Geotechnical Earthquake Engineering

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Module - 7

Lecture - 28

Seismic Hazard Analysis (Contd…)

Let us start our today's lecture for this NPTEL video course on geotechnical earthquake engineering, as we were going through in the previous lecture also. In this lecture as well we will cover module number seven which is seismic hazard analysis. So, before we start let us do a quick recap what we have learnt in our previous lecture.

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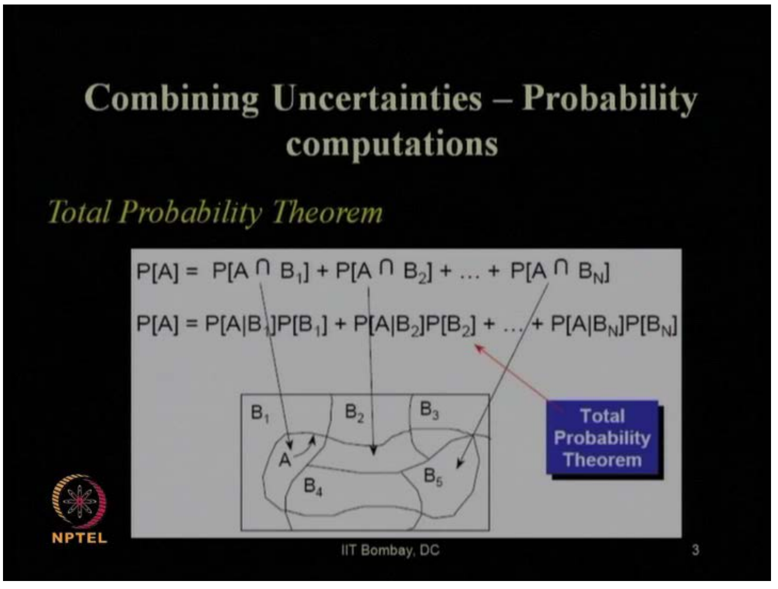

If we see, this slide, that is how to combine the various uncertainties which are involved in the estimation of probabilistic seismic hazard analysis or P S H A. So, from total probability theorem we can easily say that probability of occurrence of any event P of A can be considered as P of A intersection another event B 1 in that domain. So, you can see over here. So, this portion is A; and this part is B 1; this part B 2; this is B 3; this is B 4; and this is B 5.

So, occurrence of probability of A is nothing but probability of occurrence of A intersection B 1 plus probability of occurrence of A intersection B 2 and so on up to B n; which we can rewrite again using the probability theorem, that probability of occurrence of A equals to probability of occurrence of A for a given B 1 multiplied with probability of occurrence of that event B 1 right. Similarly for probability of occurrence of A for a given B 2 multiplied with probability of occurrence of B 2 and so on.

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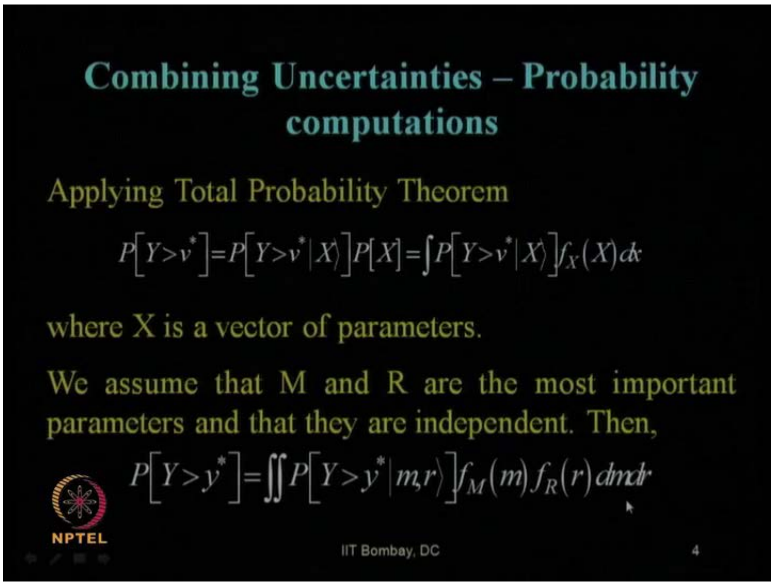

So, using this concept, applying this total probability theorem, what we can say? For our P S H A or probabilistic seismic hazard analysis probability of occurrence of any event, what we want to find out as a hazard parameter; greater than a certain number or greater than a certain event will be equals to probability of occurrence of that for a given parameter or vector X multiplied with probability of occurrence of that vector, where X is a vector of parameters.

Now in our P S H A analysis or probabilistic seismic hazard analysis we assume that magnitude M and the distance R, these two are the most important parameters and they are independent to each other. In that case what we can write? The, our probability theorem will simplify to this form that is double integral of probability of occurrence of that event Y greater than y star because that is what we want to find out; we, above a threshold number or a above a given design value we want to find out the probability, for a given value of m and for a given value of r hence we need to multiply them with respect to the probability of that M and R.

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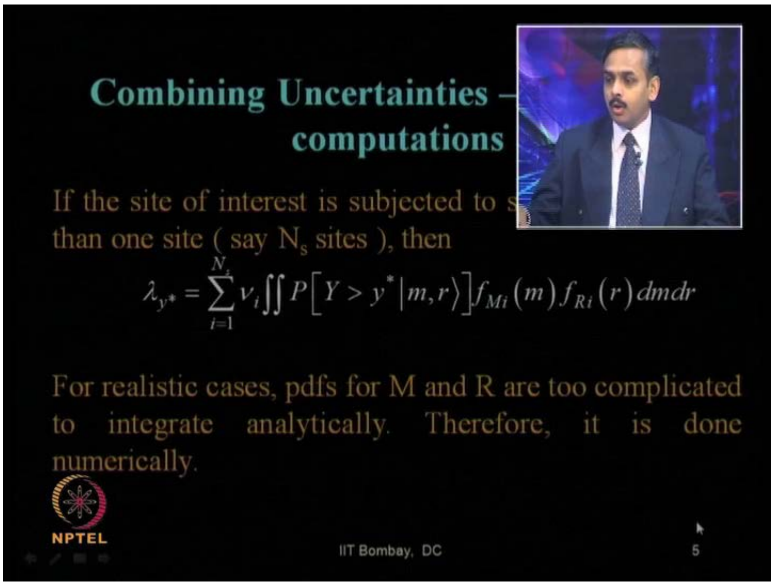

So, if, suppose the site of interest is subjected to shaking is more than one site, that is for a particular site we have influence from other sites as well, in that case we have to take care of all number sites involved say, total N s number of sites are involved, in that case we have to do the summation of all the probabilities what we are getting or mean exeedance of occurrence that we have to sum up for all sites and get the total value.

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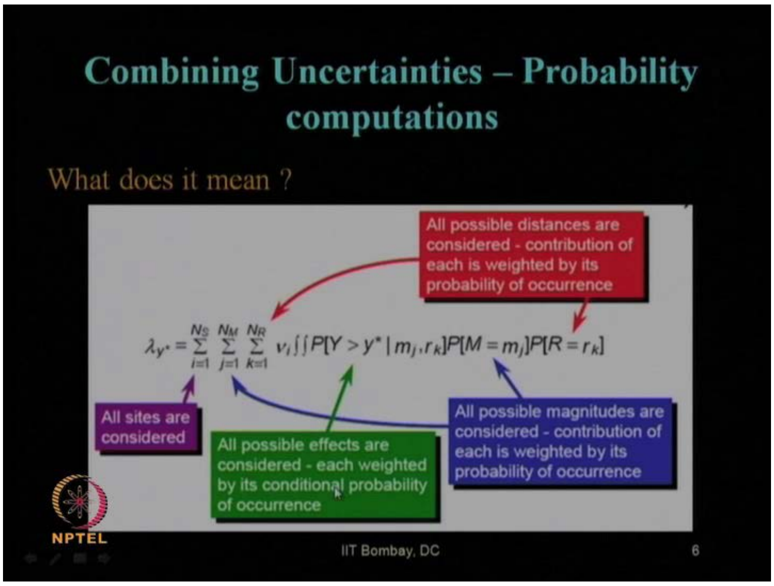

Then we have seen, when we combine this all uncertainties involved in this P S H A, what we can write? That exceedance of, mean exceedance of annual is some event lambda y star that can be represented by considering all the three independent variable that is the sites involved, magnitude involved, and the distance involved; we can get summation of each of them and write the probability theorem in this form.

So, this one, as I have mentioned, it takes care of all the sites involved. Then this one takes care of all the magnitudes involved, corresponding to their weighted probability of occurrence; and this one considers all possible distances which are considered - contribution of each is weighted by its probability of occurrence. So, we have seen how to take care of weighing factor for unequal or uneven distribution, or unequal distribution of the distances from site to source. Then this one takes care of, all possible effects are considered like each weighted by its conditional probability of occurrence.

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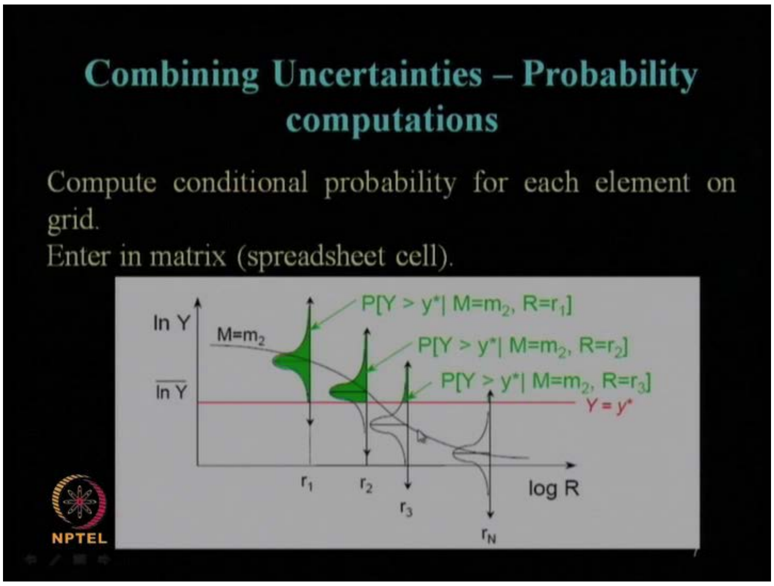

So, we need to compute the conditional probability for each element on a grid form. So, what we can say? Suppose any attenuation relationship or any particular G M P E’s if we select like this; suppose the magnitude we are selecting or fixing it at a particular magnitude of say M equals to m 2. Similarly for M equals to m 1, M equals to m 3, we will have different relationships. And this is the variation with respect to the distance R. So, at different values of R say r 1, r 2, r 3, r 4, r n, we will have the probability distribution allowing that magnitude scale, like this, for a particular event of occurrence, greater than some mean value, or some design value, or some chosen value about which we are interested to know.

Suppose we are interested to know that, let us say, this is our peak ground acceleration, or spectral acceleration, or peak horizontal velocity, because these are the standard parameters what we want to find out. And certain given value is provided to us, so that, we can make a design, or find out the probability of occurrence of more than that. So, in that case, above this line, in this shaded area of probability distribution whatever coloured shading part is given, that gives us nothing but the conditional probability for that given of M equals to m 2, because this curve relates to M equals to m 2 and for that given value of R like for this one, it is R equals to r 1; for this one it is R equals to r 2; for this one it is R equals to r 3, and so on, right.

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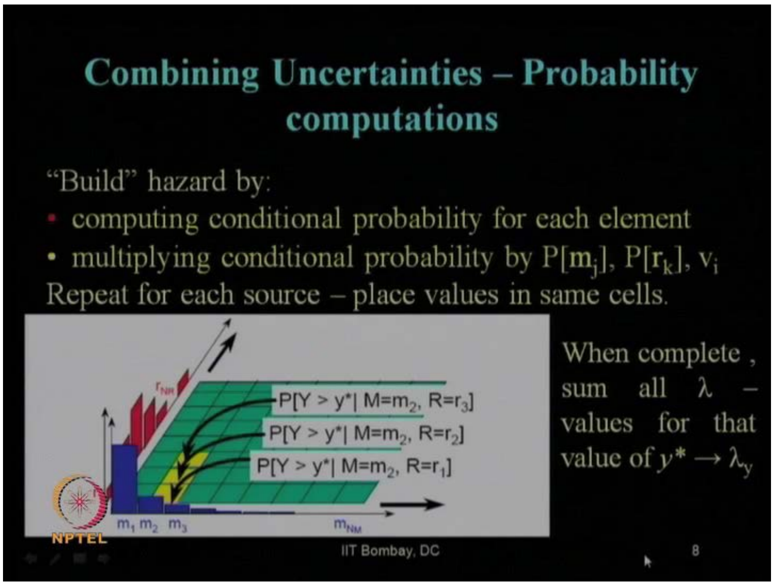

So, in that fashion, what we have seen? We can build the hazard by considering this conditional probability combining the uncertainties from both independent parameters of magnitude and the distance R. So, as we have already seen in the previous figure, for m 2 for a given magnitude of M equals to m 2, we already obtained this probability of occurrence of Y greater than that given design value of y star for R equals to r 1; R equals to r 2; R equals to r 3 and so on. So, like that we will get all these values known. Similarly we should fill up this one for other magnitudes as well.

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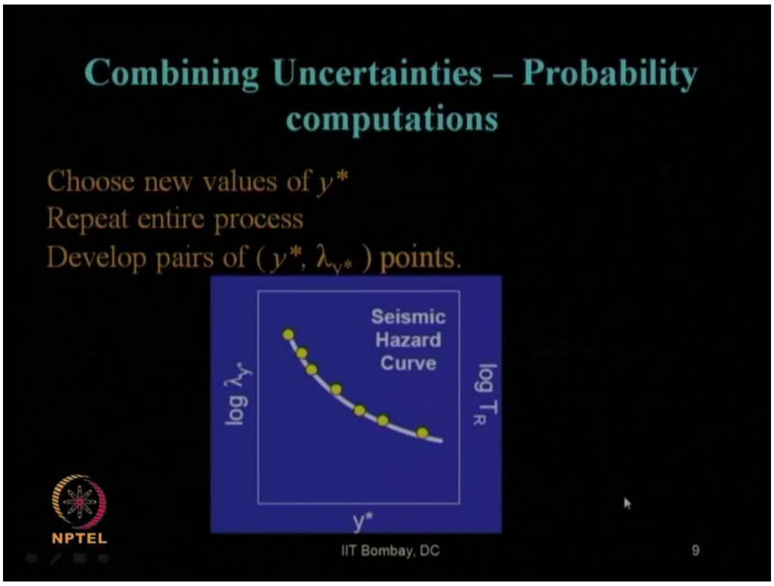

Then this complete cell will give us the final value of the seismic hazard curve, after combining these things. So, we have to repeat the entire process and develop a pair of values of this given y star with respect to log of lambda y fine or in the other side of this scale can be log of T R that is rate of occurrence, right.

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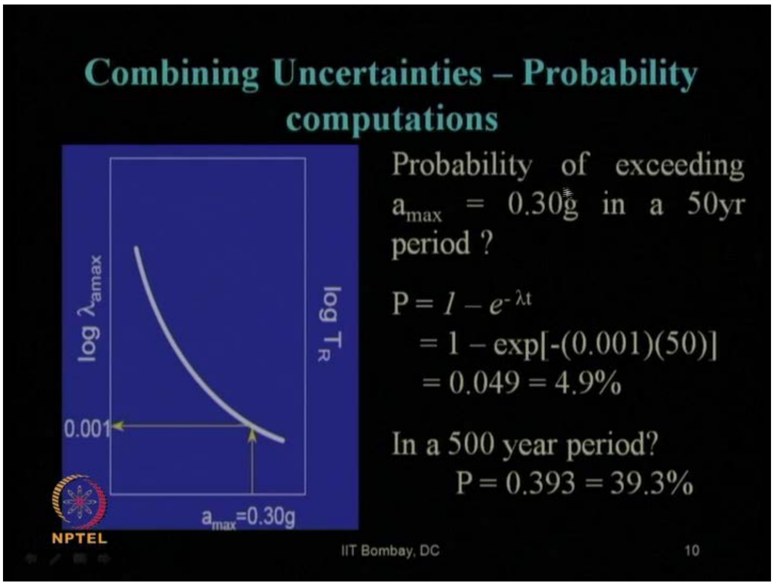

Now, we have seen how to make use this hazard curve later on, for further our design. Like, if it is known that probability of exceeding a max equals to 0.3 g, it is given to us, in a period of 50 year we need to compute from this hazard curve. Then for occurrence of it, atleast once, this is the poisson's distribution, already we have discussed in detail. So, putting the lambda value, obtained from this probabilistic seismic hazard curve. How we can obtain this, because a max is given to us. So, whatever PSHA curve we got, corresponding to a max equals to 0.3 g we need to find out what is the lambda value. And that lambda value we need to use and put it in this equation; and for how many years we need to find it out, that time we have to put it here. So, it gives us the probability of occurrence, right.

Similarly, suppose if the time scale is changed to 500 years, we can put 500 over here and get the value of probability like this.

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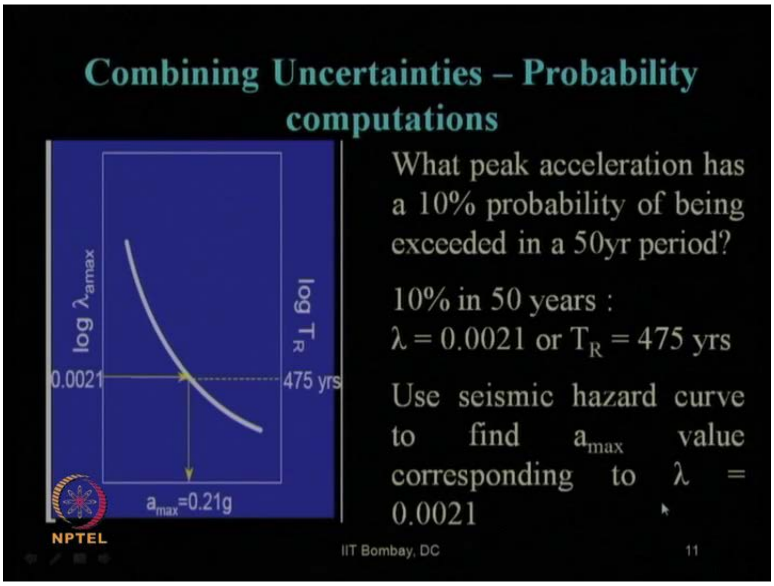

Another way of use of this seismic hazard curve, which is a more direct use, suppose, what is the peak acceleration we want to know for a 10 percent of probability of being exceeded in 50 years time. So, 10 percent of probability of exceeding an event 50 years in time at least once, we have already derived earlier that gives us the recurrence time interval T R as 475 years; corresponding lambda value is 0.0021.

So, in this seismic hazard curve, you go to this lambda value of 0.0021which is nothing but T R value of 475. Then from that curve you obtain your a max value; and that a max value will give you the design value for which you need to design, if you want to design it for that 10 percent of probability of occurrence of exceeding in 50 years time. Suppose, if it is a 2 percent of probability of being exceeded in 50 years time, in that case this will change the TR value; lambda also will change; correspondingly we have to use that value and we will get another a max value.

So, like that, actually we will get a max value over here because T R will increase and lambda value will decrease. So obviously, we have to design it for a higher value of lambda because we are taking care of 2 percent of probability that is for most important structures, as I have already mentioned.

So, that is the use of seismic hazard curve, to find out this a max value corresponding to a particular value of lambda or a particular value of T R.

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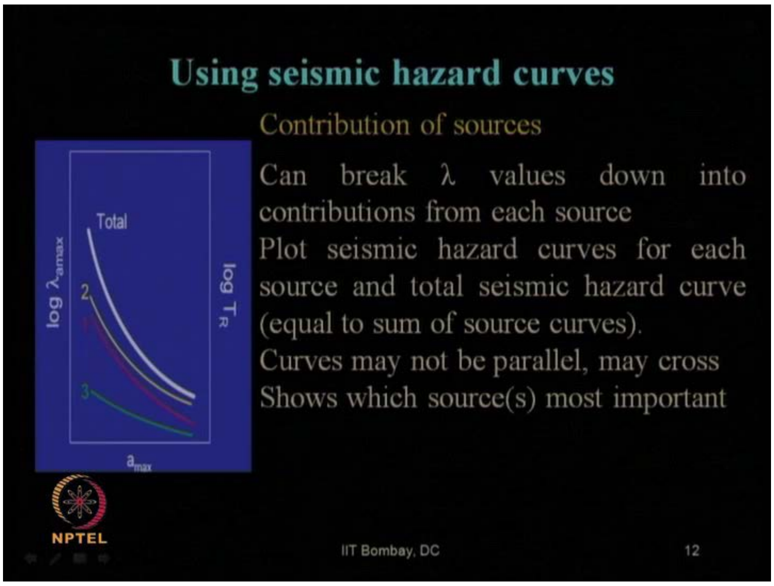

Now we had also discussed in our previous lecture, contributions coming from various sources. That is, if suppose this is the seismic total seismic hazard curve what we have obtained. Now we want to know which source is more influential to know that, what we can do? We can break it down that influence of lambda with respect to a max, corresponding to different sources. That is instead of combining them that plus of I equals to one to N S, we can find out for individual source also, what are the curves coming? And if their crisscrossing we know that, automatically says which is having more influence, right.

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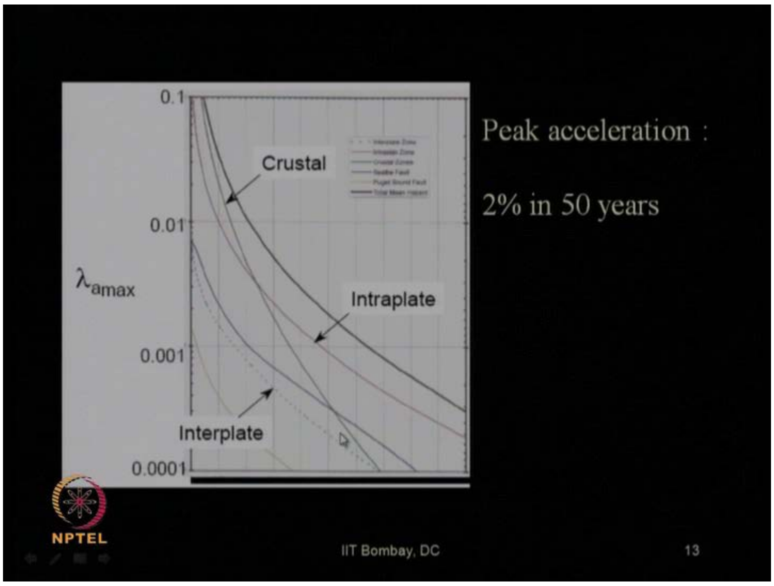

Like, for example, if we want to know the peak acceleration the lambda a max value; and this is versus a max. We have for different sources like intraplate events, crustal events, interplate events, like that for 2 percent in 50 years we can have some hazard curve like this. So, we can see which one will have more influence at a higher acceleration value or at higher a max value.

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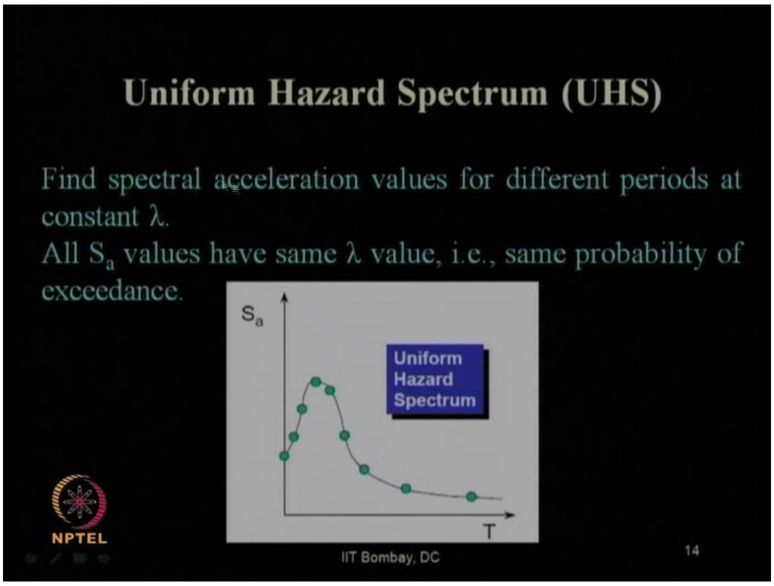

Now, we had also discussed in our previous lecture what is called uniform hazard spectrum or U H S. U H S is nothing but the spectral acceleration versus the time period, considering the simple harmonic motion of an equivalent single degree of freedom system, right which we have already discussed earlier. Now, we need to find out this spectral acceleration values for different periods at a constant value of lambda. So, how to generate each one of this points, because you will get in your seismic hazard curve like this, in your seismic hazard curve like this, suppose if you have the log of lambda value corresponding to a max or PGA versus, this is PGA, you will get this kind of result of a max.

Corresponding to a particular value of lambda, what is that particular value of lambda? That depends on what is the percent probability of occurrence or exceeding a particular year, you are considering, right. So, based on that you obtain a value of this; that to an equivalent system of S a will give you a single point like this. So, if we say this dot, that is for T equals to 0 that will corresponding to nothing but at, T equals to 0 means it will be the corresponding to a max value or PGA value. So, for corresponding to T equals to other time period say 0.2 seconds, 2 seconds we can also have this different points calculated, based on our different hazard curves which we can generate like a value corresponding to T value of 0.2 seconds; a value corresponding to A T value of 2 seconds.

So, like that we will get these points. Obviously, you have to select the particular value of damping ratio, to generate this type of curve, because you are considering the equivalence of the single degree of freedom system. So, their damping ratio makes a important role; and typically for all calculations of this U H S estimation we considered 5 percent damping for the system; and considering the 5 percent damping which generate this S a by T curve. So, that S a by T curve will finally give us the value, or design curve or uniform hazard spectrum, which is very useful for design, for a particular condition of probability of exceedance.

So, this curves say, let us say, we got it for 10 percent of probability of exceedance in 50 years time. Similarly, we can get another S a by T curve for 2 percent of probability of exceedance in 50 years time. Like that it says, for a constant value of lambda you can generate this S a by T curve. That is how in the, our any design code also the similar curve you will find in this earthquake codes or seismic codes, we will discuss that as well.

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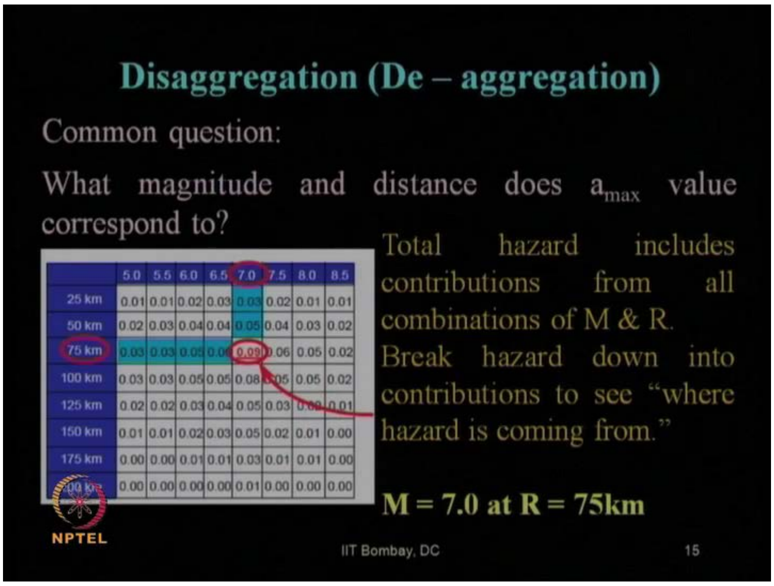

We had also talked about, in the previous lecture, what is called disaggregation or de aggregation? Like we, suppose if we want to know that a max value of the hazard parameter, what we have obtained from that hazard curve, it corresponds to which particular magnitude and which particular distance. So, that we know the influence is coming maximum from which value. So, if we go back to our grid points where we have initially found out individual probability and then sum it up, if we look at their, if we break it down, the hazard curve, we can see where the maximum value is occurring. For example, in this given grid, we can see the maximum value occurs at M equals to 7, and R equals to 75. So, that is the most influential distance and magnitude distance; and magnitude corresponds to that a max value.

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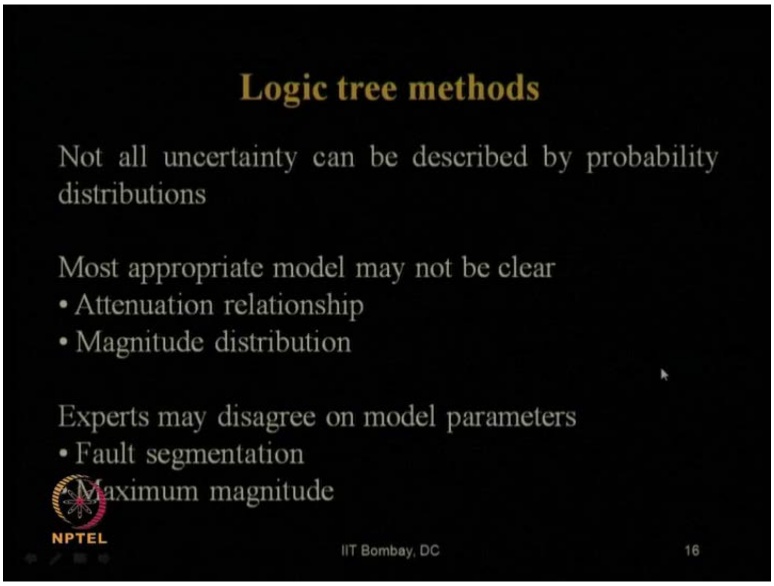

Now, we had also discussed the logic tree methods. In this logic tree, why this logic tree is required to consider? Because there are uncertainties involved in the model which we have used for estimation of the probabilistic seismic hazard curve; like there is a question always arises from the use of attenuation relationship. That is, it is always questionable whether the attenuation relationship which we are using for deriving ATPSHA is a correct attenuation relationship or not. Or there are many numbers of attenuation relationship for a particular region, let us say for our India, northeast India even the Himalayan region, there are several attenuation relationships which are available, which we have discussed in this course.

So, now which model is correct one? We do not know. So, to give different weightage, or different uncertainties involved in using different attenuation relationship, this logic tree concept has been proposed. And magnitude distribution also another thing, because we do not know which model gives us the correct magnitude prediction; through either the semi empirical relationship, or the seismic moment criteria, or crustal plate movement, various ways are there to obtain the magnitude, we have seen already. So, experts may disagree on a particular model parameters which is quite possible like fault segmentation, maximum magnitude etcetera.

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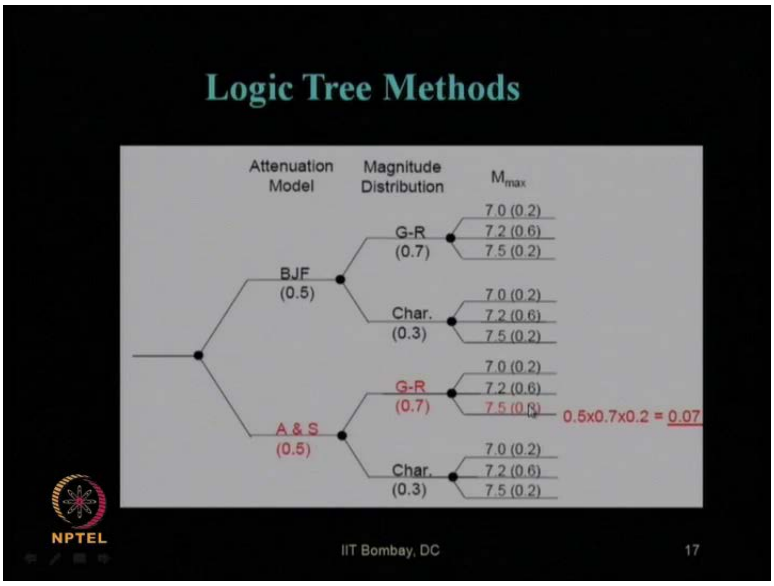

Hence this logic tree comes into picture. That is suppose in our analysis we are using different, two attenuation model. This is one attenuation model BJF, and another attenuation model of A and S. When we are not pretty sure about which one is more correct, let us give equal weightage to each of them. So, if we have two then we can give 50 percent 50 percent weightage to each of them.

Now, within each attenuation model again, we can have the formula which we have been using to obtain the magnitude distribution. We have already seen there are two ways commonly used like Gutenberg-Richter magnitude recurrence law, and another is characteristic recurrence law. So, using them, suppose if we know, or if we are confident from our given data sets which we are using for the estimation of earthquake recurrence model, say Gutenberg-Richter is a more better model. Suppose if we find it out, then characteristics model. Then we can give a little higher weightage to Gutenberg-Richter model, let us say 70 percent we give the weightage; and remaining 30 percent weightage let us give to the characteristic recurrence model.

So, what we can see over here, in this slide, that for each of the model we have given here 70 percent. Let us look at the slide, yes, 70 percent over here; and 30 percent over here. Similarly for this model, 70 percent for Gutenberg-Richter, and for 30 percent for characteristic recurrence law.

Now, again each of that magnitude distribution or recurrence law, we can obtain the different m max value, using different models once again, different equations once again. Like for estimation of m max we have several formulae we have seen. Like, we got say 77 point to 7.5 etcetera, different values. Now which one we want to consider as more realistic, accordingly we can give proper weightage to them. Let us say we have given 60 percent weightage to this 7.2; and other 70 percent and 20 percent to this 7 and 7.5, accordingly the others also. So, if we take a particular path like this, for each of these branches, we will get what is the multiplying factor or coefficients we need to consider. So, that actually gives us from this logic tree. So, this is, why the name logic tree? Because this is in the tree shape, and we are applying our logic that which model is more appropriate or equally appropriate.

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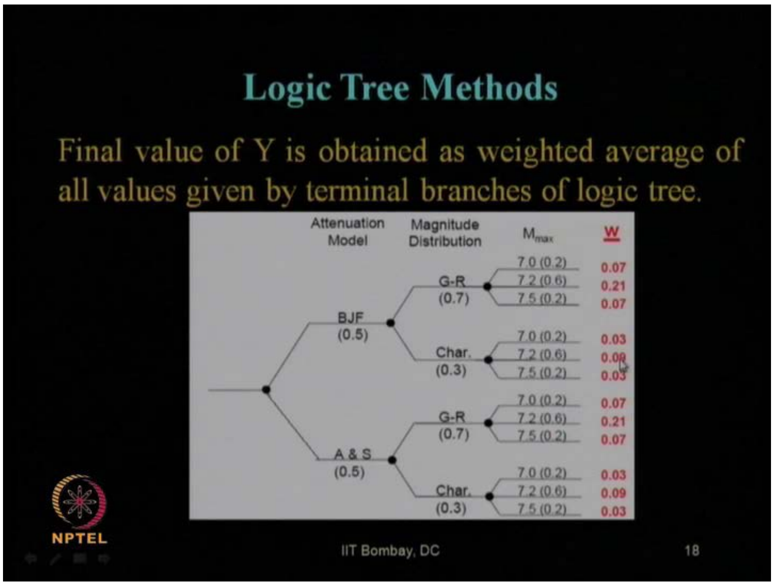

So, like that we can see from this, to find out a particular value of Y we can obtain it through the weighted average of the values given in this terminal branches of the logic tree. That is if we go through this route 0.5 into 0.7 into 0.2, we will get this value of weighted average of 0.07. Like that this is 0.21; like that this is 0.07. Similarly for others also we will get the weighing factor. This weighing factor we need to now consider, in our estimation of the value of Y.

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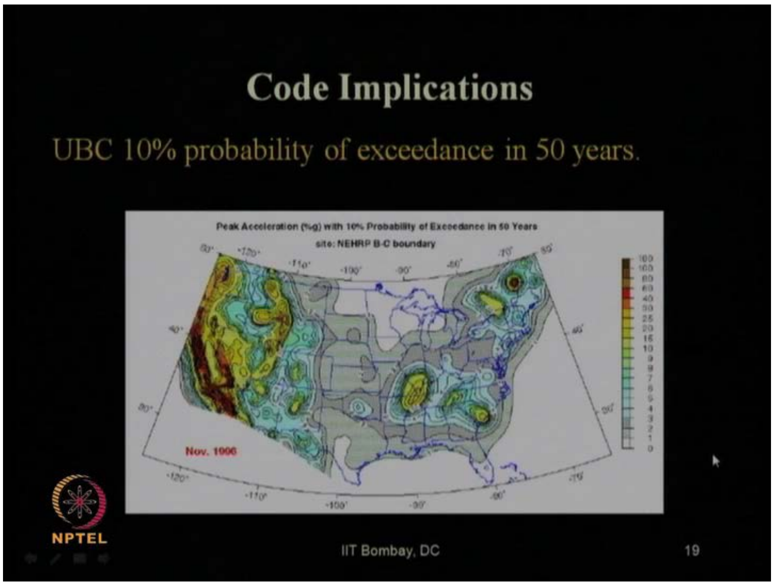

Now, let us discuss in today's lecture, what are the implications of this probabilistic seismic hazard curve, using all these analysis or all these concept in the codal provision. That is finally, we have to propose it in the design code, so that for a particular country, for a particular locality, for a particular region, it can be further used by engineers or designers to implement at particular site for design. So, how we can apply this concept of probabilistic seismic hazard analysis, through that derivation of that S a by T curve? So, let us see the code implications. You can see over here, U B C unified building code of, suggest this is the 10 percent of probability of exceedance in 50 years time, that gives us, say suppose November 1996 these are the values NEHRP B and C boundary of the site.

There are different site classifications; I will come to that site classification later on, when we will talk about the ground response analysis in this course, in due course of time. So, these charts shows the peak acceleration in percent G values; these are percent g values with 0- percent of probability of occurrence in 50 years time which is nothing but of return period of 475 years, right. So, this map automatically shows us, for a particular area, for a particular region; this is for entire US the NEHRP soil site of B and C, considering that UBC proposed; this is the map which can be used for percent g value of the peak acceleration for design; if somebody wants to design it for a 10 percent of probability of exceedance in 50 years. Clear. So, that is how, it is implemented in the design code.

Similarly, if we take another example for aashto code for aashto with 2 percent of probability of exceedance in 50 years, this is the map like peak acceleration in percent g; same considering NEHRP of B and C boundary of soil site; with 2 percent probability of exceedance in 50 years, this is the map for US.

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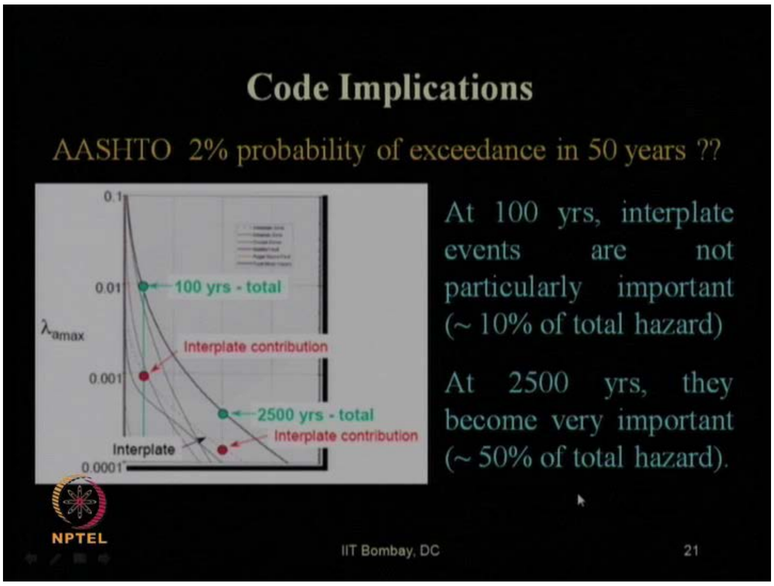

Now, aashto code with that 2 percent of probability of exceedance in 50 years time, if we have this value, say at 100 years let us take, say this value is corresponding to, let us say it is corresponding to 100 years. 100 years of T R means lambda value will be obviously, 1 by 100, so 0.01.

So, we have this, already hazard curve available with us, for a particular region, for a particular site what we have done. So, we can see from this example that, for 100 years interval of recurrence if we want to design our structure which event or which source is most important. You can see over here, in this case, which source interplate events are not particularly important, like these are interpolate right, but this one is important. Whereas, if we go for 2500 years, that is this 0.2500 years of T R will corresponding to lambda value of something over 1 by 2500 over here. So, in this case you can see the importancy of this event increases.

Now, let us come back to a case study which is applied on the Gujarat state of India. This work is done by Doctor JayKumar Shukla. He completed PHD in 2013 at IIT Bombay. So from his PHD thesis work, now we will see how this concept of deterministic seismic hazards analysis; as well as the probabilistic seismic hazard analysis, we can arrive at for a particular region. Also, how the earthquake recurrence law we can apply? And can somehow mathematically estimate the chances of probability of occurrence of an earthquake in future at a particular site, or a particular region.

That we will see through this elaborate case study, for the Gujarat region of India. Why we have chosen Gujarat region? Because we all know Gujarat has experienced severe earthquake in 2001, Bhuj earthquake. So, because of that reason, several researchers around the world they are doing the research on this area of Gujarat. There are other reasons as well which we will come to the explanation very soon.

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So, let us see now, over here. See if we look at this slide, where the Gujarat state is located in that country India, in our country India. This is the map of India. Gujarat state is the central western most state here; which is surrounded by Arabian Sea over here; and the neighbouring country Pakistan over here. So, this is the Gujarat state. Now if we look at the colours, you will see for Gujarat state of India, there are four different colour shadings are provided over here. This dark red colour; this is orange colour; this is yellow colour; and this is light sky blue colour. So, these four colours indicates the different four seismic zones as per the Indian seismic design code IS 1893, part one of 2002 version.

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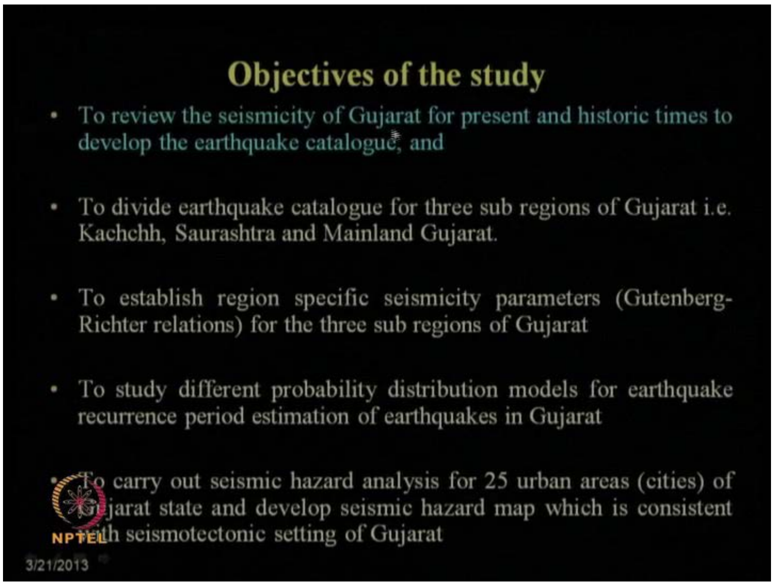

Now, what are the objectives of this study, of this present case study for Gujarat? To review the seismicity of entire Gujarat, for present as well as from historic times, to develop the earthquake catalogue that is the very first step we need to do. That is if we want to do any seismic analysis, for any particular region first step is to collect the earthquake data. From historical time to the recent times all the earthquake data or earthquake catalogue needs to be completed.

So, that is the first step to do. Next is to divide the earthquake catalogue for three sub regions of Gujarat. Why the three sub regions? We will explain it very seen in subsequent slide. So, it has been divided into three subdivisions Kachchh, Saurashtra and Mainland Gujarat. To establish the region specific seismicity parameters that is for a particular region what is the seismicity parameter, like Gutenberg-Richter relationship for the three sub regions of Gujarat have been arrived that.

Now to study different probability distribution models, for earthquake recurrence period estimation of earthquakes in Gujarat, that is various probability distribution models are available to obtain the earthquake recurrence. We will discuss that also. To carry out this seismic hazard analysis for selected 25 urban areas, or urban cities of Gujarat state, and to develop the seismic hazard map, both deterministic seismic hazard map as well as probabilistic seismic hazard map which is consistent with the Seismo tectonic setting of the Gujarat.

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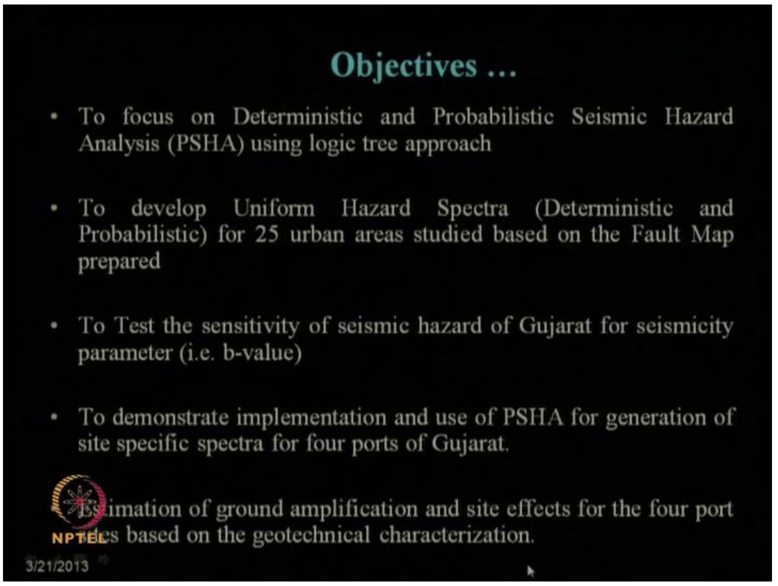

Then, to focus on deterministic and probabilistic seismic hazard analysis and; obviously, for probabilistic seismic hazard analysis we need to use the logic tree approach as well. That is which attenuation model we are using; which magnitude model we are using etcetera. Finally, once we obtain this seismic hazard curves we need to develop the uniform hazard spectra because that is the final design curve which needs to be used for further design of any structure at a particular region. So, that uniform hazard spectra either we can get it through this deterministic seismic hazard curve, or we can get it through this probabilistic seismic hazard curve right.

So, for each of this 25 selected urban cities, the, based on the fault map prepared the UHS has been developed. To test the sensitivity of the seismic hazard of Gujarat, for seismicity parameter or B value what we have seen in the Gutenberg-Richter relation, that a and B are coefficients. So, we have to find out the sensitivity of B parameter, why only B parameter? Because that is the slope of the line; A parameter is anywhere that is the intercept at the minimum magnitude.

So, we are probably not that much interested about that intercept, or coefficient, or A parameter because it is at the minimum value of magnitude. We are more interested about the higher magnitude, what are the chances or recurrence of, or chances of occurrence of a particular event. That is why B parameter or that slope inclination we are more interested to know about.

To demonstrate implementation and use of this PSHA for generation of site specific spectra for selected four ports, we will see that later. And estimation of ground amplification, and site effects for the four port sites, based on the geotechnical site characterization. These two points we will cover further again, after we discuss our next module which will be on this ground response analysis. So, remaining other case studies, or remaining other objectives we will go through, from this case study of the PHD work of Dr JayKumar Shukla under my supervision at IIT Bombay.

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So, these are the urban areas, or urban cities selected, total 25 numbers in the entire Gujarat region. As I have already mentioned, we had divided the entire Gujarat into three major zones, or three major regions based on their seismic Zonation map. So, Kachchh region which is most vulnerable as per our Indian seismic code, based on the zone parameter. Then Saurashtra which is the intermediate one, and mainland Gujarat which is the on the lower site. So, these are the various cities. Within Kachchh region Anjar, Bhuj, Dholavira, Gandhidham, Mandavi; in the Saurashtra region Amreli, Bhavnagar, Dholera, Dwarka, Jamnagar, Junagadh, Morvi, Porbundar, Rajkot, Surendranagar, Veraval; and within Mainland Gujarat Ahmedabad, Baroach, Gandhinagar, Mehsana, Palanpur, Patan, Surat, Vadodara, Valsad. So, these 25 cities we have selected. And later on, as I have already mentioned that after doing the ground response analysis we will discuss also about four port sites of Gujarat; important, four most important ports Kandla port, Mundra port, Hazira port, and Dahej port.

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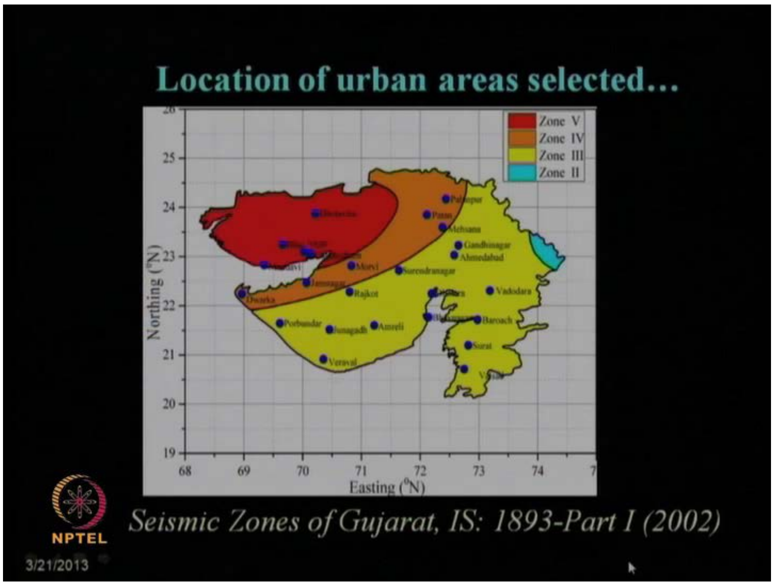

So now, these are the locations of those selected 25 cities of Gujarat region, in the subdivided into three regions. So, as per the seismic zone map of Gujarat, this is, scale is showing the northing or degree north, the latitude; and this scale is showing the degree east, degree east is, this is longitude. So, within this latitude and longitude, this Gujarat state lies. We can see over here, as per our Indian seismic code IS 1893 part one 2002, zone 5 is most vulnerable seismically. That is chances of occurrence of higher magnitude of seismicity are more in zone 5, and least or lowest in zone 2. That is how our Indian seismic code has subdivided into 4 zones which I have discussed already in one of the initial lecture of this course.

So, zone 5 is most vulnerable; zone 4 little lesser than that; zone 3 again further little lesser than that; and finally, zone 2 is the least vulnerable as per seismicity is concerned. So, you can see, why we have chosen this state of Gujarat, not only because Bhuj earthquake of 2001 was most, one of the most damaging earthquake in India which had occurred. But also Gujarat is the only state in India which is having all the four seismic zones as per our Indian seismic design code IS 1893. That is the reason, if we study the seismic hazard map, seismicity parameters, seismicity events for Gujarat state, we will do that exercise completely for all the four zones of, all the four seismic zones of India, right.

So, this is zone 5, as we have already seen, this is the Kachchh region; next this orange part is zone 4 which in Saurashtra region; and this yellow part is in mainland Gujarat which is in zone 3. Only in zone 2, this sky blue colour we have not taken any city because any way that is the least vulnerable zone as per as seismicity is concerned. So, that is why we are more interested, or confined our study for the higher seismic zone starting from zone 3 to 5; zone 3, 4 and 5.

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Now, what are the various components of a particular seismic hazard study? That is suppose, if somebody is interested to do a complete seismic hazard study, what are the various components needs to be addressed? Let us look at this slide for example, for our case, seismic hazard study for the entire Gujarat region is our final goal or final objective to do. So, what are the various things we need to do? We need to prepare the earthquake catalogue for Gujarat; we need to consider the regional seismicity parameters for Gujarat; then we need to do the sensitivity analysis of parameters. Based on this we can follow the deterministic seismic hazard analysis; and we can also follow probabilistic seismic hazard analysis.

And once all these things are done we can recommend the site specific ground motions for typical site. For example, as I have already mentioned in this thesis of Doctor JayKumar Shukla, he did the work for ports, four ports. So, that will come anyway later in our next module for this course. In this module we are going to discuss elaborately how these 5 branches are addressed to obtain the seismic hazard estimation for the Gujarat region.

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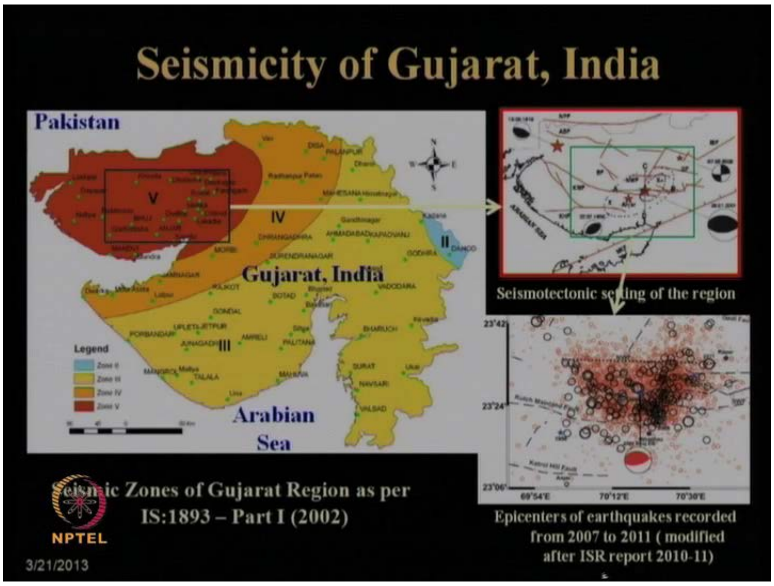

Now, let us see, once again, as I have already mentioned this is the map of Gujarat. Various cities are marked over here. Various seismic zone as per the seismic code IS 1893 part one of 2002 version. Now if we look at the Seismotectonic settings of a particular region, say let us concentrate on the Kachchh region which is in the zone 5 are most vulnerable region. So, this picture shows the Seismotectonic setting, you can see over here Seismotectonic setting for that region which further we can expand or exaggerate. We can see these are the epicentres of various earthquakes which are recorded only during 2007 to 2011 you can see so many numbers.

Now, what are the magnitude that we going to address very soon in the catalogue, when we are going to prepare the catalogue. So, these data are available in ISR, Indian seismological research institute of report 2010 to 2011, this data is available. So, from that ISR report we can obtain the Seismotectonic setting of a particular region; we can get the faults available in that particular region; we can get the number of earthquake events and the magnitudes occurred at a particular region. So, all these data will be available with us when we are starting to do the earthquake catalogue.

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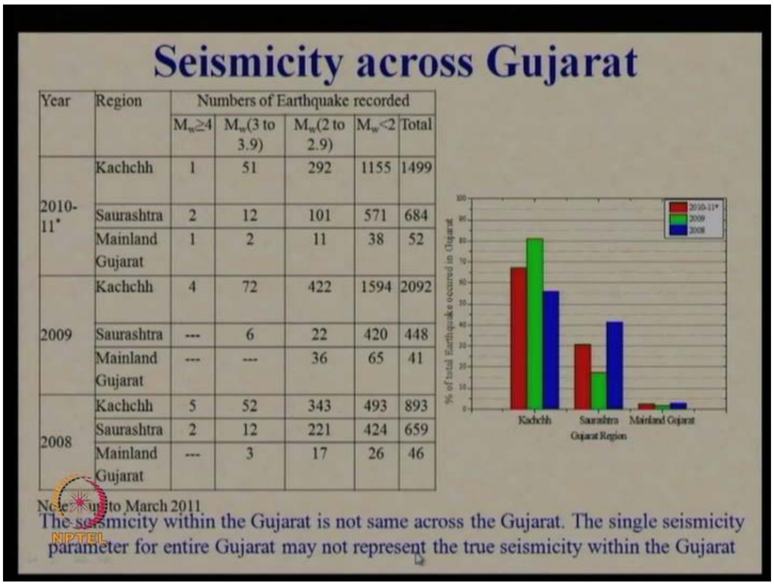

So, if we look at the seismicity across Gujarat, in this table we have shown only the data of year wise data 2008, 2009 and 2010- 11, and 11 also up to march of 2011, because Dr JayKumar Shukla collected all the data till 2011 march for estimating the earthquake catalogue. Obviously, before 2008 also there are several historical earthquake data. Just I am showing a typical example that is how year wise we can have this detailed data for each region. That is this three region Kachchh, Saurashtra and Mainland Gujarat we can subdivide the table in this fashion. That is number of earthquake occurs or recorded for different magnitudes, say magnitude greater than equals to 4, magnitude between 3 to 3.9, magnitude between 2 to 2.9, magnitude less than 2. You can these values are very low.

And already we have mentioned we are mostly not concerned about this values for our design, we are mostly concerned about more than 4, 4.5 or 5 like that right. And also these magnitudes can only be detected by sensitive instruments only. Like, they will not show any kind of damage; like magnitude less than 2 or between 2 to 3 etcetera. So, all these recorded data are collected from this ISR report. And you can see over here, in Kachchh region greater than magnitude 4 earthquake in 2008 that year itself in one year there were 5 such incidents; in Saurashtra region there were 2 such incidents; whereas, in Mainland Gujarat there were no, in, such incidents, whereas for other magnitude also you will get several numbers.

And you can see there are several hundreds or even several thousands of such events occur in the particular year. But we are not so much of interested about these numbers or these values. Because they do not make any harm to our structures, to mankind etcetera, of this low magnitude. But obviously, greater than 4 or etcetera we should be concerned about. That is why we have to select a lower bound, when we are planning to go for next level of recurrence law. We will do that very soon. Now if we plot this year wise pattern that is percentage of total earthquake occurred in Gujarat for year wise this dark blue colour is 2008, green colour is 2009, and this red colour is 2010, up to march of 2011.

So, you can see for Mainland Gujarat, it is extremely low, which is quite expected that is why we can see from the seismic Zonation map also. This is in the zone 3 right. Whereas for Saurashtra region which is in zone 4 it is intermediate; whereas for Kachchh region which is in zone 5 number of earthquake occurred in Gujarat is very high. That automatically says that seismicity within the Gujarat state is not same. Whereas our seismic code proposes only a single value for entire Gujarat, whether that is correct or not that we need to go through. Even some of the researchers, earlier researchers they also propose the single parameter for Gujarat, if we talk about the recurrence law of Gutenberg-Richter which is not correct as we can automatically see from this distribution of occurrence of numbers earthquake, right in the Gujarat region. So, that single seismicity parameter for entire Gujarat state, it may not represent the true seismicity within the Gujarat, which is quite obvious.

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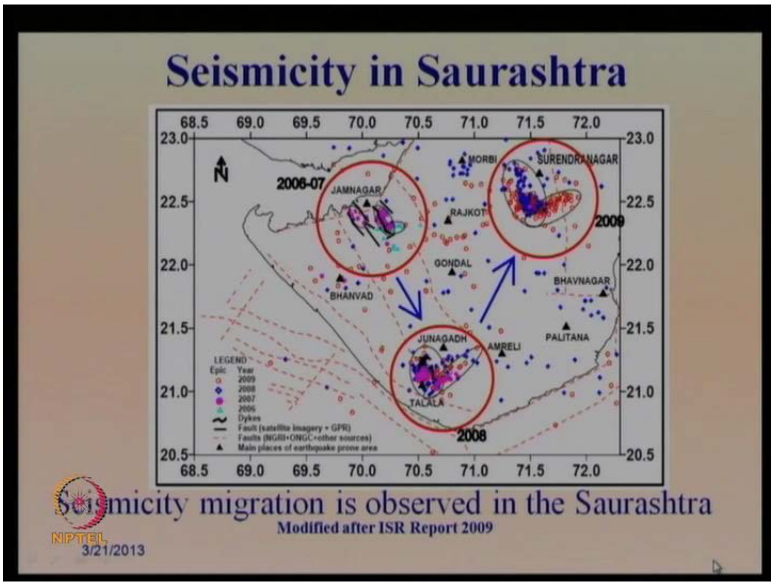

Now, seismicity in the Saurashtra region, we can see that over the years; this is again from modified I S R report of 2009 that seismicity also migrates. What is migration of seismicity? That is from one region slowly over the years it moves to another region, as you can see from this Jamnagar area to Junagadh area, then to Surendranagar area the clustering of occurrence of more number of earthquake is shifting in this fashion from 2006 to 2007, 2008 then 2009. So, that is called a migration of seismicity event, in and around a particular region; this is within the Saurashtra region. So, that also needs to be considered when we are planning to do a region specific seismicity analysis.

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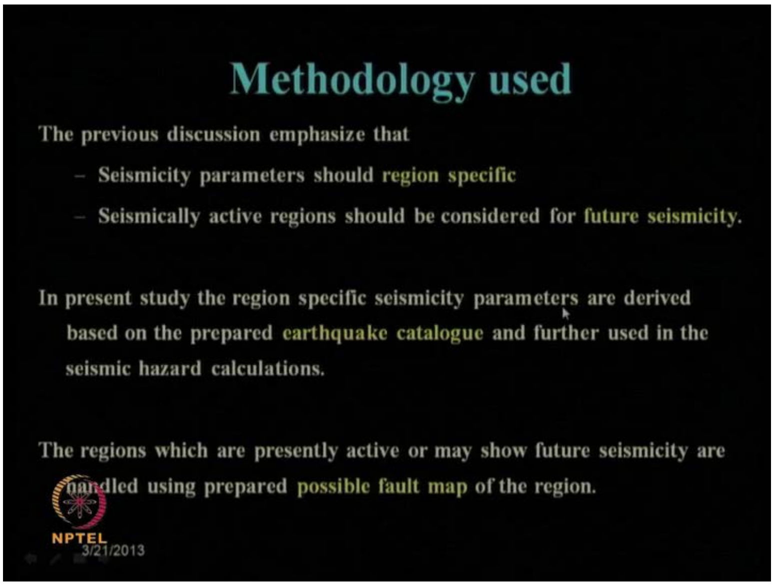

Now, what are the methodologies used? The previous discussion emphasis that seismicity parameter should be region specific. Because we have seen for Gujarat considering a single seismicity parameter is not justified; also it is not justified to consider a single seismic event at a particular region, because it migrates also over the years. And seismically active regions should be considered for future seismicity. In the present study the region specific seismicity parameters are derived based on the prepared earthquake catalogue, and further used in the seismic hazard calculations. The regions which are presently active, or may show future seismicity are handled using prepared possible fault map of the region. So, for the entire region, what is the next? We need to prepare the fault map, what are the active faults or known faults in that region are available.

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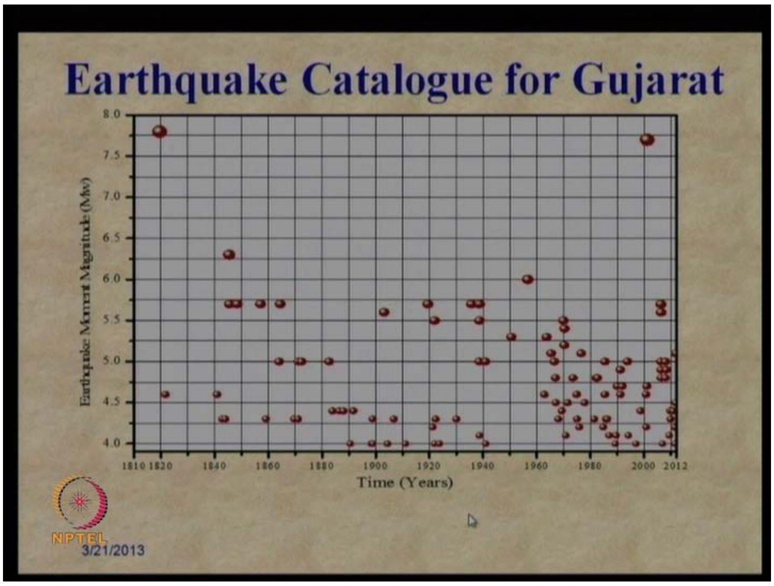

Now, let us see earthquake catalogue for Gujarat. As I was mentioning from historical data to present data, we need to first collect all the earthquake. Look at here, we have reported in this slide, only those earthquake moment magnitude which are 4 and above. That is the lower bound, we have already selected as 4. It depends on the designer, if somebody is interested they can select it as 4.5 also; if somebody is interested they can select it as 3.5 also. But for the, from the experience of what is most vulnerable for the structures are design consideration, we thought we will be selecting; and based on the numbers of occurrence of earthquake, the lower bound or the threshold value of earthquake moment magnitude as 4 for the entire Gujarat.

And you can see, we have collected the data from year scale of 1820, this first data is from 1820 to 2012. So, that is the span through which from various sources, various authentic sources like US, G S, I S R, I M D, all these various sources; like you people also have collected these information in the beginning in one of the assignment, that how to collect the earthquake data for a particular region. Suppose for India also we have collected for earthquake above 5.5 to 7. We have collected this data from various sources, authentic sources like US, GS, IMD, ISR. So, similarly for Gujarat also we have collected this kind of data. And this is the scatter of those occurrences of earthquake over the years, you can see over here, right. These values are mentioned in this case. You can see the 2001 Bhuj earthquake comes over here, you can see this value.

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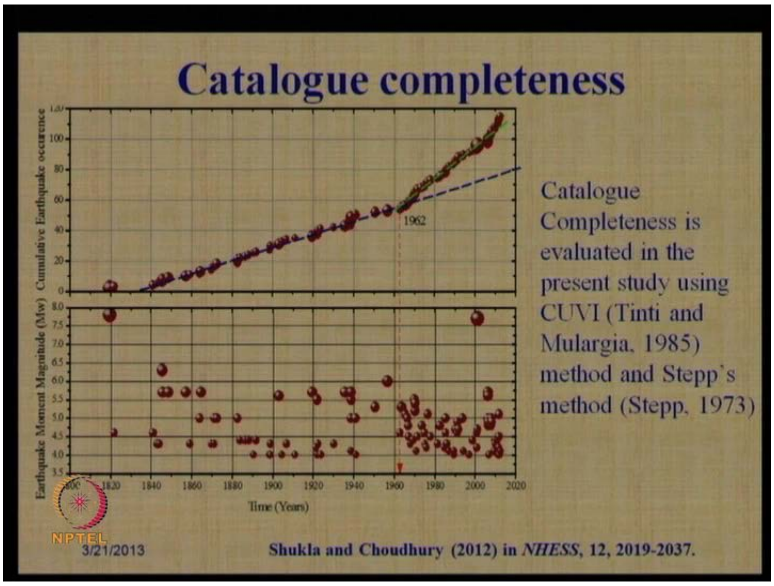

Now, whether the collected earthquake catalogue or earthquake data, whether it is complete or not, how we will know? Now next step is to ask yourself, whether the data which you have collected, for a particular region on the earthquake, whether it is complete or not. So, that catalogue completeness needs to be checked. That is the next step, to check the catalogue completeness. How we can do the catalogue completeness checking? There are various methods available. Like in the present study CUVI method as proposed by Tinti and Mulargia in 1985 is used. And also another method proposed by Stepp in 1973 that has also been used.

So, how we can find it out the catalogue completeness? In short I will explain over here. The earthquake magnitude versus time, this data already we have collected. This lower graph which is shown over here, this already we have seen in the previous slide, this one. This only we are redrawing over here. Now, if we want to change this y axis scale to cumulative earthquake occurrence, that is we are keep on adding the numbers of earthquake over the time scale of this one; then the curve will be keep on increasing because we are keep on adding these values. This is the cumulative scale.

Now whenever in your, that cumulative scale, it should be, clustering should be uniform; uniform means there should not be any gap. You can see over here as expected from 1960 onwards still present date 2012, whatever data has been collected there is no such gap; that means, a good collection of the data set. Whereas, in historical type there are few gaps, may there are not so much magnitude of more than 4 are available, that is one possibility; another possibility is, may be lack of information from the historic data; both can be true.

Now, if you look at this pattern of this cumulative distribution of earthquake data points, you will find that from historical to present data. If you want to plot a best feet linear plot of this, you will get two different slope of the line, can you see. This was giving a particular trend; whereas, in recent years the trend has changed to something else.

So, this blue colour dotted line is showing one trend; whereas, this green colour dotted line is showing another trend. And where that change of trend is occurring? That you can easily find it out, that point shows us, that from this point onwards there is a shift or there is a change of number of occurrence of earthquake. In this present case, it is 1962. You can see over here where the change of this curve is occurring. So, like that we have to check the catalogue completeness.

Details about this catalogue completeness are available in this journal publication by Shukla and Choudhury 2012 in the journal of Natural Hazards and Earth System Sciences. It is published by European Geophysical Union EGU of Germany; the volume is 12; and page numbers is 2019 to 2037. So, this is the very good journal with high impact factor. You can go through this paper to know about the catalogue completeness. So, with this, we have come to the end of today's lecture. We will continue further in our next lecture.