Introduction to Engineering Seismology

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Lecture No-26
Time history; response Spectra (design); Stochastic models

So Vanakkam, we will continue our lecture on engineering seismology. So last class we have been discussing a couple of classes about the interpretation of the earthquake records, what are the time domain parameters, frequency domain parameters, then we also seen how the frequency domain parameters will be useful to basically to get a simple theoretical model to verify the ground motion data how it is recorded.

So we have seen that basically the energy at source energy at a site where it is measured, how the energy losses you can count by taking a distance and the stiffness of the material into account. So we have seen a simple point source model and primary source model. We also understand that these models are very easy to use even in hand made calculation or excel will be sufficient. You can cross verify the data recorded, that is the application of these models.

These models are extensively used in geotechnical engineering even though it has the assumption that materials are homogeneous and then uniform throughout the travelling path, but to some extent these assumptions will help to get overcome. So we have seen that the point source models are applicable up to the magnitude of 5 beyond that the primary source models are good. We also saw that both the models were taken as an epicenter and hypocentral distance.

So we understand that the epicentral distance is more appropriate than the hypocentral distance. In today's class we are going to talk about some of the important parameters which we have discussed last time with typical examples such as a time history and response spectrum and tripartite. So what it means, why it is very important? Then followed by stochastic simulation; models available in simulating the earthquake data.

How earthquake data can be simulated in the computer and what models are available, that we are going to discuss in the today class.

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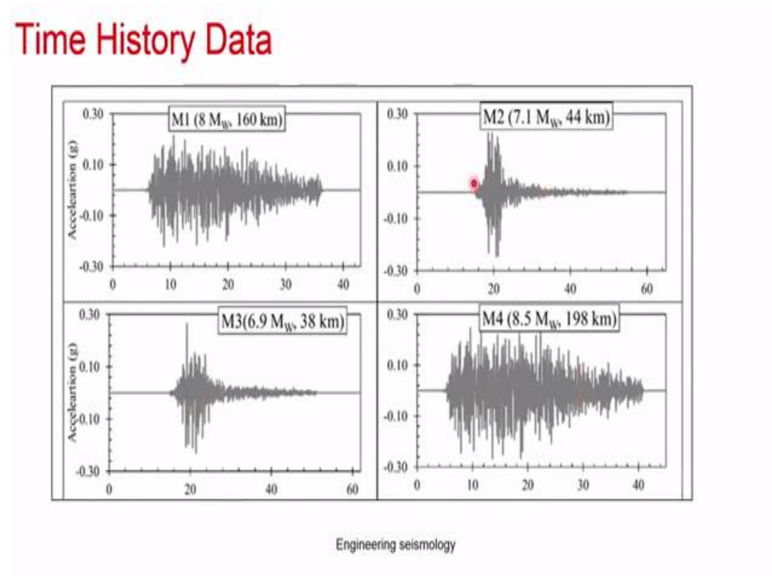

So as we have told the earthquake data what we record is actually the acceleration time history or velocity time history. This is called time history data, the variation of the acceleration or velocity with respect to distance has been measured, you can see here basically. This is the typical earthquake record for the 8 magnitude and 160 kilometer, you can see that this is a predominantly the S wave component.

You can see how the S waves are various as you know that you can pick up basically the peak points, what is the value of that and then you know how to estimate the duration also. These two parameters we can directly obtain from here, so you can pick up a peak point which may be acceleration or velocity and then displacement, in this case the acceleration versus time, you can get a peak acceleration, you can also get sustained acceleration, effective acceleration, those kinds of things.

And duration by fixing a threshold value of 0.01 and then converting into the Husid plot and then making that the energy plot and then you can also get a significant and then the effective duration kind of parameters we can obtain from here, this works we can see. You can also see these earthquakes or some of them are like a very long duration, some of them are the short duration, this is also you can use the link with the kilometer distance which you used.

For example; 8 magnitude, 8 magnitude, 160 and 198 you can see there is a long record, these are basically a larger duration record, similarly this is a 44 and 38 you can see that, it is a short record but the amplitudes are high. So depends upon the site where you basically record the data accordingly you will get basically your duration and amplitude into account, we have seen that basically.

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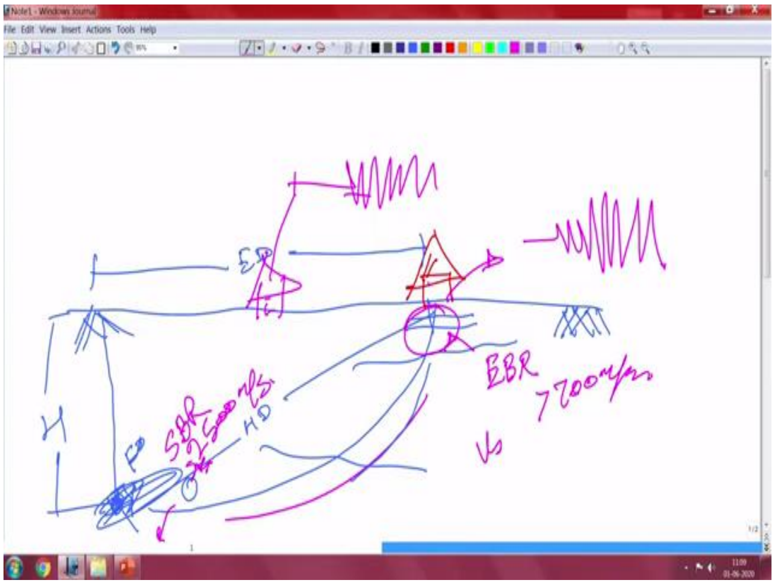

This is where the earthquake rupturing is taking place, for example, these are rupture, this is the site, this is your recording station or your house kind of things. This waves where it does basically, it travels like this and reaches here, as I told you that any place you do not find the rock itself as a surface, you will have some kind of geologically weathered materials which is called as a soil then followed by you will have a rock, then followed by your rock will keep on increasing with the different rock.

So this particular rock where the rupture is taking place, this is actually a focus, this is the focus and this is basically your epicentral distance and this one is your hypocentral distance and this is your H depth of the earthquake. Depending upon the composition of this material and this path what you are getting here is a different amplitude and then your duration, which we have seen simulating a typical data.

For example, if you have a similar setup here, this will be the different signal record, like this you will have the different record of the amplitude and duration per any earthquake. So you can understand that this variation not only with the distance this also varies with the where you record. For example, if this portion I will draw you in the detail as I told you that.

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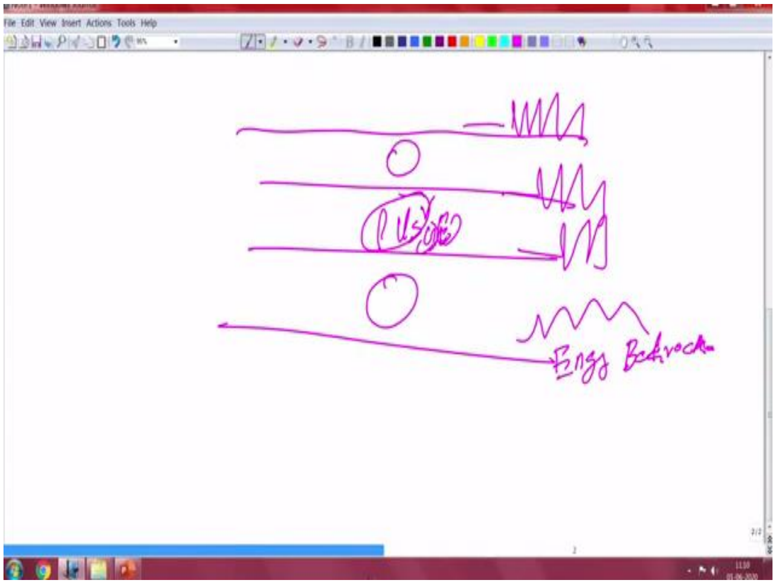

This is the surface you will have the different layers. So I have only the zoomed portion basically this one I am drawing here in the next page. So this bedrock is called an engineering bedrock, why engineering bedrock? Basically here only where the engineers rest to their foundation, that is why it is engineering bedrock. This is called a seismic bedrock where basically the earthquake originates, this is engineering bedrock, this will have 700 meter per second, this will have roughly 2500 meter per second of the Vs value generally, that is how it is defined.

So if you look at this engineering bedrock portion, we have seen that this wave is here or we have seen it is with respect to time. This same wave when you go different depths this waves will be different depends upon the basically the row and Vs value and then the g and Young's modulus which again can be defined is the function of rho, Vs and the Poisson ratio, that is what we have seen in the wave propagation depends upon these properties basically, you will get different waveforms at a different level.

These waves form what we are getting basically is directly recorded data, this is called as a time history data which may be velocity with the time or acceleration with the time, you can also measure with a different level. This is the time history based time domain parameters, you can get from that. The response spectrum we have seen that.

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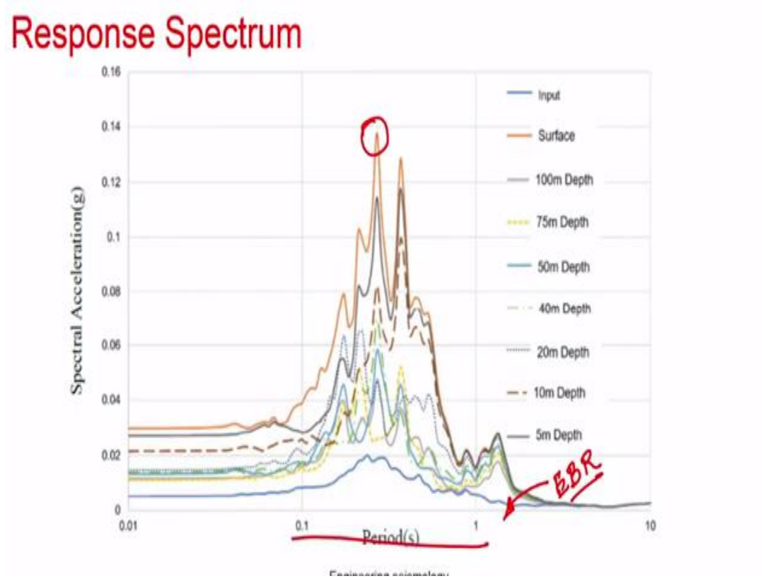

It is a response of the single degree freedom system for a given earthquake. As we said, that is the response of the given earthquake obviously here also this response what you are measuring depends upon where you are measuring the response will be different. Because the given input you are getting the response correct? So this is how you can see a typical response spectrum which was a developed part of my research to understand how the different layer velocities are getting the response.

This is actually the input response of the given earthquake which is basically an engineering bedrock side this is like rock recorded data. When it undergoes here different processes through different material starting from this is basically 100 meter, then the 75 meter, 50 meter, 40 meter, 20 meter, 10 meter and 5 meter. You can see that the red one is basically the surface, this time history value what we have discussed in the previous slide, the time history of that data from different earthquakes.

That means you will get a different time history of the data with respect to depth as long as you have changed in the material, density, stiffness and Poisson ratio. If there is no change you may get the same only if the distance is very large you may get a difference but otherwise the shorter distance, it will not have any change. You can see the surface one and then the 100 meter one, the 75 meter one, then the 50 meter one because you can see the different colors actually, the 40, 20, and 10 and 5 meter depth you can see.

Overall you can see this is actually obtaining a different peak level at a different period all of them, the peak was obtained only on this range, point one to one second of the natural period. Just basically this is the period not time this is a period which is like a natural period of the single degree freedom system. You can see there is a variation this is how you can get a response spectrum by doing a response spectrum analysis.

You can take a time history data and convert into solving that wave propagation equation by single degree freedom you can get a response that is the typical response at a different depth. These response and the time history will give you the total clear picture of your particular earthquake, but in a given region you can expect any type of earthquake as I have to mention here that, recently there was a lot of news, as on today when I recording this video the first June 2020, there are many tremor or you can say that minor earthquakes.

The minor earthquake reported in Delhi region in the last two months, so these minor earthquakes starting from magnitude of 3, 3.5, 4, 4.5, something like that, there is not causality or damage but people are felt the NCR region in Delhi this is predominantly reported in the last two month even though there was a shutdown and lockdown then lot of things are happening, but this earthquake being reported.

As a seismologist myself and also many of the colleagues who actually know about the history of the earthquake including you are studied now how the earthquakes are occurring. These earthquakes may be a foreshock, foreshock is actually a smaller event which is happening before the main earthquake, this event may be a foreshock there may be a big earthquake one can expect in that region, big means it is not that it should be like a magnitude of 9, 10 kinds of things.

Anything which you harm here human beings, it is above 5.5 and 6 which causes damage and then hazard and disaster, those kinds of earthquakes we call it as a big. The disaster earthquake we have said that the causality is more than 10 people, these kind of earthquakes in this place is expected, as on now I am talking on June 1st, I am not very sure when you see this class what date it will be, but you can check in case it happens during this period.

So then there is a gap between the mainshock and foreshock is very short, if it happens before you see, in case it happens slightly longer at the end of this year or next year then the gap between the foreshock and mainshock is slightly larger, that is what you can see. These kinds of different earthquakes can be expected in the particular place, those earthquakes because when you want to design a single spectrum may not be sufficient, then you have to go for the developing a design spectrum.

I will give you a glimpse of what is meant by the design spectrum because last class we discussed a tripartite plot, this necessary to understand what is this design spectrum also.

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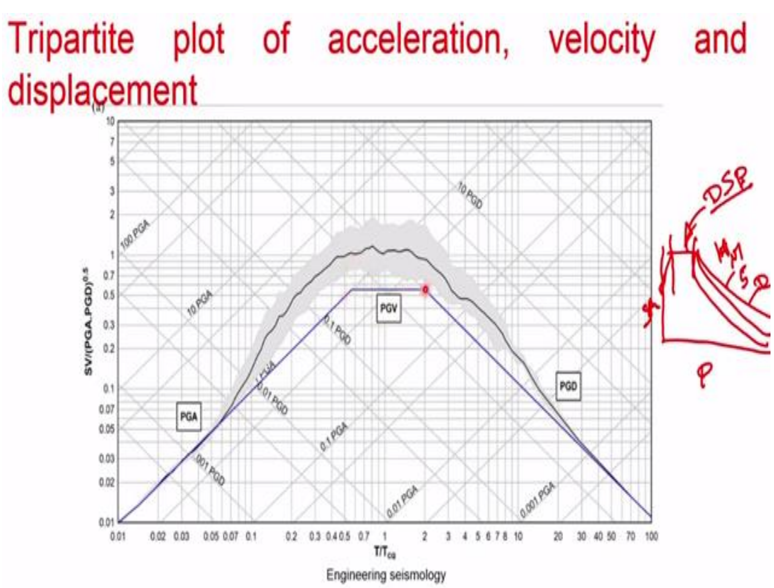

The tripartite plot is basically a plot of several median response spectrum plotted in the three dimensional graph, what is the three dimensional graph if you can see. So this axis is basically a PGA, this is the velocity values, basically this is a velocity versus time and this axis will be an acceleration versus time, the peak ground acceleration, this axis will be a displacement versus time. So you can see here 4 axes in the single graph, in that 3 axes are actually the dependent axes, 1 is an independent axis.

Here the time is basically a period, the period is actually an independent axis, the velocity and the acceleration and then the displacements are the dependent axes, which is a function of your time. You can see that the same response spectrum has been plotted here, it will look like this, you can see here, see how it looks, this is how you beautifully get this shape. So why we need to draw this basically when we discussed this time domain parameters, we found that basically the acceleration are very sensitive to the high frequency range.

Velocities are sensitive to the intermediate frequency range and the duration sensitive to the low frequency range. If you do the reverse, the acceleration sensitive to the low period and velocity is intermediate period and the duration is long period. You can see that the acceleration will be almost similar or you can make it a constant kind of value within each sensitive region. Similarly velocity can be made constant within that sensitive region, displacement where you can make it a constant.

This concept has been extended to derive a design spectrum. If you look at a Indian code, those who study civil engineering subjects, they will come across Indian code called IS 1893, now the recent version is 2016, we will also elaborately discussing about this IS code in our classes when we talk about the seismic zonation of India. Now we will only recall what is there in IS code, actually this is called as a design spectrum.

So the design spectrum which is all the country will give the design spectrum, this design spectrum basically is a period and then spectral acceleration, then they give some shape. This is basically an Indian design spectrum, which is as a three division on this part which is for the hard rock medium soil and then the subsoil. Dense medium or hard rock medium, soft soil classification, this is the period, this is the essay, this is basically a design spectrum.

This design spectrum as we have seen that the low period is acceleration, this is the velocity, this is the displacement. In order to get this picture one has to understand how this tripartite plot comes, basically your response spectrum data per a given side from the different earthquake data you can take and then after getting the response at a particular depth or a surface level you can basically combine all of them and this is like 100, 200 data's here, 100 and 200 data compile, then you take a medium.

This medium you draw as a single line, this is where you can expect a constant value, this is the constant value you will expect. When you superimpose all of them, this is basically PGA that PGA what you have seen in time domain that one, this is basically a PGV and this is the PGD. So where it interacts actually depends upon the region to region, it may not be constant to all the places. So you will get where it interacts, then how far these values are different from this PGV, PGA and PGD.

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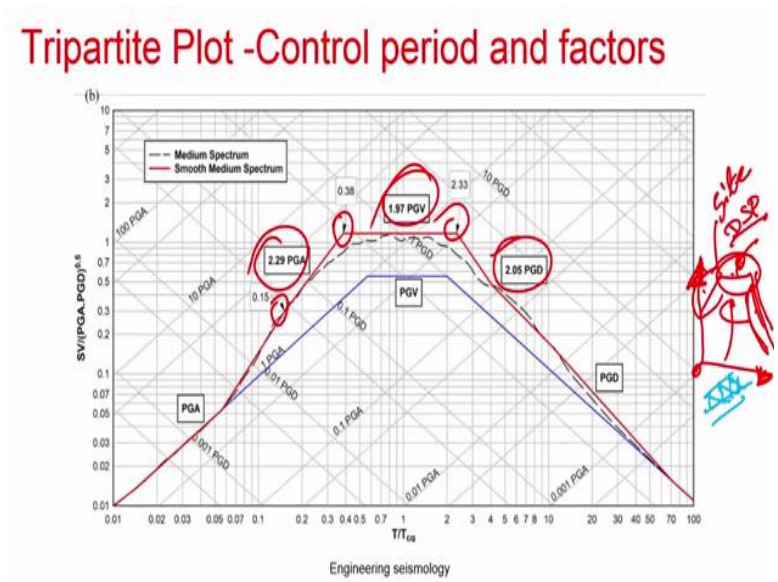

That you can arrive and if we arrive using that you can get a designed spectrum, this is the typical design spectrum we have developed for the North India part of our research this papers are under review, so I do not disclose too much about the result, but just I will give you the idea. As I said, this is the median curve, then that median curve that is the median curve smoothed and averaged from the large number of response spectrum, which is plotted in the tripartite.

Then I made it fit by a straight line, you can see I am fitting to the straight line then I get this one. So this cutoff period and the value of how it is different from PGA, how it is different from PGV and how it is different from PGD is the factor called amplification factor or a factor which is more than this PGV, PGD and this one. This PGV and PGA, PGD also can be obtained as mean value for the given data and this is the mean value which is from the response data, which is like the variation of the PGV with respect to the PGV of the data.

So then from there you get your plot, this in the normal plot, normal graph like this, this is an acceleration sensitive region, velocity sensitive region and this is the displacement sensitive region. This is called a design spectrum, this kind of spectrum will be obtained through this detailed tripartite plot. For your information the currently available IS code design spectrum is not developed like this, which is only copied from the previous works which is carried out to our elsewhere in the olden earthquake.

And this spectrum does not even account for data recorded in India. Since I do research on this, this was our observation, we have been working on updating this, maybe hopefully I will come up with the new design spectrum which after published can recommend it to the code for which will be useful. So this spectrum as I said that it is a function of your site, also if it is a rock site you will have a different shape, soil site, it has a different shape depending upon your soil thickness and a stiffness.

So this is that you can see the control period and then the factors which are about these values, these are all the values will be estimated using the systematic analysis of the recorded earthquake data in the same region. Why do I insist on the same region? As we know that India has a two type of seismo tectonic setting majorly, one of them is Peninsular India, which is like stable continent kind of things, the another one is the active region, which is very close to the, plate boundary like this indoor gangetic basin and rest up the in and around the region.

This is the two major classification you can define, even if you want to go to a minor level you can even classify the northeast part separately. So when you are talking about the seismicity of India, we will discuss how these regions can be divided differently in detail, right now I will just give you. But we have the same spectrum throughout the country, now you can understand how we have the spectrum in comparison to the state of art and knowledge available in the world.

And the second we have the variation in the soil only on this part but actually the variation, the soil can also cause here as well as here, both may affect, but the Indian code only recommended here, so I suggested as on now old data only for this part but this portion will be basically western countries code as variation here as well as here. So that is the variation you can get in the western country, but here our code is.

As and now our code design spectrums are some that need to be updated, after a proper research and understanding of this one. As the soil spectrum at an acceleration sensitive, velocity sensitive and displacement sensitive are completely different. As of now as I said that the western code being updated shows how that spectrum looks, I will just give you the glimpse of the video, I mean the drawing up that how was the western country code actually. So the western country code basically;

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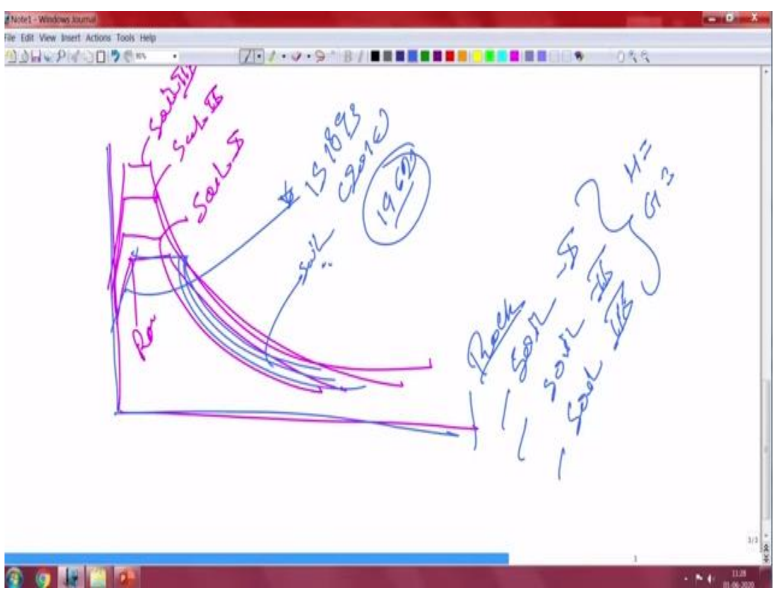

They have one for rock like this and then the one for, this is like rock, this is soil one right now I call only soil 1, soil 2 something that soil 2 and soil 3. These are basically soils with a different thickness and a stiffness, this is how modern code. So what it does is basically our Indian code is only giving like this, this one the same and here they have the variation for the different categories of soil that is the difference between the modern code and Indian code in the broader variation.

We have been working in the last two three years to update this as I told you that the present Indian code IS 1893 2016 version. Since it was developed very beginning in 1962, from that time onwards the spectrum has not changed much, this spectrum was basically copied from the previous work done in the Western countries, if this is not based on the recorded earthquake data in India which we have studied and then we understand that there is a need to develop such kind of design spectrum for Indian condition.

What we are doing actually collected is an acceleration time history of the different available earthquakes in India and then try to characterize that earthquake data as a rock and a different soil class. Right now since you are not studying this soil classification as a part of your course, I just give you a glimpse of soil 1, soil 2, so these are basically a difference in height of the soil, the thickness of the soil and then stiffness, this will make these classes.

Similarly rock is different from this one, we characterize data what we collected and group them according to which category it falls, there is a systematic analysis and the process. After grouping them that particular time history, we will take it and develop a response spectrum, from that response spectrum will go for the tripartite plot. If we have a considerable number of data on each group, you can create a mean and average and try to get a tripartite plot which we have discussed here.

This is the tripartite plot procedure that we have seen basically, this is the procedure that we have seen, this is what we got and then followed by this also we got and cut off period we estimated, finally we arrived at this shape, which is we found that the shape and the cut off period like this control period or cut off period and the factors these 2.5, 1.5 completely different for South India and North India or Peninsular India and active region as the source characteristic and a site characteristics and path characteristics are completely different.

This observation we made actually, now these papers are under communication and under review, once we have published that then this spectrum will be made available to the general public people can consider that response spectrum will be more robust way than the current response spectrum which does not include recorded data from India, there is a message from this tripartite response plot can. Those kinds of spectrum development are called the design spectrum. So as such the developing design spectrum itself a PhD topic.

Whatever I discussed in the last three slides, I was only talking about the three slides, time history data and response spectrum and tripartite plot. Doing this for a larger area and larger data, it is a topic of PhD, as you will be trying to understand how the magnitude and the distance and the site condition and the source condition affecting your shape of the spectrum. Finally, which shape you recommend, why you recommend that you will justify and give a reason.

So if you complete the entire work by 3, 4 years then it can be taken as a one of the PhD useful research for the country level improving our design practice of earthquake engineering. This is a very important area of topic, I was also surprised that when I started working on this response spectrum, design spectrum about 2, 3 years back, nobody was even thinking about and doing any work on this. You can find very, very limited publication on developing a site specific design spectrum for the Indian condition.

People have done some work here and there, but there is no development of the design spectrum, then actually maybe we will publish with the systematic data that will be the first work. There was some work done parallely at IIT Bhubaneswar, but there was some kind of limitation there. Anyway, this is not the place to discuss those things but just to give you ideas like they are also trying kind of this work part of the startup project.

One of the faculty in IIT Bhubaneswar, they are done, the developing design spectrum itself a PhD topic which requires lot of care and attention as this decides your safety of the building, as I told you that there may be a future big earthquake in and around the Delhi region because there is a foreshocks are being reported. So if the people designed their earthquake according to the proper design spectrum, they do not even have a minor crack or something like that.

Some people are not even designed to have disasters, collapse and failure kinds of things, the providing useful data is one of the main contributions that has to be made from the academic and research side where we have to give a proper design spectrum to the people. We are working towards that hopefully in the short time period, we may have that publication people can use as this one. With this basically, I will close this lecture.

Even though I told I will discuss the simulation, since it was half an hour over, the simulation part we will continue in the next class. We will see how we can simulate the acceleration time history of the typical earthquake? What are the simulation models available? What is the advantage and disadvantage? What are the parameters you need to consider? That we will discuss in the next class, thank you very much for watching this video, I look forward to meeting you in the next class. Thank you.