Earthquake Geotechnical Engineering

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Lecture 28

Local Site Effects (Continue)

I welcome you again for this NPTEL online course on earthquake geotechnical engineering. And we are in the module third which is on ground response analysis in local site effects. In this module as we discussed earlier there are three chapters and we are under third chapter which is on local site effects. And we already covered one lecture on the local site effect. This is the second lecture on the local site effects. And what we are going to talk in this lectures are listed here.

We are going to see first in detail what are the evidence of local site effect from Mexico City earthquake of 1985 that is as we discussed in the last lecture Michoacán earthquake. And so this we are going to talk in this lecture in very much detail. The second we are going to talk about compilation of data on local site effects. There are some data particularly from Mexico, so that is the case history is good.

Mexico 1985 earthquake is a very good case history on the local site effects. Then we are going to talk about what are the effects of surface topography, what are the effect of geometry basins, effects of topographic and subsurface irregularities also going to be covered. So, let me acknowledge that particularly like Mexico case history and other like that figures they have been taken from the Kramer's book and I am going to explain each and everything which will be missing if you directly read from the book. So, as for the evidence from Mexico City earthquake of 1985, you know the September 1985 Michoacán earthquake which is on the surface magnitude 8.1.

8.1 magnitude earthquake is not a small earthquake cause only moderate damage in the vicinity of its epicenter near the Pacific coast of Mexico but cause extensive damage 350 kilometer away in Mexico City as we discussed this thing in last lecture also. It is very interesting that during this earthquake in the vicinity of the epicenter there was only moderate damage not much damage, but if you go away 350 kilometer away from the epicenter in the Mexico City and the because epicenter was away from Mexico City. So, the epicenter was 350 kilometers away from the Mexico City and lot of damage has been caused in the Mexico City, but not much to the near the epicenter. So, this is very interesting, and 350 kilometer distance is not a small distance.

Studies of ground motion which are recorded at different sites in Mexico City which we are going to discuss in detail, illustrated the significant relationship between local soil conditions and damaging ground motions and which lead to important advances in understanding the cyclic response of plastic clays. So, here are continue with this evidence. For seismic zonation purposes, Mexico City is divided into three zones with the different subsurface conditions, and which is like here. Let us discuss this figure first before we discuss the slide. So, these three zones you could see in this slide like if I see you have south west side what we call the foothill zone.

So, the first zone is foothill zone. This is the first zone. Then the second you have the on another side you have lake zone, lake deposits and between foothill zone and lake deposit you have the second zone which is called transition zone. Third one is the lake deposits which is divided into two part. One is older lake deposits, and another is virgin lake deposits.

So, that is like season. foothill zone is in this side also, small is on the top of the on the north side of the lake deposits also. So, this means it can be divided into three zones. So, first is shallow compact deposits of mostly granular soil which is basalt or volcanic stuff which are found in the foothill zone. The first zone is foothill zone which is located west of downtown.

So, the first zone as we discussed is the foothill zone. So, third one is the lake zone which is a thick deposits which consists of very soft soils which are foamed by the polarization of airborne silt clay and ash from nearby volcanoes. So, it is consists of the ash of the volcanoes also which have come through the waters of an ancient lake there is a lake called Toxco which is extended to considerable depth. Between these two zones foothill zone and lake zone you have third zone, which is we are calling a transition zone.

Now, in the second part of the figure you can see the contours of soft soil thickness and these contours are showing the depth to bottom of soft clay which is in meters. So, you have 20 meter, 30 meter, 40 meter, 50 meter like this and so all these and you have seismological observatory which collect the data which we are going to discuss in the next slide UNAM and SCT sites. So, you have the soft soil generally which is the soft soil conditions are in the lake zone. So, in the lake zone you have the soft that is the third zone in the third zone which is the lake zone you have the soft soil which generally consists of two soft clay which is called basically Mexico City clay. So, you have soft clay two soft clay layers which is separated by 0 to 6 meter.

So, you have two layer and the depth difference between the two layers is 6 meter and thick compact sandy layer called the capa durad which is in Mexican name.

Groundwater is generally found at a depth of about 2 meter over most of the lake zone. So, you have the lake zone and the groundwater is on about 2 meter. Between the foothill and the lake zones lies the transition zone which we already discussed where the soft soil deposits are thin, and they are intersected erratically with alluvial deposits. Continue with the evidence from this Mexico City.

Prior to 1985 that is before the earthquake a number of strong motion instruments has been deployed in Mexico City. So, that was the good so that one could collect the data lot of data during the earthquake which are shown in the figure and two locations we already discussed, and this is for a strong motion instruments. UNAM, UNAM stand for Unistar Necrodional Autonomous De Mexico. So, this is the one where the strong motion instrument has been done. Another site is the secretary of communication and transportation which is called in SCT.

So, in the later discussion we will refer this site as UNAM and SCT sites. The UNAM sites was located in the foothills zone on 3 to 5 meter of basaltic rock which is underlined by softer strata of unknown thickness. While the SCT site is located on the soft soils of the lake zone.

So, here you have two sites one is UNAM which is shown here, another is SCT. Under these two sites UNAM and SCT sites you have a strong motion instrumentation, but the soil conditions at UNAM and SCT are very different. UNAM it is mostly a rocky site while SCT site is mostly on the soft soil sites. So, you will see what is the effect of these local site conditions which has direct evidence from the instrumentation and the damage pattern also. So, as a result this Mexico City earthquake of 1985 is a good example for studying the local site effects.

So, here is the response. We already said that there are two like a seismic instrumentation which is as you can say seismological observatory. One is at UNAM site another is SCT site. So, this is the response which is coming rather than record which is recorded at these instrumentation at different site. So, you will see at UNAM site the peak it is not a PGA, very small peak is coming.

But if I see this is SCT site for SCT site you are getting the peak values here which is certainly more than this scale is 200 centimeter per second square. So, it is more than that it will be around so around roughly point more than 0.2 g or like this. So, the time stage of acceleration recorded by strong motion instrument at UNAM and SCT sites and these records are very much different. They are not the same, they are saying the characteristics of local site effects.

Continuing with this although the Michoacán earthquake was quite large. So, because its magnitude was 8.1 so naturally it was not a small earthquake. However, its great distance from Mexico City produced at the UNAM rock site of only 0.03 g to 0.04 g. So, what is there? At the UNAM site the PGA which is recorded is very less which is 0.03 to 0.04. 0.03 or 0.04 so very small and this PGA is not much for a design purpose. So, this was the case at UNAM site. But in the transition zone which is between your foothill zone and then the lake zone in the transition zone peak accelerations which are recorded the SCT sites were slightly greater than those at UNAM site. So, in the foothill zone it was increased the PGA value have increased PGA acceleration, but still it was quite low.

They were greater than 0.03 to 0.04 g, but it is smaller. But the third case in the lake zone however peak acceleration where the two sites were about 5 times greater than those recorded at UNAM site. So, if I multiply by this 5 this one so you will get about roughly 0.2 g the last value 0.04 multiplied by 5. So, the peak value acceleration which has recorded a SCT site was 5 times than what has been recorded at UNAM site. So, this is the basically the effect of local site effect and we are going to see again for this. So, this was the effect on what we say the effect of local soil conditions on the peak values or amplitude peak acceleration. Now you know that when we talk about characteristic then frequency content is also important.

The frequency content of the SCT and CDA motions were also much different than that of the UNAM motions. The predominant period was about 2 seconds at SCT and slightly longer at CDA. So, you have the predominant period. So, like this is like at SCT site it was about 2 seconds while at UNAM site it was different which we are going to discuss. Strong level of shaking persisted over a very long duration at the SCT and CDA sites.

So, you see here this is the result which is evidence from a Mexico City earthquake and how we like you know investigate this. Here in this case you have spectral acceleration right which is in terms of g on y axis and you have period which is in seconds. In the last lecture we have discussed the soil conditions, site conditions will not only change your natural frequency they will change the peak value as well. So, first of all at the UNAM site your peak value is coming less than 1 second the peak is here. So, if I see approximately the peak is here, but if I go for SCT site your period like peak value have increased to this value and why let us in which why the peak have shifted.

So, it was a roughly less than 1 second however it gone more than 2 second here. So, around 2 second why it is near 2 second because it is called what called the period lengthening effect period period lengthening effect. SCT site period is lengthened it is extended and we discuss that when you consider the soft soil condition then your system will become flexible. If your system become flexible, then your natural frequency is going to decrease because stiffness is going to decrease and as a result omega n or natural frequency will be less. Once your natural frequency decrease f n will decrease your time period which is opposite of f n will also decrease will increase.

So, as a result SCT site the period where you are getting the peak values higher than what is at UNAM site that is one effect. The second effect you see that if you compare the value of spectral acceleration which is almost 0.1 at this here 0.1 g at UNAM site, but SCT site it is about 0.8 g. So, it becomes more than about 8 times the peak value have increased about 8 times. So, this has been like first of all predominant period was about 2 second at SCT site while at UNAM site the period was even less than 1 second. So, period have shifted. So, what will happen? What is the if I see from the building site or other site this is the spectral acceleration which is observed at the surface, but what will happen you know if you have tall buildings or you have long like bridges and other things, they are long period structure. The damage will occur maximum for the case where your period is about nearby 2 second.

So, we will see these effects in the next slides. So, the response spectra shown in the last figure we already discussed this at periods of approximately 2 second spectral acceleration at the SCT site were about 10 times or at least you can say it is if it not 10 times it is at least 8 times greater than those at the UNAM site. The SCT site was underlain by 35 to 40 meter of soft clay with an average S wave velocity of about 75 meter per second. So, the average shear velocity was about 75 meter per second at the SCT site and the thickness was about 35 to 40 meter. So, if I assume the average thickness as will be about let us say average value is 37.5 meter then I can calculate the first natural frequency f naught which is for the soil layer is simply vs by 4 h and this relation we have discussed many times. So, what you have shear velocity is given 75 meter per second and thickness is 37.5. So, as a result you get this frequency 75.

So, 1 by 2. So, this will be 0.5 hz. So, time period corresponding time period will be opposite of 1 over f naught.

So, you get 1 divided by 0.5. So, this will be a 2 second. So, you get 2 second time period corresponding time period. So, that is shown in the next slide. So, correct side period was like 2 second or directly you can find 4 h over vs directly without finding the natural frequency you can find the correct side period as 2 second. And this 2 second side period is well consistent with the peak which has been recorded this is we are getting theoretically.

Theoretically we are saying that peak should come at 2 second, but what has been observed that the SCT side the instrument records is saying yes it was a 2 seconds only the SCT response. So, structural damage which has been seen in Mexico City was very highly selective. Large parts of the city experienced no damage while other areas suffered pronounced damage. So, this is very interesting like you know the Mexico City as we discussed. It was 350 kilometer away from the epicenter, but so there was damage, but the damage was in the selective area.

So, earthquake now the issue is this one how we will explain this phenomena that earthquake damaged some buildings it does not damage some buildings what the reason for that is. So, that we are going to explain in this and this is very interesting. So, what has been said the structural damage in Mexico City was highly selective and damage was negligible in the foothill zone and minimal in the transition zone. So, in the foothill zone and the transition zone there was hardly any damage, but damage was mostly in the lake zone that is the third zone in the Mexico City. So, it is here the greatest damage occurred in those portions of the lake zone which is lake zone is underlined by 38 to 50 meter of soft soil.

So, in the lake zone you have the soft soil, and the thickness of the soft soil is about 30 to 50 meter where the characteristic size periods were estimated at 1.29 to 2.8 second. So, you have this one like you know the above 2 seconds like. So, the characteristic size periods was in this range that 1.9 to 2.8 second and if you see this range is like 2 second which we have seen was the peak value recorded lies in this range. Even within this area which area lake zone area. So, we have three zones foothill zone and then transition lake zone we are talking about lake zone. In this area also damage to buildings of less than 5 stories and the buildings which is greater than 30 stories was slight. So, it is interesting in that area those buildings which is less than 5 stories does not get damage those more than 35 stories also does not get damage.

But most of the building which got damaged during this earthquake was 5 to 20 story in the range. So, the 5 to 20 story. So, if the building height is stories are more than 5 or less than 20 story then they got maximum damage and why it is what is the reason for this. So, if we go from the crude world of thumb the fundamental period of a multi-story building can be approximated by the relation n by 10.

What is n? n is simply number of stories. So, if you have 20 story building then n by 10 you will get 2 second. If you have 5 story building then n by 10 will be you get 0.5 second. But it is extended and we will see that why this period have lengthen for the small buildings. So, most of the damaged buildings and fundamental period equal to or somewhat less than the characteristic site period.

Characteristic site period was 2 second which we have already seen. And there is a term which we have discussed called period lengthening effect of soil structure interaction. For SSI there is one effect called period lengthening effect and this is the effect of SSI. And the effect of SSI on period lengthening is simply you can understand that due to the soil extraction the time period or fundamental period get extended. And why it get extended? Because when you consider soil extraction, which is important for strong ground motion the effect of non-linearity come in picture and the effect of non-linearity will increase the period.

How it increase? The tendency for the fundamental period of structure to increase during a strong earthquake that is called nothing but period lengthening characteristic. And this occurs due to the reduction in stiffness which is caused by the structural damage, or it could be the effect of what we call the nonlinearity. It seems likely that the damage which structures were subjected to many cycles of large dynamic forces at periods near the fundamental period. So, see if fundamental period or the period of the building are matching then in the one cycle there will collapse. So, the period were 2 second, they will immediately got damaged and collapse.

But the period of the buildings which is less than 2 seconds that is about 0.5 seconds they also get damaged may not be in the first cycle but during the repeated cycles and as a result of what we call the effect period lengthening. Then there is another issue which we call double resonance condition and what is this double resonance condition which has been observed. So, amplification due to 2 regions, double region. First region which is simply you can understand using the what we call the ground response analysis.

Amplification of bed rock motion by the soil deposit that is the first region and the amplification of the bed rock motion by the soil deposit can be called as a GRA in ground response analysis. You can estimate that the second amplification is amplification of the soil motion by the structure, and this will be part of what we call SSI, Soil-Structure Interaction. So, both the components are like part of soil- Structure interaction. The first GRA is the first step and the other is SSI which will consist of what we just discussed in the last lecture, kinematic interaction and plus inertial interaction, kinematic interaction plus inertial interaction.

So, this is combined with the structural design and construction efficiency it cause damaged, devastating damage during this. Now, this was about evidence from Mexico City earthquake. We continue with this. What has been seen, there are evidence from compilation of data on local site effects and how we can compile the data on the local site effects. So, it is like comparison of peak acceleration attenuation relationships for sites which are underlain by different types of soil profiles show distinct amplifying behavior and it has been study by Seed et al in 1976 that if you have different sites or you have this on the top it may look same, but at the site at the below if it is underlain by different types of profiles then their behavior or characteristics is very different.

Although attenuation data are scattered overall trend suggests that the peak acceleration of the surface of the soil deposits are slightly greater than on the rock. So, you have some site on the rock and some site on the soft soil. When peak acceleration are small and somewhat smaller at higher acceleration levels. So, this is compilation of data on local site effects. So, what you have here? In this slide you have maximum acceleration on rock and maximum acceleration on the other sites.

So, when you examine this figure, you understand that on the x axis it is maximum acceleration on the rock only. On y axis it could be on the rock or it could be on the soft soil. So, if I do rock versus rock then this is dotted line, and this dotted line will have a 45 degree angle.

That means it will be the same value. For example, for 0.3 you will get 0.3, 0.6. So, that is the case here. So, the dotted line is just a line inclined at a 45 degree angle which is for the rocks. It is not giving any information. But if I see for deep cohesion less soils or steep soils let us talk about deep cohesion less soils. If maximum acceleration on the rock site is 0.5 then or 0.6 then it decreases. It decreases at higher value of maximum acceleration. But if I go at the maximum acceleration rock less than this value here there is fulcrum. So, this is going like this, this line. So, here it is opposite way. That means you get more acceleration on rock, more acceleration on the soft soil site but less on the rock.

But if you go away from away then it is there. But for our case the interest of point is most of the time this one, this range. In this range what happens? You get maximum acceleration more for deep cohesion less soils and more for steep soils compared to rocky sites. But if you go away from there then it is other way. So, this is the approximate relationship between peak acceleration of rock and other local soil conditions, and this has been given by Seed et al. 1976. Continuing with the compilation of data. Local site conditions also influence the frequency content. In the last slide we have seen an effect on the amplitude, the peak values. And the frequency content of the surface motions also change.

Hence the response spectra they produce is also different. Continuing with the Seed et al. computed what we call the response spectra from ground motions which are recorded at sites which are underlined by four categories of site conditions. And what are the four categories? First rock site. The second, so this is the let us say first. The second steep soil sites and steep soil site is where it is less than 250 feet deep. Then deep cohesion less soils sites which is let us say third site where depth is going more than 250 deep and site underlined by soft to medium steep clay deposits.

So, the study has been done these four sites starting from rock to the very soft soil conditions. Here when we say soft soil condition of course soft water is applicable for clay, but we can understand the loose site conditions for the sand. Normalizing the computed spectra which can be normalized by dividing spectral acceleration by the peak ground acceleration, they illustrate the effect of local site conditions on the shapes of the spectra. And let me discuss that spectra first and then we here this is the result which is again as we discussed by after seed et al.

There are four sites in this four site period on the x axis. On y axis you have a spectral acceleration versus maximum ground acceleration. When period is 0 which is there is static condition. In a static condition all the curves are at 1 normalized at 1. That means all four curves are starting from 1 and then you get peak values. Peak values are coming at different time period and the peak is also higher.

But once this peak is over and this peak when you go more than 0.4 second or like this after this value after 0.5 second you see here the maximum value is for the soft to medium clay. Then the second maximum come deep cohesion less soil, third is steep soil and the minimum value is coming for the rock site.

So here in this spectra the range of interest for us is after 0.5 seconds. So, this is our range of interest rather than this peak value. So, because it is more than 0.5 seconds like less than 0.5 second will be too like in a stiff structure so that is there. So less than 0.5 second maybe like if you say for the time period of the structure will be less. So, you may have for most of the structure time period in this range. So normalize the computed spectra the effects are apparent at periods above 0.5 seconds. We already discussed this, and spectral amplification are much higher for soft soil sites than for rock sites.

And this higher means is in this range not in this range. In this range it is opposite. The highest value in this case you get this for the rock but for 0.5 second and around you get higher value for the soft soil condition. At longer period the spectral amplification increases with decreasing subsurface profile.

This was regarding the compilation of data on local site effects. Continue with this. That clearly shows the last figure the deep and soft soil deposit produce greater proportion of long period motions. This effect can be very significant particularly when long period structures such as bridges and tall buildings are founded on such deposits. So, this is important particularly long period structures and the long period structures means bridges and tall buildings. These results also show that the use of single response spectrum shape for all conditions is not appropriate.

And this is finding which is strongly influenced by the development of building codes and standards. So here what is the message here? You cannot use the same spectra for the different sites. For the rock site this is the spectra. For the soft soils condition then this is the spectra. And you see in this range difference is very large.

If I collect the values, the values are very much different. The soft soil condition values here it is coming less than 1 but it is going more than 2 point like more than doubled. So, the soft soil conditions effect are large not only in the time period but also it is on the peak value. So now the next effect of surface topography. When we talk about the effect of surface topography, the topography effects caused by simple irregularities can be estimated from exact solution to the idealized problems like which is there. For triangular infinite waves is subjected to vertically propagating SH waves with particle motion, which is parallel to x axis, then amplifying factor could be like approximately 2 by phi.

What is phi here? Phi is the vertex angle of the waves. So here this is seen here. You have in case of topographic effect like you know you could have like kind of a ridge like in this case. So this angle vertex angle is phi. This is the peak. You have this in the case of crust but in case of trough it will be opposite, phi is the angle here and using this phi angle approximately using 2 by phi we can calculate approximate amplifications.

This approach can be used to approximate topographic trough for certain cases of ridge valley terrain. So there is the effect of surface topography which has been observed there. Then there are effect of geometry basin also. Since many large cities are located on near what we called alluvial valleys particularly like in our country India mostly Gangetic belt are on alluvial soils particularly in the if you go in the Uttar Pradesh or Bihar region then it is alluvial soil. The effect of basin geometry on ground motion is of great interest in earthquake geotechnical engineering.

So, we need to consider the effect of basin geometry also. The curvature of a basin in which softer aluval soils have been deposited can trap body waves and can cause some incident body waves to propagate through the alum soils at the surface and when they reach at the surface there will be surface waves. So, this will be the effect of the momentary basins. These waves can produce stronger shaking and longer duration than would be predicted by one-dimensional ground response analysis and consider only vertically propagating waves. In fact, in the one-dimensional analysis ground response analysis, we do not consider effect of geometric basin. The potential for significant differential motions across such aluval valleys has important implications for the design of long span structures such as bridges and pipelines that often cross valleys.

Differential moment can induce large loads and cause heavy damage to these types of structures, and this has been listed both effects of topographic and subsurface irregularities. In the first column different types of structures, surface topography, sediment field valleys that is given. In the second column what are the different conditions are there. Then type amplification is considered, increased duration what happens. Then the size of the model in the fourth column and finally as a quantitative predictability it is poor, fair, good and fair it is given.

So, you can go through this one. So, this completes second lecture on local site effects, and we will continue on the third and fourth lecture further on the local site effect where we will consider the design part where design response spectra and other things. Thank you very much for your kind attention.