Earthquake Geotechnical Engineering

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Lecture- 4

Engineering Seismology (Continued)

I welcome you again for this course on earthquake geotechnical engineering. And we are going to have today the fourth lecture on this course, which is related to engineering seismology. In fact, this is linked with the last lecture and it is in continuation of the third lecture, the topic on engineering seismology. So, little bit like in the module 1, we are at this like in module 1 and we are in the second chapter of the module 1 that is on engineering seismology. Here let us have the recap from the last lecture third. What we discussed we talk about introduction to engineering seismology, we talk about seismic waves which include body waves as well as surface waves and we also discuss in detail the internal structure of the earth.

Now what we are going to talk in this fourth lecture which is on engineering seismology itself. The first is plate tectonics. Like you know that when the earthquake, why the earthquake occurs? So, many people like when they say then there is a theory, this is called what we call the plate tectonic theory. And this is basically basic hypothesis that that plate tectonics is nothing but it is that the earth's surface consists of a number of large intact blocks which are called the plates and these plates move with respect to each other.

The earth has a layered structure, the surficial crust is underlined in turn by the mantle which is called the outer core or the inner core. And the temperature of each layer increases with that earth. As you go down it is expected that the temperature is going to rise, it is going to increase. As a result there is a large temperature gradient which is in the mantle cause the semi-molten rock to move slowly by convection. So, the difference in the temperature will have the movement and this is how the like you know the plates move.

In the case of this can be also understand that crust is broken into number of large plates and smaller platelets. Shear stresses on the bottom of these plates which is caused by lateral movement of the convecting mantle and the gravitational forces cause the plates to move with respect to each other. The earth's crust is divided into 6 continental size plates and about 14 subcontinental size. So, which you can see in this figure. What you have in this figure? On the right hand side there is a map of the world with the different plates, on the left hand side there is a list which is with the 6 major plates. So, you see like whole of the world could be divided into 6 major plates. One plate is African plate which is here, you have this African plate, this is the boundary for African plate. Then you have American plate, when we say American plate, it is both North American as well as South American plate. So, combined North American and South American plate will be called American plate. Then you have Antarctic plate, which is just below this line, Antarctic plate can be seen here.

Then Indo-Australian plate, which is combination of India's Indian subcontinent and Australia, so this is Indo-Australian plate. Then you have Eurasian plate which include Asia as well as Europe. So, this side and on another side of the globe it is if you combine both like you know that this is so Europe and then Asia, so Eurasian plate. Then you have one Pacific plate which is basically for Pacific Ocean which covers whole part of the Pacific Ocean. So, these different 6 plates are there.

Now within these plates, these are the major plates. There are minor plates are also like for example, within Indo-Australian plate there is a Indian plate. Similarly, you see Philippine plate, Cocos plate and then more of that these are there. So, here in this figure the major tectonic plates, mid-oceanic regions, trenches and transform faults of the earth. Here arrow indicate the direction of plate movement.

So, you could see that there are arrows, and they are showing that the direction of the plate movement is shown here. Continue with this. Relating movement of the plates causes stresses to build up upon their boundaries. When there is a movement within the plates, then stresses will be built and this stresses will build along the boundaries. As movement occurs, strain energy accumulates in the vicinity of these boundaries and this energy is eventually dissipated either smoothly or continuously or in a stick slip manner that produces earthquakes.

Coming to when we talk about earthquakes, then there are some geometric notations. So, like let me talk first figure and then we can come back here to understand on the slides. What you have when earthquake source is inside the earth? It is not on the surface. It may be quite deep. Shallow earthquake which is normally of around 10 kilometers in the depth while you have another like 600-700 kilometer deep earthquakes. Here there is a source of energy of earth is called focus or hypocenter. This you can say this is the point where earthquake attacks originate. Then immediately on the top of on the surface on the mother earth, the immediately vertically above is called epicenter. So, you could see epicenter. Now, on the earth we are not only always measures you know that our record on epicenter rather we could be measuring at some distance or at a site or observer is sitting here.

So, the horizontal distance between epicenter and this site is called epicentral distance while the vertical depth between epicenter and focus is called focal depth. This is kind of a triangular. The distance between the source and the site directly that is a diagonally that is called hypo central distance. So, you have in this triangle, one is focal depth, another is epicentral distance, another is hypo central distance. So, this is also explained further here.

So, when the seismic result from rupture of the rock along a fault, the point at which rupture begins and the first seismic waves originate is called the focus or hypo center of the earthquake. So, the focus of the hypo center is the same thing, whether we say focus or hypo center of an earthquake. That is the point of origin of an earthquake. All the fault rupture can extend to the ground surface, the focus is located at some focal depth or that is also called hypo central depth. So, we can say focal depth or hypo central depth that is the vertical distance between focus and epicenter of the earthquake which is on the top of the ground.

The point on the ground surface directly above the focus is called the epicenter as we discussed. The distance on the ground surface between an observer or site and the epicenter is known as the epicentral distance that is also discussed and distance between the observer and the focus is called the focal distance or hypo central distance that is in the diagonal direction. So, that the slanting this distance, so this will naturally normally if you have under the plane, so this is going to be the largest one hypo central distance or this is expected to be the larger one. So, this was about different notations used for earthquake. Now one of the important issue is to quantify the earthquake effect of the earthquake.

So, when you want to quantify the effect of earthquake, the best quantification can be done using what you call the size of an earthquake. Because it is expected that when the size of the earthquake increases, then the energy release will increase, and it will cause more destruction. And this is one of the important parameter and this size of an earthquake can be described in two different ways. One is called what we call earthquake intensity, another is called earthquake magnitude. And there is a quite big difference between earthquake intensity and earthquake magnitude.

So, when you go in the newspapers, then they talk about earthquake magnitude, but they say bhukam tivrita, bhukam ki tivrita. So, if we go literal meaning that is earthquake intensity, but whatever comes in the newspaper reports is not earthquake intensity rather they are reporting earthquake magnitude, but they are saying that bhukam tivrita. So that is not bhukam tivrita rather than it is magnitude of earthquake. Because intensity is a qualitative description of the effects of an earthquake at a particular location and this is evidenced by observed damage and human reactions at that location. So that means the intensity may vary from place to place.

Similarly, you expect that near the epicenter of an earthquake you will get more intensity as you go away from the epicenter, then intensity decreases. However, as for the earthquake magnitude is concerned, magnitude is a quantitative measure of the size of an earthquake, and this does not change with the distance or place from place to place. So, magnitudes is constant while intensity may vary with the distance. So that is the major difference. Normally earthquake intensity is represented in terms of what we call the Roman numbers.

Roman numbers are used to represent earthquake intensity that is like this first, second, third and so on. It may go normally up to 12th. While earthquake magnitude are represented by normally you have in the decimal points, single decimal points for example, M 5.7 magnitude earthquake or M 8.3 magnitude earthquake. So, this is the way how the earthquake magnitude is represented. So, what comes when an earthquake comes and you see in the newspapers that is earthquake magnitude that it have come magnitude of earthquake, but they write it like tivrita bhukam ki tivrita. So, if we go tivrita should be the intensity, but that is not intensity rather the magnitude of an earthquake. Continue with this. Now let us discuss in the detail both the points, that is first point earthquake intensity and then we will talk about earthquake magnitude. Earthquake intensity it is related to the size of an earthquake but is also influenced by other factors. The intensity is generally greatest in the vicinity of the epicenter of the earthquake. So as close as in the epicenter it is expected that its effect will be more, the earthquake effect will be more and that earthquake effect near the epicenter is highest. And the term epicenter is often used as a crude description of the earthquake size. So, whatever you have near the epicenter and that could be treated as some measure of earthquake size.

Continue with this. A plot of reported intensity in different locations on a map allows contours of equal intensity or isoseismal to be plotted. So, what is isoseismal? Isoseism are nothing but the contours which have the same intensity. Isoseismal, iso means similar, seisms means from seismic point of view that have that. So, if we plot then it will be isoseismal. Isoseismal maps can be used to describe what is called the spatial variation of intensity for a given earthquake.

Here this word spatial is coming and this spatial word is not particular, or you know like you say that like different rather it is related to space, it is not a general spatial, it is related to space. Spatial means which is related to space. So, the variation of this with the space of intensity for a given earthquake. Spatial map shows how the intensity decreases or attenuates with increasing epicentral distances and this are some of the examples of isoseismal map showing earthquake intensity.

There are two figures A and B. Figure A is from the 1968 Inangahau earthquake in New Zealand and figure B is from 1989 Loma Prieta earthquake in Northern California. And in both the cases modified Mercalli intensity scales that is called in the short MMI. MMI stands for modified Mercalli intensity scale. So, in the preparation of both the maps MMI scale has been used. In the case of New Zealand, you could see the intensity is going so high up to 10 which is naturally it is expected to be near the epicentral.

As you move away from the epicentral outer region the intensity decreases. So, you have 10, then 9th, 8th, 7th, 6th and 5th and then finally 4th is also here. So, these are the contours. So, when we say these are the isoseismal lines like for example this is one of the isoseismal line. That is a line on which the intensity remain constant then it will be called isoseismal.

As for 1989 Loma Prieta earthquake which occurred in California the intensity is given here. So here Roman number as well as the normal numbers are also written but we will prefer only the Roman numbers for to show the intensity. So, it is 8th magnitude, 7th magnitude, 6th and then you have, so here the minimum intensity of earthquake is, it is not magnitude, it is intensity of earthquake. It is 8 intensity, 7 intensity, 6 intensity.

So that is it, 6, 7, 8. You do not have the intensity 5 here because it was like maybe magnitude was high. So this was about earthquake intensity. Now popularly mostly MMI scale is used and this scale is in use since 1931 when it was proposed. Some of the salient features of this scale I will discuss, rest of the things you can go through it. So according to the MMI scale the earthquake intensity is divided into 12 zones.

First is the earthquake where you do not feel at all it, not felt. Of course if you have the instrument it may record little bit because there is some activity but normally it is not felt. So this is one thing. Then second category if you have the weak earthquake then it could be there.

Third, again weak earthquake. In the fourth you have the light earthquake. Fifth, moderate earthquakes and sixth strong and seventh very strong, eighth severe, ninth violent, tenth extreme and eleventh again extreme and twelfth is also extreme. So tenth onwards you have all three related to extreme events. Now in this MMI scale for different range to call it not felt what is on the right hand side in the table the explanation is given that what is the meaning of this. For example, severity, damage slightly in specially designed structures, considerable damage in ordinary substantial buildings as partial collapse, damage great in poorly built structures, fall of chimneys, factories, stacks, columns, monuments, walls etc. heavy furniture overturn. So, these are the different in this case categories of MMI. Depending on which category you are, you can select or other way if you know the characteristic then you can say that this should be according to this table, this should fall in this category. Next to ninth. Continuing with this, so this was all about plate tectonics and now we are going to talk about earthquake magnitude. At just now we said that earthquake magnitude is a parameter where the size of an earthquake is decided best or mostly based on this parameter.

And for measuring earthquake magnitude there are different types of magnitude scales are available normally four are popular one we are going to discuss about that little bit. The first one is most popular which you have seen in the newspapers also that is called Richter local magnitude that is called in the short in abrasion form M subscript L. So, this is called Richter magnitude based on the trace amplitude of a particular seismometer. Then you have surface wave magnitude which is denoted as MS that is amplitude of rayleigh waves. Then you have body wave magnitude where there is a amplitude of P waves.

So amplitude of P waves is measured for the determination of magnitude of earthquake. Similarly, moment magnitude it is not obtained from ground motion characteristic rather it is able to describe the size of an earthquake any earthquake. Now different types of magnitude let us first one is the most popular one which is called Richter local magnitude. In 1935 Charles Richter used a Wood Anderson seismometer to define a magnitude scale for shallow local distance as local as earthquakes. So, these are the shallow local earthquakes means distances should be less than 600 kilometer.

The Richter local magnitude ML is the best known magnitude scale, but it is not always the most appropriate scale for description of earthquake size because after certain scale it gets saturated that means after that point there is no difference comes in its measurement. So, that means Richter local magnitude can be used up to certain magnitude only. Then here the Richter local magnitude is denoted by M subscript L as you could see in this equation and the simple formula for finding the local magnitude is this log 10 multiplied by amplitude and then you have the reference on the right hand side minus after minus you have some point for the reference.

$$\boldsymbol{M_L} = \log_{\mathbf{10}} \boldsymbol{A} - \log_{\mathbf{10}} \boldsymbol{A_0}(\boldsymbol{\delta})$$

So, reference is here that this is low first of all it is on the scale of log 10 it is not log e exponentially and then they have put a function a naught delta. What is a naught delta is here the empirical formula a naught which provide a reference amplitude depends on the epicentral distance of the station delta.

So, its value of a naught will depends on delta a naught is a function of delta. So, and then you have the amplitude a so putting the value of the amplitude a you can find the Richter local magnitude for given amplitude as well as reference amplitude. So, in practice reading from all observing stations are average after adjustment with the station is physics corrections to obtain the ML value where ML is local magnitude. Now, continue with this you have the surface wave magnitude where the Richter local magnitude does not distance between different types of waves and the surface wave magnitude will require the surface wave basically. The surface wave magnitudes which were Gutenberg and Richter in 1936 is also involved is a worldwide magnitudes scale based on the amplitude of relative waves with a period of about 20 second. So, in this case so the surface wave magnitude like which is mostly used for most of the activities all over the world. In continuing with the surface wave magnitude, it is based on the maximum ground displacement or amplitude it can be determined from any type of seismograph. The surface wave magnitude is most commonly used to describe the size of shallow. The shallow means less than about 70 kilometer focal depth and distant which is further about 1000 kilometer. Moderate to large earthquakes so the basically here this is for the like you know that if you have an earthquake which is as a shallow depth which is 70 kilometer local depth and occurring at a distance more than 1000 kilometer then we can collect the information related to surface wave magnitude. Now, coming to body wave magnitude for deep focus earthquake surface waves are often too small to permit reliable evaluation of the surface wave magnitude.

So, as a result body waves are used. In case of the body waves magnitude this is for example Gutenberg 1945 is a worldwide magnitude scale based on the amplitude of the first few cycles of P waves which are not strongly influenced by the focal depth. So, those like which are not influenced by the focal depth in that case we can use this worldwide magnitude scale on the amplitude of the first few cycles. Continuing with the body waves, body wave magnitude can also be estimated from the amplitude of the one second period higher mode rayleigh waves. The resulting magnitude MB is commonly used to describe intraplate earthquakes. Continuing with moment so we have discussed two types of like you know the magnitude one is surface wave magnitude and then body wave magnitude.

Now, we are going to talk and third is moment magnitude now we are going to talk about moment magnitude third one. As the total amount of energy released during an earthquake increases however the ground motion shaking characteristics do not necessarily increase at the same rate. For strong earthquakes the measured ground shaking characteristic become less sensitive to the size of the earthquake than for a smaller earthquake. So, this is true like if you have like the large size of earthquake then the measured ground characteristic will not be so sensitive but if you have a smaller sized earthquake then even some of the parameters will be much required. So, the point where you cannot use a scale beyond a certain magnitude that is called saturation.

So, here this slide suggests the how saturation I have reached here for different magnitude scale. So, in this slide on y-axis you have the magnitude on x-axis you have the moment magnitude. So, you see there is a line with local magnitude here solid line this is not the part here. So, this solid line is for magnitude for what we call the local magnitude, but it gets saturated very soon. Then you have another magnitude which is called surface magnitude MS which is given by this dot line and then you have body wave magnitude which is given by this MB and MB here.

And then finally you have a moment magnitude. So, moment magnitude is denoted by Mw which is here and then you have Mjma also which is jma stand for Japanese metrological agency. In this slide jma is nothing but Japan metrological agency. Agency like it is kind of like our IMD in our country jma is like this. Now, after discussing about the intensity and magnitude of earthquake let us talk a little bit about the energy release. The size of an earthquake depends on the amount of energy release and the total seismic energy release during earthquake is often estimated from the relationship Gutenberg and Richter.

So, there is a relationship which is given by Gutenberg and Richter in 1956 and this relationship is here that logarithmic of E where E is same as E stand for energy here. So, E capital E is for basically energy. So, this energy in the log scale this have a constant 11.8 and then 1.5 ms. Here ms is nothing but surface wave magnitude. So, you could see that as the ms increases the energy release will also increase which is expected also. Continue with the earthquake energy. Earthquake magnitude scales are logarithmic hence a unit change in the magnitude will correspond to about 10 times change in the magnitude parameter that means ground motion characteristics or seismic moment. The energy which is released by an earthquake is related to magnitude in such a way that a unit change in the magnitude will correspond to a 32 times change in the energy. So, as a result for one of the example a magnitude 7 earthquake therefore would release about 1000 times the energy of magnitude 5 earthquake.

So, you may have 5 magnitude 1000 earthquake that will be equivalent to a single earthquake of 7 magnitude. So, when you increase the magnitude from 5 to 6 it is 32 times when 6 to 7 then again, another 32 times. So, 32 into 32 will be more than 1000. So, that is the case here. So, thank you very much for your kind attention. Thank you.