Earthquake Geotechnical Engineering

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Lecture 30

Local Site Effects (Continue)

I welcome you again for this NPTEL online course on earthquake geotechnical engineering. And today we are going to talk the last lecture on this module 3, which is on ground response analysis and local site effects. We are under chapter third of this module, which is on local site effects and this is the fourth lecture on the local site effects. What we are going to talk in this lectures are listed here. We are going to talk development of ground motion time histories and development of ground motion time history. These time histories are used for the design of the structures, for the analysis of the structures.

So, this can be done in four ways. One is modification of actual ground motion records that whatever the record is available from the seismograph or the accelerograph from the instrumentation, you modify that. Then the second could be time domain generation for these ground motion time histories. Then third frequency domain generation and the fourth one is Greens functional technique.

And finally, we are going to talk about the what are the certain limitations of artificial ground motions. So, let us have first development of ground motion time histories and starting from motion actual ground motion records. And most of the stuff is taken from the Kramer's book, all like most of the information is coming from this source. So, development of ground motion time histories on many occasions, this ground motion parameters alone will not be sufficient that we find the ground acceleration or let us say predominant frequency or maybe duration. So, like for a strong ground motion, they can simplify your problem, but that itself may not be enough and we require what we call the actual time history.

For analysis of nonlinear problems, such as the response of inelastic structures or the permanent deformation of an unstable slope, time histories of motions are required. And time history can also be required in the development of what we call the site specific design ground motion and how development of site specific design ground motions is done. It is in this case, we discuss development of site specific design ground motion in the last lecture also. But the easiest way of doing it, there are two figure A and B in this slide. In the figure A, you have original accelerogram from actual earthquake which is recorded.

So, in the figure B, what you are doing, you are scaling it, all the peaks are scaled by a factor of 1.5. So, if you compare this double ordinate or let us say this value from here to here with this value. So, in the second case, it is 1.5 times of the first case the values like difference between the values here and not only the peak values, but other peaks are also multiplied by a factor 1.5. So, you could see that even this was diminished here almost 0, but still, you could visible here. So, the peak are, but there is no change in the frequency content or let us say with the time duration, only the peak value have been. So, this is normally done when you want to have the target spectrum. So, here it is most of the time it is scaled up. So, continue with this, in some cases, time histories that match target ground motion parameters and what are the ground motion parameters, it is such as a peak acceleration or peak velocities or spectral ordinates are required.

In some cases, the local and regional geologic and tectonic conditions of the site of interest may be similar to those of the sites where actual strong ground motion have been recorded or measured. In that case, you no need to modify, those ground motion can be used directly, no modifications required. Suppose site have the same characteristics as the characteristic where this the motion has been recorded, but usually this is not the case and, in that case, artificial ground motions must be developed which can be done in a different number of ways. Now, the main challenges in their development are to be ensured that they are consistent with the target parameters, and they are realistic, these motions should be realistic.

When we say the realistic that means that their characteristics are consistent with those of actual earthquakes. So, whatever you develop the ground motion, and their characteristics should be similar to the actual earthquakes. Now, for development of ground motion time histories as we discussed earlier also, there are different methods. The most commonly used methods for the generation of artificial ground motions fall into four main categories. First one, modification of actual ground motion records, whatever the you have the record, the modified that.

Then you have generation of artificial motions in the time domain, and it could be generation of artificial motion in the frequency domain and generation of artificial motion using Green's function technique. So, we will discuss it one by one. So, first one is modification of actual ground motion records. This as we discussed earlier too, this is the simplest approach through the generation of artificial ground motion is a modification of the actual recorded ground motion. So, you have the actual recorded ground motion, modify little bit, may be you increase the PGA, or you decrease the PGA or maybe on the duration or frequency.

Maximum motion levels such as peak acceleration, peak velocity have been used to rescale actual strong ground motion record to higher or lower levels of shaking. So, most of the time as we discussed that either PGA increased or decreased. So, that is scaling up is done when you modify the actual ground motion record. Continue with this, this type of rescaling procedure requires careful selection of the actual motion that has to be used because here what you are doing, you have selected a motion from somewhere and then you are scaling it up or up down rather than changing the frequency content most of the time. In that case, the selection of this actual ground motion that is important.

A desirable ground motion record will not only have a peak acceleration or velocity which is close to the target value, but will have magnitude, distance and local site characteristic that are similar to those of the target motion. So, such a record is most likely to have a similar frequency content and duration to the target motion. So, whatever target motion you have, whatever record you select, it will be likely to have a similar frequency content and duration because it has been carefully selected. Rescaling of the time scale has been used to modify the frequency content of an actual ground motion record. One way you do not change the time scale, you know that change the peak ground acceleration is scaling up and down.

Another way you can keep the PGA and PGV constant, but the time scale has been rescaled. Once you are changing the time duration, then actually the frequency content will also change. And this is usually accomplished by modifying the time step of digitized actual record, but the ratio of the predominant period of the target motion to the predominant period of the actual motion. So, one side you have two predominant period, one is of the target motion, another is of actual record. So, you find the ratio of these two and then actual record is multiplied by this ratio to have this.

Since this approach changes the frequency content or the entire spectrum as well as the duration of the rescaled record, it should be used carefully. Here you are changing two things, one is duration as well as frequency content. So, one of the example is given here. So, what has been done in this case? This original accelerogram from actual earthquake is given in figure a while rescaled version of accelerogram in which time scale was scaled upward by a factor of 1.3. So, here this t you could see that most of the peak finish at here in this case, but they are running up to this point. So, the difference between this, this will be 1.3 times of this time. And here also the peak value which was occurring here has shifted here. So, the difference between time, this time will be about 1.3 times of the time are the peak values here because you are multiplied by a factor of 1.3, 30 percent. So, to match target predominant period, the duration has been also increased by the same factor 1.3. So, duration will also not be constant, rather this will increase.

So, continue with this modification of actual ground motion record to generate artificial ground motions of long duration without significantly changing the frequency content. So, for example, Seed and Idriss in 1969, then splicing is done, parts of actual ground motion record together. So, you have actual ground motion record, but you divide into different sectors that record and you have one group splices and then another group. And processor for this type must be also cautious because only you are changing some particular sector rather than. And finally, we need to have a careful examination of the resemblance of splice motion in both the time and frequency domain is advised.

So, we will discuss what is in the next, what is the time domain generation and then once we finish with time domain generation, then we will discuss the frequency domain generation. How using time domain analysis you can generate the time history which is used for the design purpose further. So, first the resemblance of ground motion time histories to transient stochastic process was noted earlier long back by Housner even in 1947 that there is a similarness for that. Since then a number of processes that treat ground motions as stochastic that is random process have been developed. Many of these operate entirely in the time domain, many of these process work in the time domain only not in the frequency domain.

So, continue with this, a stationary stochastic process is the one whose statics remain constant with time. A stationary accelerometer for example, would have a constant mean acceleration, constant standard deviation of acceleration and a constant frequency control. The acceleration would continue indefinitely. The fact that the acceleration amplitude of actual ground motion varies with time, it is not constant rather it will be varying with the time. Ground motions have a beginning and end, you will have starting from where your ground motions are starting, some peaks are coming when they go to the peak values and then it decreases, but it will ultimately have some end also because ultimately it have some duration.

So, within this duration you have some peaks, so it is not going to be infinite duration or like this. So, the acceleration amplitude of actual ground motion will be not constant rather it will vary, and it must be vary because you will get somewhere peak values, but in the beginning, you will not have any peak, at the end also you will not have any peak. So, studies have also shown that the frequency content of a typical ground motion is also known stationary, it changes over the duration of shaking, there is not constant rather it will be changing over the duration of shaking. Generation of an artificial ground motion time history in the time domain typically involves multiplying a stationary filtered white noise signal, you have filtered white noise signal. So, in this case you remove the unwanted and you have white noise signal filtered and it need to be multiplied by an envelope function that describe the built-up and subsequent decay of ground motion amplitude.

So, you have basically filtered white noise signal need to be multiplied by an envelope function. So, the product of these two that is one part filtered white noise signal, another is in envelope function will give the ground motion and this envelope function should describe the built-up and subsequent decay of ground motion amplitude. So, using these two products we find the artificial ground motion. For example, here is the case here, one example is given in time domain how you generate an artificial ground motion. So, here in this case example of time domain generation of synthetic time history or we say artificial time history they are the same thing.

Time history of white noise is filtered in the time domain, so this is white noise the point A and this is coming from the actual time history white noise. So, you take out white noise that means basically you could see the peak values are more or less same. So, one window you have taken, then in the figure B filtered by time history filtered white noise, filter so you have this time history filtered white noise. Here you have time history, and this is filtered white noise, so this is the filtered white noise in B case. In C case you have an envelope function, this is envelope function.

So, what you do, you multiply by B and C, and you find you multiply by B and C and then product of B and C will give you D and what is D here, artificial ground motion. So, you find, and this white noise is coming from here only from A, from A you first find the white noise and then envelope function, envelope function multiply by the white noise that will help you to produce the artificial ground motion time history which is shown in figure D. Now the similar treatment which we do for the time domain generation, there is a frequency domain generation also for the ground motion or the synthetic ground motion. Ground motion can be generated quite conveniently in the frequency domain by combining a Fourier amplitude spectrum with Fourier phase spectrum. So, you have two spectrum here, one is called Fourier amplitude spectrum, so this is the first one Fourier amplitude spectrum and the second one is Fourier phase spectrum.

The amplitude spectrum may be computed from an actual ground motion, how to compute these two spectrum? The first one can be computed by actual ground motion spectrum or may be represented by some theoretical means. So, we find first amplitude spectrum and the Fourier phase spectrum. So, that can be found theoretical means, the first one Fourier amplitude spectrum. While the phase spectrum may be obtained from an actual ground motion or may be computed from a time history given by the product of white noise and envelope function as we discussed in the time domain, you have white noise and envelope function then using this you find out the product of these two that will help you to find out what we call the phase spectrum. Frequency domain methods are particularly useful for generating motions that are consistent with target response spectrum.

You ultimately have target response spectrum. So, for the target response spectrum, your frequency domain methods are useful that they will be helpful to generate the target response spectrum. For example, here in the frequency domain generation how it is done? So, example of frequency domain generation of synthetic time history, what is figure A? Time history of white noise is shaped by envelope function to produce time history of envelope white noise. So, here you have the time history and using this you produce time history of envelope white noise. So, this is here in the B you have enveloped white noise.

That means you have within the selected window you have some envelope and in this envelope. Now, you have FPS. What is FPS? Fourier peak spectrum, Fourier amplitude spectrum, Fourier phase spectrum. So, PS is a phase spectrum while AS is amplitude spectrum. So, now you have the spectrum and using this phase spectrum, and this is combined with what you call the amplitude spectrum to produce synthetic time history.

So, final answer is here in E. This is synthetic time history, synthetic or artificial time history. Continuing with frequency domain generation, there are some computer algorithms available. For example, earthquake generation and response calculation requires, they assumes initial Fourier amplitude and phase spectrum and then iteratively adjust the ordinates of the Fourier amplitude spectrum until a motion which is considered with the target response spectrum is produced. So, the adjustment is done in the amplitude of the Fourier amplitude spectrum until you find out that there is a consistency between it and is considered with the target response spectrum. The origin of the target response spectrum must be kept in mind when generating the spectrum compatible motions.

So, where they have been calculated. There is constant risk spectra, for example, represent the aggregate effect of potential earthquakes of many different magnitudes which occurs at many different distances. Because a constant risk spectrum does not correspond to any particular seismic event, a motion which is generated from a constant risk target spectrum should not be expected to correspond to a particular seismic event because it is not generated using a particular seismic event. So, naturally it will not be should be targeted for a particular seismic event. Then you have the third what you call the Green's function technique using that also artificial time histories can be generated, synthetic time history. The Green's function approach to ground motion modeling is based on the idea that the total motion of a particular site is equal to the sum of the motion which is produced by a series of individual ruptures of many small patches on the causative fault.

So, have is done in this case Green's function you divide a number of patches and total motion will consist of some of the motions which is produced by series of individual ruptures of many patches. So, you divide a number of patches and find the motion for each the patches and then combine. Naturally when you do this combination this can be used only for the linear analysis rather than nonlinear analysis. Obtaining the site motion requires defining the geometry of the earthquake source that what is the geometry of the earthquake source. Dividing the source into finite number of patches which is the hallmark for Green's function technique.

During this defining the sequence in which the patches rupture that is which one will rupture first which one will rupture second. Defining the slip functions that is functions describe the variation of slip displacement with time for each page across the source and defining Green's functions the functions that describe the motion of the site due to an instantaneous unit slip of the source across the source. So, using this steps you can use the

Green's, but hallmark of Green's function technique you are dividing whole into like problem into number of patches. For example here one of the example here this in the slide you have n number of patches 1, 2, i h and n. So, this shows the schematic of Green's function for a fault divide into n patches.

So, n patches has been divided. Differences in the Green's function for the different patches are due to the difference in focal depth, epicentral distance and geologic structure along the source site path. So, you have one site which is basically source and here is site. The distance between source and site in general could be same, but because source itself is divided into number of patches then you need to calculate that distance from each of the patch and then influence of this each of the patch on this site condition. So, epicentral once Green's functions have been determined site motions can easily be simulated for a variety of fault rupture patterns and slip functions. Combining the Green's function with the slip functions give the motion at the site due to slip of each individual patch.

So, we find the motion first which is due to the slip of each individual patch, summing the effects of slips of each patch while accounting for the order in which they capture produces the overall ground motion at the site. Obviously, the summation process assume that all materials are remain linear. So, naturally the summation can be done. Principle of superposition will be applicable for linear material not for the nonlinear material, that is one thing here. And here what we are doing the Green's functions with slip function, so that will give the motion at the site due to slip of each individual patch.

So, we find for each individual patch and then some of the response or the motion. Calculation of Green's functions requires knowledge of the velocity structure of the crustal materials between the source and site. So, what is the soil profile between the source and site that need to be known? However, estimation of velocity structure particularly with respect for the structuring that produces late arriving waves is very difficult problem. So, this estimation of the velocity profile structure is not easy, like you need to conduct some test or maybe what particular distance is large, area is quite wide, so it is also sometimes difficult. So, another way considerable completion of what is also required to calculate Green's function, finite element, finite difference and ray theory techniques are usually used for this purpose.

So, you can use in the Green's function technique or like numerically rather than the actual. The Green's function approach is particularly useful for generating near-fill motions. So, this technique is for applicable rather than far-field motion, this is for near-field motion. That is the motion at sites which are close enough to fault that fault dimension becomes significant. For far-field test sites, the fault can be treated as point source without undue loss of address.

If your source is quite away, then we can consider it is like a point source. The nature of the rupture pattern including the general direction in which rupture progresses and the size azimuth which is related to the fault can strongly influence ground motion in the near field. So, in the near field, there are different parameters which can influence the result. Actual ground motions are complicated, they are influenced by and consequently reflect the corruption of the seismic source and the rupture process, the source to travel path and local site conditions. So, you have you know that different, so you have source site travel path and local site conditions.

So, actual ground motion will be influenced by both source to site travel path, what is comes between when the waves travel from source to site that is one part, another at the same site the effect of local site condition will also change. So, therefore actual ground motions because they are very complicated and generating artificial time history or synthetic time history is not easy. It may match, it may not match with the actual ground motion. Although it is convenient to characterize them with a small number of parameters, it is important to remember such characteristics can never be complete because it may represent the actual case or may not. Artificial motions that match a small number of target parameters are not unique because the motions are not unique.

For the same parameters, many different motion can produce the same target parameters. So, our target parameter is same, but still the actual ground motions which can predict the target parameters may be different. So, I can produce something else, the other person may produce something else and ultimately still they are leading to the same target parameters, so it is possible. If such a set of motions are used to analyze problem for which damage correlates well to the target parameters, the predicted damage is likely to be consistent. So, what can be done? One of the target parameters could be the simulation of the damage which occurred during the pass-off phase.

For example, a set of different motions with the same peak acceleration will produce similar base shears in a stiff linear elastic structure which is founded on rock. If you have linear elastic structure, but structure is stiff and it is founded on rock, so in that case because it is founded on rock the effect of SSI is not going to be negligible. So, in this case a set of different motions with the same peak acceleration in that case will produce similar base shears. The same set of motion however might produce a broad range of base shears in a flexible or inelastic structure or a structure founded on soft soil. Now you have another scenario where you may have your structure is still situated on the rock, but instead of you have the flexible or inelastic structure, in that case the broad range of base shears produced may be different.

So, in another way you could have a structure which is founded on soft soil. Soil conditions are not on the rock, you may have one side so it will influence. Instead of rock if you have soft soil that is going to influence. Instead of the rigid structure if you have the flexible structure then also results are going to change. They could also produce significantly different estimates of permanent slope movement or liquefied potential.

When using artificial motion, the eventual use of the motions must always be reconciled with the criteria from which they were developed. So, whatever the criteria using these motions have been developed that need to be also revisited. So, with this I conclude the last lectures on the local site effects and we have finished the module number 3 and almost 50 percent of the course is over exactly. Thank you very much for your time. Thank you.