Earthquake Geotechnical Engineering

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Lecture- 3

Engineering Seismology

I welcome you all again for this course on earthquake geotechnical engineering. Today we are going to discuss third lecture of this course. The first we already covered about the introduction and the damages in the past earthquake. So, this is the part of the first module which is so called introduction. So, geotechnical issues during earthquakes has been already covered. Today we are going to talk about the engineering seismology.

So, let us have some recap from lecture 1 and 2 which we already finished. First is what we have done is introduction of the course seismic geohazards, historical earthquakes, seismic damages and damages observed during past earthquakes. So, this is already covered and today we are going to talk about engineering seismology. So, in this lecture in the engineering seismology we are going to talk about first static loading and then dynamic loading.

So, the idea here is what is the difference between static loading and dynamic loading. So, the static loading is basically kind of loading which does not change with the time, that remain constant with the time and so it is constant in a steady state and produce a single response. So, the equation, which is given here kx equal to p, this is for static loading.

$$Kx = P$$

For example, weight of a building on the ground like it can be treated as a static loading. So, this is one of the example for static loading where a heavy weight has been put for conducting static pile load task. So, that means this weight is constant with over the time, it is not changing, so its response is unique, so answer will be also unique here. Compared to this dynamic loading have a difference and what is the difference when we go for the dynamic loading A load of which either its magnitude direction and the position varies with time. So, if any of the three points whether its magnitude or direction or the position or more than one point varies with the time, then it will be treated as a time varying loading or dynamic loading. For example, it is possible that magnitude remain constant, however the direction is varying with the time then also it will be treated as a dynamic load. In such a scenario when we consider the dynamic loading, the response of the structure or the foundations will also varies with the time.

So, that means your answer is also not constant rather than time down. Now the equation of motion. Basically, equation of motion you have here. So, in this equation of motion this is called equilibrium of forces, so this is nothing but equilibrium of forces. So, in this equation of motion and in short in the dynamics we called it equation of motion.

$$m\ddot{x} + c\dot{x} + kx = p(t)$$

So, this is the equation of motion for single degree of freedom system, where m is the mass, c is damping coefficient and k is the stiffness. So, what is the difference? Now this the right hand side force p is not no more constant rather it is varying with the time number 1. Second thing you get three terms on the left hand side, one is what we call this inertial force, the second damping force and third one is stiffness force or elastic force. So, the third one was there before also, but now you have x double dot and x dot that means acceleration as well as velocity is also involved. To solve this equation of motion it is a differential equation.

So, that means x this acceleration and velocity need to be represented in terms of displacement, once this is done then we can solve this equation and find out the displacement and then later again by differentiating a velocity and acceleration. Now, examples of the dynamic loadings are like earthquake is one of the example, wind loading is example, blasting, machine excitations they are the kind of examples of dynamic loading. Here types of prescribed loading for dynamic case can be categorized in two categories, first is called periodic loading and another is known as non-periodic loading. In periodic loading you could have some example like simple harmonic motion which could be a sinusoidal wave, or it could be a complex motion. So, the periodic means the motion which is repeating after certain period.

So, the period is fixed that means its frequency will be constant for periodic motion it will repeat again, but there are non-periodic motions also like impulsive forces or long duration which So, earthquake is a complex issue where you have non-periodic motion as well as long duration. So, here like one of the time history which is we call that acceleration time history of 1994 Northridge earthquake is given on the right hand side. So, what you see here that this is the acceleration which is varying with the time and it is not only like you know that going it is positive as well as negative that means it is going when we say positive and negative that means basically the change of the direction. One side we will call positive let us say when it is moving this side it is positive when it is moving this side it is negative. So, now the issue is here that the value of acceleration it is not constant rather it is varying with the time and when it is varying with the time the maximum value in the acceleration time history which is typically called here like in this case it is here.

So, it is called PGA and many of you may be perhaps aware that PGA is nothing but Peak ground acceleration. So, it stands for acceleration. So, this was about dynamic loading. Now coming to this brief background, the difference between static loading and dynamic loading let us talk about something about seismology and that is basically about a engineering seismology though this course is not on seismology but little bit background is required for the for understanding various issues during this course about engineering seismology. So, in the third and fourth lecture we are going to talk about engineering seismology.

So, that is the second chapter and we are working on the second chapter of module 1 that is an engineering seismology. Now when we talk about seismology in the study of earthquake geotechnical engineering requires understanding of the various process by which earthquake occur and their effects on ground motion. So, we need to understand how the earthquake occurs, what is the reason for earthquake and what is their effect on the ground. So, that we need to discuss and when we talk about seismology in fact it is coming from a Greek word sesmos which means earthquake and logos means related to science. So, the science of earthquake is seismology.

So, the seismology is an area which deals with the science of earthquakes. Developed from a need to and then it will require the internal structure of the earth the behavior of the earth particularly as these relate to earthquake phenomena. So, we will discuss about the internal structure of the earth also in this lecture. A clear advance in the science of seismology was done with the invention of a sensitive and reliable seismograph. Here seismograph when we say seismograph, seismograph is not actually a graph it is an instrument and when we say seismogram that is basically graph.

So, it is other way seismograph is not a graph rather it is an instrument which measures the earthquake records for this and in this case the accumulation of reliable records of distant earthquakes that is recorded using what you call teliseismic events made possible the systematic study of the earth's seismicity and its internal structure. So, basically the recorded data which have come for earthquake instrument which record the earthquake it help to know what the internal structure of the earth is and what is the different properties which we are going to discuss about that in this lecture. Now, when we talk about earthquake, so in the simple sense if I say what is an earthquake, so let me put it again here what is an earthquake before I go ahead. Earthquake if I say in the simple term’s earthquake is nothing but release of energy. So, if I say in this earthquake release of energy, so basically three words.

So, here energy is a keyword. So, the energy will come out of the earth when an earthquake occurs and that is the energy which cause destruction, or you know which cause the issues. Here when we talk about energy release this energy release comes in the form of elastic waves. Seismic waves are nothing but what we call elastic waves. And this elastic waves are those kind of waves which you can feel their impact, but you are not able to see the waves.

When an earthquake comes the waves will start. An earthquake wave will come but it will cause some damage or it will you can see effect of the wave but you will not be see the waves running. So, this is basically elastic waves and when we say two types of waves are there which are produced when an earthquake occurs. First is called body waves and then second is called surface wave. Now, what is the difference between these two? In the first case in both the cases seismic energy is released however body waves are the waves which travel inside the earth and when these waves reaches to the ground then they turn up in the form of surface waves. So, in fact the second one surface wave is product of body waves only.

When the body waves travel from the ground they are traveling inside the earth they are body waves. When they reaches to the ground then they become surface waves. And in the first case energy is released at a point near the surface of the homogeneous medium and part of this energy propagates through the body of the medium as seismic body waves. So, that means you have a medium where you have a point near the surface of the homogeneous medium and the part of the energy partly will go back to the earth and then it will travel in the form of seismic body wave. While the remaining part of the seismic energy is spread out over the surface as a seismic surface waves.

So, that means when the waves are traveling earthquake wave comes some energy goes inside the earth back some energy come on the surface in the form of surface waves. Now, when we talk about body waves, body waves are also two types one is called P wave in another is called S wave. So, let us talk about when we have in fact there is what we call this spherical wave front to generate these waves both like P waves as well as. When a body wave reaches a distance some distance r from its source in a medium which is homogeneous then a wave front which is defined as the surface in which all particles vibrate with the same phase. So, the phase should remain same for all the particles then we called it a wave front and its shape is normally spherical shape and this wave front is called a spherical wave front.

So, you have a wave front and the shape is spherical wave front and the waves originating from this like when you have the distance from the source increases the curvature of a spherical wave front decreases. So, when you go away from the source of energy release then the spherical wave front will decrease. At great distances from the source the wave front becomes almost flat that it can be considered to be a plane rather than a spherical wave front and seismic wave in that case will be called a plane wave after that means after certain distance from the source. The direction perpendicular to the wave front is called the seismic ray path. So, this was about body waves in general.

As we discussed that there are two types of body waves one is called P wave another is called S wave. P wave is also known as primary wave, compressional wave or longitudinal waves. In this case these waves involves successive compression and rarefication of the materials through which they travel. So, they will either compress or expand. They are analogous to sound waves the motion of an individual particle that a P waves travel through is parallel to the direction of travel.

P waves can travel through solids and fluids. So, that means P waves can travel through the solid medium as well as liquid medium. Contrary to this when we have the S wave which is also known as a secondary wave or shear or transverse waves and as the name suggests they will cause shear deformations as they travel through a material. So, P waves will have the compression or expansion while the S wave will be generating the shear deformations. The motion of individual particle is perpendicular to the direction of S wave travel and the direction of particle movement can be used to divide S waves into two component.

Vertical component will called SV and while horizontal plane movement that is horizontal component will called SH. So, now let us see how the body wave looks. So, I can take this slide first. What do you see in this case on the top you have this P wave where the wave is like you know there are two things when we talk about wave. One is called direction of particle direction of wave propagation another is called the direction of particle motion.

So, here so let us I can write it here there are two issues. So, one is called direction of wave propagation direction of wave propagation, and another thing is called direction of particle motion. So, in the P wave both are same direction and in S wave they are perpendicular to each other. S wave both are perpendicular to each other. Here I can explain it further in case of P wave like suppose this is the direction of wave propagation is like this.

So, waves will propagate in this direction and it will direction of particle motion will be also like this. So, the direction of particle motion will be like in the same direction while in S wave if direction of wave propagation is this direction of particle motion will be perpendicular like to this in the horizontal direction for SH wave. While for SV wave which is shown in this figure the direction of particle motion is this or direction of wave propagation is like this, and particle motion will be up down. So, that means both are perpendicular to each other. So, that is why in case of P wave it is like a compression while in S wave it is like for SH wave.

So, because now the P waves travel the fastest because geologic materials are stiffest in compression. So, as a result P waves will travel faster than other seismic waves therefore, the first wave at arriving at any point will be the P wave. So, anyway the first wave is coming near the source or at any some distance that will be a P wave and because the liquids do not have any shearing strength. So, S wave or secondary wave cannot travel through the fluids. So, with this information we compete with the body waves.

Now, the second waves type of waves is called surface waves and surface waves result from the interaction between body waves and the surface or surficial layer of the earth. It is simple when the body waves touches when they reaches near the surface then they turn up in the surface wave they travel along the earth surface with amplitude that decrease exponentially with the depth. So, when you go with the depth the amplitude will decrease. Because of the nature of the interaction which we are required to produce these waves surface wave are more prominent at distances farther from the source of the earthquake. In fact, rate of attenuation of the surface wave is less than the rate of attenuation of body waves which we will discuss later also.

So, as a result body waves attenuate fastly, but surface waves even after some time you will get some peak values for the surface wave. The most important surface wave for engineering purposes are two, one is called Rayleigh wave and another is called love waves. And the names are kept on the scientists who invented these waves. So, Rayleigh waves produced by interaction of P and SP waves with the earth surface and this involve both vertical and horizontal particle motion. While love waves will be by the interaction of SH wave with a soft surfacial layer and have no vertical component of particle motion. So, you will have vertical component in SP, but not in SH. And how the Rayleigh and love wave looks you can see here. The top one is showing the Rayleigh wave and the bottom one is showing love waves. So, what you could see in case of Rayleigh wave which is a combination due to P and SV wave you have there is in the movement in the vertical direction. While in case of love wave it is in the horizontal direction, you have only SH components that means no vertical component is there.

So, basically the movement is in the horizontal direction like when it goes wave propagate then it will move like this particle motion will be like this. In case of P wave like this. Then similarly in case of Love wave you have both this is showing that this moves like in rotation which is shown by this the circle here in the part A. This was about surface wave. Coming to the engineering seismology one of the important issue is that how the internal structure of the earth is there.

So, some of the things which I am going to discuss is of course covered up to 10 plus 2 level also, but it is better to that let us have review of that. And in fact, that have come from the seismology side. One of the achievements in seismology was the determination of the internal structure of the earth. And large earthquake produce enough energy to cause miserable shaking at points all around the world. As the different types of seismic waves travel through the earth, they are either reflected or refracted at the boundaries between these different layers reaching different points on the earth surface by different paths.

So, here is the internal structure of the earth. And let us see let us discuss this here. So, this is kind of in the first figure on the left hand side you could see a kind of a globe. And in this globe what you see here like it is cut down which is further details are given. The most inner part of the earth almost near the center of the earth is called inner core.

So, you will have a small sphere of inner core. And then on the top of inner core on the surface you will have what is called outer core. On the top of that you have the mantle and finally crust which we like you know the crust is a part of the earth on which buildings are constructed or the roads are constructed. So, basically on the surface we can see. So, the cross section is given on the right hand side and approximately in kilometer distances are given, thickness of these four sections are given. For example, inner core and outer core together consist of the major part of the earth which is goes about 3470 kilometer.

So, that is more than 50 percent because the radius of the earth is around 6200 something. So, you have here like out of this core inner core is about 1270 kilometer thick while outer core is 2200 kilometers thick. Then between outer core and mantle there is a discontinuity boundary which is called Gutenberg discontinuity which we are going to discuss further. Then mantle you have about 2850 kilometer which is given here, and this include this asthano sphere partially melted this both the 2850 kilometer. On the top of the mantle you have the crust but between mantle and crust there is a small thick small you know thin layer which you have which is called Moho.

Moho is the name of the scientist who invented this layer. So, we are going to talk about these different parts in details in the next slides. So, here this is about the internal structure. So, as for the crust is concerned thickness of crust is about 5 to 70 kilometer thick, oceans are also lying on this Moho as well as earth is also lying on this.

So, now coming to here internal structure of the crust. The crust is the on which human beings lives is the outermost layer of the earth. And the thickness of the crust range from 25 to 40 kilometers. The internal structure of the crust is complex but can be represented by what is called basaltic layer that is overland by granitic layer at continental locations that means you have basaltic layer and below that you have granite layer. Continuing with the crust a distinct change in wave propagation velocity makes the boundary between the crust and the underlying mantle which is called the Moho as we discussed. This is called Mohorovicic discontinuity or simply the Moho which has been named after the seismologist who discovered this in 1909.

Below the like you have the crust Moho and then the below the Moho you have the mantle. The mantle is about 2850 kilometer thick and we can be divided into the upper mantle which is about 650 kilometer in thickness and then you have the lower mantle. No earthquake has have been reported in the lower mantle that means the focal depth of the earthquake may go up to the at the most upper mantle and of course the crust and then upper mantle. So, no earthquake has been recorded in the lower mantle which exhibit a uniform velocity structure and appears to be chemically homogeneous except near its lower boundary.

So, this is the about continue with this. Now continue with the internal structure of the earth. The mantle is composed of silicate rocks which are richer in iron and magnesium than the overlying crust. So, crust we may not find much on the on the crust iron and magnesium but if you go inside the mantle then it is like lot of there. Although solid the mantle is extremely hot silicate material can flow over very long time scales. Convection of the mantle propels the motion of the tectonic plates in the crust.

So, now we are going to discuss in the next lecture that how what is tectonic plate theory which generate the earthquakes. So, in fact the tectonic plate movement is movement in the mantle which will propagate and as a result there will be motion. The outer core or liquid core is about 200 2260 kilometer thick as a liquid. It cannot transmit S-waves. Why? Because it is fluid and S-waves cannot transfer through the fluid.

So, this was about mantle. Coming to the internal structure of the earth and different velocities. So, you have in this slide what is shown here or like you have on the top part the again cross section is shown where you have inner core outer core mantle and crust. So, it is four divisions and on the lower part you have velocity in kilometer per second while you have density in gram per centimeter cube. So, when we talk about here, p-wave velocity is quite high when you have near inner core you could see here with the inner core. So, here this p-wave velocity dip little bit near the junction between inner core and outer core and then again it little recover and then from outer core again it decreases.

Why this p-wave velocity is decreasing when we are moving from deep to the shallow side? Simple reason is it is here because the density is more at the down stiffness is more so which is reflected in the down density graph between the density. You could see the density is here decreasing, density is highest here and that is to start decreasing and then again all of sudden it decreases and then again decreases here. So, continuously density is decreasing. So, when the density decreases it is expected that p-wave velocity will also decrease up to this point and then all of a sudden there is a jump in p-wave velocity which is at the junction between outer and core and mantle because and this is showing that all of a sudden what you get? All of a sudden you get that there is a change in the like you know that is material property and material becomes when it is increasing that means it is all of a sudden some stiff material have come and the p-wave velocity increases. And then again when you move from this junction to the crust then again p-wave velocity decreases.

However, as for the s-wave velocity is concerned, s-wave velocity remains almost 0 up to the outer core on the top of it you have a layer. So, here it is why it is 0 because the s-wave cannot travel through the fluid and this medium outer core and inner core is like a fluid situation. And what is here it can be also seen here that so this is here let us go back. Here you have Gutenberg's discontinuity.

So, the between outer core and mantle you have Gutenberg's discontinuity. So, this point is showing you related to discontinuity and then again similar to p-wave s-wave is decreasing. Regarding density we have already discussed the density is decreasing as you move from bottom to the towards the surface. So, this continue with this internal structure. So, we already discussed the s-wave velocity drop to 0 at the core-mental boundary or Gutenberg's discontinuity. The outer core which consists of primarily of molten iron which helps that can be explained that how high specific gravity of you get 9 to 12 for this case.

As for the inner core is concerned it is a solid core very dense and specific gravity may go up to 15 and it normally may consist of solid nickel iron material compressed under tremendous pressure. The temperature of the inner core is estimated to be relatively uniform at over more than 4000 degree Fahrenheit. So, the inner cores is the temperature. In fact, what happens when you come from the bottom to the top the temperature decreases.

As a result when the temperature decreases there is a convection. As a result there will be movement of plate tectonics. So, this is what we are going to discuss in the next lecture . So, thank you very much for your kind attention and I will like to stop it here before we continue for the engineering seismology. Thanks.