Earthquake Geotechnical Engineering

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Lecture- 7

Seismic Hazard Analysis

I welcome you again for this course on earthquake geotechnical engineering. And today we are going to have the fourth chapter of this course and that is the seventh lecture which is on seismic hazard analysis. This seismic hazard analysis will be covered in two lectures, lecture number 7 and then lecture number 8. So, like whatever has been covered we are working on the module 1 of this course and we already talk about the geotechnical issues during earthquakes in the first two lectures, then engineering seismology in another two lectures and the last two lectures that is lecture number 5 and 6 was on strong ground motion. Today we are going to start a new chapter which is called seismic hazard analysis and which is very important for particularly for finding the site specific design earthquake parameters. So, what we are going to have in this lecture like before going that let me acknowledge that the following is the source of most of the information given in this lecture and this will be used just to educate the masses.

Actually, this is most of the stuff is from Kramer's book of 1996 geotechnical earthquake engineering and I will explain in my way even the contents may be similar what has been given in the textbook. So what we are going to talk, first let us discuss what is the objective of SHA, SHA here will stand for seismic hazard analysis. So while talking about SHA because you know that we discussed in the beginning of this course that you need to design earthquake resistant design of structures as well as foundation. To carry out earthquake resistant design it requires that what should be the level of shaking which should be considered for the designing of these structures and this is not easy task because it depends on your locality, it depends on many other factors.

So the structures should be designed earthquake resistant without excessive damage and the level of shaking described by design ground motion which is usually determined with the aid of seismic hazard analysis. So most important objective is that you want to have a design ground motion and for that you need to carry out seismic hazard analysis which we are going to talk today. Now what are the approaches for SHA that is that is a seismic hazard analysis. Naturally our objective will be to quantify the things rather than only qualitative this quantitative estimation of ground shaking hazards at a particular site. So when we say quantify it simple meaning is that whether one site is more hazardous another is less hazardous so like that way but there should come in some numbers rather than saying more or less only.

And this seismic hazard may be analyzed with the two ways one is called deterministically where a particular earthquake scenario is assumed, or another way is probabilistically in which uncertainties in earthquake size, location and time of occurrence are explicitly considered. So basically, in the former you require the earthquake data in deterministic approach, and you create a scenario for that particular earthquake. While in probabilistic approach we can account for the uncertainties which is related to earthquake size location. So we are going to talk about that. So today we are going to talk in this first lecture that is both DSHA in the short it is called like you know like deterministic seismic hazard analysis and probabilistic seismic hazard analysis.

We will discuss about the concept. In the second lecture we will talk about the uncertainties which is basically for PSHA. Coming to the first point for this basically for DSHA and of course it is a bit applicable for PSHA also, but this must for the deterministic seismic hazard analysis. You need to find first identify the seismic sources which are our concern. So, to relate seismic hazard for a particular site or a particular reason you need to identify all possible sources of seismic activity.

They should be identified of course some source will be strong some source will be weak that is okay, but we need to identify which is applicable to that site and we need to find what is their potential for generating future strong ground motions. So again generating future strong ground motion potential will be different for different sources. It is not going to be the same for all the sources. So that is we first identify the sources. The second thing is identification of seismic sources which will require some detective work and natural nature clues some of which are obvious, and others are quite complicated, and they should be observed and interpreted.

So, we are going to discuss it in detail further. Coming to availability of earthquake data is important for particularly for deterministic approach is good as long as you have many earthquake data is available to you but if you have scarcity of the data then perhaps deterministic approach will not give you the right answer. So the availability of modern seismographs and seismographic networks has made it observation and interpretation of current earthquake rather convenient. So earlier in the earlier days maybe let us say two three decades back when we do not have much seismic network particularly in our country then we do not have data but now we have lot of data available. Of course, that is still not enough but compared to the earlier days we have the data availability better compared to earlier days and the reason being we have many seismographs and a lot of are installed particularly in the Himalayan region, Himalayan belt and many stations are placed by our department of earthquake engineering at IIT Roorkee.

So, the occurrence of large earthquake is now recorded by hundreds of seismographs around the world. There is one of the agency from United States called USGS. USGS is agency which monitors continuously in different parts of the world USGS, United States

Geological Survey. It is similar to what we have GSI but in our country you may be aware that the nodal agency which measure the earthquake is called IMD, Indian Meteorological Department. So IMD does this job and in USGS it does.

So anyway, whether it is a station from USGS or IMD so hundreds of seismographs are placed around the world and within the hours when an earthquake comes seismologist are able to determine its magnitude, located rupture surface and evaluates source parameters. So rather than saying within hours I think it will be within minutes nowadays time have changed so this should be read within minutes. So because within 10 minutes, 15 minutes most of the information comes sometime within 5 minutes an earthquake have come like that. And not only that it is said that an earthquake have occurred but you get its detail related to what was the magnitude, where location of rupture surface and evel source parameters. Source parameters means for example what we discussed in the last lectures PGA or PHA so that is also find out.

So that means availability of earthquake data have made our task bit easier compared to earlier. Now as already discussed there are two methods of seismic hazard analysis, one is called deterministic seismic hazard analysis DSHA, another is called probabilistic seismic hazard analysis. So, in this lecture and the next lecture we will be using this abbreviation DSHA and PSHA frequently. Coming to DSHA in the early stage of geotechnical earthquake engineering the use of deterministic seismic hazard analysis was prevalent. So earlier this was only DSHA in fact PSHA came quite later.

So earlier we had only one method that is DSHA only. Then in the DSHA it involves the development of a particular seismic scenario upon which a ground motion hazard evaluation is best. So for a particular like you know this scenario you create that this type of magnitude of earthquake is accepted in this region and then what we need to do and then we need to carry it out according to hazard analysis. The scenario consists of the postulated occurrence of an earthquake of a specified size occurring at a specified location. So that means when you do for this earthquake you decide about size, size of an earthquake is mostly represented by its magnitude and at what location it will occur so that is also important.

So in the DSHA there are four steps and these steps we are going to talk one by one in detail and this was given by Rieter in 1990. So it is almost now more than 30 years that these DSHA is like known. So first step is identification and characterization of all earthquake sources capable of producing significant ground motion at the site. So we need to identify the sources and then characterize. Characterize means the characterization of these sources will be done from many ways.

One way is that its size, that its magnitude, what is the magnitude so that will be its characterization. So, first thing is identify and characterize all earthquake sources which are capable of producing significant ground motion at the site of your interest, the site where you want to know and site of your interest could be your project site where you want to construct a dam, or you want to construct a bridge or maybe tall buildings or nuclear power plants whatever this one. So, site of interest or maybe like thermal power plants or many like structures. Then this include the first step source characterization including definition of each source geometry and earthquake potential. So what is the geometry and what is the potential it may cause? Potential will depends on the magnitude and suppose if size of earthquake is high then earthquake potential is expected to be high. Then the second step once you have decided about characterization of the source then selection of how far the source is there. So source to site distance parameter is also important. Suppose an earthquake is high magnitude but it is far away so it may not cause any issue for us. So and if it is near even a small earthquake that may be important. So in this most DSHA the shortest distance between the source and the site of interest is selected.

So what is the shortest distance? So because the shortest distance will give the worst case. So I mean the source may be little long let us say source some fault is there and fault has some different distances from our site but the shortest distance will be of our concern. And this distance may be exposed press as a epicentral distance or hypo central distance depending on the measure of distance of the predictive relationship required in the next step. What is the in the next step? Third step we find out the sources identified, we find out the shortest distance of the sources from our site. Now selection of the controlling earthquake out of these you have showed different sources and different distances.

Now the issue is which earthquake will be governing so that is the selection of the controlling earthquake that is the earthquake that is expected to produce the strongest level of shaking naturally. So strongest level of shaking will depend on its magnitude as well as its distance from the site. And this is generally expressed in terms of some ground motion parameters at the site. The selection is made by comparing the levels of shaking produced by earthquake identified in step 1 which is assumed to occur at the distance identified in step 2. So, in step 1 we identify the source in step 2 the distances.

The controlling earthquake is described in terms of the its size usually expressed as magnitude and distance from the site. So this is controlling earthquake. Now continue with the step 4. The hazard at the site is formally defined usually in terms of the ground motion produced at the site by the controlling earthquake. So that will be like you decided about the controlling earthquake and now last step in the last step you want to determine what is the hazard like level of hazard basically in terms of whether it is low hazard, medium hazard or high hazard.

So that is decided by the in terms of ground motions and this ground motion which will be produced by your controlling earthquake and its characteristics are usually described by one or more ground motion parameters. Ground motion parameters we already talked particularly when we talked of ground the strong ground motion SGM in the last lectures and this is normally by 3 parameters one is amplitude another is frequency and third one is its duration. So on the basis of those parameters we identify. So these for example in that it is peak acceleration, it could be peak velocity or it could be response spectrum. They are usually commonly used to characterize the seismic hazard.

So, all the 4 steps are summarized here for DSHA, seismic hazard analysis. So this slide is very important to define in the single slide we have defined all the 4 steps. You could see in the step 1 you have different sources M1 and when we say source it may not be a point source though we can understand that there is a line. So it could be a fault line M1 then you have M2 in some area M3. So, what do you do from different your site is there in the first step.

So first step is only to identify the sources and in the second step what you do after identifying these sources you find the shortest distance. So here the shortest distance in the second step is given R1, R2 and R3. So R1 is from source 1, R2 is from source 2 and R3. Now in the third step what you do you have 3 magnitudes M1, M2, M3 and R1, R2, R3. You put these data on a graph and on this graph form on the x axis you have distances which is given R1, R2, R3 you could see R1 is the maximum in this case while R3 is minimum.

And because these sources do not have the same size let us say we selected the characterization as a magnitude of earthquake so M1, M2, M3. Now you could see that here the largest magnitude earthquake is M3 and this magnitude is highest M3 out of 3 then this have the shortest distance which is R3. So as a result it is expected this will be controlling earthquake because its size is large and it is nearby only. However if I see that this R2, R2 size is minimum and distance is medium. So R2 and R1, R2 have a small distance but size is very low at least.

R1 have more magnitude than R2 this M2 but its distance is higher. So anyway so it is very clear out of these 3 data that the governing earthquake will be third one M3 at a distance R3. Now on the basis of this you determine ground motion parameters Y and ground motion parameters as we already discussed this could be your PGA or we call PHA or it could be PGV or it could be response spectrum. So the Y could be variable depending on that so this completes this talks about DSHA. Now continue with the DSHA what the advantage and disadvantage limitations of the DSHA and this area is in fact in reference to the you can say another approach.

So, first advantage it is very simple procedure and in fact many respect it is really simple it can be done otherwise if we some PSH is little complicated which we are going to talk in the next part of this lecture. So the most important advantage is simple and when it is applied to structures for which failure could have catastrophic consequences for example you have nuclear power plants, large dams DSHA provides a strict forward framework for evaluation of worst case ground scenarios. So what could be the like when we carried out DSHA it may give you which may be the critical situation for your facility particularly for example nuclear power plants which earthquake and at what distance so that could be find out from DSHA. But there are certain limitations for DSHA. DSHA do not provide any information on the likelihood of occurrence of the controlling earthquake and the likelihood of its occurring where it is assumed to occur.

So the issue is this one we have selected that for designing of our structure that this is my controlling earthquake but we do not know how good our chance that this earthquake will be repeated or it will come or not come. So the probability or chances that earthquake is not included. Here in DSHA we already assumed kind of a conservative approach where we see this is a controlling earthquake and it is certain to come but sometime you know that it may happen or it may not happen. So it does not talk about like chance like what is our likelihood or what is the probability of occurrence that is one thing and because it is also important where this earthquake will occur that is the distance, shortest distance will depends on the its location. So that is also not sure whether it will occur in the location which we are considering or not.

Then the second this DSHA also do not provide information on the level of shaking that might be expected during a finite period of time. Now when we say finite period of time it is normally considered to be lifetime of a structure for example because you know that major structures for example dams, bridges or they have their lifetime they are designed maybe for 50 years or 100 years or like this normally. So normally the lifetime is of a structure is maximum considered to be 100 years or so. So whether during this 100 year periods whether that level of shaking will occur or not that is also one of the issue and the effect of uncertainties in the various steps which is required to compute the ground motion is also missing in this. So like uncertainty is missing, the probability is missing in the first part and then what is the uncertainty.

Continue with the limitations. This involves subjectivity decisions like you know that expertise are required like it is to be decided whether how much chances of this earthquake to occur here. Some people say yeah great chances, some may not be the chances or like this one. So then it becomes subjective and subjective decisions comes good decisions will be depends on experience. So some experts are there they know about their condition so they will be in a better position to decide. Particularly regarding earthquake potential that can require the combined experience and opinion of seismologist, seismic geologist, engineers, risk analysis, economist, social scientist and government officials.

All need to sit down together and decide what should be the, so there is a committee which is at the national level that is called NCSDP. And this committee is called National Committee on seismic design parameters. This is a high level committee in the government of India and this committee is normally by CWC, Centre Water Commission, Government of India.

So this committee this have high power, head department of earthquake engineering of IIT Roorkee is the member of this committee by default. And in this committee NCSDP like as I said that many experts sit down and then they decide about the issues after some calculations and after this that scenario that what should be there. So for major project for example dams you have then bridges and other projects. So this committee mostly look after the dams and this is mostly for dams under hydro dams, hydrological projects. So, it is decided by this committee that what should be the scenario or what should be the controlling earthquakes and others.

So, continue with this. Now there are terms which are used for earthquake potential in this DSHA approach. First is called maximum credible earthquake that is MCE. Then second is called design basis earthquake that is DBE, shaft shutdown earthquake that is SSE, maximum probable earthquake MPE, operating basin earthquake OBE and seismic safety evolution earthquake. So like some of that name itself is suggest little bit more background on that. MCE that is maximum credible earthquake, is defined as the maximum earthquake that appears capable of occurring under the non-tectonic framework.

So, you can say that MCE will be the highest among all these group. So DBE and all these will be down. So you cannot expect more than MCE. Then DBE and SSE are defined as again maximum earthquake. First DBE is for design of a structure and the SSE is related to self shutting down a facility when an earthquake comes like nuclear power plant need to be shut down.

So, what should be the level of the shaking where we say that okay, we will shut down our plant before any damage occurs. So this is related to SCE. DBE that means your structures are designed for that design basis earthquake that we have designed. So, DBE and SSE are going to be in magnitude less than MCE. Then you have maximum probable earthquake from you decide from maximum historical earthquake and also as the maximum earthquake likely to occur in a 100 year interval.

So, what we have probabilistic seismic hazard analysis in this so this completes about DSHA. So now the second parts of the lecture which is on PSHA. So whatever the limitations are there for DSHA we try to remove that limitation in this method PSHA. So PSHA is going to be more complicated compared to DSHA.

It is not simple like DSHA. However it will be better because it will be based on more like you know data, more research, more technique. So we are going to talk about that. So as the name suggests probabilistic seismic hazard analysis provide a framework in which the uncertainties can be identified. So this is one of the issue which was missing in the DSHA. They are identified, quantified, and then combined in a rational manner to provide a more complete picture of the seismic hazard.

So, what is the concept of PSHA? Seismic concept allows uncertainty in the size, location and rate of recurrence of earthquakes and in the variation of ground motion characteristics with earthquake size and location to be explicitly considered in the evolution of seismic hazards. So this is one of the like what are the chances, what are the probability so that is included here. This is also described in the four steps and each of these steps are similar to the steps of the DSHA procedure with some more information. So it is here. The first step again the same identification and characterization of earthquake sources.

It is similar to like DSHA but some more input is given in this step that what is the probability distribution of potential rupture location within the source must also be characterized. So in addition to the information which was for DSHA, we include in this first step probability distribution function which decided that what is the chances of occurring an earthquake. In most cases if no information is available, you can consider uniformly probability distributions and that is assigned to each source implying that earthquakes are equally likely to occur at point within the source zone. Continuing with this first step, these distributions, probability distribution, it is combined with the geometry of the source to obtain the corresponding probability distribution of source to site distance.

So, that will come in the next step source to site distance. The DSHA on the other hand implicitly assumes that the probability of occurrence is 1 at the points in each source zone closest to the site and 0 elsewhere. So here is the philosophical difference. When we talk about DSHA, DSHA assumes the sources which are very near to the site chances of occurrence is 100% 1 and those far away the chances are 0. But there is something between 0 and 1 like either it would be 1 or 0 in the case of DSHA, but in PSHA method it is suppose there is some probability could be 50% chances are there, 30% chances are there, 40% are there like that is considered here which is missing in the DSHA. Now in the second step, the seismicity or temporal distribution of earthquake recurrence must be characterized.

And in this case, a recurrence relationship which is specify the average rate at which an earthquake of some size will be expected is used to characterize the seismicity of each source. So, what is the chances, again what is the rate at which the earthquake at some site is expected, so that is also included here in this system. The recurrence relationship may accommodate the maximum size earthquake, but it does not limit consideration to that earthquake as DSHA considered. So, in this case again, we also consider the maximum size of earthquake, but we are not restricting ourselves to that only which was the case in the DSHA here like others also considered. Now the third step, the ground motion produced at the site by earthquakes of any possible size occurring at any possible point in each source zone must be determined with the use of predictive relationships.

So, in the second step, you have a relationship that is called recurrence relationship, and we are going to talk one of the recurrence relationship in the second lecture today. So, and based on this recurrence relationship, the ground motion which will produce at the site is must be determined using this relationship. And the uncertainty inherent in this predictive relations also considered in PSHA. The last step as like DSHA, finally the uncertainties in earthquake location, earthquake size and ground motion parameters predictions are combined to obtain the probability that the ground motion parameter will be exceeded during a particular time in period. So, here what you do, you find out like you have combined all the uncertainty which is related to size or location size and ground motion parameters.

And then you try to after combining you want to find the probability that the ground motion parameter like for ground motion parameter could be your PGA which will be exceeded during a particular time period. So, we determined how many times it is exceeded and we will discuss this with one of the examples in the next lecture. So, all the four steps of PSHA are combined here in this slide and you see it looks like similar particularly the first step looks similar. You have three sources again M1, M2, M3, but you are not putting the magnitude here which was the case in the case of DSHA. Rather what you have, you have within the source like with the distance how the magnitude is varying probability.

So, within the you have a fault line and in the fault line what you have done in the last case DSHA. You consider you pick up the maximum earthquake and minimum distance. Here you do not neglect other earthquakes due to the source and you have the source and distance and so for each case this is probability function source 1, source 2 and source 3. So, this is the variation that with the distance.

So, that is also covered. Now in the second step where you have the distances, so what you have logarithmic of earthquake which are greater than a threshold value M. M is the value which is decided by you a threshold value. So, threshold value and those earthquake which have greater than this certain value you consider on the y axis and then on x axis you have the magnitude. So, for different sources such as 1, 2, 3 you have. Now finally in the third step with the distance you have ground motion parameter and now in this case you do not have the points rather you have the curves like for example 3 scenarios or 3 sources are there.

So, you have 3 distributions here 1, 2 and third one is very different than the other two. And finally you combine and find a parameter y and on this case you have the probability. Here on y axis you have the probability rather than the seismic parameter here. The probability y is greater than y star that means what are the chances that you will get at a particular site earthquake than a given value of a threshold value. So, that means threshold will be a value let us say a certain magnitude or certain PGA more than that what are the chances of occurrence of an earthquake at that site.

So, these are the all four steps of PSHA. Continue with this the PSHA the proper performance of a PSHA requires careful attention to the problem of source characterization and ground motion parameter prediction and to the mechanics of probability computations. So with this all thank you very much. So, we talk in this lecture on seismic hazard analysis we talk about the concept and then DSHA and PSHA. Now because PSHA involve lot of uncertainty so we will discuss in the next lecture that about. Thank you very much for your kind attention.