Geotechnical Earthquake Engineering
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Module - 7
Lecture - 24
Seismic Hazard Analysis (Contd…)

Let us start our today's lecture on this NPTEL video course on geotechnical earthquake engineering. In today's lecture, we will continue with our module number 7 that is seismic hazard analysis, which we were discussing in our previous lecture also. So, a quick recap, what we have learnt in our previous lecture.

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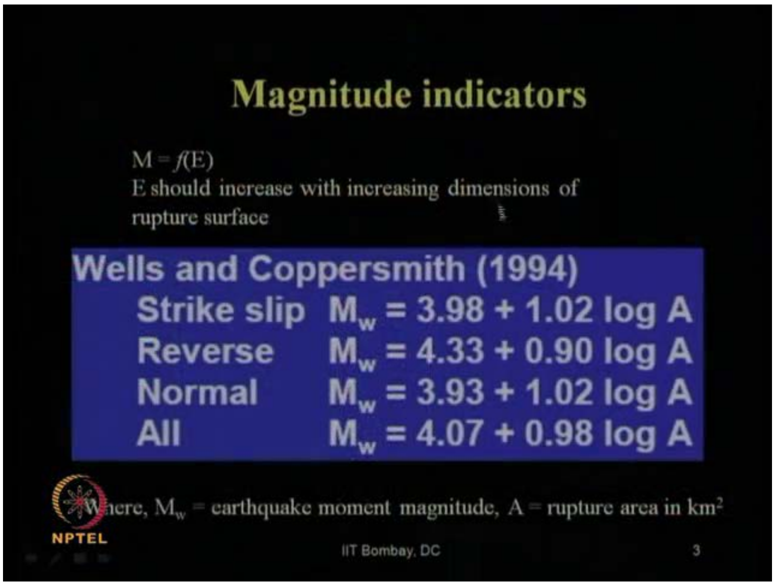

We have seen that how to estimate the earthquake magnitudes, that is magnitude indicators required for the seismic hazard analysis, so that magnitude is a function of nothing but, the energy released during an earthquake. So, Wells and Coppersmith in 1994 they proposed various empirical relationships with this moment magnitude of earthquake with the rupture area of a surface fault, which is expressed in the unit of kilometer square through these expressions or different types of faults. Like for strike slip fault this is the equation. For reverse fault this was the equation. For normal type of fault, this is the equation and when fault type is not particularly known or when we consider all types of faults together or it is a combination of various types of faults then the all type of fault equation is proposed to be used.

So, when that means the magnitude of past earthquakes are not available for a particular site for doing the hazard analysis using the present fault characteristics one can easily estimate the earthquake moment magnitude possible using this empirical relationships proposed by Wells and Coppersmith.

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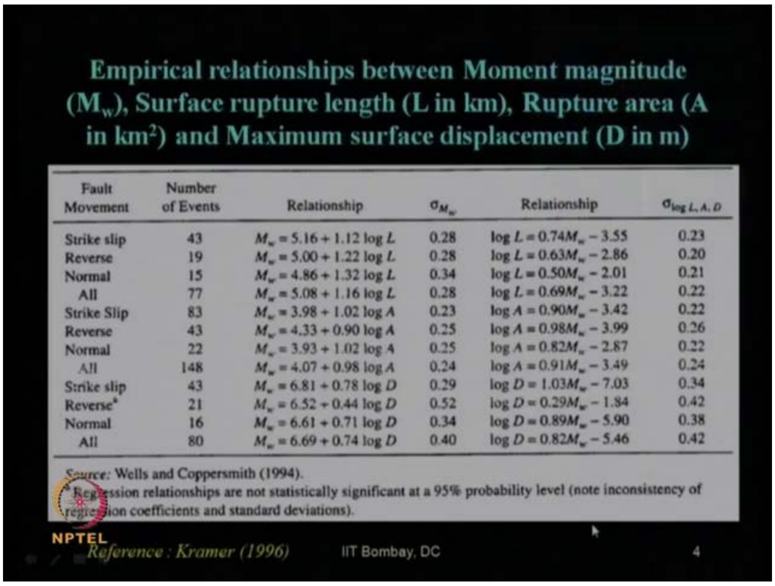

We have seen that they have also proposed similar relationship with respect to length surface, rupture length of the fault in kilometer unit in terms of l. They have also proposed similar expressions for the maximum surface displacement D in the unit of meter like these four equations. So, four sets of equation in terms of surface rupture length, another four sets of equations for surface rupture area and another four sets of equation for maximum surface displacement with respect to the moment magnitude of earthquake based on the collected number of events.

Then they have also proposed while proposing this empirical relationships for the given number of data points how much was the standard deviation for each equation. So, you can see among these proposed equation the minimum one was with the rupture area, with respect to rupture area whatever equations were proposed those are having minimum standard deviation. That is why those are considered to be the best among those three sets of equation with respect to rupture length with respect to rupture area and with respect to maximum surface displacement. Second best is the with respect to surface rupture length l.

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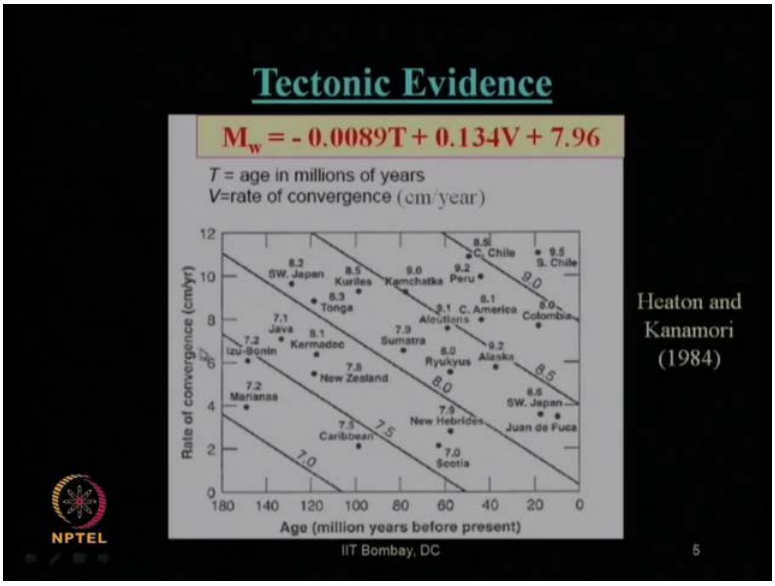

Next, we had seen in the previous lecture that the, from the tectonic evidence that is from plate tectonic movement. If we want to find out the earthquake magnitude, moment magnitude, what is proposed by Heaton and Kanamori in 1984. This is the expression given in terms of the edge of that plate which is moving in millions of year’s unit and what is the rate of that movement of the plate in the unit of centimeter per year so based on that this was the equation proposed till the data collected of 1984.

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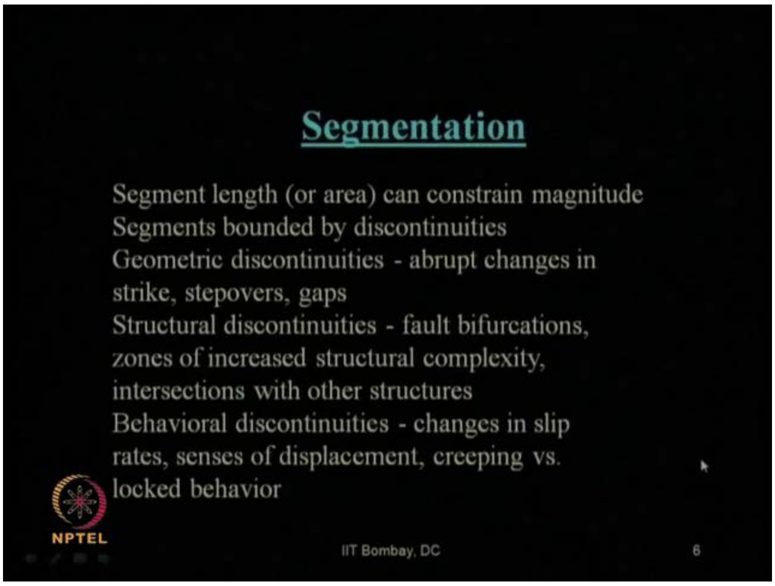

Next, we had seen after magnitude indicators in the previous lecture we had seen what is called segmentation of a fault that is the ruptured portion of a fault. We have to find out what are those segmentation length and various characteristics for considering or various parameters need to be considered for that segmentation, identification were discussed.

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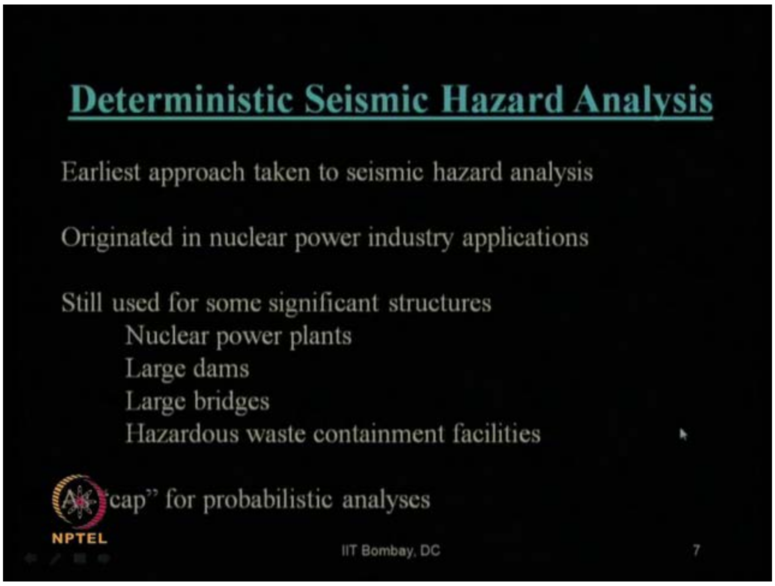

Next, we had seen where the deterministic seismic hazard analysis are used it is the earliest and simplest approach among all seismic hazard analysis. It was originated from the nuclear power industry application and it is still used even today also for most significant structures like nuclear power plant, large dam, large bridges, hazardous waste containment facilities etcetera. And we have also mentioned in our previous lecture that it is considered as the cap for the probabilistic seismic hazard analysis. That means this deterministic seismic hazard analysis will always give the worst case scenario or the maximum value of the design parameter.

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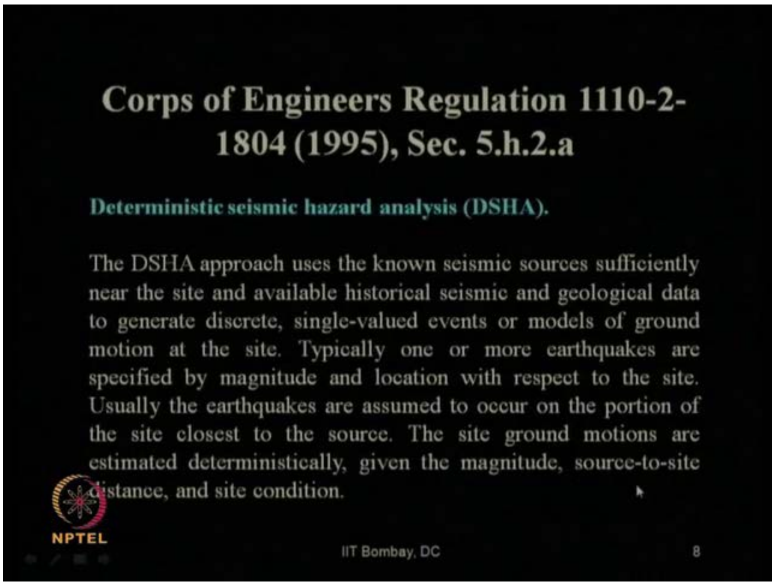

We have also discussed what is the recommendation by the corps of engineers regulation by this clause number, section number of 1995 version for DSHA analysis.

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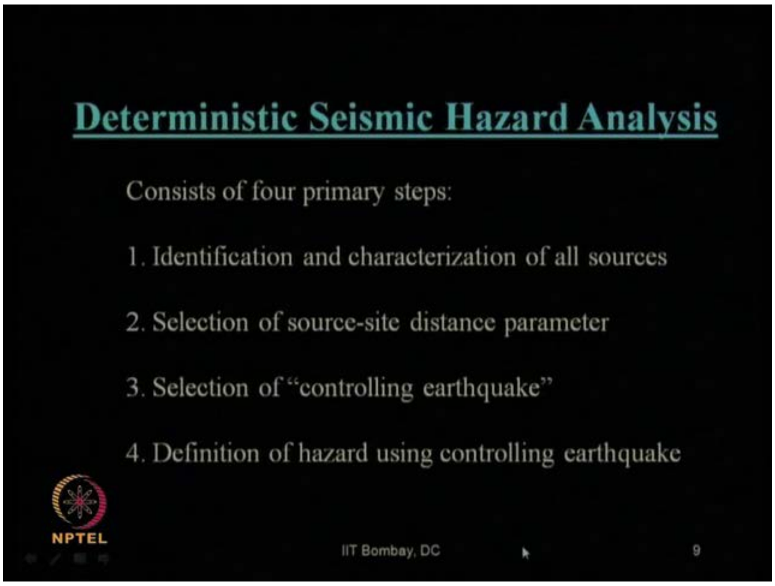

And we discussed what are the major four steps for deterministic seismic hazard analysis, these are the four major steps like identification and characterization of all earthquake sources, selection of source to the site distance parameter then selection of controlling earthquake and definition of the hazard using that controlling earthquake.

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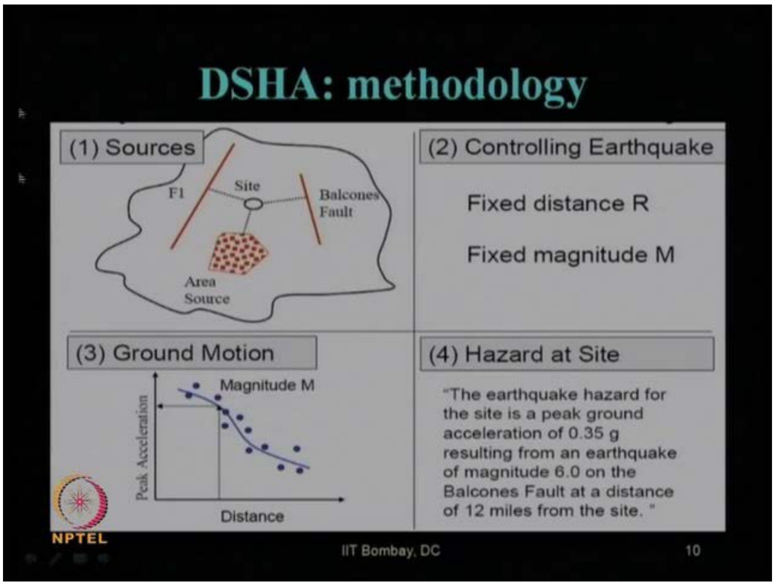

So, in through picture we have seen these are the four steps of identifying the sources of earthquake with respect to the proposed site of construction. These are the various sources that can be of various shapes also and for those sources we have to identify what magnitude of earthquake, what distances etcetera. So, minimum distance need to be considered and maximum magnitude of earthquake needs to be considered for deciding on the controlling earthquake. Then whatever ground motion you are interested to know that hazard parameters you have to identify by yourself that is which hazard parameter I want as my design. That attenuation relationship you need to use with respect to distance, with respect to that you identify what is the distance where your site is located. It will give you the final hazard parameter which can be finally stated in this format that is which source is the controlling source and which earthquake is the controlling earthquake.

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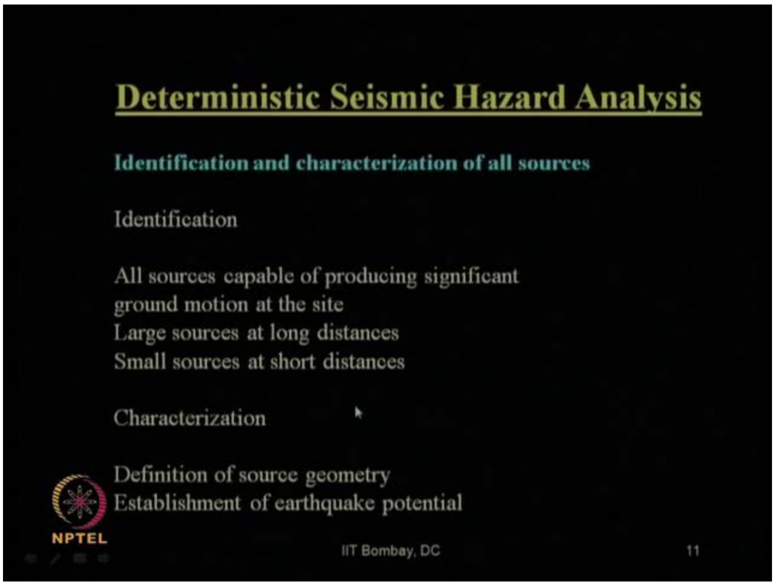

Next, we had seen the identification and characterization of the all sources and in deterministic seismic hazard analysis we give equal weightage to each and every source. That is we do not discriminate that this is more active source and this is less active source, no, not like that. We give say all sources are capable of producing equal amount of ground motion at the site, then we have to use the attenuation relationship properly based on large source to the long distance and small source to short distance, those relationship. And characterize the sources like what is the source geometry whether it is a area source, point source etcetera and establishment of the earthquake potential.

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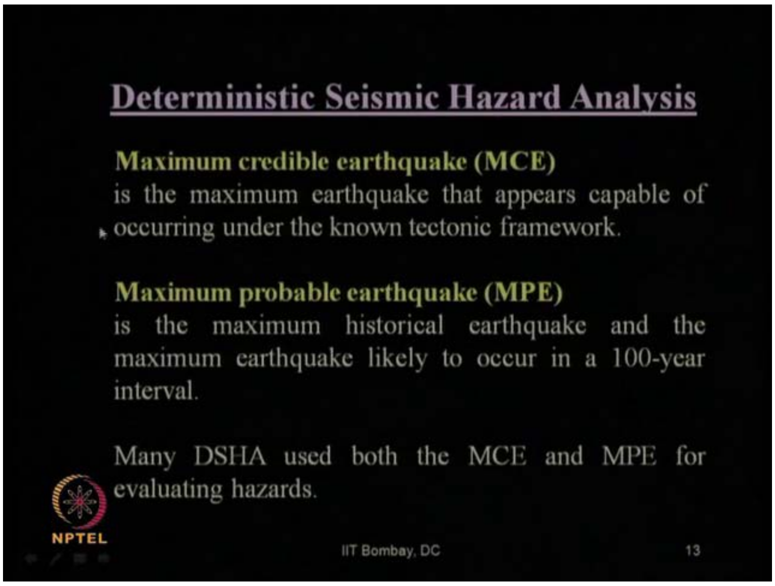

For establishing the earthquake potential, we see who are the important people should work together like seismologist, geologist, engineers, risk analyst, economist, social scientist and government officials and common terminologies, which are used for defining the earthquake potential are MCE, DBE, SSE, MPE, OBE, SSEE. Now, among those parameters again for deterministic seismic hazard analysis let us see which are important. So, up to this we had discussed in our previous lecture. Now, let us see and continue in our today's lecture what these parameters or controlling earthquake defining parameters mean.

Let us look at those parameters which are used for our DSHA or deterministic seismic hazard analysis. The most common one used is called maximum credible earthquake or MCE. What is that? As the name suggest it is the maximum earthquake that appears capable of occurring under the known tectonic framework that is the definition of MCE. That means when you know the plate tectonic movement or when you know the complete fault characteristics, like length of the fault etcetera, you know from that source how much maximum earthquake can occur.

That is form the past history or using those proposed empirical relationships of wells and Coppersmith or the Heaton and Kanomori depending on type of your source you can estimate what is the maximum earthquake which that source had experienced or can experience either using old historical data, collected data or from those equations. So that maximum value of the earthquake will be considered or called as a maximum credible earthquake for your site, so that is called MCE.

And another term which is also used for this deterministic seismic hazard analysis is known as maximum probable earthquake which is the short form is MPE. What is that? It is the maximum historical earthquake and the maximum earthquake which is likely to occur in a 100 year of interval. So, in this case our time span which we consider for calculation is based on a probability. So, what probability we have to use based on your historical earthquake recorded data you know how much is the occurrence of your earthquake, that we can establish the relationship which we will see little later in this course.

So, once you know how what is the rate of occurrence of a particular earthquake in due course of time in your 100 years span or time interval you need to estimate what is the maximum value or you have to take the maximum historical earthquake which can be considered as MPE.

So, you can see here the span of 100 years is given whereas, in MCE there is no such span given in this method. So, depending on your life span of your structure typically say 50 years, 75 years or 100 years even for your most important structures you can use this concept of MPE rather than MCE. But it is on the designer's choice of course, or the engineer's choice that is which value of this earthquake potential; needs to be used for calculation of this deterministic seismic hazard analysis.

So, many DSHA used both MCE and PCE for evaluating hazards and they compare. So, that is the best way that is you check with respect to both the values then you find out what is your final output or seismic design value you are getting considering whether MCE or considering MPE. Then you take the worst case scenario may be for your design for the using DSHA or deterministic seismic hazard analysis.

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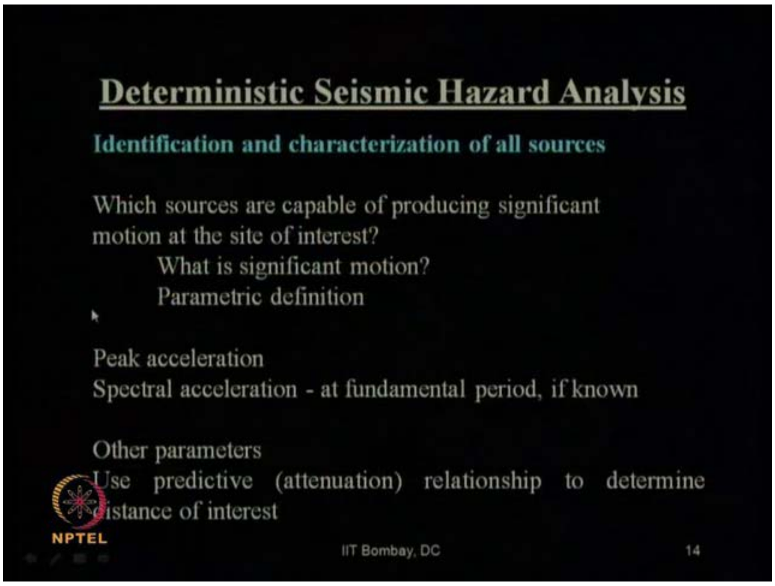

Now, coming to on this identification and characterization of sources which sources are capable of producing significant motion at the site of interest? Now, you should know what is the significant motion? So, what value you will call at significant motion that you need to identify. How to identify? We will see that very soon. So you have to define something which you considered as a minimum value or we call as a threshold value which you will consider as a significant motion.

Suppose, for your structure or for the locality or the vicinity or the site where you are going to construct your structure say a particular magnitude of earthquake acceleration say p g a of 0.05g is of your interest, like as we consider for our earthquake analysis. That is any value of above 0.05g we consider for the bracketed duration and all those things we have learnt earlier.

Similarly, here also for your designed structure you need to tell what will be the minimum value or the threshold value or the significant value which you will choose for your DSHA. So, that is, what is the significant motion you have to decide and the parametric definition of that. The peak acceleration or the spectral acceleration at the fundamental period, if it is known for your proposed structure that can be considered as your one of the parameter. Now, what are the other parameters like you can use the predictive or the attenuation relationship to determine the distance of the interest.

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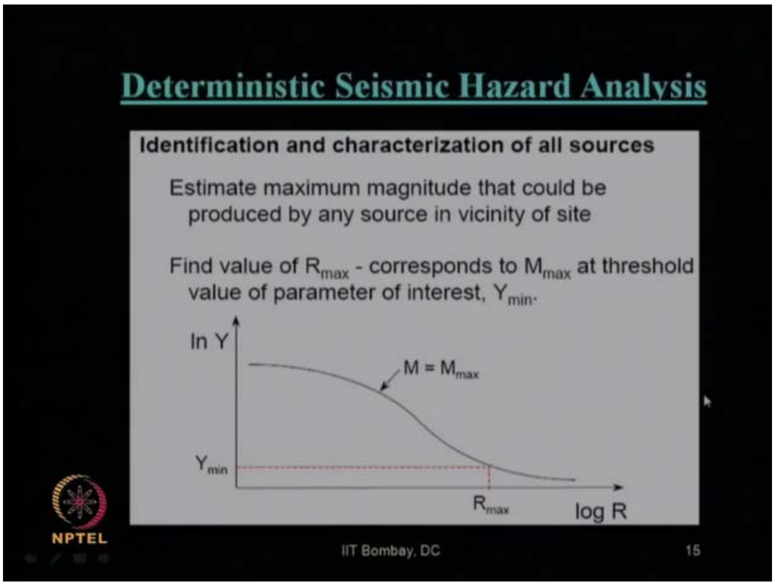

Now, estimate the maximum magnitude that could be produced by any source in the vicinity of the site. That vicinity also I have mentioned that it can be say 250 kilometer from the site or 300 kilometer from the site depending on your number of faults or sources which you are having and also depending on how much magnitude those faults are experiencing.

So, you need to find out the R max that is the maximum distance which you are interested to consider and corresponding to that maximum distance from that your site to the source; you find out what is that M max at the threshold value of parameter of your interest. What does it mean? Let us look at this graph.

It is in log log scale. This Y axis shows your chosen parameter of design, that means l n of Y, this Y can be suppose PGA that is peak ground acceleration, it can be PHV peak horizontal velocity, it can intensity or it can be spectral acceleration. So, that is your design value right which you are finally, going to obtain.

Now, what is that minimum value of the design that you are interested in, that you need to identify first. So, that is you first fix this point Y minimum that is your duty to fix first this value of Y minimum and you have this distance versus that parameter relationship from your attenuation relationship, from the source to site. So, for that particular source where that maximum earthquake is occurring considering all the nearby sources from the site you plot that attenuation relationship of that parameter say if it is a PGA you plot the attenuation relationship of peak ground acceleration with respect to distance R is nothing but the distance for earthquake moment magnitude let us say.

So, for that considering this Y minimum now what you need to do, you draw this line, see where it intersects your curve, drop it from there, then you will get this parameter R max. That R max will guide you that is how much distance you should consider for your seismic hazard analysis deterministically for that particular site, is it clear.

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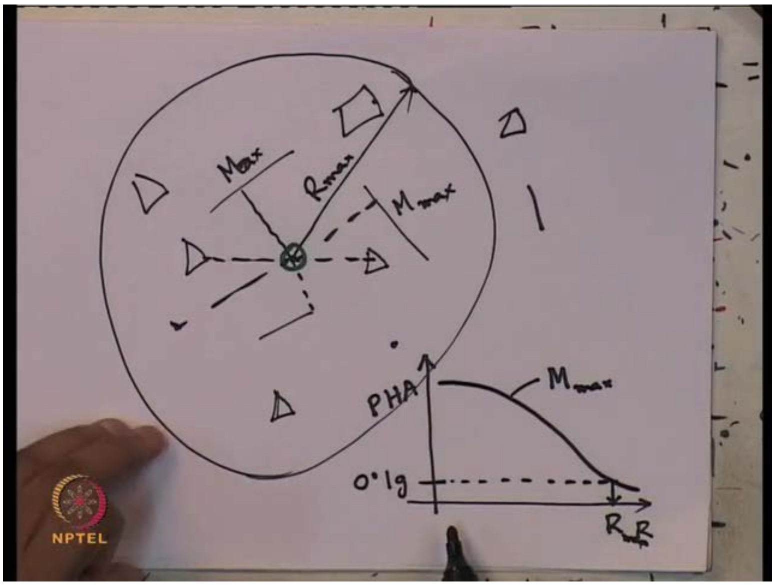

Suppose, if I take here one case say I have one site at this point where I am going construct some nuclear power plant in future. I have say several sites, several sources, these are various faults around this proposed site say this green color and these are our various faults etcetera. Now, what you can see over here different sites will have different distances. Now, minimum distances we have to calculate always from this source to various sites. Now, all these faults, different types of faults will have different value of M max, each of them will have some value of M max. Am I right?

Now, for your now you have this distance versus your chosen value say PHA peak horizontal acceleration I want to know the attenuation relationship for each source. So, we consider that is whether I should take this source or not that is a doubt right that is I do not know how much distance or how much radius from this point I should select that is whether I should select this portion and neglect this side, this source, this source or I should include them and consider them.

So, the extent which I should take the R max I should know, that is why this attenuation relationship will help us now if I have the minimum value say I am interested for my structure from 0.1 g onwards. That is my minimum value, I do not bother below this. So, corresponding to 0.1 g and this belongs to that with respect to M equals to M max, this is the relationship, you have attenuation relationship several attenuation relationship we have seen, for your site you have to use the attenuation relationship.

Now, corresponding to these value now let us draw this, project it here whatever R value we get over here that is the maximum distance we should consider. That means from here now you draw a circle with radius of this R max. So within that circle whatever sources are coming you have to consider those sources, if something is outside that you neglect that source. So, that gives us the idea what should be the range of doing your deterministic seismic hazard analysis. What I am telling typically 250 kilometer, 300 kilometer how these are determined this is the way we need to find out how it is coming, that maximum distance R max.

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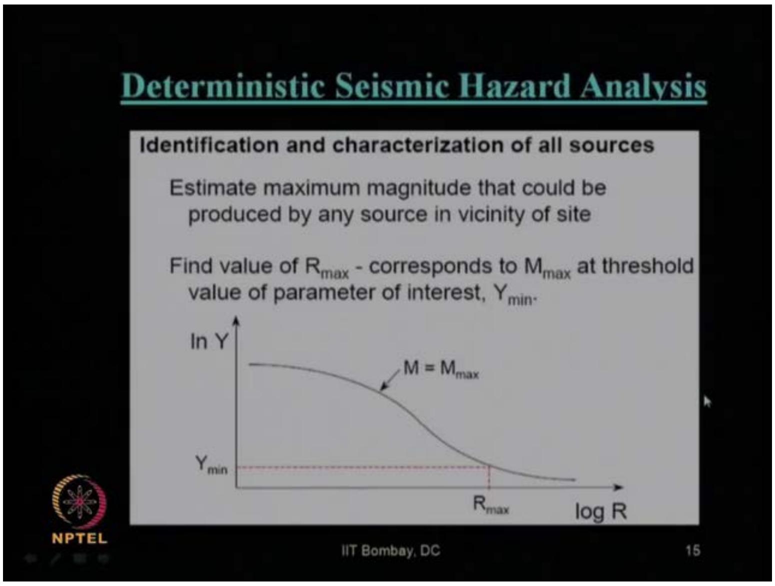

So, we can look at this slide now. This is what we have seen.

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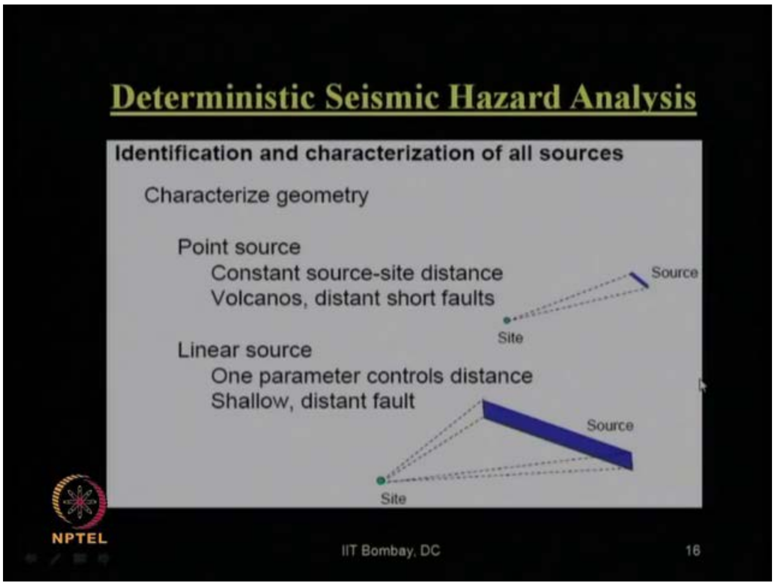

Now, we need to next characterize the geometry of the sources, to characterize that we can have various types of sources one is point source another is linear source. What is point source? Point source is nothing but where there is a constant source to site distance. That is source is so small, your earthquake source, earthquake fault is so small that it can be considered as a single point. That means form your chosen site of construction to that source the distance is not changing if you take any distance, it is not changing that shows it is a point source.

For example suppose there are volcanoes, those can be consider as a point source like distance short faults, very large distance you have a very short fault that can be considered as a point source. Otherwise, actually faults cannot be your actual point, it will always have some kind of length, but if it is at a far distance from your site obviously distance or changes of distance from site to source will not vary a much. That case you can consider it as a point source that is what it means. So, that is the definition of point source.

Next is linear source, linear source is that where one parameter controls the distance. What does it mean one parameter that is one linear parameter, from this to this if you draw a perpendicular that parameter will guide the distance that will be the minimum distance; so, this in one dimension. So, it is length wise only it is having a length that means fault is having only a length, that will have one parameter from the site to source even point is also having one parameter, but that is the fixed parameter whereas, for a linear source it is a one parameter, but it is a variable parameter and among those variable distances you have to take the minimum distance for this deterministic approach, for probabilistic we will see later.

There you have to take all the distance. So, that is why we are mentioning it is a one parameter which describes the source to site distance, only one dimension right from here to here one scale of distance that value can vary, but it is only one value whether if you consider in x y plot it is only suppose if you say this is as your one of the axis then only the other axis will give the value, am I right? So, example of that is like shallow faults, distance fault those can be considered as a linear faults or line segments those can be considered as the linear source of fault.

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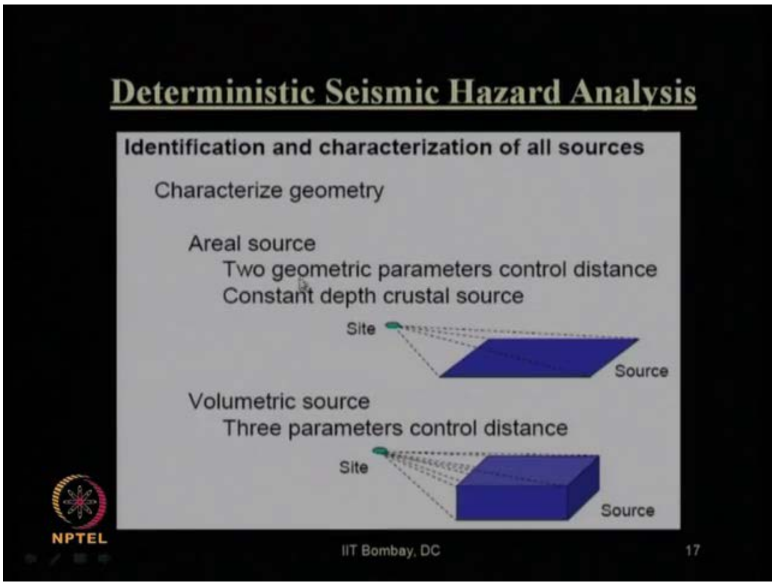

Next is area source of fault. What is area source? Where we have two geometric parameters which controls the distance what does it mean? When the source is of something this shape that is where there is some area between which comes up in the ground surface, on the ground surface. And that from your chosen site if you take that as a single point you have to express the distance we using two dimensions that is, it is a two coordinate system x and y. That is why it says two geometric parameters control the distance that is with respect to x and with respect to y combinedly you need to find out the minimum value.

So, we will do example problem that time it will be more clearer and another is called volumetric source. So, what is the example of Areal source? Constant depth that is depth remains constant, but area changes, different area, different shapes, depth crustal sources are called as area source. What is volumetric source? Three parameters when it controls that distance between the site and source then it is called volumetric source. Three parameters means it will be in the coordinate system, three dimensions in x dimension in y dimension in z dimension all needs to be taken care of for your source. So, there for the source in linear source you have only length visible for the source, in area source you have both length and width visible for the source, in volume source you have both length, width and depth of the source are visible or distinct, which is noticeable to identify this volumetric source with respect to this three parameters from the site. So, that is the way you have to identify or characterize the geometry of each and every source, first.

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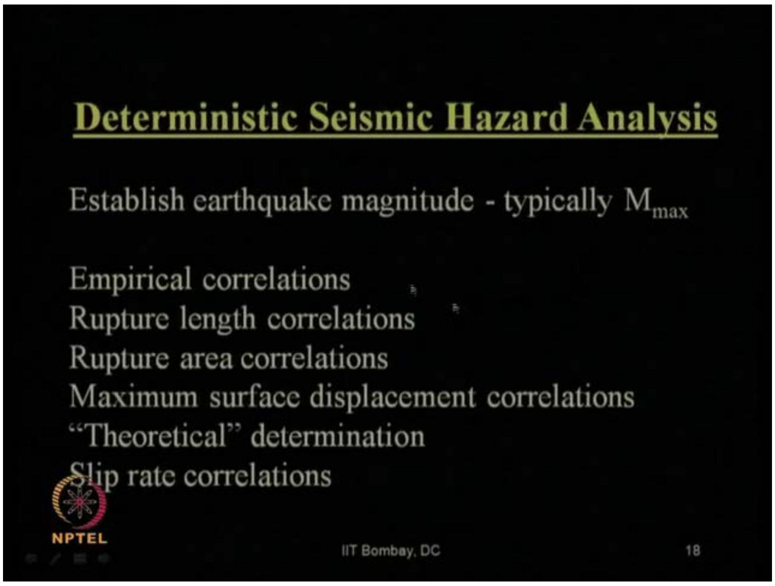

Then establish the earthquake magnitude and typically for deterministic seismic hazard analysis it is always M max that is maximum earthquake magnitude. Now, how to establish that maximum magnitude for your site, for your source that is based on the empirical relations, we have seen various empirical correlations like rupture length correlations, rupture area correlations, maximum surface displacement correlations. These are based on Wells and Coppersmith equation and various theoretical determination, also based on the slip rate correlations like tectonic plate movement correlations what we have seen. So, based on those relations one can find out what is the maximum value of M for that particular source.

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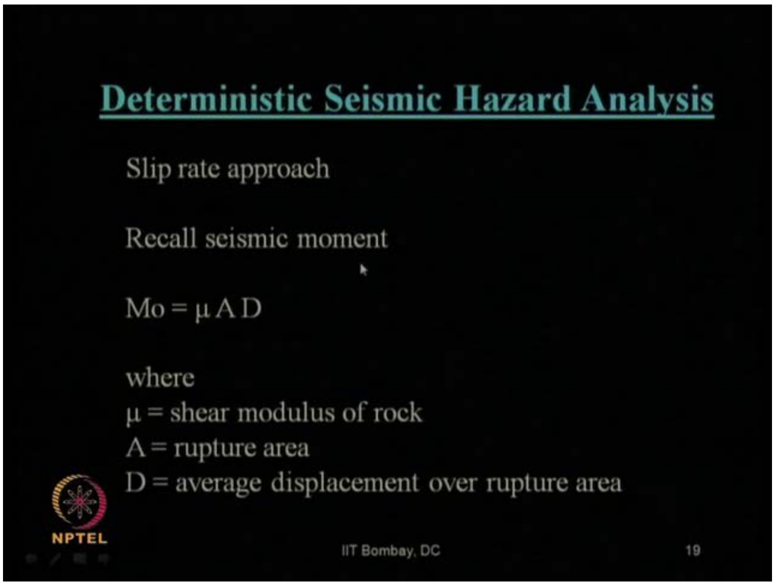

To do that one can also use this slip rate approach which we already learnt like from the seismic moment which is expressed as seismic moment as mu times A times D, we have discussed it earlier. mu is shear modulus of the rock depending on shallow or deep earthquake, which crustal layer shear modulus you have to take that is already discussed. A is the rupture area. D is the average displacement over that rupture area.

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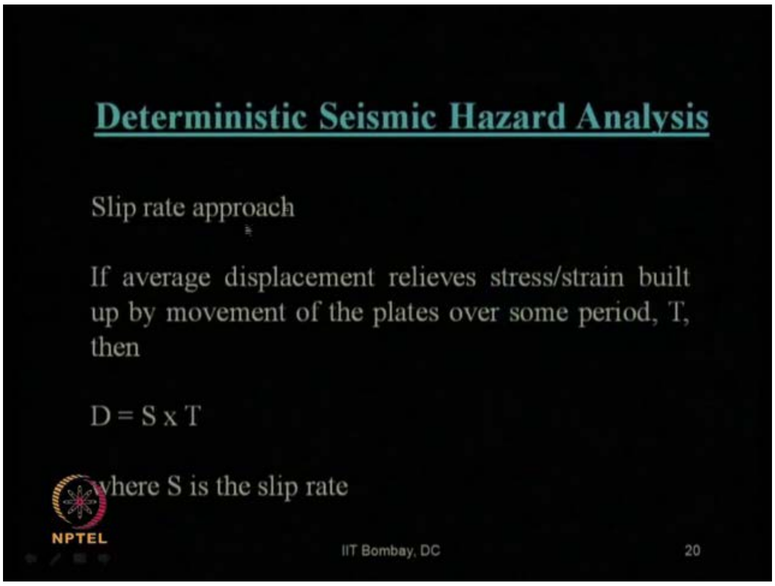

And if that average rate of displacement that is average displacement relieves the stress or strain built up by the movement of the plate over a period of time say T. Then it is expressed as D equals to S times T where this S is nothing but slip rate. Do you remember in the plate tectonic movement equation tectonic based evidence we use this slip rate. So, that is the another way to find out the slip rate if it is not known, if you know your amount of displacement of the fault and if you know over how many years it has occurred you can easily find out what is the slip rate.

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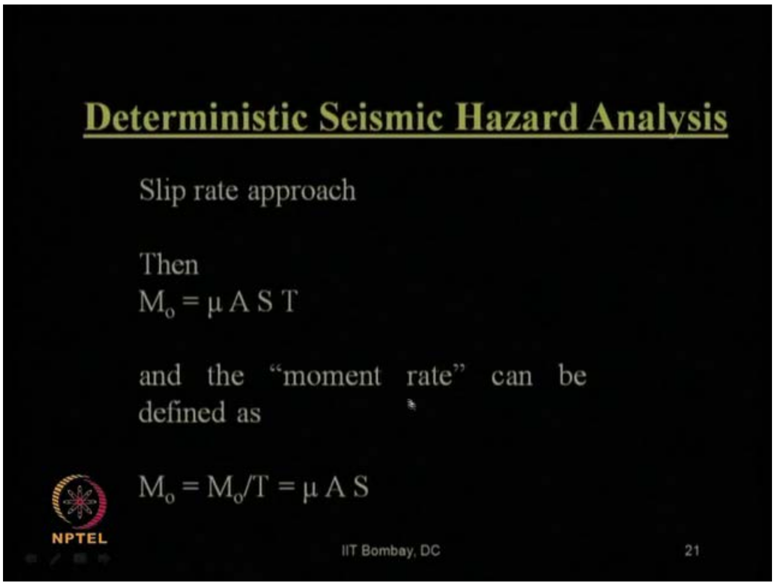

Then your moment seismic moment can be further expressed as mu times A times S of T because D is equals to S T and the moment rate can be expressed as M naught by T, rate will be per unit time of course, so mu times A times S.

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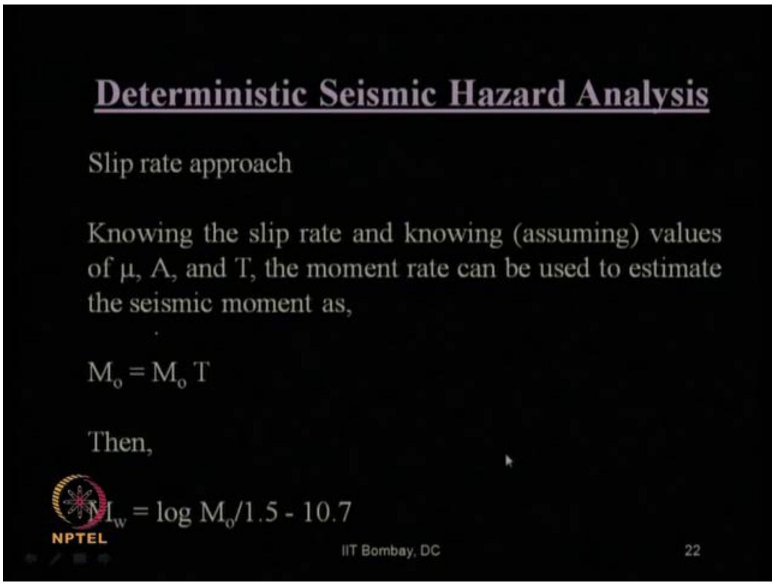

So, knowing that slip rate and knowing that assuming the values of mu A and T, the moment rate can also be estimated. Once, it is done from the seismic moment one can get the earthquake moment magnitude which we have already seen earlier. So, M naught will be M naught dot, M naught dot is nothing but, seismic moment rate times that T time.

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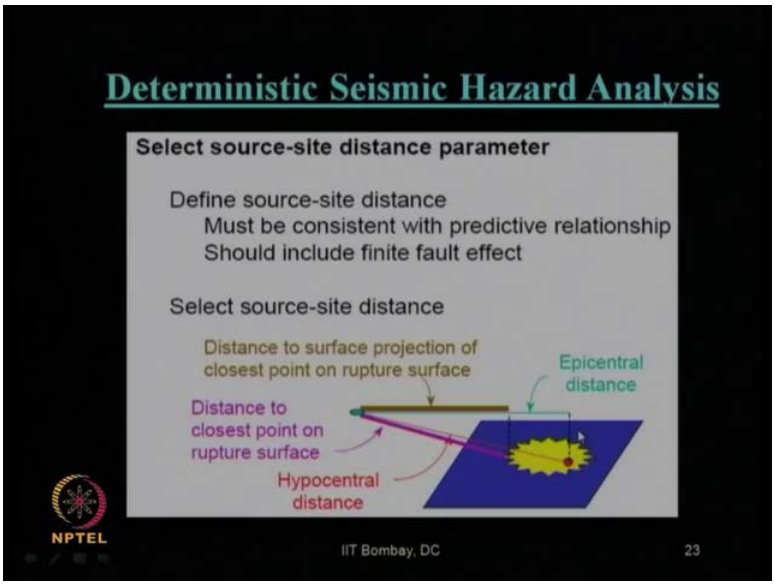

Now, let us see how to define the source site distance. Which distance we should take. It must be consistent with the predictive relationship and should include the finite fault effect, like select the source to site distance in this fashion that is distance to various distances we can have. Suppose, we have this is the zone where energy get released that means it is nothing but, your hypocenter or focus of your earthquake where the energy got released during an earthquake. So, from that point it will be obviously at a particular depth from the ground surface and say this is your ground surface. So, this point to your distance of your concern that is at your site that can be considered as your hypo central distance, see red color line, this line red color line written in this red color is nothing but called hypo central distance.

Now, that rupture open up area will not be obviously a single point like this, it will have a certain dimension. So, from the closest point if you draw a line like this, that is from this site to your closest point of the rupture will give you the distance to the closest point on the rupture surface. So, this color, purple color gives us the distance or from the site to the rupture area, this is the closest distance. And if you take a vertical projection of this focus of the earthquake or hypocenter of the earthquake to the ground surface that is nothing but, your epicenter. So, this point is in your epicenter on ground surface, from that point to your site if you take the distance that green color is nothing but, the epicentral distance. So, among these distance you have to decide which distance you are considering. Among those it is desirable for deterministic seismic hazard analysis to take the minimum of these three.

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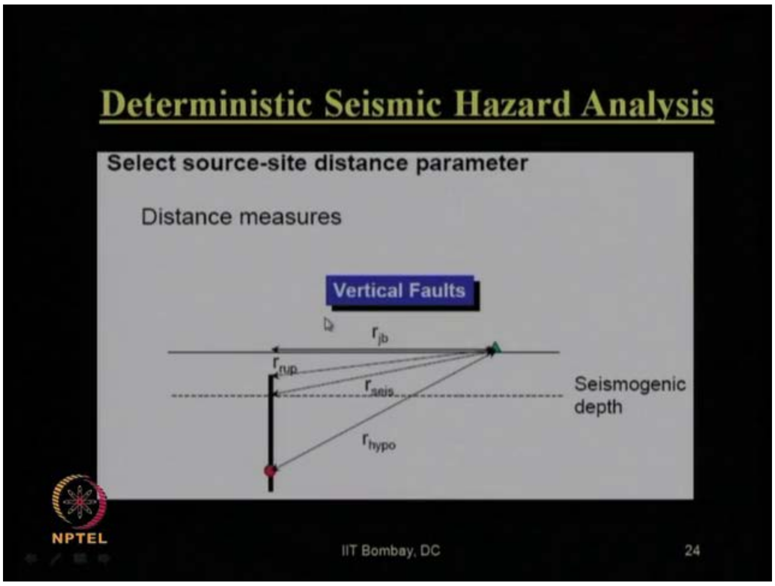

Now, another distance measure like if we have a vertical fault like this, like fault is perfectly vertical then say the focus of the earthquake is this point, red color point then this is the hypocenter from this point to the site of your concern on the ground surface is this green color point. This will be your r hypo central distance. Now there can be a particular depth which we define as a seismogenic depth that is we consider mostly say for your construction of your structure, you consider a particular depth where you are concerned about the seismic activity. You may not be bothered too much about a far distance say several hundreds of kilometers away from the ground surface the earthquake. You may be interested to a particular depth which goes with respect to which tells us about the shallow earthquake may be, may be within 70 kilometer depth.

So, that seismogenic depth you have to identify based on that where your rupture that vertical fault crisscross or intersect that seismogenic depth from that point to your site of interest will be your seismogenic distance. And what is your rupture distance that is from the opening of the fault, this is the nearest point to your site. So, that distance will give you the rupture distance and this r j b is on the epicentral point from the site.

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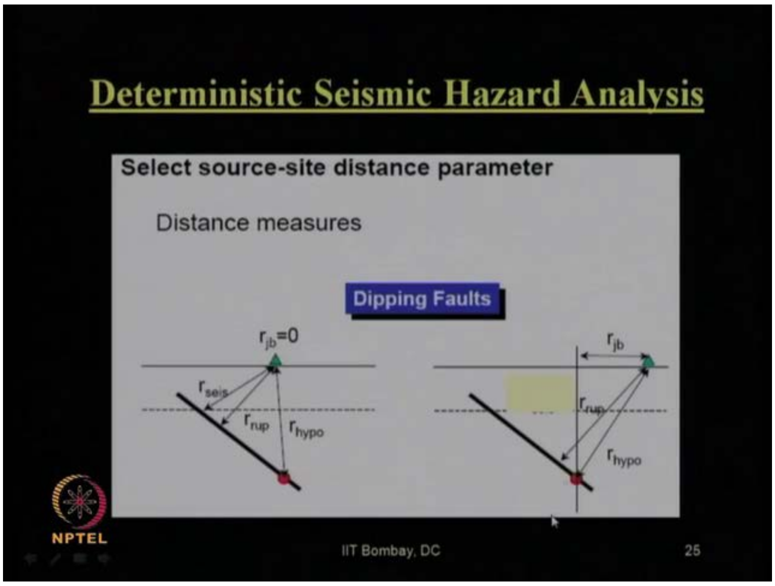

Whereas, instead of vertical fault if you have a dipping fault like this, your different values will be like this r hypo central, r rupture, r seismogenic you can see it is coinciding with your epicenter so r j b is 0. Whereas, you can have other definitions like this from dipping faults.

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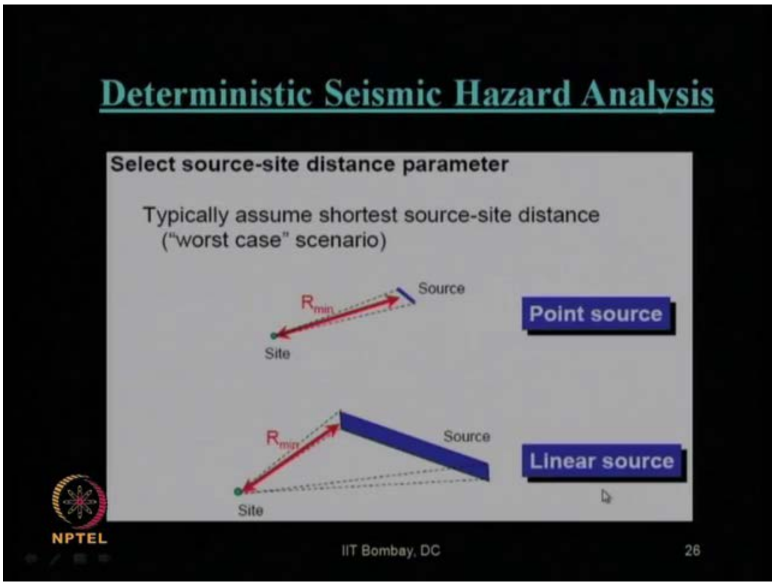

Now, when we identify this various distances what you need to take for deterministic seismic hazard analysis, typically assume the shortest distance, shortest source to site distance which is known as worst case scenario. So, if you have a point source obviously you have a fixed distance, you do not have any other choice, but whatever R value from the site to source you have that itself will be your minimum value. But if you have a linear source like fault which is having a visible length, but no other dimensions like width is very small compared to the length and depth is also very small compare to the, compare to length then you have to find out from your site what is the minimum distance of that fault, source. It should be always like if you draw from a point a vertical on this line.

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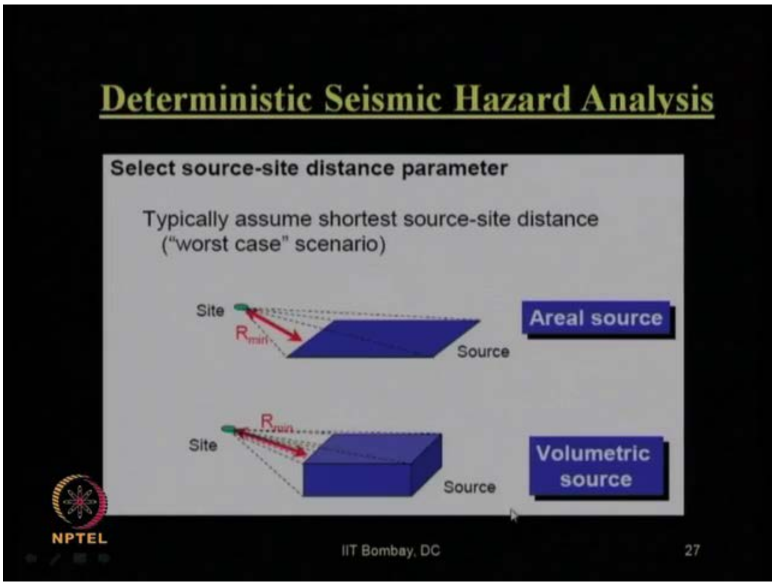

For a areal source, area source you have to find out again what is that R minimum. Now, here two parameters are involved x coordinate and y coordinate as I said. So, you have to take root over x square plus y square and minimum of that value whichever comes from this site to that source that will give you the R minimum for that particular areal source and for volumetric source what is the minimum value here three dimensions you require to represent the source. So, you have x coordinate y coordinate and z coordinate. So, you have to take root over x square plus y square plus z square minimum of that should be taken as the R minimum for your source to site distance as a worst case scenario.

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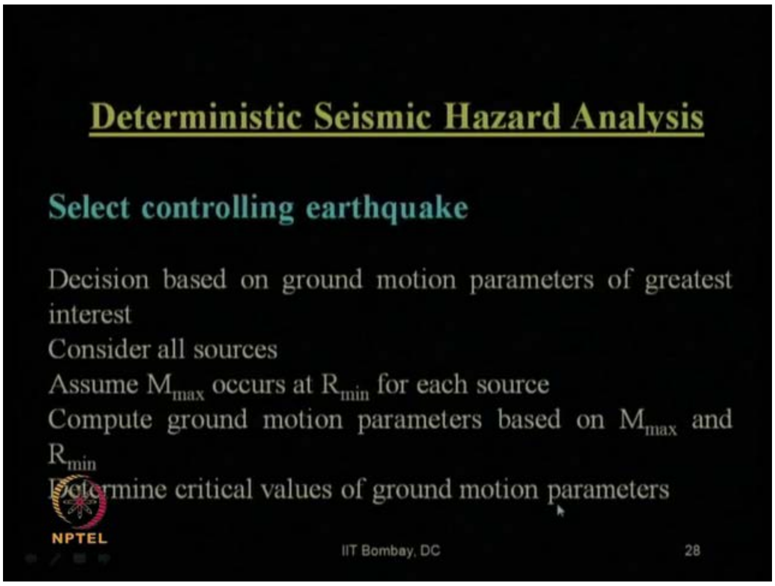

Now, selecting the controlling earthquake is the next point. So, decision based on the ground motion parameters of greatest interest has to be identified, consider all the sources and assume M max occurs at R minimum for each source. That is another assumption because it is not necessary your M max suppose if you have a linear source which is ranging for several kilometers it is not necessary that at every point of that fault you will have the same value of m w. Depending on your rupture or opening of your earthquake energy, that value may differ at different points as we have seen from the attenuation relationship etcetera earlier but in this deterministic seismic hazard analysis we assume that M max occurs at that minimum distance of R whatever we identified from this concept. And compute the ground motion parameters based on that M max and R minimum that I have already mentioned.

Now, determine the critical values of these ground motion parameter based on these combination, which we have seen in the few slides back, what is the DSHA methodology? That final step. We will come to an example problem soon.

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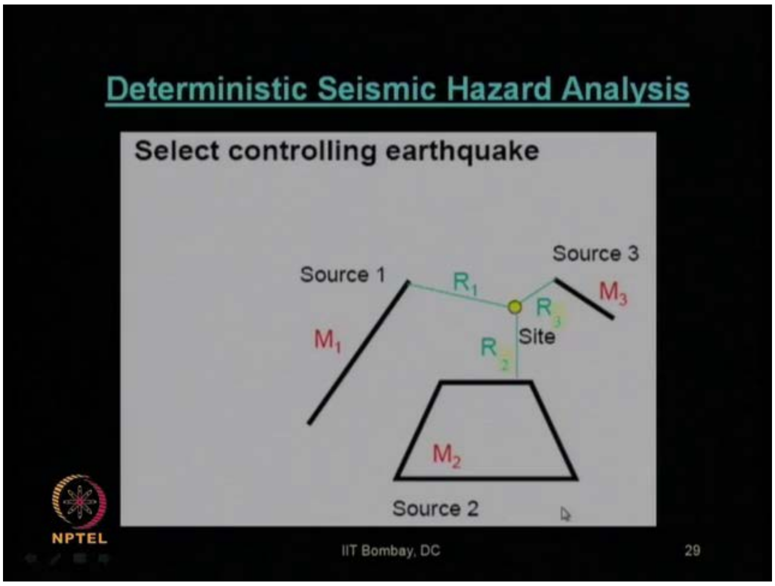

So, this is the example which shows that suppose if it is your site you have three sources close to your site which you have identified by selecting your R max up to which all the sources you are planning to consider based on that threshold value of your consoling earthquake. So, suppose these are the three sources which are affecting your site that is you have identified. Next step is what type of sources these are. Now, looking at this we can say this is a linear source, this is a linear source whereas, this is a areal source.

Now, you need to find out what are the minimum distance from that site to each of the source, source 1, source 2 and source 3. So, this is R 1 is the minimum distance from site to source 1, R 2 is the minimum distance from site to source 2 and R 3 is the minimum distance from site to source 3. For each of the source you know now what is the maximum value of the magnitude of earthquake. So, these are maximum value of magnitude. M max for source 1, M max for source 2 and M max for source 3.

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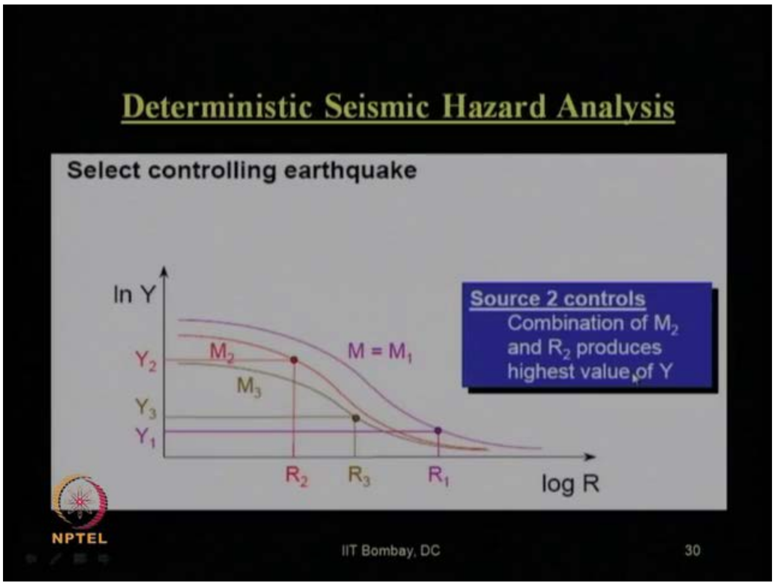

Now, once you know what you need to do, you need to plot attenuation relationship for all these three sources with respect to your chosen parameter or interested parameter which you want to find out for your hazard analysis. As I said suppose it is a peak horizontal acceleration which you are interested or peak horizontal velocity which you are interested. It can be any parameter or spectral acceleration which you are interested. So, that in log scale versus the log of distance that attenuation relationship you can plot for each of the three sources like this color shows this coffee color shows source 3 can you see M 3 R 3, this red color shows source 2 M 2 R 2, this violet color shows source 1 that is M 1 R 1. What are these things each attenuation relationship we have plotted based on their maximum values with respect to Y versus R and on each of this curve. Now, we know R 1 R 2 R 3 from this calculation. So, we have taken those points R 1 R 2

R 3 and projected them up from this x axis to corresponding attenuation relationship. Now, you put from that projection you put it what value your recording from your y axis like for this one you are getting Y 1, for this one you are getting Y 3, from this one you are getting Y 2. Is it clear?

Now, among these three which one gives us the final maximum result? Y 2 gives us the maximum result, can you see that. So, that is what it is mentioned source to which is controlling your design. Among these three sources source 2 controls the design because of the reason that Y 2 is maximum among these. If we suppose what is the next maximum that is Y 3, next more vulnerable source is our source number 3 and least vulnerable is source number 1. So, combination of M 2 and R 2, it produces the highest value of y that you need to find out in this process, that is your final result of Y.

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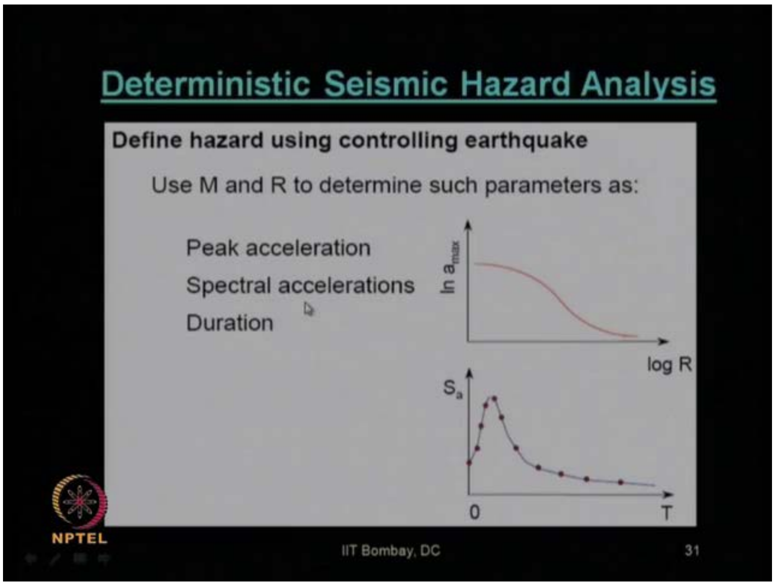

So, use this how to define that hazard using controlling earthquake, use that M and R to determine such parameters like it can be peak acceleration as I said or spectral acceleration like this or it can be duration. So, it can be any parameter which you are interested.

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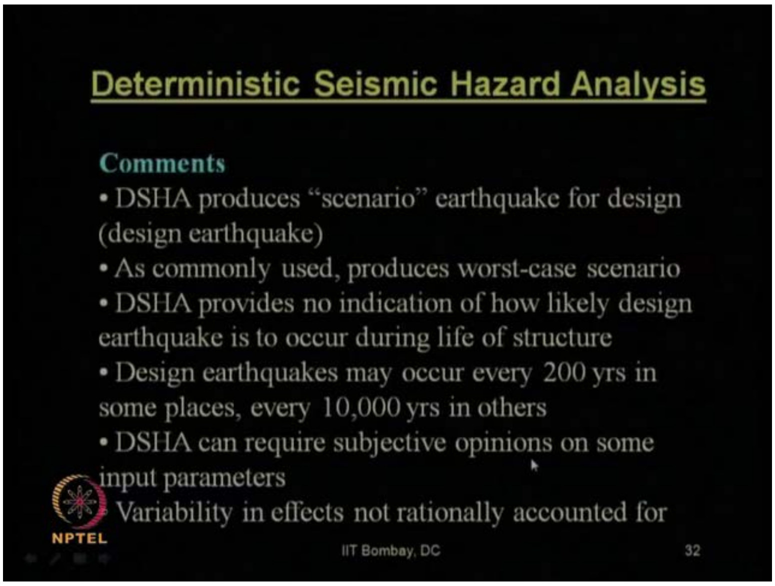

What are the various comments about then DSHA we can see that DSHA produces the scenario earthquake for design, that is it is a design basis earthquake. As commonly used it produces the worst case scenario and DSHA provides no indication of how likely that design earthquake is going to occur during the lifetime of the structure. So, this is the limitation of this method, you remember it is not necessary that hazard value which you have obtained and used further for your design, even may not occur in the lifetime of your structure, in probability analysis you can probably get it.

But there is no scope of changing that if you use that deterministic seismic hazard analysis so that is the limitation. Design earthquakes may occur every 200 years in some places or even say 10000 years in some other places that DCE what we have chosen. DSHA can require subjective opinions on some input parameters. Subjective opinion means like fault characteristic what type of fault, what type of the magnitude, whether equal magnitude which is already taken is correct and also subjective opinion on your threshold value to select that distance of R max at the very beginning of identifying your controlling area for DSHA. So, all these are subjective.

It based on the engineers choice as I said repeatedly and variability in effects not rationally accounted for like variability of all these points are not taken care of. So, that is another major limitation of this DSHA, but still it is in use as I said because of the importance to apply in important structures.

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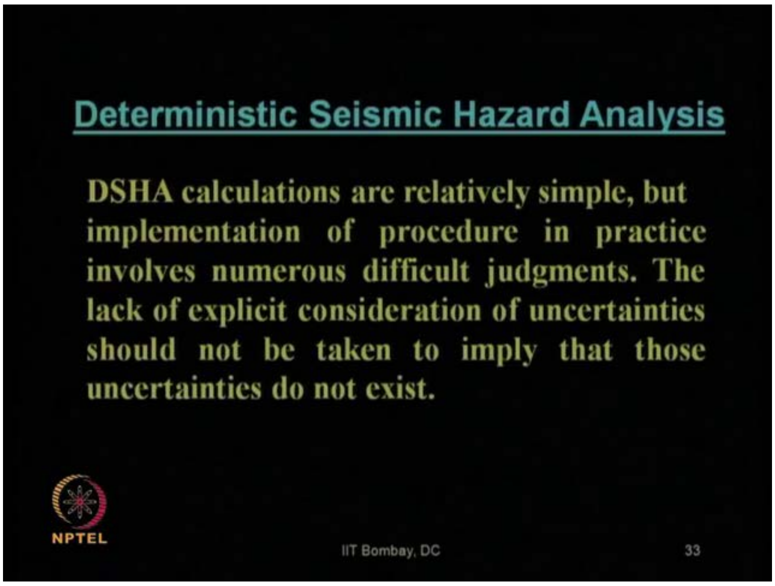

So, in a nut shell we can say DSHA calculations are relatively simple, but its implementation of procedure in practice involves numerous difficult judgments. Why difficult judgments because several decisions are involved with respect to engineers choice or judgment. The lack of explicit consideration of uncertainties because we are not taking care of any type of uncertainty, which are involved, should not be taken to imply that those uncertainties do not exist.

That is though we are not taking we should not make us understand that okay that means uncertainties does not exist, it is not so. Uncertainties do exist that is whether that magnitude of earthquake will occur, whether the all area or line sources of faults are active or not, whether the distance, the minimum distance selected from source to site, whether that creates the maximum earthquake or not. So, all these are uncertainties whether that repetitions of earthquake in terms of probability or occurrence, that is also not taken care of. So, all these uncertainties still remains, but in DSHA there is hardly any scope to consider these uncertainties. Now, let us go to an example problem of this DSHA which will clear our doubt that is how the solutions for this DSHA is done. Let us look at the problem statement first.

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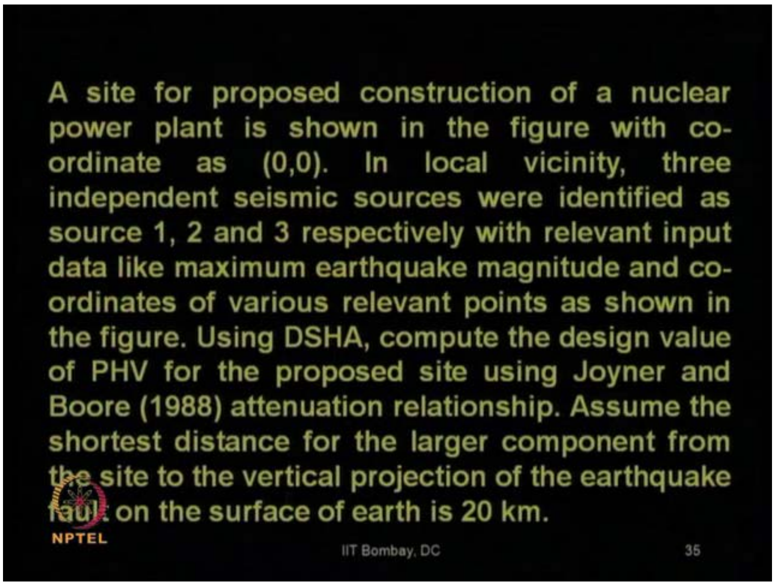

So, the problem statement says a site for proposed construction of a nuclear power plant is shown in figure. So, this figure I will show you very quickly.

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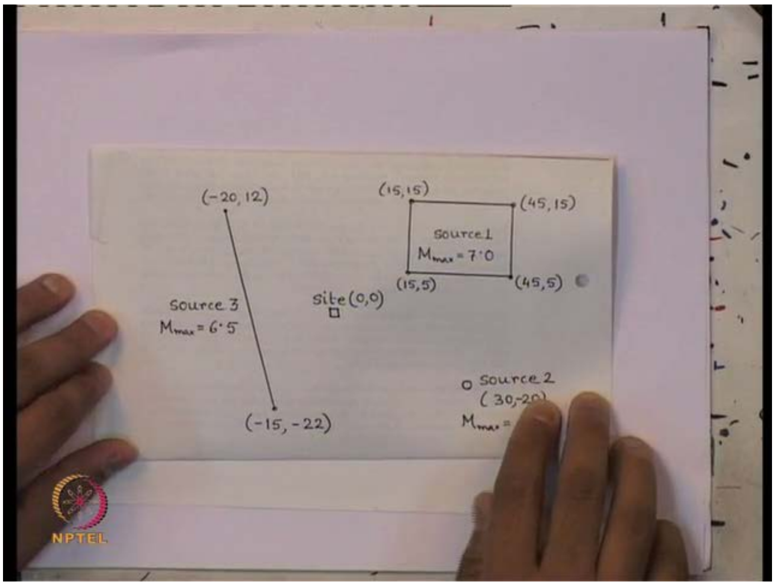

So, this is the figure you can look here. Yes, so this figure we are, which we are considering this is the point site, you can see site is written over here. So, that is our proposed site for say a nuclear power plant. You can now see. So, is shown in the figure with coordinate as 0 0. So, let us take that is as a origin. So, that is why it is shown in this paper site is 0 0 coordinate. Now, what next is mentioned in local vicinity three independent seismic sources were identified as source 1, source 2 and source 3 respectively with their relevant input data like maximum earthquake magnitude and coordinates of various relevant points as shown in figure.

So, let us look at this. These are the three sources, source 1, the coordinates of this four corners are given over here and maximum earthquake for this source 1 is given as 7. What is this type of source? This is a areal source, area source. Source 2 is this one, its coordinate is also given over here and maximum magnitude is given as 6, this is a point source. This is a source 3 another fault with maximum magnitude of 6.5 and these are the coordinates x y coordinates. First value is x coordinate of course, and second value is y coordinate as we used. So, this picture is not in scale, it is just a rough representation. So, this source 3 is nothing but, a linear source so these three are independent sources which needs to consider for this site what is the seismic hazard for this site.

So, what hazard parameter we need to find out, let us see now. What is asked here, it is asked using deterministic seismic hazard analysis compute the design value of PHV that is peak horizontal velocity is asked, that is the design value we have to identify for that proposed site using which relationship it is mentioned use the Joyner and Boore 1988 attenuation relationship of this PHV. Assume the shortest distance for the larger component from the site to the vertical projection of the earthquake fault on the surface of earthquake is 20 kilometer. This Joyner and Boore 1988 attenuation relationship for PHV we have discussed in our earlier lecture, when we discussed in detail about attenuation relationship.

So, now let us see how this solution will be. So, the solution of this problem will be first let us make a table like source, then minimum distance in kilometer unit. So, those values of the coordinate what was given were in kilometer and what is the corresponding M maximum value. So, for each source we need to find out that. Source 1, source 2 and source 3. Now for source 1 let us see from our site to this source 1 what is the minimum distance in kilometer? So this is our site, this is our source 1. What will be the minimum distance, obviously this corner will be at the minimum distance from this site to source. Am I right?

So, we have to take root over x square plus y square of this to get the minimum distance, linear distance from this site to source. So, minimum distance will be in kilometer root over 15 square plus root over 5 square because this is itself is 0 0. So, minimum distance is 15 square plus 5 square which gives us 15.81 kilometer and what is the corresponding maximum value it is given to us 7, for source 1, so it is 7.

Now, for source 2, let us look at source 2, source 2 is the point source with this coordinate, x is 30 kilometer y is minus 20 kilometer. So, what is the distance from this site to source, again root over this x square plus root over this y square because for this, this is the fixed distance, there is no concept of R minimum. So, here the distance comes root over 30 square plus 20 square which comes out to be 36.05 kilometer and what is the corresponding value of M max is 6 that is given to us. So, M max is 6.

Now, for the third source this is the third source which is a line source. What we can do? The correct way is first you write down the equation of this line which we can easily find out from the x y coordinate and then find out the vertical distance from this line to this site. Now, using our simple calculations, we can see it is far away from at least 15 kilometer in terms of this distance, can you see that looking at the x and y variation. So, it is obviously more than 16. Why I am not showing that interest, actually in calculation you need to find out that distance also because M max is 6.5 over here, which is less than this and already I got these distance as 15.some kilometer, that is why I can simply mention this is much greater than 15 kilometer. You can find out correct value easily using the equation of that line and here value of M max is 6.5.

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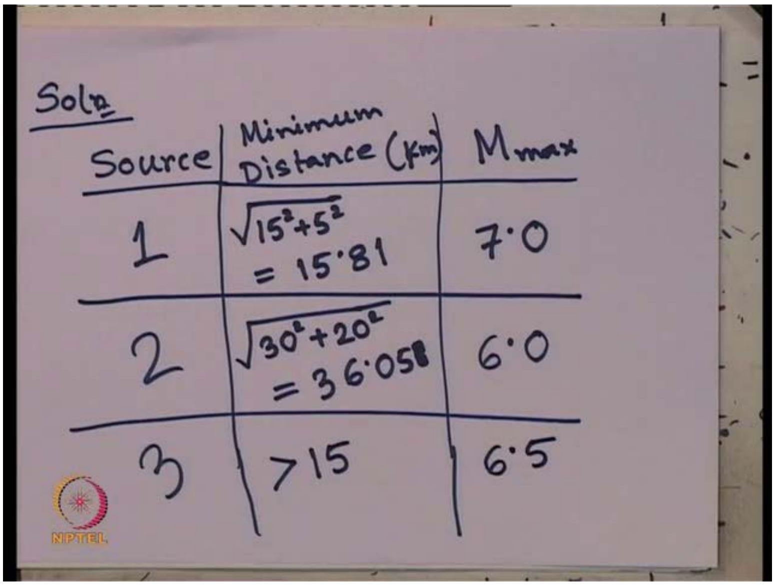

Now, looking at this table, what will be our controlling earthquake in this case? The controlling one is with minimum distance and maximum value of magnitude. So, source 1 comes out to be. So, this is our controlling source. So, once you identified the controlling source next step is easy, you need to just use the attenuation relationship to estimate your required design parameter that PHV using that Joyner and Boore equation.

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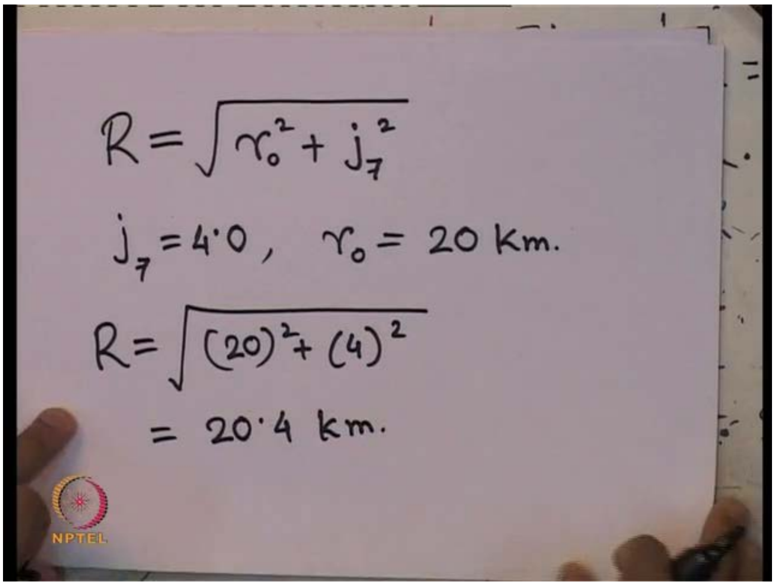

Now, what is the Joyner and Boore equation, let us use that. Let us calculate now. In the Joyner and Boore equation there is the parameter called R which is defined as this r naught square plus 1 coefficient j 7 square and for the larger component as it is asked in the question this j 7 is given as 4. There are two cases, one is random and another is larger. So, both the cases j 7 is given as 4 we have seen earlier, if you refer back to that slide of our one of the previous lecture you will get that coefficient.

And what is r naught? r naught is nothing but it is the vertical projection of the side from the earthquake fault to the surface, that distance and in the given problem what is given look at the slide it is 20 kilometer. So, r naught is given as 20 kilometer. So, that means capital R works out to be 20 square plus this 4 square that gives us 20.4 kilometer.

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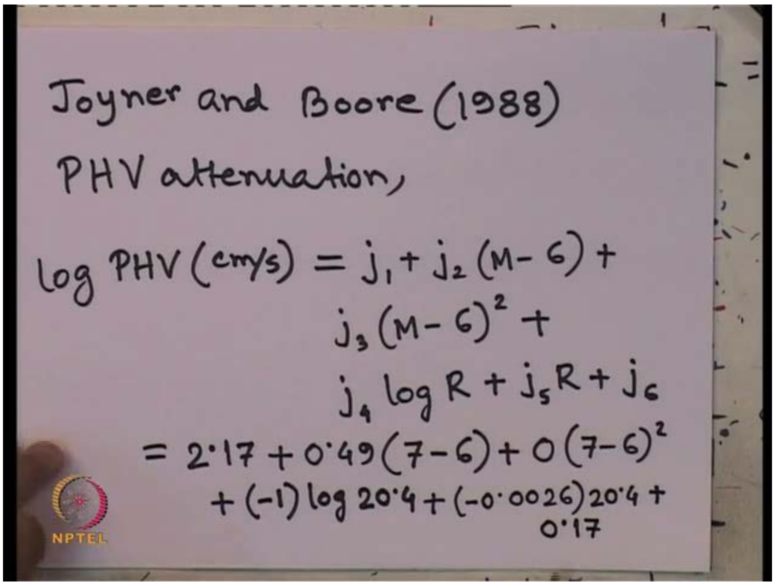

Now, what is Joyner and Boore’s attenuation equation? So, let us write that Joyner and Boore’s 1988 PHV related attenuation relationship is given as log of PHV in the unit of centimeter per second, it was given in the equation is equals to j 1 plus j 2 times M minus 6 plus j 3 times M minus 6 square plus j 4 times log of R plus j 5 R plus j 6. This j’s are various coefficients for random and larger, Joyner and Boore had given all these coefficients.

So, now picking up those coefficient we can calculate it j 1 is 2.17 or larger then j 2 is 0.49, what is our M value, just now we have identified, 7 right 7 minus 6 plus j 3 from the table we can find out it is 0 7 minus 6 whole square plus j 4 is given as minus of 1 log of R. What is the value of R? We calculated 20.4, 20.4 plus j 5 R. What is j 5? j 5 value is given as minus 0.0026 times R is 20.4 and j 6 value is 0.17.

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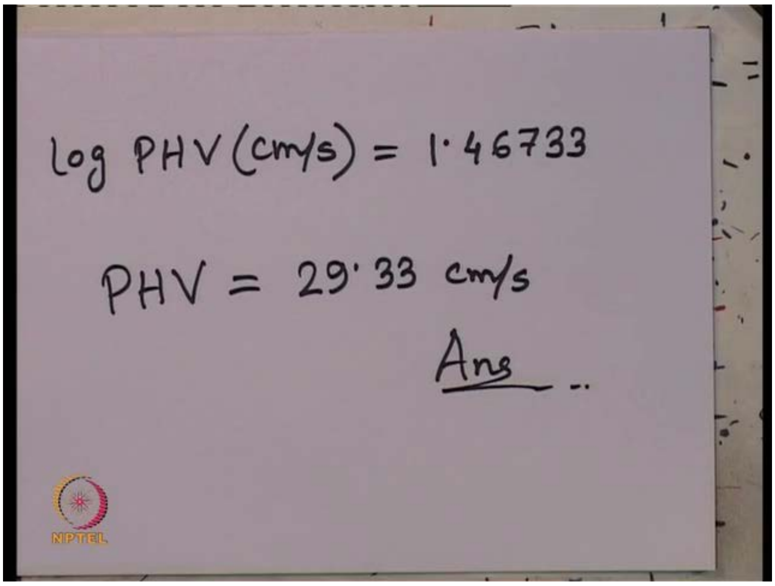

These are the coefficients from Joyner and Boore's given table which we have discussed earlier. So, using these values what we can calculate just it is a numerical calculation. You can get log of PHV in the unit of centimeter per second comes out to be 1.46733. So, what will be your PHV, the design value of PHV is 29.33 centimeter per second. So, that is the answer for this problem. That is this is the design value of PHV, which you need to consider for your site, when you are going to use this nuclear power plant.

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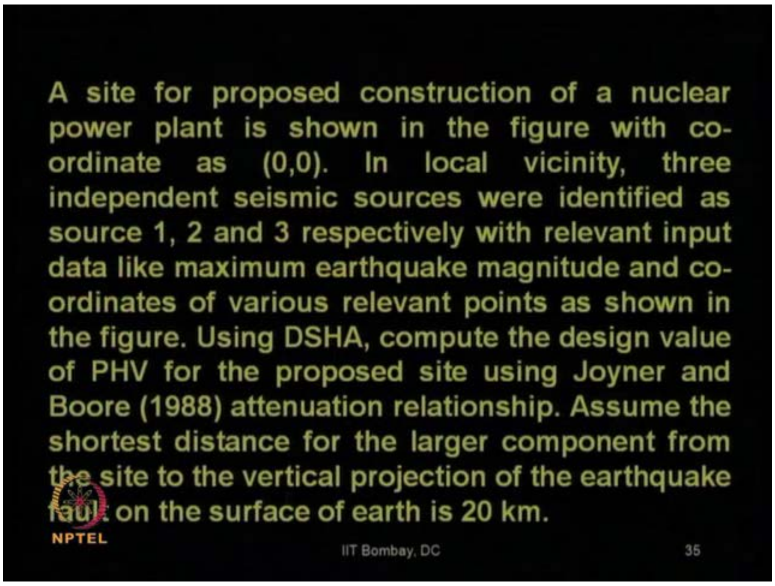

As you can see, it is asked for that nuclear power plant at that site, you need to find out what is the design value of that PHV. So, this is the value of PHV using DSHA. With this we have come to the end of today's lecture. We will continue further in our next lecture.