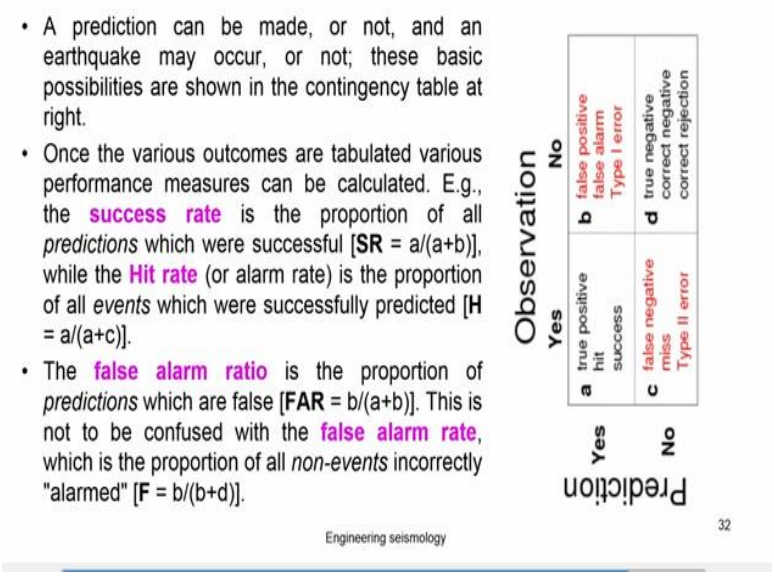

So, that kind of research only I do, not the prediction of earthquake okay, so because of this reason, I have most of the materials what I have taken from the Internet okay, it is not my own material. So, the prediction accuracy can be accessed by the known setup conditions described by the this one, so you can see that the observation and prediction, the yes true prediction hit success, a, okay how much success is. So, the b; false, positive, false alarm type one error okay, false negative miss type 2 error, true negative, correct negative and the correct rejection.

So, these are all the a, b, c, d, okay with observation and prediction, yes and no criteria, so you can say the accuracy of prediction and then the false alarm using some kind of mathematical formation, a prediction can be made okay are not and earthquake may occur or may not, these basic possibilities are shown in the contingency table at right side. So, one of the various outcome are tabulated, various performance measures can be calculated, the success rate is the portion of all prediction which were successful okay SR is equal to a divided by a + b, okay.

So, this conditions are coming, this is the success rate, so while the hit rate, the alarm rate is proportion to all the event which were successfully predicted a divided by a + c, this is the hit rate, the false alarm ratio is proportional to the prediction which are false okay b divided by a + b and this not be confess with the false alarm rate which is proportional to the b by b + d, so this is the success rate, hit rate, false alarm and false alarm rate.

So, this is some kind of quantification people have given with respect to the rate of prediction, success, hit and false rate kind of theories, so which will be useful basically to evaluate how accurately you can predict an earthquake okay. So, as we have seen that in the last couple of classes, last 3 classes we have been discussing about the earthquake prediction okay. So, we found that as on today, there is no confirmed theory to accurately predict a earthquake okay.

That means, nobody can say that this is the magnitude, this is the place, this is the time, it going to occur that is very clear okay, nobody can predict an earthquake but however, there are some scientific basis okay, which has a scientific proof and as a concept related with the plate tectonics and rupture phenomena during the earthquake. So, one of them is animal behaviour okay, so since before the big earthquake going to happen, the earth will undergo a highly stained wave okay, it will stressed, highly stressed.

That stresses will radiate some kind of chemical as well as some kind of unusual waves which will be sensed by the animals okay which is very sensitive animals like a dog, rat, burrow animals like snakes okay, so those are all the animal, birds, so these are all sense that their behaviour, the unusual behaviour of the animal can be observed before within 24 hours of the earthquake, big earthquake particularly is possible.

They observed that it is behave very unusual way close to the earthquake time, 2 to 3 hours before the earthquake, it will behave very unusually okay, so that is a proof they have seen, then if you link with that other prediction like the foreshock okay, foreshock, then the prediction will be having more success rate, then the hydro chemical precursor okay, the change in the water chemical concentration at a particular place okay, then the water level raise, oil level raise, temperature raise and drops.

So, these are all the behaviour, these are all the phenomena one can monitor and then linked with the animal behaviour where this is possible closely the crust is close to the ground okay, those are all the region which is highly possible to predict earthquake using linking up these three, we have seen that the China 1975 okay, 7.6 magnitude predicted by linking three this condition continuously, help of foreshock, and then animal behaviour and then the water wells level variation and all, so which can be taken as a very basic relation with the earth crust deformation behaviour.

So apart from that if you have the instrumented data at some location, so where you can see the seismic gap okay where you can predict an earthquake size in the seismic gap, we have also seen that seismic gap in Himalayan region which we will be discussing in detail when we are talking about the India seismicity where this is very necessary, then we also seen that P wave, S wave ratio, lead time okay, the lead time change before the earthquake, so that also we have seen, one of the useful parameter.

And then the seismic activity by monitoring the movement of the plates okay, so you keep monitoring the movement of the plate, so as we assume that the active faults where there is a seismic movement is taking place, so these are all the method you need basically instrumented data basically, waveform data recorder, then only you can estimate what is the foreshock, you nearly earthquake history of the region where you can find out a seismic gap, you need the digital recorded data at different places where you can find out Vp, Vs and lead time variation in the several days and month.

Then you can compare the unusual variation what you are observing will be counted under this one. So, here I can also say that this unusual behaviour sometime get into the wrong prediction because of the some kind of phenomena which happens, as you know that so now because of the Covid, okay the lock down was happened throughout the world at different period. So, this lock down basically reduce considerably the human activity in the planet.

So, this human activity in the planet reduction will source very good raise in the seismic recordings of the tide, earth tide okay, the earthquake prediction okay, earthquake wave recording and assessment is becoming more easy because of the lockdown due to the human movement stoppage okay. So, people movement have stopped which helped, so these kind of variations also has to be a accounted when you talk about the prediction of lead time okay, lead time studies and all one has to talk about that.

So, overall you can see that all these prediction okay whatever we are talking may not be very accurate as we are expected, it depends upon the solely a data and observation how you link 2, 3 method together. So, you might have seen that I do not know many of you familiar with this covid background actually. So, now the covid virus has been put on several restriction, people have locked down and all on, a year or 2 year back, there is a group of people they simulated if this kind of virus are going to come, how the world will behave, which are the industry will affect, how much will affect, how much economic loss will.

So, then after that it happened, so there are people who believe that there is a linkage between the that model studies okay that prediction model with the real one. Why? Because many people they raise their share values and sold it okay by based on this, then this covid has come, many people get affected, the economic loss begin and lot of things were happen in the financial sector, those who are interested to see those kind of things, you please Google it and find out okay, there is there.

So, this kind of modelling okay the modelling and prediction, so may be very accurately match with the artificial kind of things but may not match with the natural scenario. But natural scenario you cannot work with one model, for example, lead time alone may not be sufficient

okay seismic gap alone may not be sufficient, foreshock alone may not be sufficient but if you link 4, 5 success cases out of 9, then there is a possibility that you can predict very accurately earthquake but that needs lot of instrumentation and finance support to monitor.

If you monitor that is possible, this is kind of technology is really needed in Himalayan region, as I said that there is a seismic gap okay. If somebody monitor all these parameters in those region which will basically help you to predict a big magnitude and save at least life of the people, if not infrastructures okay, so but this prediction if it is not accurate, it create a socio-economic impact okay.

That socio-economic impact many times larger than the impact created by the earthquake, for example the earthquake magnitude of 6 okay, if it happens at some location only 100 people will die, 500 crores will loss but if it is predicted in advance wrongly and informed to people there may be 1000 people will die and 5000 crores loss will be there. So, these kind of unusual socio-economic impact of the earthquake predictions are very important.

So, scientist believe that how the socio-economic impacts are important, why their predictions should not be told just like that without verifying the prediction, so that we will discuss in the next class, so with this we close today class, thank you very much for watching this video, so we will see you in the next class, thank you very much.