Earthquake Geotechnical Engineering

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Lecture- 5

Strong Ground Motion

I welcome you all for this lecture 5th. On earthquake geotechnical engineering and we are under the module 1 and today's lecture will be on strong ground motion. So, under the module 1 we already covered geotechnical issues during earthquake, then we talk about engineering seismology. Now, today we are in the middle of this series and today we are going to talk on strong ground motion. So, let us have a little recap from the last lecture we discussed plate tectonics, geometric notations, size of earthquakes, earthquake intensity and earthquake magnitude. So, today we are going to talk about strong ground motion.

So, in general this is like a chapter 3rd of the module 1 and which will be again in two parts, first part we are now and then this today we will talk about the second part also. Before I go for a strong ground motion I will in brief tell you that in general mother earth vibrates continuously. It is not that the vibrations is only when you feel an earthquake rather earth is vibrating continuously only the thing sometime the amplitude or the let us say that the intensity of these vibrations is so small, so thin that we are not able to even feel that. And these vibrations as you know the amplitude may vary which may be in nanometers to in the meters.

Similarly, when we talk about its wavelength it may also quite varying. So, frequency content will also much varying. So, for a seismologist the small vibration is also important for the research and other purpose, but as for engineers particularly like geotechnical earthquake engineering discipline and other things it is a strong ground motion which is most important and today, we are going to talk about that. Now coming to this as I just mentioned the earthquake engineers are interested primarily in strong ground motion that is the motion which have sufficient strength to affect people and their environment. So, if suppose some vibrations are coming with which do not have any effect on livelihood or let us say on like on environment then it is not so important for engineers.

To emulate the effects of earthquakes at a particular site it requires quantitative ways of describing strong ground motion. We need to quantify that in different parameters. So, what are the parameters which quantify this strong ground motion we are going to talk about today. Especially with this the ground motions which is produced by earthquakes they are mostly quite complicated. At a given point they can be completely described by what we say three component of translation and three components of rotation. In 3D space you have three components of translation like this and the rotation also. So, you have x, y, z normally the coordinates. So, in the x, y, z you may have displacements and then you may have rotations also. In practice the rotational components are usually neglected, and three orthogonal components of translation motions are most commonly measured. This is one of the example of strong ground motions which has been recorded at two sites which is located in Gilroy, California during the 1989 Loma Prieta earthquake.

So, during this earthquake Gilroy number 1 and 2 there are little difference in the site. First site is on the rock while the second site is on the soft soil. So, you see the acceleration time history then for the for the all the both the sites acceleration time histories are there actually and these representing three translation components of earthquake motion in terms of acceleration time history. So, in case of acceleration time history on x axis you have time which is varying in seconds and on y axis you have acceleration which is normally represented in terms of g that is an acceleration due to gravity. So, if you see it here that this is the acceleration due to gravity. So, it is represented in terms of g. So, 0.5 g where 1 g you already know is nothing but 9.81 meter per second square so, in terms of acceleration. Here what you have for both the sites three components of acceleration time history.

First one is east west component, north south component. So, east west component and north south component they can be said in general lateral or horizontal components while third one is vertical component. So, all three components together describe the completely the earthquake time history and this is for Gilroy number 1 as well as for the second sites also. So, now what you see in these records that the values are very much fluctuating. They are initially like you know starting from 0 and then they start reaching some peak value and after the peak again start decreasing at the end again it becomes almost 0 after certain time.

So, when it becomes 0 that is a like no kind of a duration of the earthquake which we will discuss in detail later. Continue with this strong ground motion measure, then what are the techniques for the measurement. So, the identification and evaluation of strong ground motion parameters, it will require some measurements for actual earthquake and the recording of strong ground motions provide some basic for earthquake engineering. And without that knowledge of the ground shaking, it is not possible to access a hazard rationally or develop a plot of methods for seismic design. So, we need to measure what is the strength of the ground motion, strong ground motion and then accordingly we design our structures or foundations for so that they can survive.

Similarly, they are measured relatively weak ground motions or measured by the seismographs and the records they produce are called seismograms. So, here there is one controversy, seismograph is not a graph rather seismograph is one instrument which measure the earthquake record rather the earthquake record is called seismogram. So, I think this should be clear that the seismograph is an instrument which measures. So, when you use for measurement for the relatively weak ground we use seismographs, but for strong ground motions normally they are measured what we called accelerographs because our objective is to measure acceleration time history which is called accelerograms. The simplest time of seismograph can be illustrated by what we call the single degree of freedom system which consists of a mass, a spring and damper.

So, let us what is this next here this is like this taken from the Cramer and as I mentioned earlier also the quite like this much of the things are from the Cramer's book here. So, here what you have this is simple ground motion measurement which is like single degree of freedom system. What you have in this system? You have a mass, and you have stiffness k and c. So, this is basically single degree of freedom system. What happens? This mass is situated on the roller this is you could see that there is a roller.

So, two rollers are there. So, what will happen? When earthquake wave comes in the lateral direction roller will mass will move like this. As a result, this attachment will move and there is a drum, and this drum is vertically moving. So, it is like this vertical drum is moving and on this moving drum you have this pen which will mark the wave. When it moves like this, it will because due to the vibration's earthquake vibrations will go like this and it will record while drum is moving.

So, this is the case. So, this is the normally the earlier one because when the digital was not there and usually the first kind of seismograph was like this. So, that has been invented and it has gone quite long time and successfully they are quite like as I mentioned earlier. The first engineering record of earthquake was during 1940 El Centro earthquake.

Continue with this. The relative movement of the mass and the ground will be indicated by the trace made by the staylus on the rotating drum. So, which is what we already discussed, and a typical seismograph have three seismograms oriented to record motions to the one vertical and two perpendicular horizontal directions. Most accelerograms currently in use are accelerometers and some transducers that produce in terms of output in terms of voltage which will be proportional to acceleration. That means there is a variation in the voltage and when acceleration increases so voltage will be high. Strong ground motion measurements are here.

So, it is you could see here on the left hand side it is seismological vault and, on another side, it is analog seismographs. Both of these photographs are taken from our seismology observatory located in the Department of Earthquake Engineering at IIT Roorkee. So, this is from our own lab, department's lab. So, there is a vault and at the bottom there is you know that based on the top of like kind of a rock instrumentations are done which is normally you call sensors and on right hand side zoom picture of one of the instrument analog seismogram is shown. Now, it is time to characterize the SGM.

SGM stand here for in the short strong ground motion. For engineering purpose, it is important that we characterize the earthquake motions and when we characterize earthquake motion, they are done normally using three parameters. What are the three parameters? First is amplitude of the motion which is indirectly measuring energy content, then you have frequency contents, how frequently like you know that with the time the motion like it is changing the peaks and troughs are changing that will be coming in frequency content and duration of the motion that means for how long the earthquake duration lasts. So, these three parameters together can help to characterize a strong ground motion and in the next slides we are going to characterize these we are going to discuss one by one each. So, normally for amplitude acceleration content parameters are used and for acceleration you have the amplitude which represent, and acceleration and it can be represented by amplitude can be represented by either acceleration, velocity, or displacement.

Similarly, acceleration times here there is one difference when you have acceleration time history then significant portion of that time history is normally in high frequency range while for displacement time history it is dominated by relatively low frequency motion. So, for high frequency acceleration time history will have large portion for that while for displacement time history low frequency contents. For example, this is one of the acceleration time history from Bhuj earthquake of 2001 and this is lateral component. What you can see on y axis there is an acceleration and on x axis you have time. So, this record lasted about 75 seconds, but you could see the signals are very weak up to 30 seconds.

Initial 30 seconds the peak values are very low, but after like around 32 seconds it all of a sudden jump and you get some peak values around 47 seconds here. Here when we talk about peak our meaning of the peak is absolute peak it does not matter whether it is positive side or negative side. Here in this case the maximum value is more than 0.1, but that is happening towards the negative side. So, the peak will be here not this side.

So, irrespective of whether it is positive or negative . Now we collect the peak values and then we further process. So, what is done for the amplitude the most commonly used measure of the amplitude is called for particular the peak horizontal acceleration PHA. So, it is saying the acceleration in the horizontal direction the maximum value of the acceleration in the horizontal direction will be treated as a PHA and the PHA for given component is simply the largest absolute value of horizontal acceleration. Here absolute means simple that it can be on the positive side or negative side.

Here one thing I will most of the time instead of PHA many times PGA is used, and you would have come across many times what is called PGA which is stand for simply peak ground acceleration. Peak ground acceleration and this is the term widely used PGA. Here instead of PGA we are using PHA because this is like more clarity when we write PHA it is very clear that this peak will be in the horizontal direction, but PGA could be either in the horizontal or vertical direction. However, if nothing is written with the PGA then it will be considered that it is in the horizontal direction because the peak value is in the horizontal direction is more important than in the vertical direction. So, we will discuss it again later.

In this slide you have three components of 2001 Bhuj earthquake which occurred on January 26 and the record taken was at the passport office building in Ahmedabad and this record is taken by Department of earthquake engineering at IIT Roorkee using our instruments and what you see on you have acceleration time history, on the top you have longitudinal components, then you have transverse components. So, first two components are both horizontal components and third one is vertical component. Normally vertical components values, peak values are less than the two horizontal components which you can see here in both the figures that the values that is the amplitude is less and out of these two longitudinal component or transverse component whichever is giving you the higher peak value we consider that for determining PGA or PHA. So, here you can see that the top one have little higher values which is here about as we discussed are going about 0.1 but here it is less than this. So, here maximum value is around 0.7 and if you go for the vertical the left it is around 0.05 only. So, this was about records obtained from the Bhuj earthquake. Continuing with that we further explore what is in the horizontal accelerations.

They have commonly been used to describe ground motions because of their natural relation to inertial forces. Because inertial forces will be governed by the horizontal acceleration. Basically, for inertial forces will be simply mass multiplied by the horizontal acceleration. So, that is why this is important and largest dynamic forces induced in certain types of structures that is very stiff structures are closely related to what we call the PHA peak horizontal acceleration. For vertical accelerations have received less attentions in earthquake engineering than the horizontal accelerations and the margin of safety against static vertical forces in constructed works provide adequate resistance to dynamic forces induced by vertical acceleration during the earthquakes.

So, basically what it says you know why this like for earthquake engineering already if the structures are designed for a static load without earthquake also, they are survived or like without earthquake like you know their design is done. But what happens during the earthquake there is a lateral component which during the earthquake it not only the vertical force, but horizontal force is also applied and the result most of the structures are designed only for vertical force because they are assuming there is no earthquake. So, as a result they can take the vertical force because they have may have enough strength but because earthquake also apply the force in the horizontal direction or the lateral direction and if your structure or building is not designed for that earthquake lateral force then it is going to be damaged or even it is going to be collapsed. So, this is like that is why like again when we consider the earthquake if we can consider all the three components both horizontal and one vertical component that is the best thing. However, for many analysis for engineering purpose only one component is considered and if you are going to consider only one component then it will be the horizontal component not the vertical component and out of the horizontal component which one, we should consider which give you the highest value of PHA.

So, the characteristics of a ground motion at a particular site depends on earthquake magnitude and on the distance between the source of the earthquake and the site. So, how much is the magnitude and how far is the site from the source that is from the epicenter basically. So, as a result ground motion parameters also vary with earthquake magnitude and source to site distance. So, that will be governing parameters if earthquake magnitude will change. So, this ground motion parameter will be expected to be higher.

For engineering purpose, the peak vertical acceleration is often assumed to be two-third on the of the PHA. So, if we have a single record let us say I have a record of only peak horizontal acceleration with the time, time history and I do not have like you know the vertical and I simply I need to design for the structure for the horizontal load as well as vertical load. In that case, our code IS 1893 is also suggest the same thing. So, this is also suggested by Indian standard code IS 1893 which is the latest version is 2016.

You can see the part 1. So, the same recommendation that vertical acceleration can be considered as two-third of horizontal one. So, ground motions with high peak accelerations are usually, but not always more destructive than motions with lower peak accelerations. So, naturally if a peak acceleration value is higher then it is normally more destructive though it may not be the always because it depends on other things like frequency contents and others which we are going to discuss later, but most of the time this is the case. However, the very high peak acceleration last only for a few seconds only a very short period of time and if time for which this is only for a very short then it may cause little damage to many types of structures. So, it is also depends this peak value is sustaining for how long? It is for the like a fraction of seconds or few seconds that is there.

Although the peak acceleration PHA or PGA is very useful parameter. However, it do not provide any information the frequency content or duration of the motion which the latter two comp part that is frequency content and duration is also important when we design the structures. A number of earthquakes have produced peak acceleration in excess of 0.5 g. It has been observed in the past that the PGA value is going to 0.5 g, but still there was no significant damage was done to the structures and why? Because the value this peak acceleration occurred at very high frequencies and the duration of earthquake was not long. Very high frequencies means in few seconds in if some time it runs very fast. So, it move you know the peak acceleration was there, but then it have come momentarily very like you know fraction of seconds and then it have moved. So, in that case not much damage was considered. Here this graph is gives you kind of a relation between acceleration which is on y axis in terms of centimeter per second square and on x axis this intensity earthquake intensity and which is on MMI scale modified Mercalli intensity scale which we have discussed in the last.

So, there is a relations. So, in general you see that the line is going from down to up that means when in general relationship looks linear that means when you increase acceleration value on y axis then intensity is going to increase or the other way on x axis when intensity increases that will require the higher value of acceleration. So, the linear is kind relationship is kind of linear. However, different researchers have given different lines, but ultimately, they fall in a narrow band and you could see in general we can say that when this like acceleration exceed 100 centimeter per second square which is roughly 0.1 g then intensities you get is around eighth. So, here you have second, fourth, sixth, eighth, ninth and then in between you have.

So, one thing you notice in the graph you have linear scale on the x axis while y axis you have the logarithmic scale. So, while using this chart. So, using this chart we can roughly get an idea that for given value of let us say acceleration how much is the intensity. So, if I draw and then here around sixth and seventh, eighth so you can have this one. So, and intensity is as usually represented in terms of Roman numbers.

So, there should not be a fraction. So, if you get the less intensity suppose I get some value between six and seven then I will go on the higher side rather than average or like you know that this in Roman number this should be whole number for intensity. It cannot be 6.5 or 6.8. Now, coming to the next parameter for a characterization of amplitude is velocity.

We have discussed lot about acceleration. When we talk about velocity, velocity is for the intermediate frequencies, acceleration is for high frequency, displacement is low frequency, but velocity works at intermediate frequency and velocity are characterized by the parameter which we call p h v and p h v is here nothing but peak horizontal velocity. So, earlier we have p h a which was peak horizontal acceleration, here we have peak horizontal velocity. And this is another useful parameter for characterization of ground motion amplitude. Since the velocity is less sensitive to the highest frequency component of the ground motion, the p h v is more accurate than the p h a to characterize ground motion amplitude at intermediate frequencies and this is for intermediate frequency. Velocity for structures or facilities there are sensitive to loading in this intermediate frequencies.

For example, if you have tall or flexible buildings, bridges, then p h a may provide a much more accurate indication of the damage than the p h a. So, p h v that is peak horizontal velocity will give you better result than the peak horizontal acceleration. And the reason being because it work in the intermediate frequency range rather than the high frequency range. This work in the high frequency range, p h a for the high frequency as we discussed. While this p h v this will work intermediate frequency intermediate.

Third component to describe the amplitude is displacement. And we already discussed that displacement work in the lower frequency and peak displacement are generally associated with the lower frequency components of an earthquake motion. And since because it is difficult to determine accurately due to signal processing errors which is because being in the low frequency side then filtering and integration of a ground. So, as a result peak displacements is less commonly used as a measure of round motion than a peak acceleration or peak velocity. So, peak this peak round displacement is not much use. In the short sometime peak round displacement is also called PGD peak ground displacement.

But as mentioned due to the reason peak ground displacement PGD but they are this is less use compared to p h a or p h v. Then we have what we call sustained maximum acceleration. So, that is another parameter for the measurement of the amplitude and this parameter is like given by one of the researchers who used lower peaks of the exclogon to characterize strong ground motion by defining the sustained maximum acceleration for 3 or 5 cycles as a third or fifth largest value of acceleration the time history. So, here what you have you have a time history and in this time history you have largest you select the largest value and out of these largest value up to 3 to 5 cycles will be used to define this sustained acceleration. Then let us have some again some example here you have this acceleration velocity and displacement content parameters, and they are from 1940 NS component of El Centro earthquake.

So, 1940 of the year NS component and El Centro ground motion and El Centro ground motion again El Centro earthquake was in California USA. So, this is from El Centro, it is in California. What you have you have acceleration time history which is saying you the maximum peak is 0.348 which you can verify it is here this is the peak value here. Then you have another what you have here velocity time history. So, maximum value is 38.1 centimeter per second. So, which is again at this peak value and however if you see that when you go from acceleration to velocity time history then frequency contents are like they are very close in acceleration time history. But in velocity time history that is that is scattered, but when you go to displacement time history it got fit. So, there is no like peak or troughs rather than it is continuously increasing and this is the like you know you get ultimately this displacement are continuously increasing when the shaking completes then you get the maximum displacement at the end which is around 189 centimeter.

So, similarly this is for Gilroy earthquake, Gilroy for this El Centro that is Loma Prieta earthquake as we discussed Gilroy these are the restriction name each phase component and Gilroy number 1 and 2, one is for rock another is for the one number 1 is for rock another number 2 is for the soft soil. So, what do you see here acceleration time history, velocity time history and displacement time history and what interesting point is there you get in acceleration time history peak value higher than the site 2, but in displacement velocity time history it is other way. Velocity time history the peak value is more for Gilroy number 2 which is due to the effect of local soil conditions and again displacement is higher compared to what you have or the site 1. So, this was all about strong round motion. Thank you very much for your kind attention. Thank you.