Introduction to Engineering Seismology

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Lecture No -27
Ground Motion Simulation models

So Vanakkam, so we will continue our lecture on Engineering Seismology. So today we are going to talk about the ground motion simulation models. So the ground motion means basically as we have discussed in the previous class the time history data, acceleration versus the time the plot of the earthquake is called as a ground motion data. So these data basically, you need to be recorded during the earthquake.

As we have seen that the seismic instrumentation itself developed on 1880. Then in India the first seismic instrument was installed only after the big Shillong earthquake. So by considering that we have seen also the upto 1960, there is not much seismic instrument in the country and initially there was a many analogue instruments was there then followed by those analog instruments are basically shifted to the digital instrument.

Now, we have reasonably instrumented the this one, but unfortunately, there are many big earthquake which was reported earlier in the last century under even layer before 40 decayed and 30 decades. But we do not have recorded acceleration time history data, if you want to do analysis, so like we have seen that time history and response spectrum tripartite. So there are two type of structural analysis people will do.

So one is they do a time history analysis. Time history analysis means they take a structural system model that completes structure in the computer and apply here, we are typical recorded earthquake as a time history data, just apply that and then see and how the displacement varies at a different places where the given structural configuration and then if they needed they will basically modify that and to see that it is safe.

And does not cause a failure or a collapse or the more displacement that is what they do that kind of analysis called as a time history analysis. So you take a typical earthquake data and give us directly input, so that is the one way. The another way is people take a spectral values. So we have seen the design spectrum last time know, they take that spectral value and design a structures.

So which is like a simplified way of the time history analysis because the time history analysis you need very complicated computer modeling software as well as a computing facilities. In the response spectrum analysis, you no need like that, you can even do here and calculations or excel based calculations kind of thing. So this is the way structural people design the structures. So as I said that the world earthquakes are not available under recorded data is not that.

So then how do you design? So that is the way the designing requirement to fulfill those kind of requirement. Scientists come up with the idea called ground motion simulation model. So that means whatever the earthquake physics you are understand how the earthquake mechanisms all understand that modeling you solve that equation, then you will get here your acceleration time history data at a particular place.

So generally the simulation models most of the time develop a S wave portion of the earthquake not the P wave and surface way as this does not cause too much damage to the structure which we have seen during the wave propagation. So today class we are going to talk about the earthquake simulation model basically. So we are going to talk about your earthquake simulation model, so which will help you basically.

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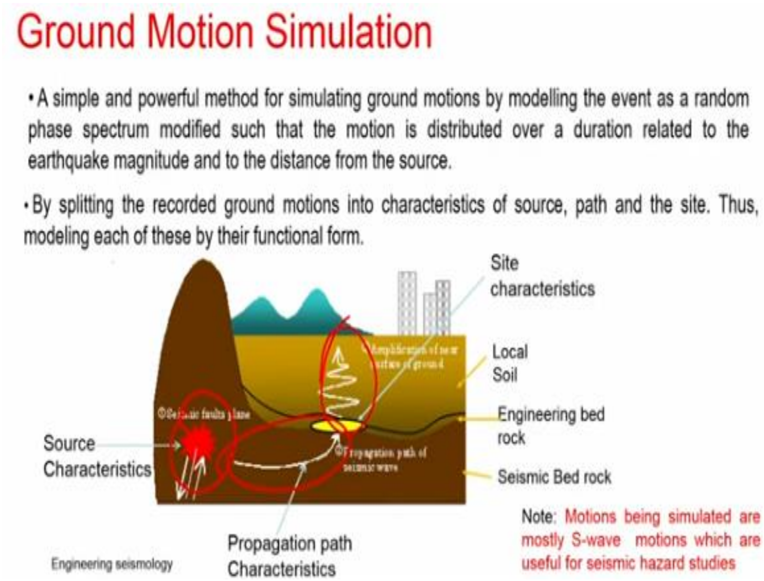

To simulate synthetic growth motion of the any record data. So the simulation model, the simple and powerful method for simulating the ground motion by modeling a event, the earthquake event has a random phase spectrum modified such that the motion is distributed over here duration related to earthquake magnitude and distance from the source. You can see that the simulation model the main parameters is actually the earthquake magnitude and the distance from the viewer origin of the earthquake.

So if you take a random phase spectrum, which we are discussed, what is the phase spectrum during the frequency domain parameters and you can even Google it under read about if you want to know what is the phase spectrum. So by making a phase spectrum, so that by splitting the recorded ground motion into characteristics of source, path and site that modeling of each of this by their functional form will be become easy to understand how it is modeled.

So this is the typical earthquake so occurring in the generally. So this is where you are looking at your design of the ground motion. So this is the hill and then there is this one. So this is where basically your source so this is the source. So, this is the basically so this is where you can see a source this is the one which is where earthquake is origin the fault is rupturing. As I said that the waves are getting traveled like this.

So when it reaches a engineering bedrock, you can see this is the engineering bedrock. So the wave which travels very long distance from the parent source to the engineering bedrock that is called as a seismic bedrock. So this is will have roughly the velocity of 3 kilometer per second to around up to 1000 or 1200 are less than 1000 kilometer per second up to this phase then followed by you will have the soil, this soil velocity will be always less than 760 meter per second this thickness varies depends upon the place to place.

So that means the entire process what do we deal actually can be grouped as a three category. One is the source characteristics which is taking into the account of even source what happens. So this place what happens is the source characteristics. The second is the path characteristics, the another one is the site characteristics. So by solving what happens here. What do we understand the propagation characteristics seismic moment corner frequency cutoff frequency.

So by solving all this equations separately and the clubbing together, you can get what is the typical event waveform look like in the surface that is what the simulation model does basically. So this motion mostly simulator further S wave component and the predominantly for the rock side condition has the soil conditions are various location to location, as might have seen you that.

So in your house the soil the found in that place may be different depth and different thickness and different type and if you go little 50 meter, 100 meter away, you will have again a different depth the different soils kind of thing. So the modeling of site characteristics is not so effective people only concentrate up to the modeling at a engineering bedrock level. So this is the level they try to model the; your simulations.

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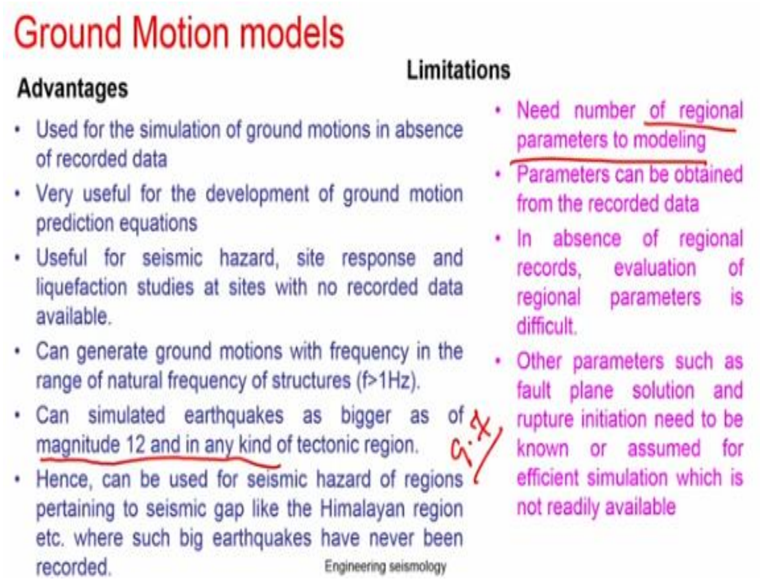

So this simulation ground motion simulation models as a great advantage as I told you that so used for simulation of ground motions in the absence of the recorded data in the region. Very useful for development of ground motion prediction equation, which will be discussing what is the ground motion prediction equation in the later stage. Useful power seismic hazard and citrus points and liquefaction studies at the site with no recorded available data.

So it is also used for the seismic hazard site response and liquefaction where there is no recorded data is available and can generate a ground motion with the frequency in the range of natural frequency of structures. So since it is simulation one, you can only generate a frequency where you are structural is important. For example more than one hertz, so less than one hertz something like that can simulate earthquake as bigger as magnitude 12 in any kind of tectonic region.

As we have seen that so far the maximum reported magnitude in the world was actually 9.7. So if you want to go iron magnitude the only simulation is possible. So hence can be used seismic hazard region and designing the very important structures and the simulation of the earthquake in the seismic gaps are the expected area of the earthquake as we are telling that there may be a main shock of the earthquake which you can expect in the daily region.

Because there is a foreshock. So you if you want to simulate a estimate what is the magnitude expected that and you can simulate that earthquake and try to understand if that earthquake comes what happens to the different part of Delhi. So those kind of studies are needed this kind of simulation. So what is the limitation of this ground motion models basically need number of regional parameters to model because depends upon the input parameter.

So your acceleration time history changes. If you assume so many parameters, which is not measured in the; your region you will end up in the wrong acceleration time history. Then the parameter can be obtained from the recorded data then it will more reliable in the absence of regional records, recorded data means not a big earthquake even a minor earthquake you will give the your cut off corner and then the seismic moment.

So then the attenuation characters all those things you can be obtained even here minor earthquake data. So the evaluation and regional parameters all those things will be in the absence or recorded data evaluating these representative regional parameters are difficult. Other parameters such as a fault plane solution rupture initiation need to be known are assumed for the efficient simulation, which is not really available.

So the recorded data will give you some type like this automation characteristics corner fixency cutoff frequency where you can also estimate a seismic moment by knowing the corner cutoff frequencies and also by knowing the expected magnitude. But the fault plane solution what type of fault it is if there is no big earthquake in that particular fault, it may be difficult to get your fault plane solution.

Second where it rupture start and how it initiate how it propagates. So that data also difficult so this information if you assume without detailed this kind of information you will be ending up in the wrong simulation of the ground motion data. So anyway as on now this is the only way you can get here simulation data as much as possible we will try to get a regional source and the path parameters.

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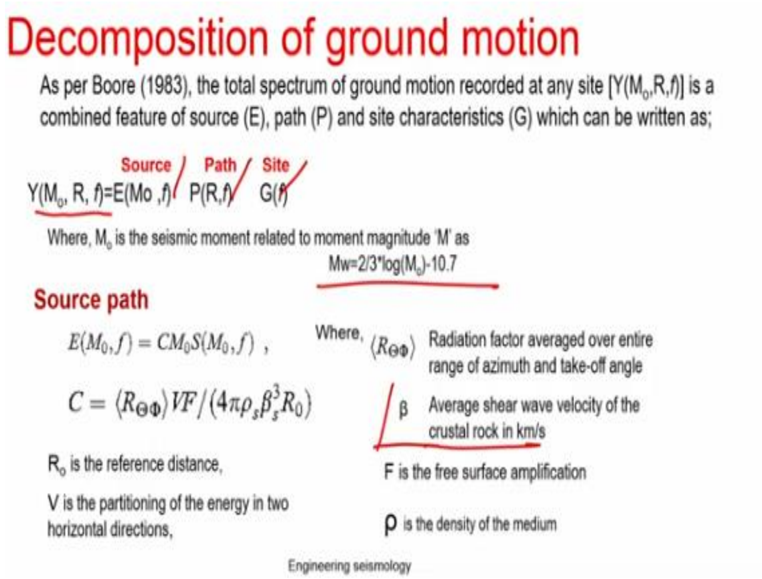

So recently we have done this kind of parameter development and also simulation large extent and developed here ground motion prediction equation, so if time permits will be discussing one class how we have done what we have done what are the equations is available in the latest stage. So what the Boore done 1983 you can see the model when it was developed just about less than 40 years back. So the Boore who is the USGS seismologist, well known world famously seismologist even I do have some interaction with him.

So said that the total spectrum of ground motion recorded at any side, so is the function of combined futures of source, path and the site characters, this is what we understand. So this is a the ground motion at any particular site. So any particular site is the function of source, path and site characteristics. So as we have seen that the source is controlled by the seismic moment and frequency, the seismic moment is M0 is the seismic movement which is directly related to the magnitude of the earthquake.

So this is what we have seen so the M you know, so the source effect the energy at source equal to the function of sizing moment at M equal to CM0 S into M of f. So the C actually is depends upon this which is basically R0 is a reference distance. So, the row V is a partitioning energy into the two horizontal direction and then this R the factors is radiation factor average over here enter azimuth.

The beta is average shear wave velocity of the crustal rock. So this is the velocity at where the source going to rupture, F is the free surface amplification rho is the density. So by knowing this you can solve this equation and you can get here source the related the wave path.

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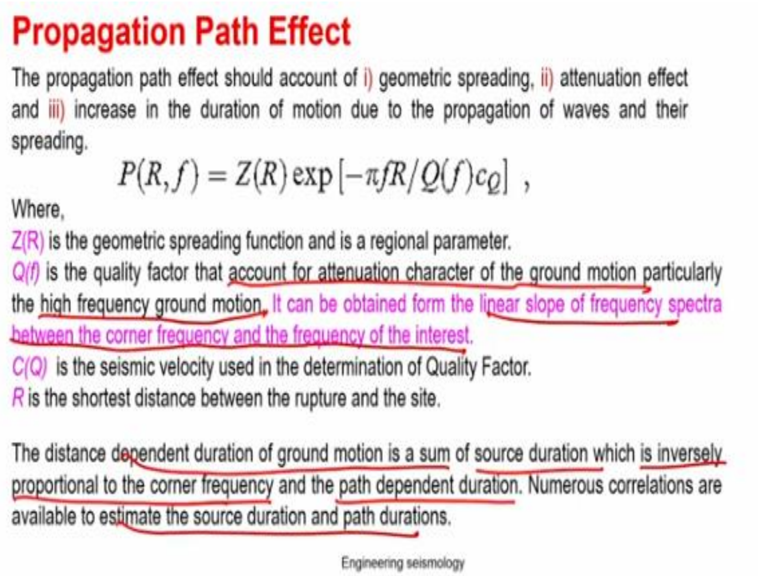

So then the next is a propagation path. So the path effect should be account geometric spreading attenuation effect and increase of duration motion due to the propagation waves there spreading as we have seen that when the waves are travelling on the very long distance, you will have the long duration. So that has to be accounted here. So the path effect P is the function of R and f, R is the distance from the side preferably it is hypo central distance is the ZR exponential of pi fR into Q of f and CQ.

So here the ZR is basically the geometric spreading function and it is a regional parameter can be estimated from the minor accorded earthquake in the region. QF is the quality factor account for attenuation characteristics, attenuation character ground motion particularly high frequency ground motion. It can be also obtained from the linear slope of the frequency spectra between the corner frequency and the frequency of the interest.

The Qf can be obtained like that using the regional data CQ is the seismic velocity used to determine the quality factor, R is a shortest distance between the rupture and the site. So the distance depends upon depend duration and ground motion is sum of source duration, which is inversely proportional to the corner frequency and the path dependent duration. So there are a number of correlations are available.

But you should see that these correlations are applicable to your region depends upon the seismotectonic and the regional attenuation characteristics, which is arrived from the minor earthquake. This is what here path duration.

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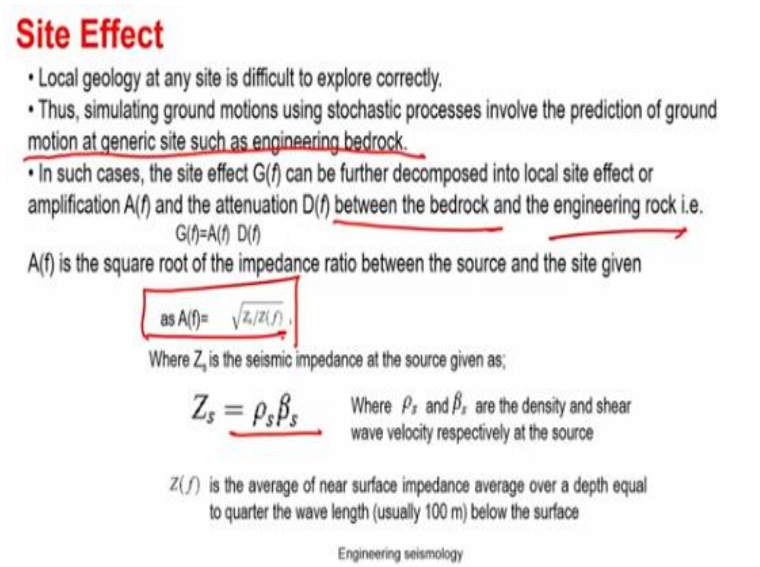

The site effect generally counted a local geology at a site it is difficult to explore very correctly as I discussed earlier. The simulating of ground motion using the stochastic process involves a prediction of the motion at the generic site such as a bedrock conditioner. So, most of the time the; simulation they do for the bedrock condition not for the soil condition. So because of that the site effect study is not much addressed in this simulation model.

So in such case site effect Gf can be further decomposed into locals site effect and amplification and attenuation between the bedrock and the engineering bedrock. So here the seismic bedrock, engineering bedrock attenuation what happens. So the Gf is amplification and Df the factor which attenuates the Af square root of the impedance ratio at the source and the site, so which you can obtain from like this you amplification factor that is a Zs is the seismic impedance.

So the Zs is rho into Va, Bs. Bs is basically the density and shear wave velocity of the respectively at the source on the different medium Zf average nearly implement ratio over a depth equal to quarter length, usually 100 meter below the surface. So using this you can get a Af.

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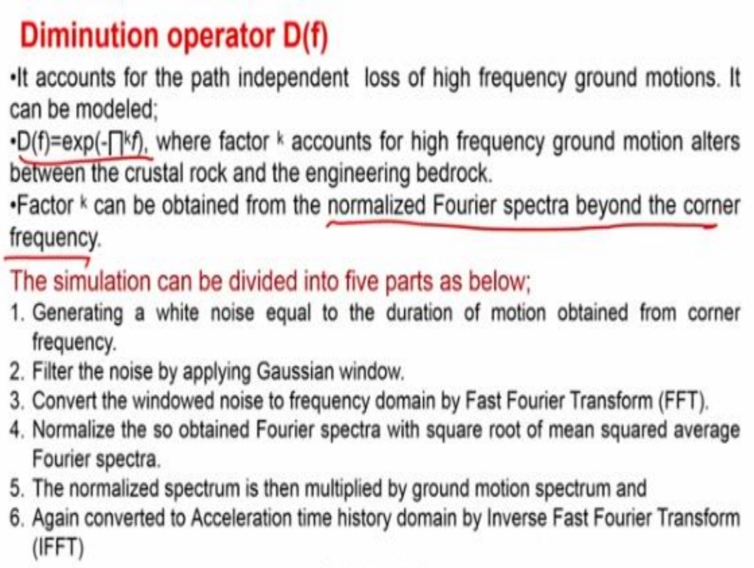

So the diminution fact operator Df, it accounts a path dependent loss of high energy ground motion, it can be modeled using the this function where the factor k accounts the high frequency ground motion alter between the crustal rock and the engineering bedrock, factor can be obtained by normalizing the Fourier spectrum beyond the corner frequency. The simulation can be so this steps whatever we discuss in detail can be clubbed as here 6 simple step.

One is that a generating a first white noise equal to the duration of the motion obtained from the corner frequency and then filter the noise by applying a Gaussian window convert the window noise to the frequency domain by fast Fourier transformation and normalize by obtaining the Fourier spectrum with the square root of mean squared average spectrum, then the normalize spectrum then multiply the ground motion spectrum again convert acceleration time history domain by the inverse Fourier transformation then you will get here acceleration time history.

So you can see that as I told you during the frequency domain parameters the parameters we discuss in the frequency section basically helps in the simulation part predominantly that is why you can see corner frequency cut off frequency, then the Fourier spectrum and normalizing this Fourier spectrum. So, all those things parameters are very useful in the simulation. So, simulation of the ground motion itself is a PhD topic.

So one can work on simulation of the ground motion for a one region and try to get here different ground motion get a ground motion prediction equation that is a PhD topic in the repeated institute, there are very few ground motion simulation and the GMP developed in India so far.

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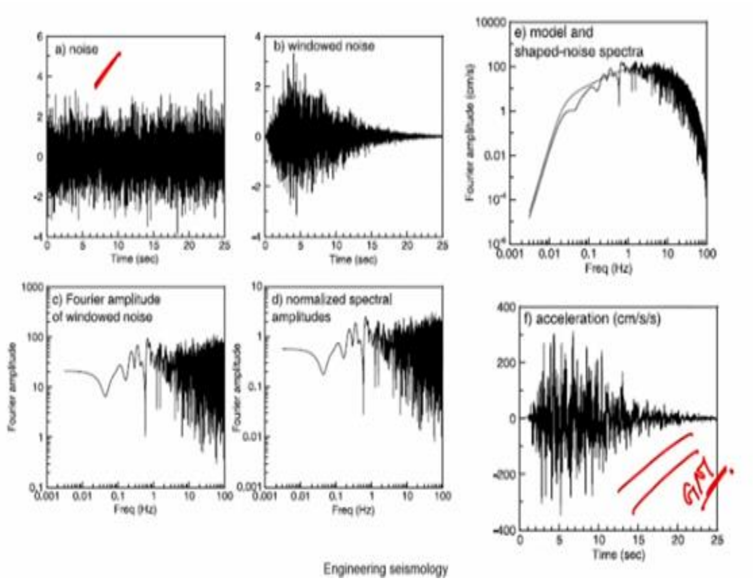

So this is that 6 steps has been broadly explained pictorial way. So this is basically a noise which is simulated based on the duration. Then the; apply here Gaussian window noise filtering so then you will get here this was as it become like this. Then model noise spectrum you can this is the spectrum you will get which is taking into account of your corner frequency all those things then the Fourier amplitude of the same window.

You can get here then normalized spectral amplitude you get from this you get a acceleration time history by again the inverse Fourier transformation. So this data is basically your record ground motion simulation data. This is what you do at the end of the simulation even though I explained this the; entire step in the last 10 minutes, but it is very complicated mathematical modeling work.

So, very few people actually contributed to development of the models. So most of them are only using that model using the regional data. So, for example in the world so far only there are one simulation model which is a primarily developed later it has been modified. So far nobody developed independent simulation model other than Boore, rest of them are developed on modified the Boore model and called as a different model name which will be discussing followed by this slide class.

So right now India people only use those models simulated models which really available in the website and try to simulate for the different distance and the M some people use here regional parameters, some people does not even consider regional parameter, they use model input to parallel parameters or example parameters and the end up in the some kind of acceleration time history data which may be relevant may not be relevant depends upon the input given in the particular location.

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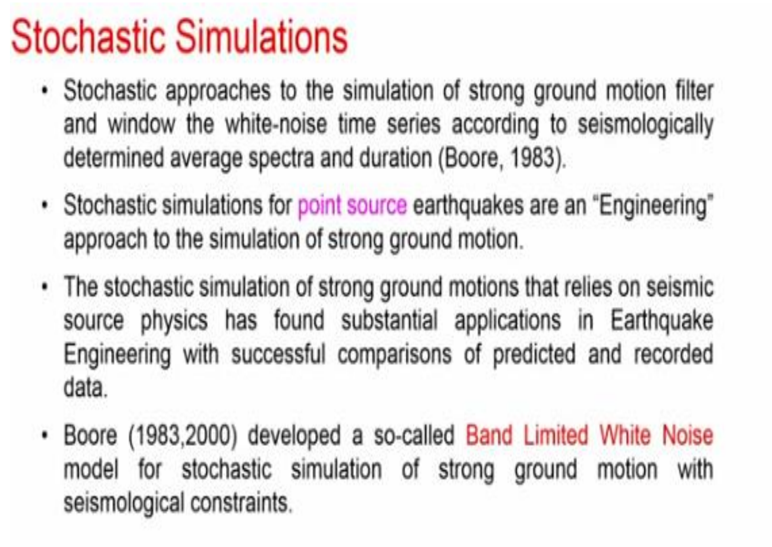

So the stochastic simulation the approaches the new simulation of ground motion filter and window white noise time series according to the seismological determination of average spectrum and duration the stochastic simulation points source model. So earthquakes are engineering approach by simulation of ground motion, which was developed by the Boore in 1983.

The stochastic simulation of strong ground motion that relies on the seismic source physics has found substantial application in the earthquake engineering with the successful comparison of the predicted and recorded data. So Boore developed this stochastic simulation model under it he found there is a good application the engineering seismology. He also validated his model by comparing the really recorded earthquake from the simulated earthquake.

So the Boore updated his model again 2000 developed so-called band limit white noise model for stochastic simulation of the ground motion so with the seismological constraints.

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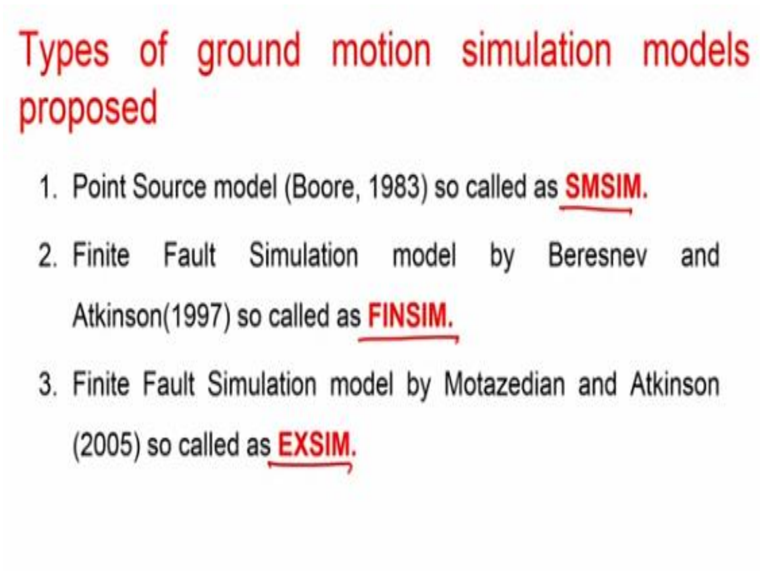

So this is simplified models so there are 3 type of ground motions simulation models are available. So one is the point source model, which was the origin for the rest of the other two model. So it was developed by 1983 Boore which is called as a SMSIM model. The another one is that model actually further modified by the Beresnev and the Atkinson they call it as a finite. So fault finite model which is called as a FINSIM.

It is developed on 1997, the finite point model simulation model again modified by the Motazedian and Atkinson. So that model is called as a EXSIM. So these are all the; three different simulation model, which is widely available in the world and people use to simulate a ground motion data. We will discuss these models and its advantage and limitation, what are the input needed in the now.

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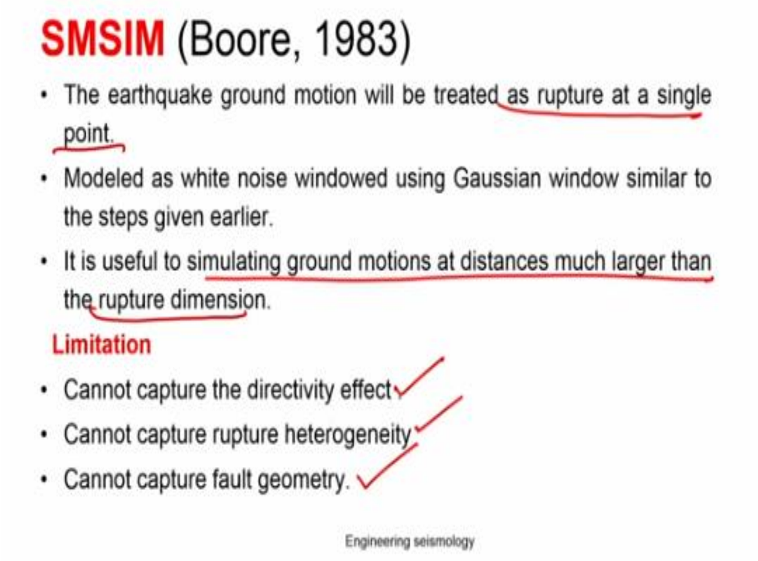

So SMSIM model was developed by Boore in 1983 the earthquake ground motion will be treated as a rupture at a single point. So you treat that as a point source. So model does a white noise window using the Gaussian windows similar to the steps given earlier, useful to simulating the ground motion at a distance much larger than the rupture dimension. So this will be the rupture dimension should be smaller and the distance where simulator will be larger.

It cannot capture a rupture directivity, cannot capture rupture heterogeneity, cannot capture the faulty geometry. So these are all the limitation of this model. So that means you can simulate these kind of earthquake, further smaller magnitude where this effect not much noticed smaller means magnitude of 7 and less as we have discussed in the simple model we have found if I know, so this that is a very simple model.

So this is slightly complicated model it works up to magnitude of 7, people are done with the different cases on compared and reported that.

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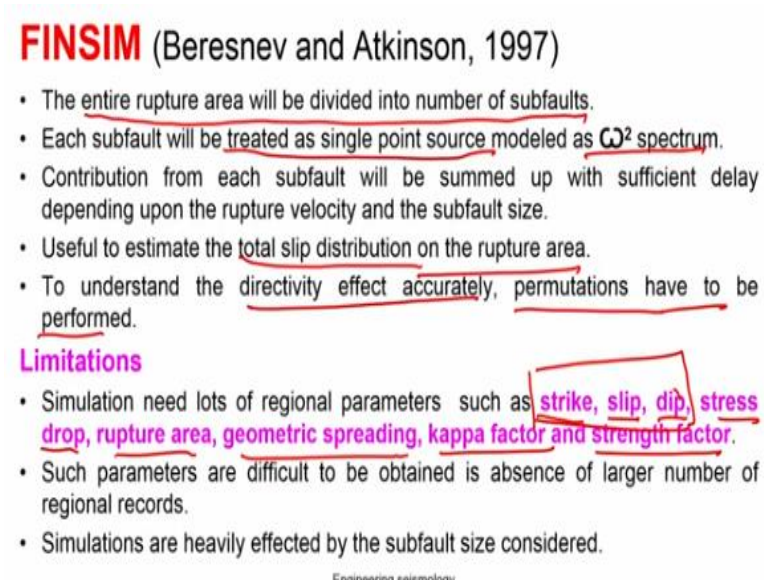

So then another one is the FINSIM model. So the FINSIM model actually developed by the Beresnev and Atkinson 1997, as I say that the entire rupture area will be divided into number of subfault. So, they take a entire area and rather the each subfault will be treated as a single point. So here instead of one single point simulation by the Boore this people divide the area rupture areas as this one.

And then model each segment as a point source and with the omega square spectrum. Contribute from each subfault will be summed up and sufficiently delayed depending upon the rupture velocity and subfault size then finally the arrive here total slip total ground motions from the; this small things. So useful to estimate total slip distribution of the rupture area to understand directivity effect of the accurately.

So permutation have been performed. So, this directivity and then the slip distribution can be easier. The limitation is simulation needs lot of regional parameter such as a strike we know what is the strike? Slip, dip, stress drop, rupture area, geometric spreading, kappa factor and strength factor. So, this kappa, strength so you can get from the recorded minor earthquake recorded in the region.

So the geometry spreading should be have from the previous past earthquake data. So in case you should not there it is a problem. Rupture area again you should have the rupture dimension versus the different magnitude occurred in the region. So right now overall in the world only very few equations are available with respect to rupture area. Stressed up you should we have discussed that before and after earthquake what are the drop of stress.

So that is again depends upon the region which has to be obtained for different magnitude level. So the fault parameters strike dip and slip this you can get by doing the deep geophysical survey. So if you do a deep geophysical survey, you can get. So, this kinds of many complicated parameters are recorded in the FINSIM model. So such parameters are difficult to obtain in the absence of larger number of regional record.

If you have the larger number of regional records you no need to go for the FINSIM simulation itself. So the simulations are heavily affected by subfault size considered. So this was that means if we take a bigger subfault or smaller subfault depends upon that it was simulations are will be differ. So this is the limitation of this model.

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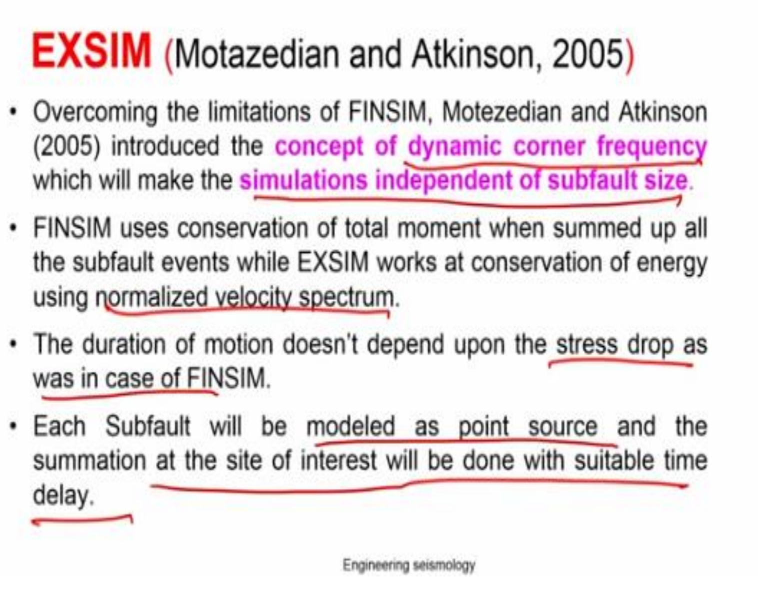

So the EXSIM, so EXSIM Motazedian and Atkinson 2004 so in order to avoid the limitation in the FINSIM model so there the overcoming limitation of the FINSIM Motezedian and Atkinson a developed introduced the concept of dynamic corner frequency that means that the corner frequency, you can keep on changing which will make a simulation independent of the subfault size.

So now this model will overcome the subfault size kind of thing. So if FINSIM uses conservation of the total moment when summed up all the subfault event while EXSIM works and that conservation of the energy using the normalized velocity spectrum. So the duration of model does not depend upon the stress drop, so this also is another benefit of, the each subfault will be modeled as a point source and then summation of the site interest will be done suitable time delay.

You can see that the point source model was the origin, so where this mathematics and simulation concept has been expanded and studied in detail. So as of now the EXSIM models are the better one which needs a good one, but this also before below magnitude 7 EXSIM and SMSIM does not make much difference. The above 7 earthquake, you need to use a EXSIM depends upon the place.

So even now you can categorize that if you want to use simulation at a Peninsular India where you expect here moderate earthquake. So like the below 7.5 and 8 magnitude you can go for the SMC mostly 6, 6.5, you can easily create by the SMSIM model. But if you want to simulate earthquake at the Himalayan belt or North India where you expect the earthquake magnitude of 7 and above, so you cannot use SMSIM model you should use here the SMSIM model you cannot use you can use a EXSIM model.

EXSIM model you should use in the North India. So this is the difference of making more understandable the engineering seismology part in the course. So, this is the typical earthquake recorder data under synthetic ground motion data. So as I told you that the entire fault so is consider as a point source.

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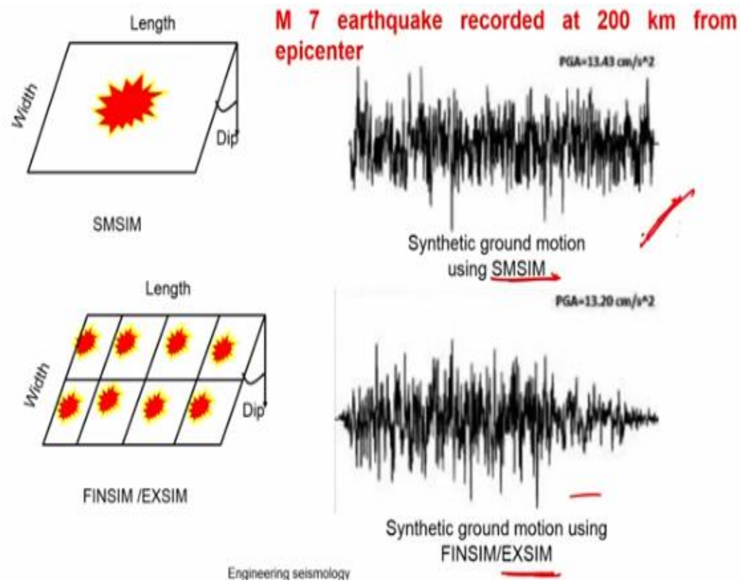

So here the again the entire fault divided as a different segment each has been taken as a single record. So this is the single which is produces one time history. This is the multiple time history clubbed together and finally arrived to this one. So this is basically the SMSIM this is the EXSIM. So this is more suitable for the Peninsular India, this is suitable for the North India above magnitude of 7. You need to have the source information which is required for the input.

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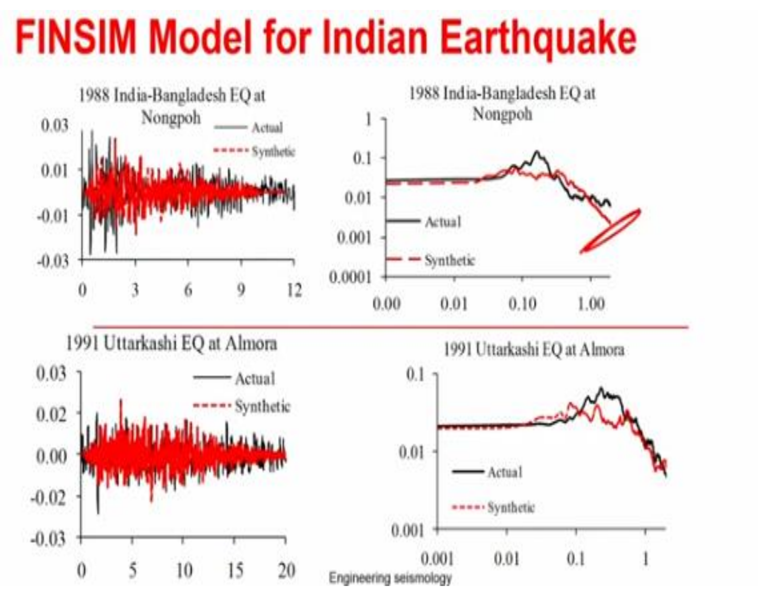

So, this is how the simulations are done. So this is the typical earthquake where we have simulated in Indian sub science. So as I told you that the simulation and getting a ground motion model itself a PhD topic. So in 2004 when I joined the Institute for the PhD, so I have been asked to work on the seismic microzonation of the Bangalore City. So where I started my research.

So that time there was a Professor R N Iyengar, he was one of the pioneer person in the engineering seismology in the country. So he was in the structural group. So I was working with the Professor T G Sitaram, who was my PhD guide mentor. So, we are in actually soil mechanics engineering at geotechnical engineering group. So with the Professor R N Iyengar there was a student called Raghuganth, so now Raghuganth is a faculty at IIT Madras.

So I have faculty at IISC. So he was actually doing the stochastic simulation model for Indian Peninsular region and try to develop a ground motion prediction equation. So that was PhD work actually as why I want to tell you that the simulation of the ground motion model itself a PhD work. So then I also try to understand, so since he is working on the simulation of ground motion.

I need acceleration time history further site response analysis which we have discussed what is a time history response spectrum now. So in order to get here response spectrum time history at ground surface, I need acceleration time history at the bedrock to give us the input. So in that purpose I start learning the simulation of the data. So finally, I have been success in simulating the SMSIM model, using SMSIM model and the regional data which is studied by somebody else.

I simulated the first acceleration time history for Bangalore region, we can say some of my papers we can find which is published in 2006 and 07 seismic hazard analysis and all. Then we started I started working on this region followed by I also my next student Abhishek Kumar who is a faculty at IIT Guwahati, who also done simulation for the Lucknow region. So then followed by the recent my student Kathan Bajaj who was done extensive simulation by deriving a regional source path parameters using the recorded earthquake in India, that was one of the highlight.

So we compiled data after my PhD as I became a faculty. I compiled all the acceleration time history from the different part of India and tried to estimate the parameters source and path parameters which we have discussed to q k and stressed up and then the attenuation characteristics different part using the data and then using that we simulate a earthquake ground motion for Himalayan region for different earthquake and Peninsular Indian different earthquake and this is the typical example how our simulations are matching well with the recorded data.

This is actually 1988 so India, Bangladesh earthquake, so where you can see the black one is actually recorded data, so the red one is synthetically simulated data by us. You can see how quite it matches well. So as I told you that the source parameter path parameters all contribute that. So we add made even some parametric studies to fix the particular earthquake source parameter when it is not available.

So that means we alter the parameter and try to match exactly 2-3 record of the same earthquake once it is recorded, well the same parameters has been used to simulate at a different distance and a magnitude in the same source that was the assignment the process we have taken up. You can see a spectrum comparison. So it is very good nice the well comparison of the spectrum basically further this particular earthquake.

This is 1991 Uttarkashi earthquake. So again the actual data and recorded data. So you are also you can see the comparison of the spectrum which is very well acceptable. So the part of simulating like this, you are large number of earthquake in North India and South India. So finally, we have come up with the ground motion prediction equation for North India, South India.

Very recently which is robust with respect to magnitude which is applied to the wide range of magnitude and wild range of distance which is not possible applicable in the previously generated GMP so far so those who are interested on a simulation and development of ground motion prediction equation, you can refer those research papers which will be useful, so you can go through and get if you are interested to continue your research or want to do some contribution basically you can work on this area you can approach me.

So this is how the ground motion simulation data’s are useful and which will be generated for any earthquake by knowing the regional parameters. So with this we will close the today class, so next class we will continue about the; what is mean by the ground motion prediction equations. How it is useful what is the state of art knowledge in the ground motion prediction equation is in the next class. So thank you for watching this video I look forward in the next class, so thank you very much bye.