**Introduction to Engineering Seismology**
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Lecture – 36
Recapitulation - 8

So, vanakkam, so we will continue our engineering seismology lecture recapping the last part, so this is the part 8 actually, this recapping as I told you that the next class onwards we are going to talk about basically, how you can effectively predict this earthquake hazard okay. So, the prediction of this earthquake hazard, will help you basically to design a new structures as well as the retrofitting the existing structure also plan like how many houses will collapse okay, what is going to happen and how many facilities you need.

So, basically the disaster management and planning, so in this actually, we have seen that so the whatever the knowledge so far we have gained okay or interpreted. Okay, the seismic wave okay, the earthquake is actually measured okay, so are recorded in the form of the seismic waves, this wave amplitude, duration, frequency contents are useful for the; to represent how this wave will behave okay, for the any engineering application. Okay, so basically we need here complete information to estimate a force, okay force caused by the particular earthquake.
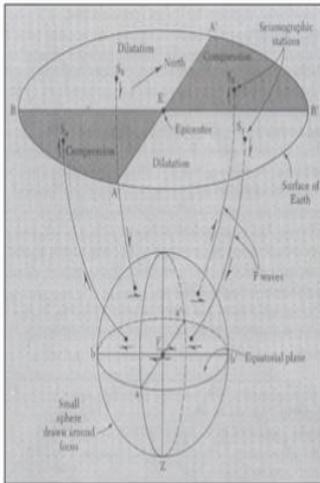
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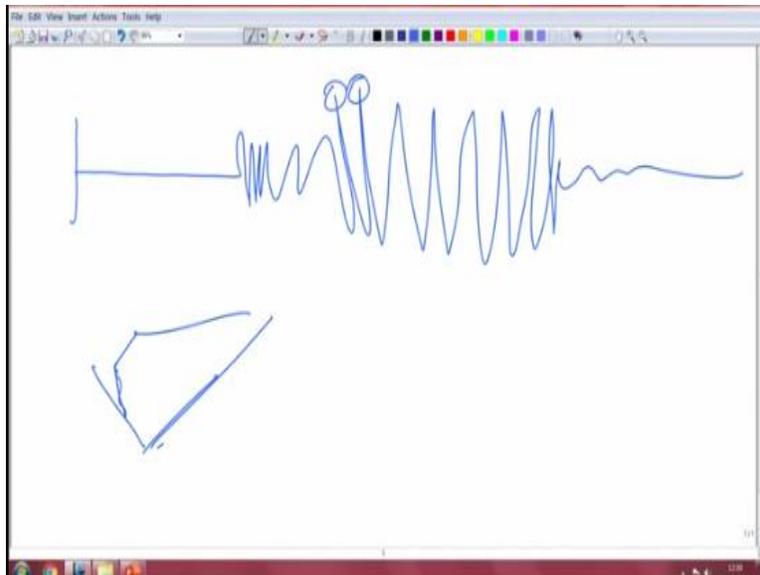
So, the prediction of the earthquake hazard okay basically will focus on getting this waveform what you get. Okay, so this wave form where since we do not have the many recorded earthquake data, so this waveform prediction or as we have seen that the values. Okay, so the PGA, PGV those kind of prediction also is there or you can also get a spectrum. Okay so response spectrum, recursive spectrum, okay that so this kind of information we needed for the engineering application.

So, our objective is basically, estimate this parameters very accurately and reliable manner that is what we studied in the understanding of the; this subject. So, today class we are going to see the source parameters, source characterisation which we have discussed in detail earlier and then a simple models which used to arrive a, your amplitude path like peak ground acceleration, peak ground velocity at particular location or a stochastic simulation where we can simulate a acceleration time history of the data at particular location.

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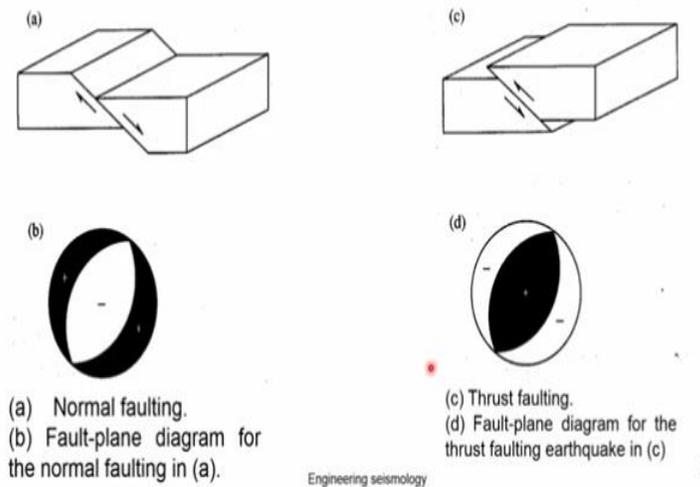

So, these are all the aspects we will be seeing today recapping class actually, so the source mechanism; source mechanism means what type of fault it is. Okay, so what type of fault means like the normal fault, reverse fault, thrust fault, so those things we discussed, so much the compression, tension and a shear forces are created in that particular earthquake will be used to say that.

So, particularly if you look at that this is a typical picture where the earthquakes are occurring, the faults are rupturing, so then it depends upon this rupture, so the compression and tension wave propagates all around direction, so you have the seismometers recorded kept at different place, this records which compression or tensile force, so this part, okay the shaded part. Okay so basically, compression and white part is dilation tension, so then it forms a some kind of shape, that shape okay represents a beach ball okay.

So, the source mechanism is represented as a beach ball, so the beach ball basically a ball which is having a stripe of colours, stripe, stripe colours it has basically, so here the black and white is produced to represent a beach ball.

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(a) Normal faulting.
(b) Fault-plane diagram for the normal faulting in (a).

(c) Thrust faulting.
(d) Fault-plane diagram for the thrust faulting earthquake in (c)

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So, this beach ball diagram is unique for a particular type of source, for example the normal faulting you get a beach ball similar to this. Okay, this is a beach ball for the normal faulting system, you can see a compression, tension alternate shaded part. Similarly, the thrust fault you will get a beach ball like this complete thrust fault, so where you can see this one. Okay, so the normal fault and then reverse faulting system. Okay, so then similarly the strike slip. Okay so, transverse fault will have the different kind.

So, the combinations also will have, so this is the typical case where the easiest way to understand is given but in the real earthquake, this shape may not be the similar, it may be a

smaller, higher depends upon the how the compression and tension force take into share. Okay, so, this kind of representation is actually a source mechanism derivation or source mechanism arrived.

So, this part generally seismologist get okay, data from the different earthquake record and then identify a tensile and compressor source and prepare this diagram and release that along with the source earthquake information, these are very useful to feature to predict that this one kind of things, okay.

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Source Models of Energy Release by Tectonic Fault

- These are simplified models used from historic time in geotechnical earthquake engineering.
- Models continue to be used for quick assessment when data, time, and other resources are limited
- As more sophisticated methods become available through the increase of computing power and software development, simplified models will be used for rough checks on those models
- Simplified models should satisfy several requirements. They should offer conceptual clarity and physical insight
- They should be simple in physical description and in application, permitting an analysis with a hand calculator or a spreadsheet in many cases.
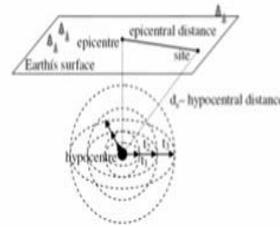
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So, then apart from this, we seen that there is a simple source models okay, which is works based on the energy release concept in the tectonic fault will help you to identify how the peak displacement or acceleration or velocity varies with the distance okay.

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A Simplified Point-Source Model

So, this is a basically assumes a wave travel at a particular location, spherical form and then the time delay between the arrival of P and S wave. So, then that velocity is taken into account and then there is an amount of energy transmitted location away from the source decreases with the distance okay, this total energy okay, wave front equals to the energy less okay, happens due to the loss due to the heating of that medium and then followed by that plane, so which is a proportionally to the your distance okay.

So, this concept has been extended and tried to arrive how the amplitude at particular location using the point source model and planar source model. So, the point source models are used for the magnitude which is magnitude 5 and less, the planar source model used for the magnitude which is 5 and above.

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Planar Source Model

- Their calculations assumed that a planar tectonic fault radiates the energy as a wave train uniformly in all directions in a medium with an average material damping coefficient k_d.
- However, their model requires knowledge of the fault plane size and location as well as of the attitude and thickness of the non-seismogenic zone, information that has to be assumed by the engineer a priori.
- First one is again valid for distances up to source-to-site distances of a few tens of kilometers, where the body seismic waves dominate the ground motion at the surface.
- At greater distances, where the surface waves dominate the ground motion at the surface, above Equation may be replaced by
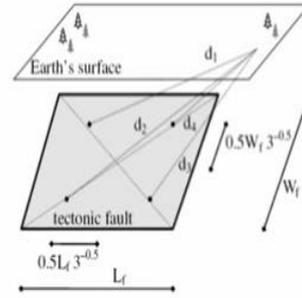
$$\sqrt{\frac{E_d}{E_o}} \sim \sqrt{L_f W_f \sum_{i=1}^{4} \frac{1}{e^{k_d d_i} . 4.\Pi.d_i^2}}$$

$$\sqrt{\frac{E_d}{E_o}} \sim \sqrt{L_f W_f \sum_{i=1}^{4} \frac{1}{e^{k_d d_i} . 2.\Pi.d_i}}$$

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So, here they consider each grid of the plan area as a point and then finally the integrity, you can see the difference between this length and width is incorporated here, so here there the length and widths are not incorporated okay. So, the 4pi and all accounted to sphere shape of the earth okay.

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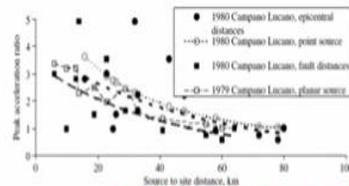
- There is a good agreement between predicted peak acceleration ratios based on the planar source model and the best fit of ratios (shown by thick dashed line) calculated from recorded peak accelerations using the fault distances as well as between predicted peak acceleration ratios based on the point source model and the best fit of ratios (shown by thick dotted line) calculated from recorded peak accelerations using the epicentral distances.
- It is possible to notice a number of outliers, i.e. values that are significantly different from the best fit, at the site-to-source distances greater than about 20 km particularly when the epicentral distances are considered. This *suggests that the use of epicentral distances is not always appropriate when considering attenuation of peak accelerations associated with radiation damping.

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So, this kind of models are very much useful to compare okay, realistically validate what kind of pattern of this seismic wave travels at a particular location, so the even we have seen that there are typical case studies people have taken the data and try to estimate using this kind of simple model and observed data and try to compare and fitting the data and try to arrive how the patterns are going okay, so that was analysis are done.

So, this quite the simple models are very useful for several cases, only thing this simple models are assume materials are homogeneous. Okay and then uniform though out the region which is not practically possible that is why you may have some bias. Okay, so that bias in some places which acceptable because of the smaller variation someplace, it may b**e** having the very large variation. Okay, so those kind of things has to be taken into account when we use this model, okay.

So, this is a way you can get a time domain parameters from the models. Okay, so this is the simple model which accounts the wave arrival time and then the energy release and equating them, you will get a your peak ground acceleration, peak ground velocity.

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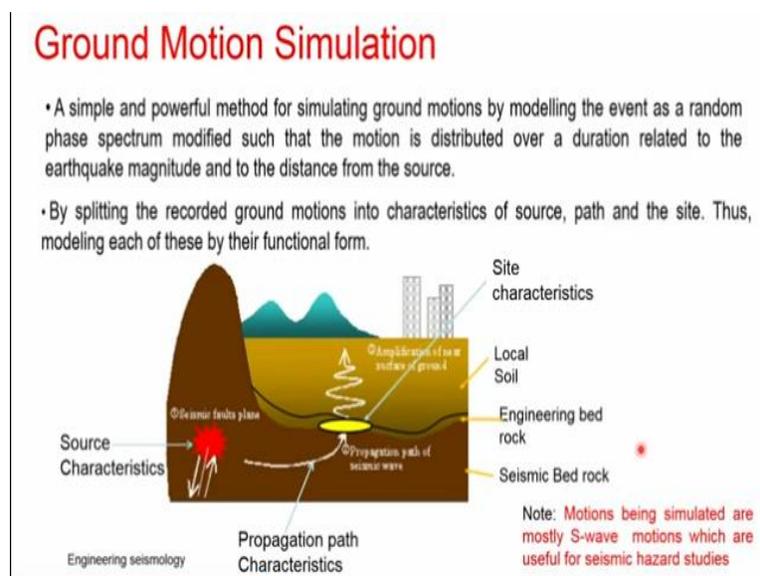
So, from this kind of analysis generally, it is found that the hypocenter, okay the hypocenter measurement is more reliable to represent a variation of the acceleration values than the epicenter that was a major findings from this kind of model analysis. The next is so this is the peak ground acceleration, a simple model which gives this data. So, another is as I said that so this peak ground is a single value.

So, if you want to understand how the wave form, complete waveform, its frequency and duration, you need an acceleration time history data, since all the location we do not have the

recorded earthquake data, people developed a simulation ground motion models. Okay, so simulation of ground motion, this was done by basically, Boore okay by segregating the source, path and site parameters.

So, as we have seen that the any waveform at particular location controlled by the source, property and characteristics okay, like the rupturing direction, path properties and then varied travels path characteristics and how it reaches site characteristics, so in this simulations model predominantly used on the rock site, so because of that the soil based characteristics are given less important which is also very difficult to simulate as you know that soil varies spatially considerably but rock does not vary that much variation.

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So, modelling up source okay, then path characteristics accurately one can get a simulation model, this simulation model was basically developed by a Boore 1983. Okay, so where he take total spectrum ground motion recorded at any site is the function of source, path and site characteristics. So we have discussed about what is the source, how it affects basically, source is controlled by the your corner frequency and seismic movement.

Path is controlled by the distance as the function of frequency. Okay, the site is controlled by the diminishing factor. So, as we have seen that MW, moment magnitude related to the M0. So if you assume what is a magnitude record, you can get a what is a seismic moment that will be

feeded here and then the R, where if you assume a location we can add. So this how much decay, damping factor, coda wave factors all those things are gone into the equation of the source path.

So that solving of equation will get you the your acceleration time history and path. So this entire simulation is actually divided as a 5 major part. Okay, one is that generating the white noise equal to the duration of the motion obtained from the corner frequency, filter the noise by applying the Gaussian window and then convert the windowed noise to a frequency domain by effective Fast Fourier transformation.

Normalise the obtained Fourier spectrum with square root of mean squared average Fourier spectrum, the normalised spectrum is then multiplied by a ground motion spectrum they again converted to acceleration time history domain by inverse fast Fourier transformation. So this details basically give you the simulation of data.

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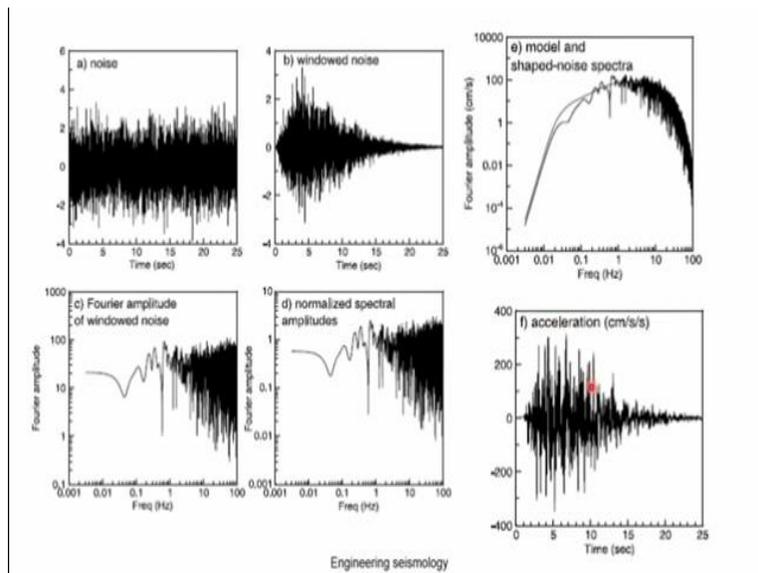
So, this can be explained by these; are explained earlier. So using the simple diagram, so where you can get a lot of noise this one and then apply a Gaussian filter and then transform to Fourier amplitude. So then the Fourier window noise filtering is there. Then the normalised spectrum finally you get an acceleration time history representing the your regional source characteristics okay.

So, the Rose regional earthquake character is reflected in this. So this is the very useful data whenever there is no recorded earthquake in the region. Okay, so there is no instrument in the region, so synthetic ground motion data's are useful for the design future level. Okay so, this is how the Boore model becomes a more and more famous okay, so more and more popular.

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So, this model actually the Boore was the first person who develop this model. So he was a scientist at USGS okay, United State Geological Science, okay USGS. So where they actually come up with the first model called SMSIM model. So then later his students are modified those model, then it is called as a FINSIM and then EXSIM, okay. The FINSIM was Berensev and Atkinson developed. So, EXSIM was developed by the Motazedian and Atkinson, so in 2005, so all these models are in use, so each model is has its own advantage and disadvantage, we will be discussing now.

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SMSIM (Boore, 1983)

- The earthquake ground motion will be treated as rupture at a single point.
- Modeled as white noise windowed using Gaussian window similar to the steps given earlier.
- It is useful to simulating ground motions at distances much larger than the rupture dimension.

Limitation

- Cannot capture the directivity effect .
- Cannot capture rupture heterogeneity
- Cannot capture fault geometry.

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So, the SMSIM model the earthquake ground motion will be treated as a rupture at a single point. The model is a white noise window using Gaussian window similar to the steps given earlier. It is useful to simulating ground motion at a distance much larger than the rupture dimension. So, this is basically the rupture dimensions should be smaller, the distance would be larger. So this does not take into the fault type into activity, so fault consideration.

So, because of that there are some limitation for example, it cannot capture the directivity effect of the fault, cannot capture the rupture heterogeneity, cannot capture the fault geometry, so these are all the limitations of the value but still this models are very well work up to the magnitude of 7. Okay, so that is a highlight of this model, somebody want to synthetically generate a earthquake where the stable continent region where the expected earthquakes are lower in magnitude like below 8 okay.

So, this model will be more suitable as it works up to 7 but above 8 magnitude you cannot use SMSIM because there is a controlled source and the path parameters which is modelled in the FINSIM.

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FINSIM (Beresnev and Atkinson, 1997)

- The entire rupture area will be divided into number of subfaults.
- Each subfault will be treated as single point source modeled as ω^2 spectrum.
- Contribution from each subfault will be summed up with sufficient delay depending upon the rupture velocity and the subfault size.
- Useful to estimate the total slip distribution on the rupture area.
- To understand the directivity effect accurately, permutations have to be performed.

Limitations

- Simulation need lots of regional parameters such as strike, slip, dip, stress drop, rupture area, geometric spreading, kappa factor and strength factor.
- Such parameters are difficult to be obtained is absence of larger number of regional records.
- Simulations are heavily effected by the subfault size considered.

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So, the entire rupture areas will be divided into number of sub faults. Each sub fault will be treated as a single point source model with omega square spectrum, contribution from each sub fault will be summed up and sufficient delay depending upon the rupture velocity and sub fault size, useful to estimate a total slip distribution on the rupture area, to understand directivity effect accurately.

So, this basically needs regional parameters such as a strike, slip, dip, stress drop, rupture area, geometric spreading, kappa factor and strength factor. These are all we discussed earlier, those parameters are very important and here actually, the simulation depends upon the sub fault size. This is the one of the major limitation of this particular method.

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EXSIM (Motazedian and Atkinson, 2005)

- Overcoming the limitations of FINSIM, Motezedian and Atkinson (2005) introduced the **concept of dynamic corner frequency** which will make the **simulations independent of subfault size.**
- FINSIM uses conservation of total moment when summed up all the subfault events while EXSIM works at conservation of energy using normalized velocity spectrum.
- The duration of motion doesn't depend upon the stress drop as was in case of FINSIM.
- Each Subfault will be modeled as point source and the summation at the site of interest will be done with suitable time delay.

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So that is why the people scientist start working on the updating that. So the same Atkinson group, so where they created model called EXSIM. So, the EXSIM overcome the limitation of the FINSIM. Okay, so which is developed by the Motazedian, Atkinson, 2005 introduced concept of dynamic corner frequency which will make a simulation independent of the sub fault size. FINSIM use conservation total mass when the summed up with the sub fault even size while EXSIM uses a conservation of energy using the normalised velocity spectrum.

So, the duration and motion does not depend upon the stress drop was in the FINSIM. Each sub fault will be modelled as a point source and the summation at interest will be done with suitable time. So, the EXSIM is the most robust way of simulating the ground motion data. So as I told you that simulation of ground motion data itself a topic of Ph.D research. Because it is not that simply even though the models was universally developed only few models. It is not that you simply take that model and use, you should know how to use that model effectively.

And using that model, what we generate how it is useful that data how you can converted into the ground motion prediction equation and other predicted equation that is why this simulation models are very important. As I told you that very few people work on simulation models in India. The first student who worked on the simulation model is Raghukanth okay, then followed by Abhishek Kumar, okay my student and I also did something and then my others student Ketan Bajaj.

So these are all the people worked in simulation of the ground motions and followed by using that simulated data to get the other ground motion prediction equation and things like that which is very much essential and needed for the seismic hazard analysis.

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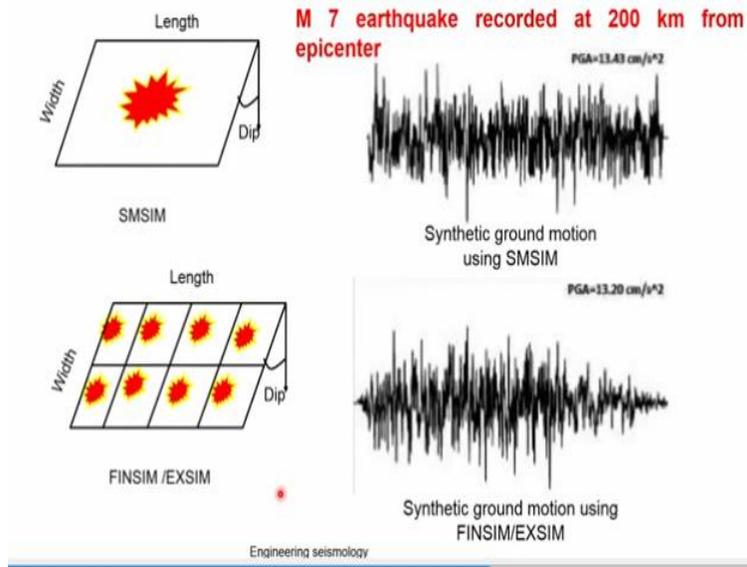
So, this is the typical recorded data. Okay, so using the SMSIM, and FINSIM and EXSIM at the magnitude of 7 and then a kilometre. So, you can see how the sources are assumed in the SMSIM, the single source with larger sizes assume, so which is reflected like this? So in EXSIM, FINSIM, several segment of the sources assume, so each one rupturing happens like that. At the end of the day, all these data's are clubbed together and finally arrive the bigger earthquake what you are looking for. So, this is how the difference between the SMSIM and the FINSIM model which is useful to get a synthetic ground motion data.

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FINSIM Model for Indian Earthquake
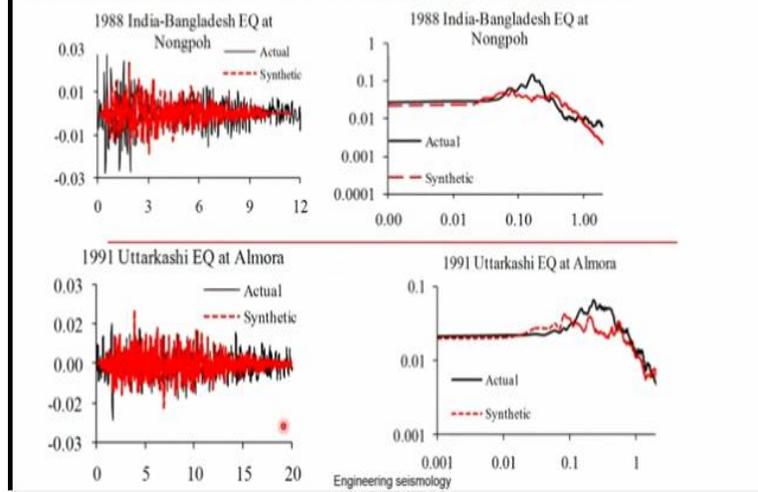
So, this is the another case where we have done a typical Indian earthquake simulation using the available source parameters. So some of the earthquake where there is no such parameters are available, so we range okay. We adjusted the values by parametric analysis and try to match recorded and then observed. You can see the Indo Bangladesh earthquake so and during 1988 and 1991 Uttarkashi earthquake, the actual and synthetic.

So, these data's only further use it to derive a spectrum of those earthquake, from there it is went to develop a ground motion prediction equation. Okay, so ground motion prediction equation this the ground motion prediction equations are the type of predictive equations okay, which is useful to get a peak ground velocity and peak ground acceleration or peak horizontal acceleration or peak horizontal velocity that is a ground motion prediction equation.

You will get a time domain parameters as the function of M and R, the other factors which is easily obtainable. So, this is about the simulation of the earthquake as I told you that we have been simulated large number of earthquake and using in our research.

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Predication Relations

- Proper design of earthquake-resistant structures and facilities requires estimation of the level of ground shaking to which they will be subjected.
- The level of shaking is most conveniently described in terms of ground motion parameters, methods for estimating ground motion parameters are required.
- Predictive relationships, which express a particular ground motion parameter in terms of the quantities that affect it most strongly, are used to estimate ground motion parameters.
- Predictive relationships play an important role in seismic hazard analyses
- Predictive relationships usually expressed ground motion parameters as functions of Magnitude, distance and some cases other variables

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So, the next part of that, so as I told you that the objective of this is to estimate a hazard. To estimate a hazard, you need some kind of function. Apart from this model which is very complicated, very limited people can use. So the functional form which predict a hazard. Okay, so that kind of functional form is called as a predictive relation okay, the predictive relation is basically is the function of M and R, some other parameter depends upon the region.

This functional form okay, is very much useful to estimate what is the future expected similar kind of duration, amplitude, intensity. Okay, so those are all the parameters. So that is why the predictive relations are very important in engineering seismology particularly, the next process onwards we will be handling those kind of things.

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- The functional form of the predictive relationship is usually selected to reflect the mechanics of the ground motion process as closely as possible.

- This minimizes the number of empirical coefficients and allows greater confidence in application of the predictive relationship to conditions (magnitudes and distances) that are poorly represented in the database.

$$\ln(y) = \underbrace{C_1}_{1} + \underbrace{C_2 M + C_3 M^{C4}}_{2} + \underbrace{C_5 \ln[R}_{3} + \underbrace{C_6 \exp(C_7 M)]}_{4}$$

$$+ \underbrace{C_8 R}_{5} + \underbrace{f(\text{source}) + f(\text{site})}_{6} + \underbrace{\sigma_{\ln y}(=C_9)}_{7}$$

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So, this equation development has to be done systematically. So okay, so the each place the predictive equation functional form should be different, depends upon the their regional data it has to be arrived in a best suitable form. So the universal prediction equation model is given here, you can see the 1, 2, 3, 7 up to 7. So each component represent some kind of natural phenomena happens at earthquake okay, what happens in the earthquake is represented here.

So, the y, okay all the predictive equation (()) (21:23) one is always a logarithmic function of the this one okay so and also, we also seen that the magnitude also varies in the form of logarithmic base 10 similarly, ln and then the other parameters take care of the magnitude and source and its variation and then there is a movement although since are modelled in this form. So, this form some constant may vanish when you check its suitability for a particular region, okay.

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Prediction Equations of World up to end of 2019

- 468+ empirical GMPEs for the prediction of peak ground acceleration (PGA)
- 302+ models for the prediction of elastic response spectral ordinates
- Arias intensity (32 models),
- Cumulative absolute velocity (10 models),
- Fourier spectral amplitudes (18 models),
- Maximum absolute unit elastic input energy (6 models),
- Inelastic response spectral ordinates (5 models),
- Japanese Meterological Agency seismic intensity (4 models)
- Macroseismic intensity (50 models, commonly called intensity prediction equations),
- Mean period (6 models),
- Peak ground velocity (137 models),
- Peak ground displacement (35 models),
- Relative significant duration (17 models) and vertical-to-horizontal response spectral ratio (12 models).

Douglas, J. (2019), Ground motion prediction equations 19642019, http://www.gmpe.org.uk. will be updated roughly once every six months.

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So, the people have developed large number of predictive equation throughout the world which has been summarised by the Douglas 2019 okay, so he has prepared since 2004, he has been preparing this predictive equation data's and models and try to understand how the predictive equations are going okay. So, here you can see that as I told you that he compiled all the predictive equations about 468 empirical ground motion predictive equations are available to estimate peak ground acceleration like PGA and PHA.

And 300 and zero models of the predictive elastic response spectrum available to estimate a spectrum okay for a different time period, so the arias intensity 32 models are available. Okay, the cumulative absolute velocity time model, Fourier's amplitude at 18 model. Maximum absolute amplitude is 6, in elastic Japanese spectrum is 5, Japanese metallurgical agency is 4, intensity model and then macro intensity model 50, commonly called as a intensity prediction equation.

The mean period model is 6, peak ground velocity 137, peak ground displacement 35 and relative amplifications 17 and vertical to horizontal isolation 212. So these are all the number of model which is together comes as a big volume of book, so which is published in this link. If you see this link, you can download this books and data's which will be useful for several application. So, this predictive model okay, so as I told you that each region, there will be 100 sub predictive models or few predictive models.

So, you have to identify what are the predictive models available for your region that model is how useful to interpret your or estimate your predictive value. So there are intensity predictive equation, duration predictive equation, peak ground predictive equation, peak ground velocity predictive equation, peak ground displacement predictive equation, peak ground acceleration okay that is a predominantly used at several places.

So, those predictive models are actually very well used in the several application. So this give summary of all those equation as I told you that you even though India has very long history of earthquake, the number of model, okay the number of conversion equation, number of anything related to this prediction like intensity model, duration models are very, very limited. We can also remember here that the predictive equations developed for the Peninsular India may not be applicable to the north India.

Why? Because that seismotectonic okay and seismic activity of the region. So if you do mismatching this kind of equation without a systematic procedure, the result what you are giving is actually useless, it may not be record at all. So that we have to remember when you are talking about the predictive equation. So, but all the summary of equation you can find, so India for the Peninsular India we have very few predictive equations okay, which is basically around like may be 4, 5 equations you can find.

And intensity equation, only one is available. So north India considerably you have the good number of predictive equation but still those equation applicability for the wider magnitude distance are again question. So, in order to overcome that in our group also. We have done a synthetic ground motion and then we also develop a predictive equation considering both the data as well as the one of the data, so that the issues can be solved amicably.

This predictive equations are identification based on the locations are very important. You cannot use a Kutch equation in the Jabalpur, you cannot use Kutch to the Uttarkhand. So something like that there is a considerable difference in the seismotectonic okay, the way of magnitude size and then how this wave form reaches at particular location which is precisely

modelled in the predictive equation, so this predictive equation. Okay, so the understanding of predictive equation, selection of predictive equation itself a separate topic. We will be discussing in the coming classes for the hazard estimation.

So, when we talk about the predictive equation, what about the predictive earthquake, prediction of earthquake. So can we predict an earthquake; if the earthquake is predicted, what will happen? So, generally if we predict an earthquake, it is very nice because you can minimise lot of people die okay like your forecasting Tsunami and storm know, people will move that is the one thing, it is a very big advantage.

But then if you have to predict the earthquake, so okay; so what are the parameters which you can see? How reliable that parameter to get a more accurate prediction; accurate prediction means; the earthquake should tell where exactly the earthquake will come, earthquake predictions should tell where exactly the earthquake going to occur, how much the size okay, so that is also very important.

And then what time, where size and time, these are all the 3 major challenges in the prediction of the earthquake. If you understand how the earthquakes are occurring, okay. So the prediction of the earthquake is not a very difficult and we will understand that the prediction of earthquake is not that easy as the understanding of the source and then the stress building is very complicated. If you understand that very well how much of stress is built, how is moving, what is the geological age then you can predict the 3 parameters which is very challenging.

So, this prediction of earthquake and then the associated problem, even if you predict an earthquake, what is going to happen, how for it is the knowing and not knowing the earthquake going to occur will impact at particular place like socio-economic problems due to the prediction of the earthquake, prediction of the earthquake due to that will be discussed in the next class. So, with this, I thank you very much for watching this video on this recapping up all the class notes.

So, I hope you might have understand a many parameters which is useful and then also we recapped. So that even some of the classes you miss, you can see here. And so we highlighted all

the most important which is exam point of view as well as the understanding the subjects also very important. So, if you have any questions although since basically, you can write to TA or me or call TA or me. So that we can try to rectify your questions okay, which is technically sound, not somebody is taken your work and publishing somewhere not that kind of social unrelated questions should not be handled during the assignment period. Okay, so thank you very much. We will see on the next class.