Earthquake Geotechnical Engineering

Prof. B. K. Maheshwari

Department of Earthquake Engineering

Indian Institute of Technology Roorkee

Lecture 27

Local Site Effects

I welcome you again for this NPTEL course on earthquake geotechnical engineering. Today we are going to talk on ground response analysis and local site effects which is the third module, and we are going to continue on this. So, what we are going to talk is on the local site effects that is the basically third chapter. So, under the third module which is on ground response analysis and local site effects these are the topics. We have already covered the two chapters and the third chapter local site effects will be covered into four lectures.

Today we are going to talk first introduction what are the local site effects, then what are the evidence from theoretical ground response analysis from the past earthquake and then what are the signature from the measured amplifying functions or the evidence from major surface motions. So, you will see that practically it has been observed that there is effect of local sites conditions on the response of the systems. So, we are going to talk about that here. Before I go ahead let me acknowledge that the source of most of the information given in this lecture and this is just to educate the masses.

As for the introduction is concerned the influence of local geologic and soil conditions on the intensity of ground shaking and earthquake damage has been known for many years. For you know that it was known that if geological or soil conditions are different then this is going to make a difference on the intensity of ground shaking. As a result, the local site effects play an important role in earthquake resistant design and must be accounted for on a case by case basis. Normally the local site effects is it is accomplished by the development of one or more of design ground motions. The design ground motion which is used for the design of the foundation and structures the motion that reflects the level of strong motion amplitude, frequency content and duration that structure or facility at a particular site should be designed.

Actually, if you recall that when we talk about strong ground motion then there was three issues which we have like you know discussed in detail for strong ground motion. Three characteristics amplitude, frequency content and duration of the earthquake is important. The development of site specific design ground motions involves concepts of dynamic soil properties and ground response analysis. So, as for ground response analysis and dynamic soil properties are concerned, we have already discussed and that now we will apply whatever we have discussed for dynamic soil properties and ground response analysis in this local site effects. The local site conditions can influence all the important characteristics and what are the characteristics as we already discussed it is amplitude, frequency content and duration of strong ground motion.

The extent of the influence of these characteristics depends on the geometry and material properties of the surface materials, on site topography, on the characteristics of the input motion. So, this is like three factors normally the first factor is what is your geometry and material properties, the second is how the topography of the site is there and then finally, third it will depends also on the the the characteristics of the input motion. But as for the characteristics of the input motion are concerned, we have already discussed three important characteristics that is amplitude, frequency content, duration. So, the first one we will go one by one that what is the effect of the subsurface material and then topography. So, this way we will cover in this local site effects.

Now, the nature of local site effects can be illustrated in several ways, and we are in this lecture we are going to cover in three ways. First one is by simple theoretical ground response analysis and as for ground response analysis is concerned, we already discussing this in much detail particularly 1D ground response analysis and 2D ground response analysis. The second way approach could be the measurement of actual surface and subsurface motions at the same site that you do some instrumentation and then you measure it. Third one is by measurement of ground surface motion from the sites with the different subsurface conditions which may be similar, you may not have instrumented the same site, but if we find like ground surface motion from the similar conditions then we can get some result from there. Now, the first one that is the evidence from theoretical GRA that is ground response analysis.

There are important theoretical reasons why ground surface motion should be influenced by local site conditions. At most sites the density and shear velocity of materials near the surface are smaller than greater depths. If the effects of scattering and material damping is neglected, then the conservation of elastic wave energy requires that the flow of energy flux. What is energy flux? Energy flux is given by rho v s into u dot square where rho is the mass density of the soil, v s is the shear velocity and u is particle motion. Here like what happens it will be varying from depth to the ground surface because this need to be this product need to be constant from when you go from depth to the ground surface, but what happens? Because rho and shear velocity they are not constant rather rho and mass shear velocity normally when you approach to the ground surface then they decreases from bottom to top if you go from top to down then they increases. So, as a result because rho and v s when you go along the depth, they increases so the particle this velocity will change.

So, as a result ultimately what it says that there will be effect because this energy flux will require to be constant and there is a change in the properties. So, when you go from ground surface to the bottom like then you will be decrease or other way if you approach to the ground surface then you must increase. So, basically the in the local site effect when you go from bottom to top top wards then there will be what we say most of the time amplification. So, when the earthquake waves start from bedrock and reaches to the ground surface, you get the effect of amplification. So, this explains why this like amplification occurs particularly from ground response analysis.

Continuing with this the characteristics of local site deposits can also influence the extent to which ground motion amplification will occur when specific impedance is constant. The basis for such amplification can be illustrated analytically also. Let us consider one example where we are going to consider two soil deposits which are shown in the figure and thus the deposits basically here you have two cases A and B. In the both the cases they are identical thickness of the soil layer is same, damping is also 10 percent and unit weight of both the sites is same, only the one parameter that is the shear velocity is different. In the first case it is 400 feet per second, in the second case it is 1600 feet per second.

Now, if you find what we say the natural frequency of the system the natural frequency of the system is given by the relation omega n equal to k by m and this if I convert to f n particularly for this side then you find out v s by 4 h that is the natural frequency. So, using this relation for this layer if I find the natural frequency for the first case it will come 400 divided by 4 into 40. So, you get 10 divided by 4 that is 2.5 hertz. In the second case you get f n f naught.

So, this will be the f naught. In the second case because it is 1600 divided by 4 into 40. So, you left out with the here 10 hertz. So, as a result the natural frequency in the second case is 10 hertz while in the first case is 2.5 hertz. So, you will see the effect what is the effect of this change in the natural frequency of the soil layer on the response. So, this is the case here when this is subjected to some motion there is a amplification factor for site A is like here because the amplification factor if you recall when we discuss at the peak value of amplification factor depends only on damping ratio. So, here the peak value amplification factor f 2 omega when the at the peak value will be simply 1 into pi by 2. So, the amplification factor in this case 2 divided by 10 percent damping into pi. So, this you get 20 over pi. So, this comes out to be around 6.37. So, this value is 6.37 and the peak value here also 6.37.

In both sides amplification factor is same site A as well as site B. But what is the difference for the site A the peak is coming around 2.5 hertz while for the site B peak is coming at 10 hertz. So, suppose in the first case which is a soft soil because 10 hertz frequency is not of our interest particularly for the structures for civil engineers. If I compare it at 2.5 hertz, then the amplification is very large for site A compared to site B. But for 10 hertz because this is some frequency range which we may not be interested particularly for the design of structures. So, naturally though site B at site B it is opposite site B at 10 hertz or like site B is the peak value while the site A have the lower value. But the frequency of interest for us is site A and the site A is for 2.5 hertz. So, that is the basically effect of the local site effect. Even the same wave is coming properties are because it may be different damping is same thickness is same geometry may be same. But even one parameter with the shear velocity it may not be able to change your peak value because the peak value is simply depending on damping ratio. However, where the peak will occur that will be decided by the shear velocity. If each soil is assumed to be linearly elastic so, the clearly the softer site that is site A will amplify low frequency bed rock motion and this low frequency bed rock motion is the motion of our interest and it need to be however, if you go for site B it is opposite way.

Now, continue with this since earthquake produce bed rock motions over a range of frequencies. So, what will happen some components of actual bed rock motion will be amplified more than the others depending on which range because the amplifying factor depends on the frequency because in the ground response analysis you have seen when there is a change in the frequency then amplifying factor will change. So, and a earthquake wave consist of a number of frequencies. So, some component may be amplified some component may be deamplified. For the more realistic conditions of elastic bed rock the nature of the local site amplification will be influenced by the specific impedance of the bad rock.

Consequently, any description of local site conditions should include the density and the stiffness of the bed rock. For example, the harder crystalline bed rock which is found in much of the eastern United States would be expected to produce amplification factor which is about 50 percent higher than those associated with the softer rock condition. But again, I cautious when we make this statement then you need to see at what frequency you are working. It will depends on your frequency of interest. So, at some frequency softer site may be giving peak value at another frequency the harder soil may give the peak value.

The idealized assumptions of simple one dimensional ground response analysis which we have carried out and one of the example you know the assumption which we have discussed at that time if you recall that the soil layer for 1D case, 1D ground response analysis it is assumed that the properties are constant along the horizontal direction there is no variation in the horizontal direction. The property may change along in the vertical direction but not in the horizontal direction that is then we consider homogeneous isotropic and elastic condition for the 1D ground response analysis. So, simple one dimensional ground response analysis where you consider uniform material, horizontal layering, vertical propogaatig shear waves produce smooth amplification functions. So, you get a smooth amplification functions. However, since these conditions are rarely exist in the actual field so actual amplification functions are not so smooth which you get from 1D ground response analysis.

Still the interpretation of strong ground motion data from sites where both surface and subsurface instruments had been installed allows actual amplification functions to be computed. The strong amplification which is at the natural frequency of the soil deposit which is shown in the next slide clearly illustrates what is the importance of local soil conditions on ground response. So, what you have is the site where some there are evidence from measured amplifying functions and this site is basically Richmond field station which is you may be knowing that some of it is at area for near University of California at Berkeley. So, the Richmond stations, field stations some of the like the so in the first figure the shear wave velocity with the depth is shown. Shear velocity as well as P wave velocity.

You have like the wave velocity in meter per second. So, P wave velocity is like maximum values going more than 2000 meter per second while shear wave velocity is around 900 to 1000 meter per second. And you see if I talk only about shear velocity, so up to a depth of 35 meter the shear wave velocity is about 150 meter per second. But at higher depth it is jump at a very large value. The same thing happen on P wave velocity.

In fact, there is a relation between P wave velocity and shear velocity both are linked through the Poisson's ratio, and you may be like you know that relation that v p by v s that relation that depends on the square root of 2, 1 minus nu and then 1 minus twice nu. So, this is the relation where nu is nothing but Poisson's ratio. So, this is we already discussed when we talk about the when we discuss the wave propagation. So, this relationship. So, when the Poisson's ratio is 0 then this will give to this when the Poisson's ratio is 0 then this will be give you v p by v s will be simply square root 2.

But when Poisson's ratio is 0.5 then this equation will give the infinity. So, these things we already discussed. So, there is a relation between shear velocity and P wave velocity. So, if you know the shear velocity you can calculate the P wave velocity provided you know the Poisson's ratio. Now, what is has been done? So, in the first figure the v p and v s is shown.

In the second figure location of accelerometers where the accelerometer is installed is given. So, it is at soil profile at 3 locations it is along the depth up to 40 meter depth and you have what type of soil you have in the top silty clay sand and then clay and then at the bottom shale and other things. The last figure part of this figure that is spectral ratio versus frequency. So, you see that initially at such some lower frequency there are peak values are coming and 2 major peaks are here then they start decreasing and finally, it diminish. This is the evidence from measured amplifying functions which is like done at the University of California. Continue with the measured amplifying functions for the evidence. The site which consists of various soils of relatively uniform shear wave velocity, overlying bedrock, consequently the frequency dependence of the actual amplifying functions is qualitatively similar to that predicted by simple ground response analysis. As we just discussed that simple ground response analysis have its own limitation because it is based on the certain assumptions. But still if your site is relatively uniform shear velocity not very large variation which we have seen here in this case also in the site shear velocity is not much varying up to a depth of 35 meter like you know up to this depth after this there is a large variation.

So, up to this depth this can be said this is relatively uniform. And as a result, overlying bedrock the frequency dependence of the actual amplifying functions is qualitatively similar to that predicted by simple ground response analysis. So, in general we can say that simple ground response analysis are able to predict that able to predict these cases. Continue with this. For sites with more complicated subsurface conditions or for stronger earthquakes ability of simple ground response analysis to predict the irregular peaks and values of actual amplifying function decreases.

So, if you have complicated site where subsurface conditions cannot be characterized as a uniform in that case particular for the stronger earthquakes the simple ground analysis may not be able to predict the peaks and valleys which troughs comes during actual amplitude functions. The effects of soil non linearity also cause amplitude functions from a strong motion to differ from those of weak motions because what happens? We like when we talk about dynamic soil properties when one of the topic, we have discussed is related to the soil non linearity how to deal with the soil non linearity. We talk about equivalent linear model then we talk about cyclic non-linear model then we also discuss about advanced constitutive models. So, and you know that the effect of non-linearity is large at a strong ground motion if your weak motion there is no issue. But if you have a strong motion then there will be a there will be effect its effect on the amplification.

So, the evidence of the importance of local site conditions so this was about amplifying functions. Now we deal with evidence from major surface motions. So, evidence of the importance of local site conditions from the particularly the major surface motions. There is a motion which is measured of the surface on the ground surface and some of the data which is collected from the past earthquake that also help in this evidence. And that can be done by comparing ground surface motions measured at different sites.

Suppose you have different sites, and the data has been collected from different sites then when you compare the data then you can guess what we sometimes say back analysis. So, using back analysis we try to get the what is the soil properties and then we can say if you have the same earthquake. In the same earthquake you have recorded the motion at two different places and the characteristics of these motions will be different.

Basically, the difference is coming due to the effect of local site effects. So, that way also we can call that these are also evidence or signature of local site effect.

One of the example is recording of round motion at several locations in San Francisco which was made during in a magnitude 5.3 earthquake in 1957. But there are after that there are other examples also where it is clearly observed that there is effect of local site. Continue with the on the major surface motions. Ground surface motions at the rock outcrops were quite similar, but the amplitude and frequency content of the motion at site which is underlined by thick soil deposits were markedly different.

So, you may have some sites where on these sites below this soil layer below the surface layer you can have thick deposits, and this is thick soil deposits could be there. In that case, the similar effects have been observed in many other earthquakes from the eastern point of what we call the local site effects and two of the most significant earthquakes though it is not very recent now. One earthquake was of 1985 or what we call Michoacán Mexico earthquake and the second 1989 Loma Pita that is in California earthquakes. So, these two earthquakes of one is 1985 another is 1989 one could easily observe what are the effects of local site effects. In fact, the 1985 Michoacán Mexican earthquake we will discuss in detail in the next lecture and then that is what is the signature of local site effects.

So, continue with the evidence from major surface motions. There are well documented earthquake produced strong motions records at the sites which are underlined by variety of different subsurface conditions in Mexico City and San Francisco area. Particularly a brief we are going to discuss the case histories from the Mexico site during the 1985 Michoacán earthquake and when we talk about this case history in the next lecture you will see that the damage pattern which has been observed during this earthquake is corrugated with the like you know that the effect of local site conditions. Interestingly this is an earthquake where damage was not so much near the epicenter, but it was quite away from the epicenter about 350 kilometer away from the epicenter. This is very interesting that damage is not much near where earthquake occurred, but it is more at the like you know far away and that is basically nothing but local site effects.

Then not only that even at the far distance some of the buildings get damaged some of the buildings get damaged during this earthquake and we will explain all these using the local site effects in the next lecture. Thank you very much for your kind attention. Thank you.