Geotechnical Earthquake Engineering

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Module - 4

Lecture - 12

Strong Ground Motion (Contd…)

Let us start our today's lecture on this video course Geotechnical Earthquake Engineering. Let us look at the slide here on this course of geotechnical earthquake engineering; we were going through module 4 that is strong ground motion. Within module 4 in the previous lecture we have discussed about how to estimate various sizes of earthquakes that is whether it is intensity scale or magnitude scale.

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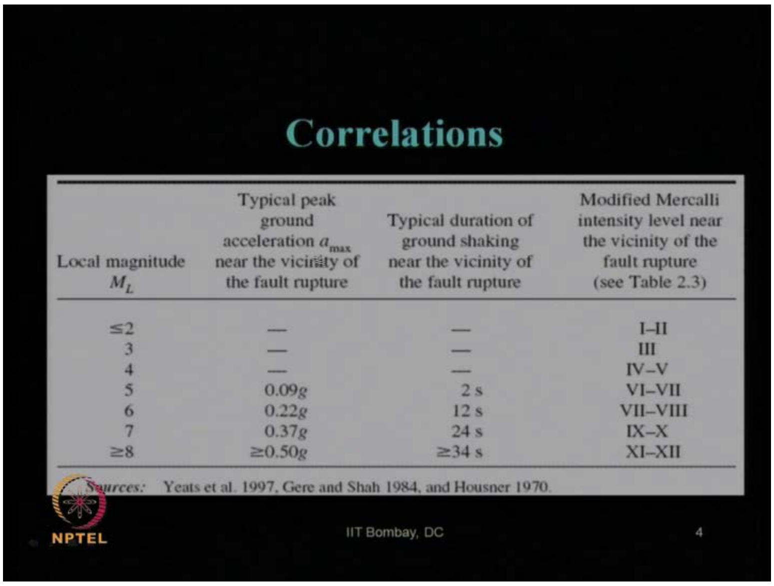

Local magnitude M_L	Typical peak ground acceleration a_{max} near the vicinity of the fault rupture	Typical duration of ground shaking near the vicinity of the fault rupture	Modified Mercalli intensity level near the vicinity of the fault rupture (see Table 2.3)
≤2	—	—	I–II
3	—	—	III
4	—	—	IV–V
5	0.09g	2 s	VI–VII
6	0.22g	12 s	VII–VIII
7	0.37g	24 s	IX–X
≥8	≥0.50g	≥34 s	XI–XII

A quick recap of what we have learnt in the previous lecture. We have seen the correlations between local magnitude or Richter magnitude and the M M I scale or that is modified Mercalli intensity scale, and corresponding typical peak value of the ground acceleration and typical duration of ground shaking as given by these researches.

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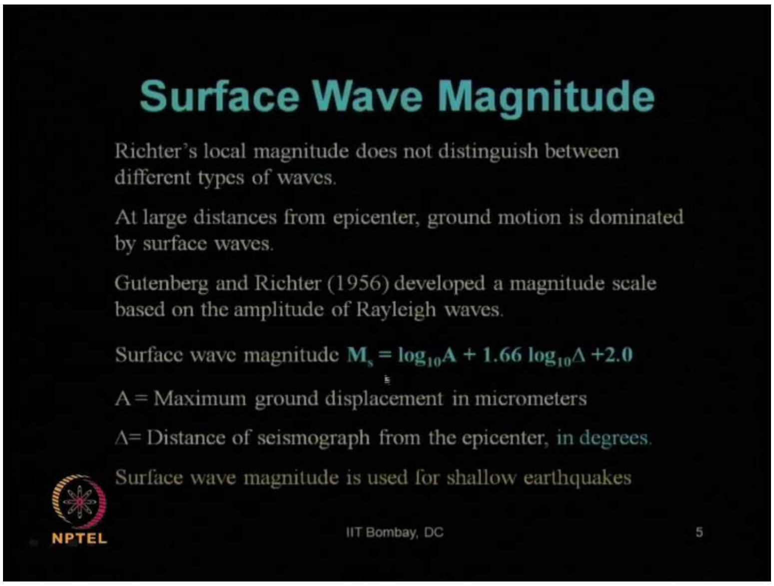

Then we have discussed about the surface wave magnitude, and we have seen what is the proposed equation by Gutenberg and Richter in 1956, how to estimate the surface wave magnitude, knowing the maximum ground displacement, then distance of seismograph from the epicenter; knowing these two parameters, we can estimate the surface wave magnitude at any place for a typically shallow earthquakes.

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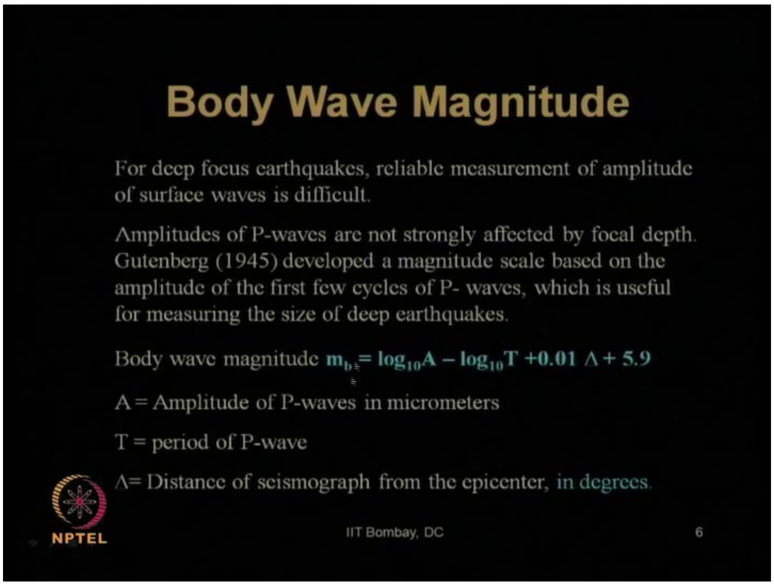

Whereas, for deep earthquakes, we have seen another scale that is body wave magnitude, and Gutenberg in 1945 gave this equation, how to estimate the body wave magnitude knowing the amplitude of P-wave parameters in micrometer unit, T is the period of the P wave and delta is the distance of the seismograph from the epicenter. And as we have mentioned this body wave magnitude is mostly used for deep earthquake.

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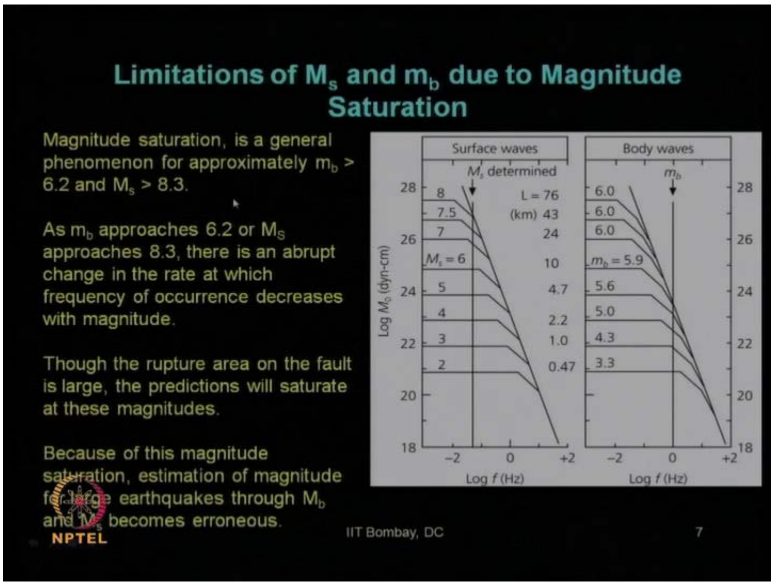

Then we have also seen what are the major limitations of using this surface wave magnitude, and body wave magnitude scale, because of the magnitude saturation that is at high frequency, they tend to get saturated and the typical value that is for body wave magnitude more than 6.2 and surface wave magnitude more than 8.3, they tend to give abrupt result or in accurate result. So, that is why when we are observing any data beyond this points, we have to be very careful about the use of these two scales.

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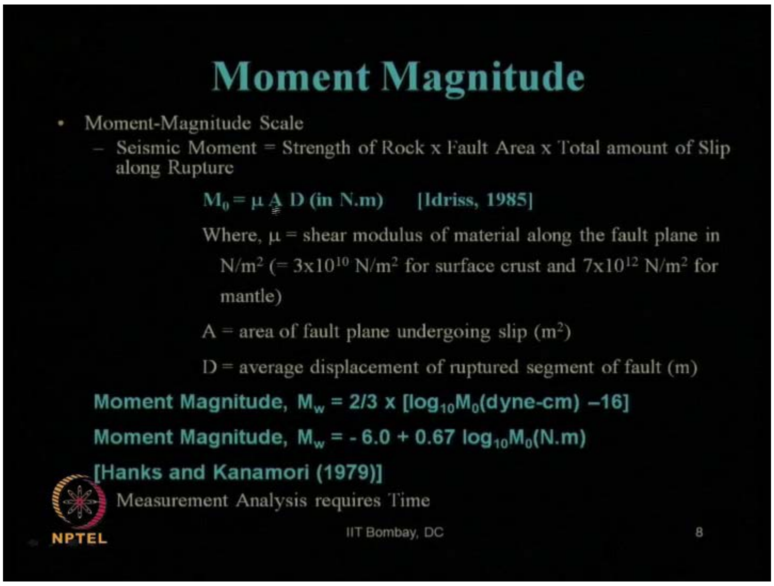

Then we have seen the best technically best or correct scale to estimate the earthquake magnitude is seismic moment magnitude scale. So, to estimate the seismic moment magnitude first parameter we need to estimate is the seismic moment, which is proposed by this equation, where mu is the shear modulus of the material of the fault plane. And for surface crust that is when we are considering shallow earthquake we have to use this value of mu and when we are considering the deep earthquake then the value of mu should be like this for the mantle. And A is the area of the fault plane which is undergoing the slip in meter square unit and D is the average displacement of the ruptured segment of the fault in meter unit.

Then we have seen the equation of moment magnitude based on this seismic moment estimation was proposed by Hanks and Kanamori in 1979 using these expressions. Both are same expressions leading to same value of M W only difference in the two equations is the unit of this seismic moment M naught. In this equation M naught has to be in dyne centimeter unit whereas, in this equation M naught has to be in Newton meter unit. But as we can see this estimation though it is accurate, but it requires time to analyze because of the proper estimation of this A parameter D parameter etcetera to estimate the seismic moment and hence the moment magnitude.

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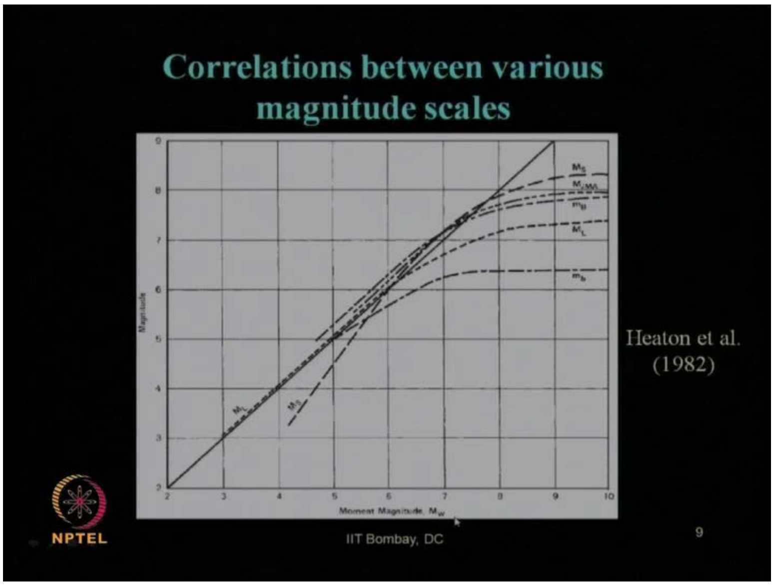

Heaton et al in 1982 proposed these correlations between various magnitude scales with respect to the moment magnitude here and these are various other magnitude scale. As we can see this dark solid line is the line of equality, we can see at higher magnitude all the other scales like the surface wave magnitude, body wave magnitude, Richter magnitude tend to saturate. So, that magnitude saturation problem can be seen easily here, but in absence of any particular data suppose at a location you are notable to estimate M W quickly in that case you can use your local or Richter magnitude scale like M L; and use this correlation chart to obtain the corresponding value of your moment magnitude for further design or calculation or analysis.

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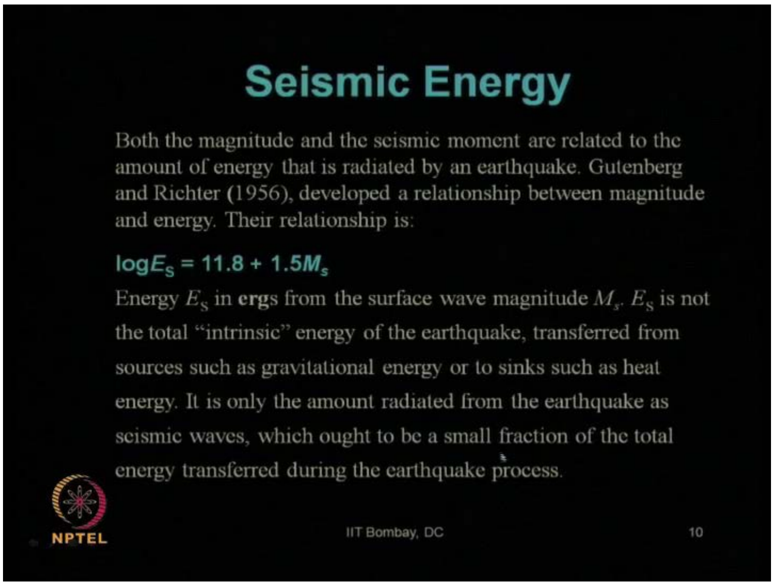

Then we have also seen how to estimate the seismic energy, which is getting released during an earthquake. So, Gutenberg and Richter in 1956 proposed this equation where energy E S is in the unit of ergs and M S is the surface wave magnitude and it is mentioned that, it is not the total intrinsic energy which is getting a emitted during an earthquake. Because there are several losses of the energy, which cannot be estimated through this expression.

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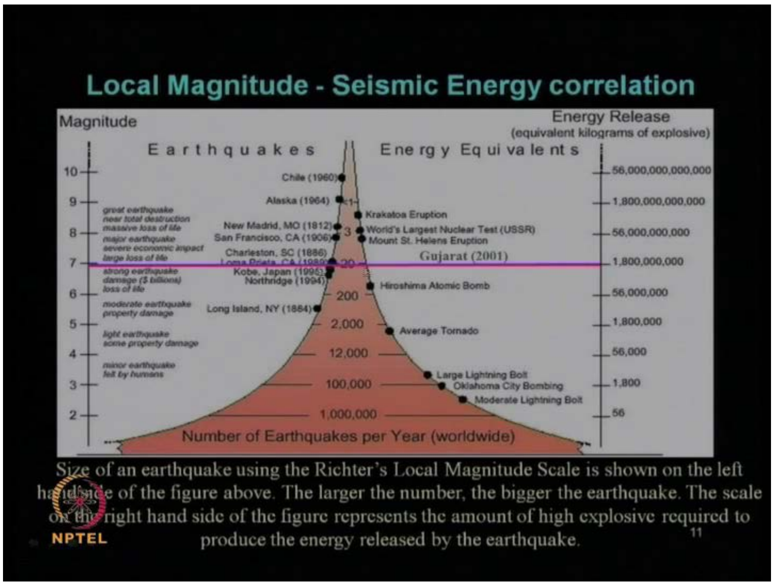

Then we have seen a compression between the energy released during an earthquake and energy released during a bombing activity. So, you can see these are the magnitude earthquake scale and these are the energy released for that how much kilogram of explosive one need to burn. So, it can be seen that huge amount of explosive is required if we want to get similar energy to be getting released which is getting released during an earthquake magnitude given over here. And these are number of earthquakes per year, obviously, higher magnitude of earthquake they are occurring lesser in numbers of worldwide and smaller earthquakes say below 3 or so they are several 100s and 1000s of earth quakes which are occurring every year all over the world.

Then we have also seen an example problem through that problem, we have seen how to estimate various earthquake magnitudes like, surface wave magnitude, then the Richter magnitude, then the using the correlation how to estimate the moment magnitude etcetera we have seen through the example problem. Now, let us start our today’s lecture in today’s lecture we will start with the strong ground motion their discussion and the estimate etcetera.

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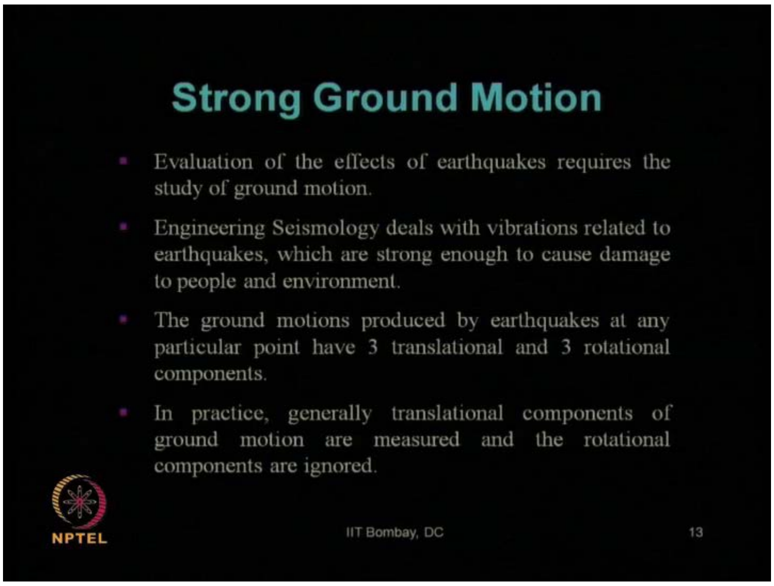

So, evaluation of the effects of earthquake it requires the study of the ground motion and engineering seismology that deals with vibrations, which are related to earth quakes which are strong enough to cause the damage to the people structures and environment. So, the ground motions, which produced during an earthquake at a particular point they will typically have 3 translational component and 3 rotational components. So, all together there can be 6 components. So, 3 translational ground motion and 3 rotational ground motion.

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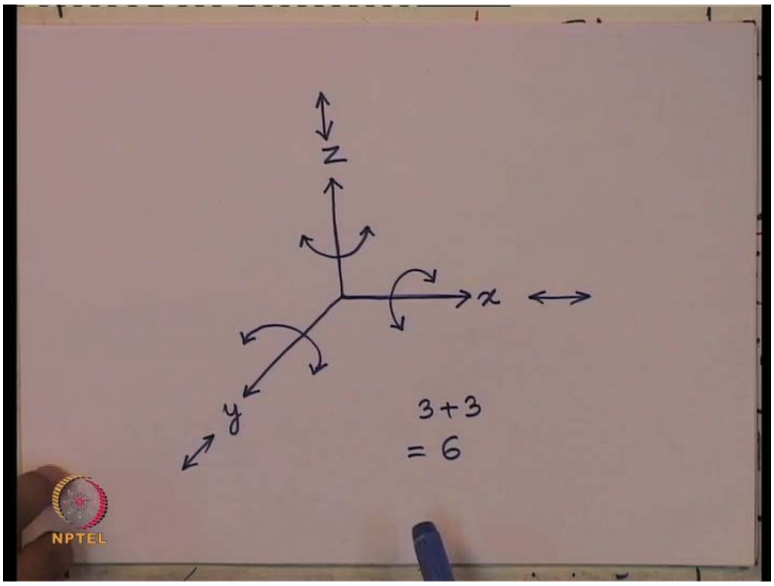

If we see the picture over here, if we can draw in the three dimensional space, the variation of this see these are our axis system say x so this is y and this is z. So, we can have the horizontal acceleration in x direction like this, then we can have another horizontal acceleration in y direction like this, then we can have vertical acceleration translational in this direction. So, these three are the translational ground motion, which one can record through seismograph. But in addition to that during an earthquake there may be other accelerations, like this is the rotational acceleration about x axis. There can be rotational acceleration about y axis as well as there can be a rotational acceleration bout z axis like this. So, total 3 rotational plus 3 translational, so 3 plus 3 total 6 types of ground motions one can expect to estimate during an earthquake.

It is not necessary that always all the 6 components will be present during an earthquake, there may be some combinations of them may present and some may not be present, but these are the possible all 6 directional ground motion, which may occur during an earthquake process. So now, let us look at here what is mentioned over here, that in practice generally or typically the translational components of ground motions are measured and the rotational components are ignored. Because many researchers have found out that the contributions coming from the rotational seismic accelerations are comparing to the translational seismic acceleration are lesser. So, that is why rotational components manier times it is not measured. But translational components of course, they are very important as we have seen in earlier that 2 horizontal like north south direction and east west direction of ground motions we measure and also the vertical ground motion we measure.

These 3 translational motions are accurately measured at any seismographic location, but rotational components at some places those are can be measured, where very sophisticated instruments are available, but otherwise the rational components are ignored in practice at various places. Let us look at the slide over here, so that why it is said that translational components are generally used, but rotational components are typically ignored.

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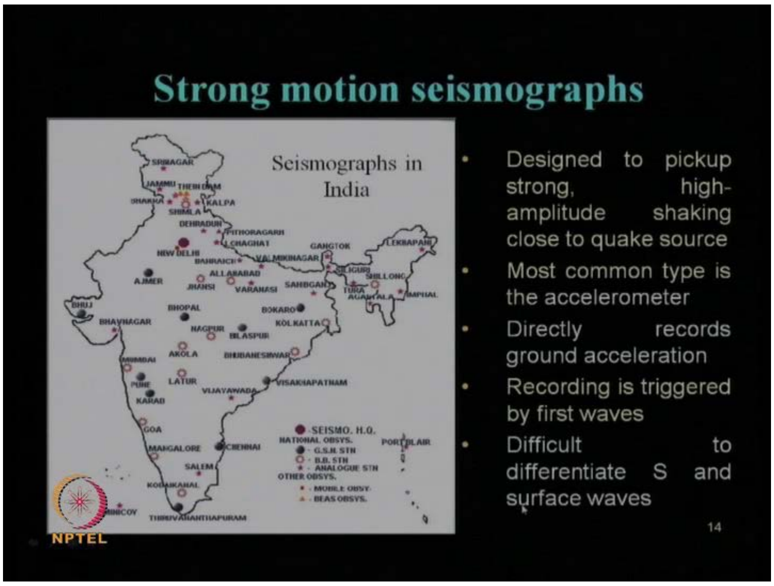

Then we want to see the strong motion seismographs located at various parts of India, so these are typical map of seismographs they are of course, several new seismographs came up this a map of about two thousand. So, these are designed to pick up the strong high amplitude shaking closed to quake source most common type is the accelerometer that is through using the accelerometer we can estimate the strong motion. They directly records the ground acceleration, and recording is triggered by first waves, that is first P wave then followed by S wave and surface wave. And as we have already discussed in detail it is difficult to differentiate between S wave and surface wave, because of their velocity ranges we have discussed this things. So, this is the typical map of locations various seismographs at several parts of India.

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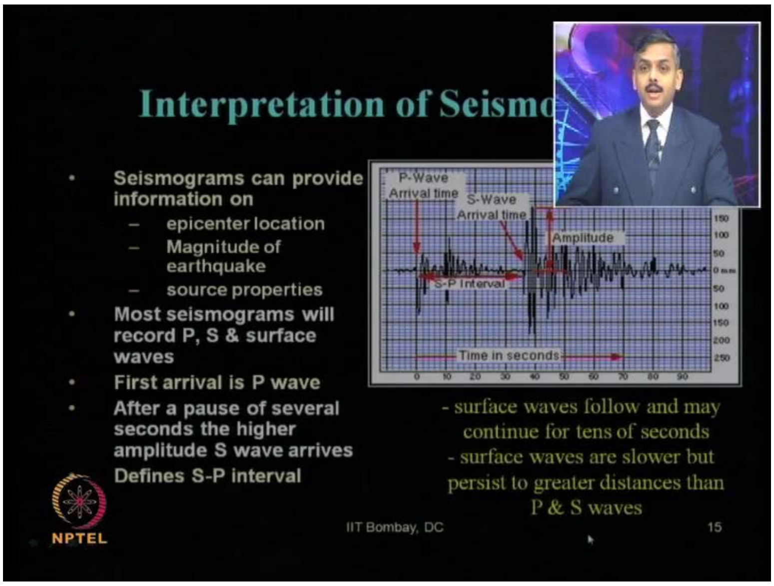

Now, how to interpret that seismogram that is the data which we collect from the seismograph is nothing but called seismogram as we already discussed that. So, this seismogram after obtaining this we need to interpret it. So, seismogram can provide information on epi central location, that we have seen how to estimate the epicenter of an earthquake using this seismogram data. So, this seismogram data will be very useful to interpret or to obtain the earthquake epicenter, but not at one location of course, we need minimum 3 locational seismographic data or the seismogram data.

From these, we can also estimate the magnitude of earthquake, that we have seen like using standard wood Anderson seismograph one can estimate the Richter scale using this amplitude value maximum value; and the arrival time difference between S and P using that equation of Richter magnitude we can estimate the Richter scale of magnitude or local scale of magnitude.

So, that is why magnitude of earthquake also can be obtained using this seismogram. Also the source properties we can say depending on the time difference between the arrivals that is how much time it is taking based on the layer through which the material through which it is propagating. So, most seismograms will record P wave S wave and surface waves provided they are not located in the shadow zone of either this P wave or S wave. And the first arrival of the wave as we already know is the P wave.

Now, after a pause of several seconds the higher amplitude S wave will arrive, so amplitude wise also if we see from this seismogram, what we can interpret the P wave amplitude and S wave amplitude are much difference S wave amplitude will be much higher. Compare to that even the surface wave magnitude amplitude will be higher than that. And we can obtain the time difference between the arrival time of this S wave and P wave, so this S minus P interval of time. So, that is very useful as we have seen for an obtaining epicentral location as well as magnitude of earthquake. So, surface waves follows and may continue for 10s of seconds as you can see from this picture, surface waves are slower, but persist to greater distances than P and S waves.

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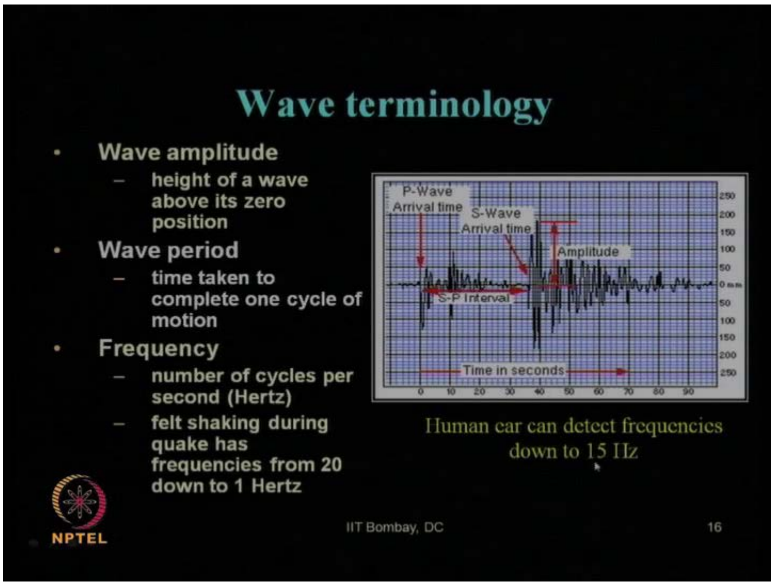

Now, various wave terminologies, what typically we use generally these are commonly known to us like wave amplitude, amplitude is nothing but the height of a wave above its 0 position. So, if it is the 0 position, what is the height maximum height, so that is called amplitude. What is wave period? Wave period is nothing but time taken to complete on cycle of motion, so suppose starting from here it takes this much time to complete one cycle is called wave period. What is frequency? Wave frequency is number of cycles per second, it is expressed in the unit of hertz, it is felt shaking during quake has frequencies from 20 hertz to 1 hertz. So, this is the typical range of earthquake frequency, you can note down this is important to note down that, typical range of earthquake frequency is between 1 hertz to 20 hertz.

Actually, I will say it is more closer to 1 to 4 hertz or 1 to 3.5 hertz. Later we will discuss more on these issues; where as I will try to correlate this problem to you to another dynamic problems, suppose what are the basic difference of frequencies. When we talk about the design of machine foundations or the machines, which are running at various frequencies there frequencies ranges are very high compare to this earthquake frequency. Also suppose, if we want to handle the problem of design of sub grade below a railway track, then we have to consider the dynamic frequency, which is caused by the movement of the railway.

So, in that case also the frequency will be of very high range much above 20 hertz. So, when we are handling different dynamic problems, we have to be very careful about this parameter that is what are the different frequency ranges of the concerned problem, because depending on that the behavior etc will of course, change corresponding to different dynamic problem. So, as for as our earthquake is concerned, you can see it is between 1 hertz to 20 hertz and mostly the shallow earth quakes, which commonly we see are commonly cause the major destructions will be between 1 to 3.5 or 4 hertz. Whereas, human ear can detect the frequency from 15 hertz, so that is why manier times it will not be possible to detect the earthquake sound by Human ear.

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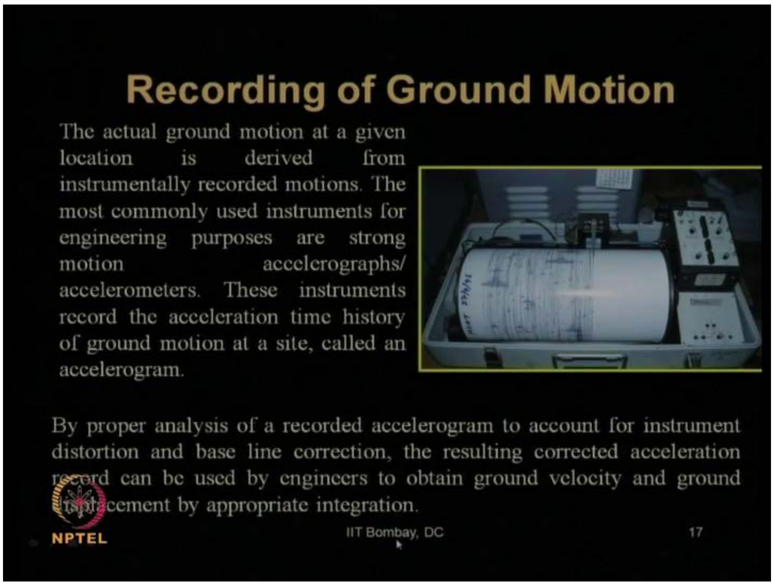

Recording of the ground motion, you can see the actual ground motion at a given location is derived from instrumentally recorded motions, so this instrumentally recorded motions. The most commonly used instruments for engineering purposes are strong motion accelerographs or accelerometers like this. These instruments record the acceleration time history that is with respect to time they record the accelerations of a ground motion at a site, these are called accelerograms.

So, by proper analysis of a recorded accelerogram to account for instrument distortion and base line correction, the resulting corrected acceleration record can be used by engineers to obtain ground velocity and ground displacement by appropriate integration. Because as we know as we are measuring the acceleration, if we integrate that acceleration with respective to time first we will get velocity and further, if we integrate we will get the displacement. So, velocity variation as well as the displacement variation with respect to time also can be obtained from this recorded ground motion data.

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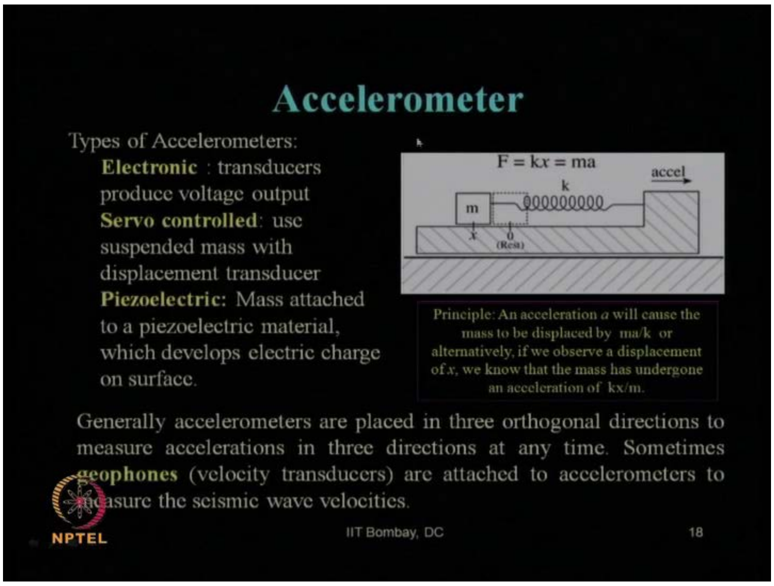

So, what is the basic principle on which an accelerometer works let us see, there are basically three types of accelerometers, one is called electronic accelerometer, another is called servo controlled accelerometer and the other one is called piezoelectric accelerometer. In electronic accelerometer that transducers, which are used they produce the voltage output. And based on that voltage output, we in the change of the voltage output will be calibrated and correspond to some value of the accelerations with respect to time. Where as in servo controlled it is it uses suspended mass with displacement transducer, so earlier whatever picture we have seen for the accelerometer in pervious lectures that is nothing but servo controlled. Where a suspended mass were hanging on the tip of that graphite or the pencil kind of arrangements were provided which records through the shaking of the ground various acceleration versus time record.

So, that is nothing but servo controlled piezoelectric it is the mass attached to a piezoelectric element different type of piezoelectric elements are there, that corresponding to that mass will be attached which develops the electric charge on the surface of this piezoelectric material and that creates the recording of the accelerometer, when there is a shaking.

So, generally accelerometers are placed in three orthogonal directions, as I have already mentioned three orthogonal direction, like two horizontal and one vertical to measure the accelerations in three directions at a time. And sometimes the geophones, geophones are nothing but velocity transducer. So, these are acceleration transducers were as geophones are velocity transducers. Those are also attached to the accelerometers to measure the seismic wave velocity that is along with the acceleration profile with respect to time; one can easily measure the velocity of various seismic waves; which are arriving at the station of where the seismograph is located through use of this geophones.

Now, what is the basic principle on which this accelerometers work? Let us see this is from another basic course on this soil dynamics, which the video record is available with NPTEL. In that course, we have seen that the basic concept of a single degree of freedom system under the vibration, you can see this is the mass m this was initially at this position at rest with 0 location. It was initially at this 0 location at rest, it is connected through a spring with spring constant k. And when an acceleration occurs to this block stationary block it is nothing but this is your accelerometer which is recording and this is the block, which is located on the ground surface where it is going through a shaking. So, whenever there is a ground moment or accelerations coming due to the earthquake at an instant, what is happening? If acceleration is in this direction abusively, your mass will move in the other direction it is common physics as we know, so mass has moved by certain distance say x.

So, what will be the force coming on this body that is nothing but k times that is the spring force which has to be equal to this mass times acceleration to maintain the equilibrium right. So, mass times acceleration, so the principle that is an acceleration this a, we need to measure that value right. So, an acceleration a will cause the mass to be displaced by an amount.

So, how much displaced this x is occurring that is nothing but m a by k. So, m a by k by this amount this mass will get displaced all or alternatively we can observe a displacement suppose we measure a displacement x. How to convert it to acceleration, when we know the mass which has under gone through the acceleration of, so the acceleration in that case will be k x by m. Like in this case you should know the spring constant which of course is known you are using it here mass of your suppose you are using here servo control that suspended mass, mass is known to you. Now, you have recorded how much value it has displaced through, so you can measure the acceleration am I right.

So, this is the simplest way by which one can measure the acceleration. So, once you know acceleration at one instant of a time. So, abusively with respect to time, you can known the variation of this acceleration. So, either you record the displacement or you record the acceleration with respect to time recorded through this moment of your suspended mass in this case servo controlled accelerometer. So, this is the principle on which any accelerometer works, this is the basic fundamental principle based on the single degree of freedom system mass spring model.

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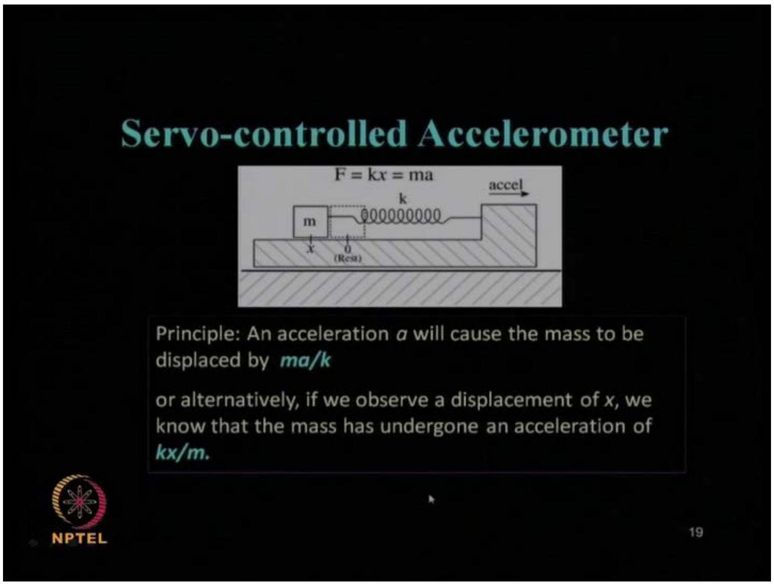

So, we can see over here servo controlled accelerometer, we have just now we have discussed in detail, either the acceleration can be measured by this. If acceleration is known the amount of displacement can be measure like this or the displacement is known acceleration can be measured like this, so they are interrelated through this expression.

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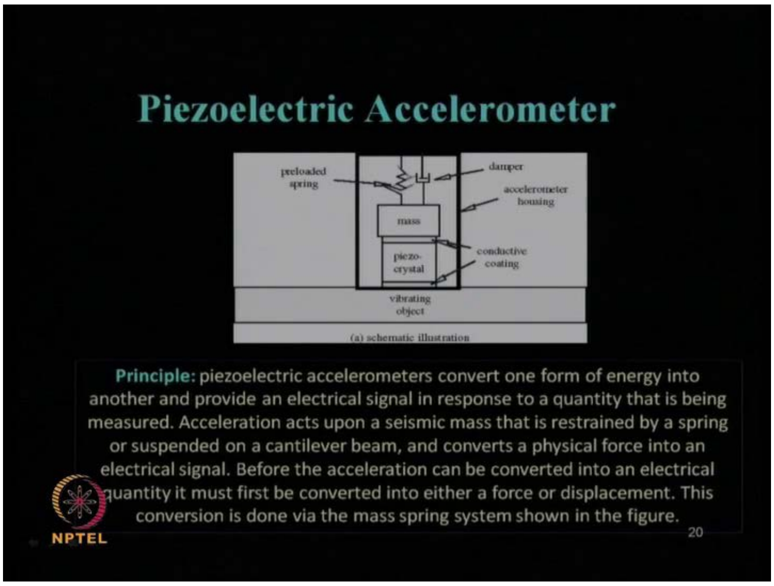

For piezoelectric type of accelerometer, you can see over here in this picture that there is a pre loaded spring a damper, this is the housing of the accelerometer, and these are conductive coating, this is the piezoelectric crystal and mass, and this is the vibrating objects which vibrates. So, on which principle it works, so piezoelectric accelerometers they convert one form of energy into another; and provide an electrical signal in response to a quantity, that is being measured. So, whatever vibration it comes that vibration it passes through a electrical signal, because it is passing through this piezoelectric material. And acceleration acts upon a seismic mass that is restrained by a spring or suspended on a cantilever beam.

So, this is the restrained on a spring, this mass and converts a physical force into an electrical signal. So, that moment is getting converted from this physical force to an electric signal through this piezoelectric material. Before the acceleration can be converted into an electrical quantity, it must first be converted into either a force or a displacement; that is the basic fundamental as we have already discussed that. Either you convert it to a force or you can estimate the force or you convert it to displacement. Once you do that, then you can find out the acceleration and that acceleration can be converted through this piezoelectric signal. And this conversion is done via this mass spring system shown in the previous figure as we have already discussed.

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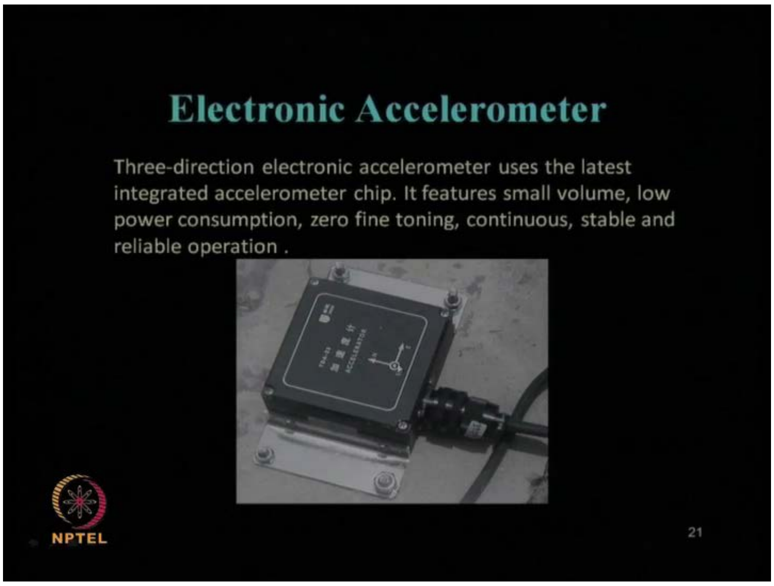

Another type of accelerometer is electronic accelerometer which looks like this, so in this case the three direction electronic accelerometer they uses the latest integrated accelerometer chip. So, in this case all the three directions are recorded together as you see from this. So, this is north direction, east direction and this is the upper vertical direction, all the three through a chip they record. So, it features a small volume obviously, this is a very small compared to your suspended servo controlled type or the other piezoelectric type. And here low power consumption 0 fine toning, because it is already tuned continuous, there is no disruption and stable and reliable operation, that is why manier places the senders electronic accelerometers are used.

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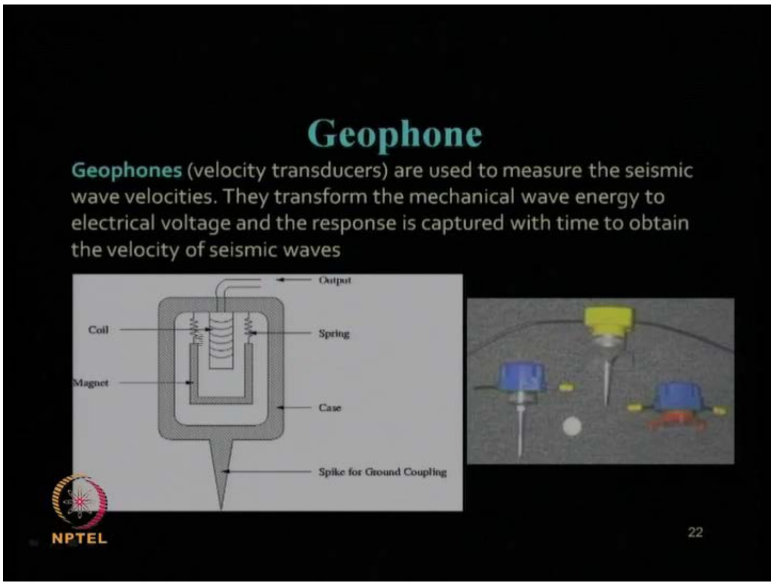

Coming to the measurement of this velocity seismic wave velocities as we have mentioned, geophones are commonly used which are nothing but velocity transducers. So, this is the picture which shows various geophones and one geophone is enlarged over here, these are used to measure the seismic wave velocities. So, they transform the mechanical wave energy to electrical voltage and that response is captured with respect to time to obtain the velocity of seismic waves. So, we will discuss, when we will talk about the field data of various seismic wave, how this geophone records what value and from that how we can estimate the various seismic waves.

So, this is how a geophone will looks like, this is the output comes out from this, inside there will be spring arrangement, coil arrangement a magnet over here and this is the casing; and this spike is for ground coupling that is you can put this insert it on the ground surface like this.

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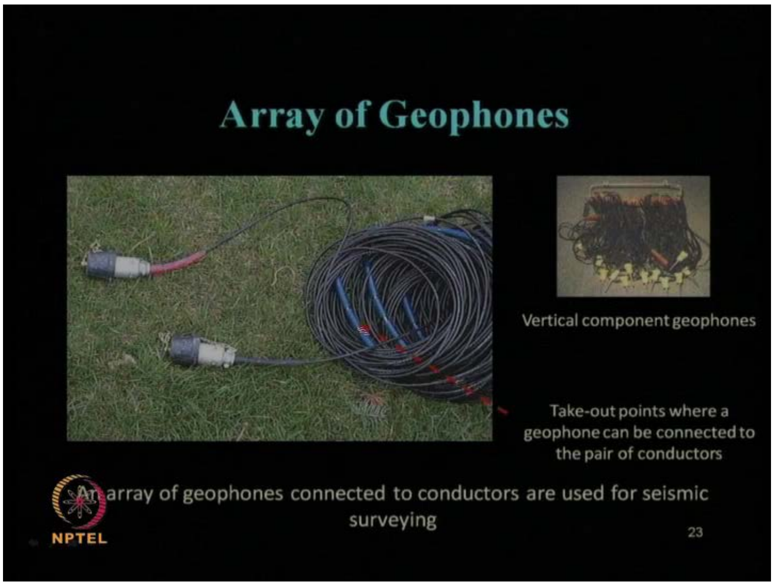

These are showing array of geophones, you can see over here these are array of geophones an array of geophones connected to the conductors are used for the seismic surveying like whether seismic refraction or seismic reflection technique, we use this geophones and these are vertical component of the geophones. These are takeout points, where as geophone can be connected to the pair of conductors through this points.

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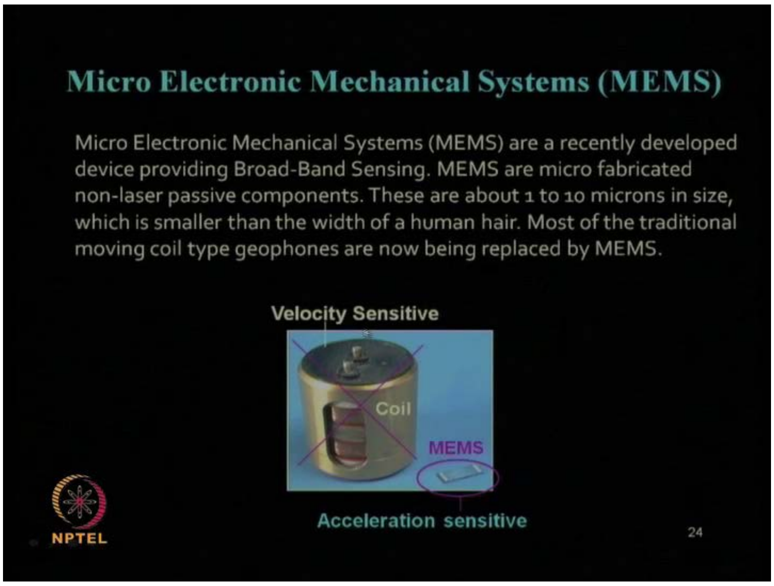

Coming to another latest type through which these are measured are called MEMS what is MEMS micro electronics mechanical systems. These are latest development in this area. So, microelectronic mechanical systems or MEMS in short they are called, these are recently developed device providing broad band sensing. So, MEMS are micro fabricated non laser passive components and these are about one to ten microns in size, so very small you can see these are looking like a small chip, which we use for our say mobile or other electronic gadgets and devices.

Where as the olden days methodology for the velocity and measurements are as big as like this, so you can see the comparison between the olden device and the latest MEMS technology, which is very smaller and but very accurate enough. So, and it is easy to control and handle as well. So, which is smaller than the width of an even human hair, you can see even that much thin, so most of the traditional moving coil type geophones are now being replaced by these MEMS. So, these are conventional coil type geophones now a days getting replaced by this latest equipment, which is instrument we call as MEMS. So, these are very acceleration sensitive and where as the earlier geophones were velocity sensitive.

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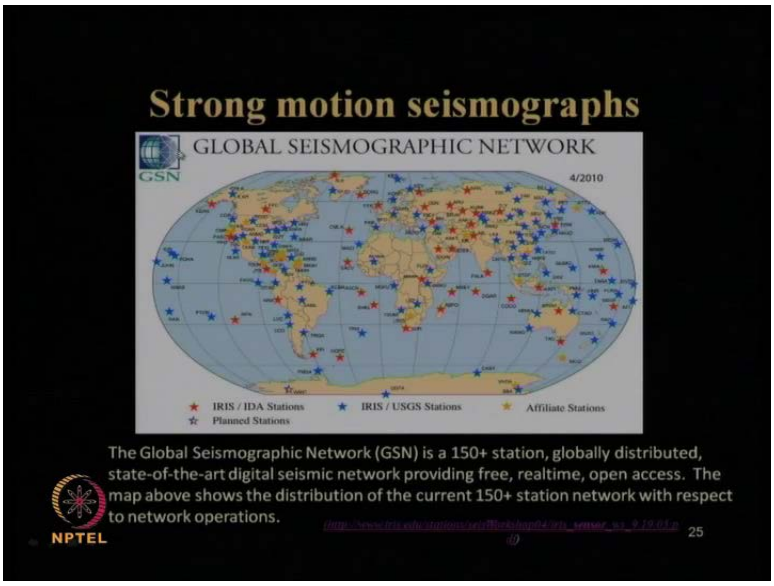

Now, this picture shows the various strong motion seismographs, which are more than 150 stations as provided by this Global Seismographic Network, GSN. You can see the reference over here for this GSN. So, this global seismographic network GSN is more than 150 stations globally distributed all over the world. And state of the art these are showing state of the art digital seismic network providing free real time open access.

So, you can get real time seismic monitoring through these points all over the world, whenever any earthquake is accruing any point on the globe. So, the map above shows the distribution of this current more than 150 stations network with respect to the network operations. See you can see these are IRIS or IDA stations the red colored dots then this one shows planned stations, this one shows IRIS or USGS stations, this blue color stars and this yellow or orangish yellow color stars are showing affiliate stations. So, that way all over the world this data your recording real time continuous monitoring of any earthquake. And remember these are freely available, so if you go to this site you can get this data continuous data worldwide.

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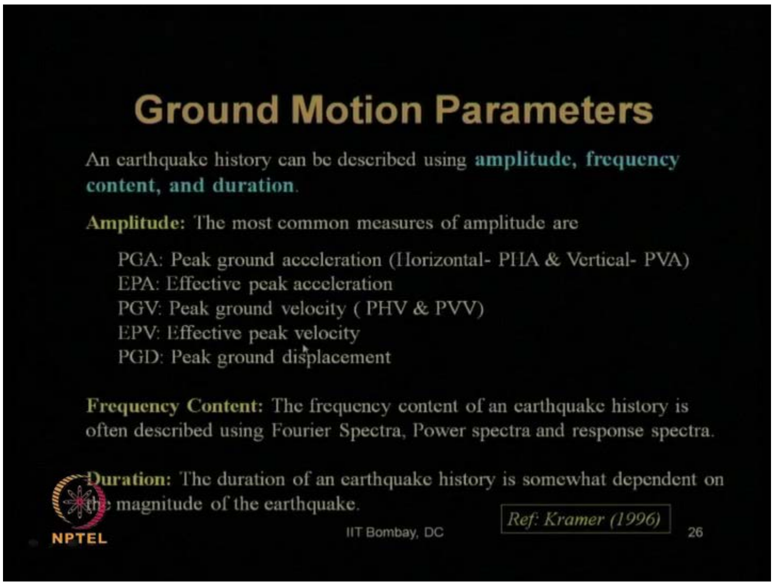

Now, coming to the ground motion parameters, what are the various ground motion parameters and why they are important what are their uses let us see over here. So, any earthquake history can be described using three major parameters. These are three major ground motion parameters one is called amplitude, another is called frequency content and another is called duration. You remember why these three are the major ground motion parameters, why not one because typically Layman or common people are having tendency or an idea that a large magnitude or a large amplitude of an earthquake will be more damaging, but it may not be always the case.

It may so happen that say at one place a large amplitude of earthquake occurred for a small duration whereas, compared to that at another place of similar nature say moderate earthquake occurred for a very long duration. Then what can be more damaging for our civil engineering structures? In most of the cases you will find it depends on several other parameters of course, but most of the cases we will see that the one which was lasting for a very long time or duration; that may be more damaging to our structures than the one which was having a very small duration. Though that was having larger amplitude than the other one, why it is so? Because our structure it needs some time to respond to this earthquake motion, whenever earthquake waves arrives at ground surface in the form of surface wave and then passes through this super structure or the corresponding foundation and substructure etcetera.

So, it is not only that amplitude which matters amplitude of course, it matters, but along with amplitude it requires, how much frequencies containing in that earthquake; how much duration of that earthquake depending on that it will behave, it will get some time to respond to that behavior. So, even if a very peak or very large magnitude occurs for fraction of a second or for may be one second; that may not be that much damaging, if a moderately small amplitude occurs for a long duration say 30 seconds. So, that is why as an example we can say not only the amplitude is important, but along with amplitude this frequency content of an earthquake as well as how long it is lasting that is the duration of earthquake is also important. So, these three parameters together decide, how much damage of an earthquake can cause to a structure.

So, a ground motion depends on all these three major important parameters not the one amplitude. We can take a common practical example like the Japan earthquake of 2011 in March 11, that was Tohoku earthquake. Its magnitude was high enough yes, its amplitude was high enough, but more than that why it was more damaging because it lasted for a longer time. Even if I give another good example of this importance of various three types of ground motion parameters, I can cite the example of September 2001 earthquake of Sikkim in India.

So, that Sikkim earthquake, the amplitude or magnitude was not that very high, it can be called as a moderate or moderately high magnitude of earthquake depending on its range. But what was the problem the major problem was its duration was pretty long it lasted for more than about 30 seconds. So, that was the reason why it causes more damage to the structure compared to a large magnitude, which probably occurred for a small duration.

So, that is why the most important ground motion parameters, if somebody ask you it is not only the amplitude, we always tell all these three parameters that is amplitude frequency content and duration. Manier times common people want to get rid off or are not, so much concerned about this frequency content and duration. So, as a technical person we know now that all these three parameters are important, so with time we will see much more about all these three major parameters.

So, amplitude the most common measures of amplitude are either PGA, that is called peak ground acceleration it can have three components translational as I said two horizontal, which are called PHA that is Peak Horizontal Acceleration and Peak Vertical Acceleration PVA, these are the commonly used short abbreviations. PGA is a very commonly used abbreviation for Peak Ground Acceleration EPA is called Effective Peak Acceleration, what is effective peak acceleration?

I will give the definition very soon; it means not only that one single peak will decide about your earthquake nature, it may occur just for fraction of a second. It may not be that important, but whatever lasted for a couple of seconds or for a sufficient duration, that is can be an effective acceleration which is acting on your structure. So, that effective peak acceleration is another important parameter, which engineers should consider for the design. So, that is why EPA as we can see on this slide EPA is another important parameter.

Now, PGV is called Peak Ground Velocity like PGA it is PGV. It also can have three components two PHV and one PVV that is Peak Horizontal Velocity and Peak Vertical Velocity. Then similar to acceleration here also we consider effective peak velocity that is which are more damaging or which should be considered for design, which are effective not a single peak. So, EPV is the Effective Peak Velocity and PGD is called Peak Ground Displacement. So, how much ground displacement occurs the peak value we need to consider.

In this case remember we are not using that EPT, why because when displacement is occurring, we are really concerned about what is maximum value of the ground displacement, engineers should use their design concept etcetera based on the peak ground displacement which is occurring not that effective ground displacement there no such effective. So, that is why that terminology is not present over here, you can see from this line. Now, frequency content what is the frequency content frequency content it is the frequency content of an earthquake history is often described using this mathematical functions like Fourier spectra or the power spectra and response spectra. So, these three are the common way to expressed the frequency content. That is how much frequency contains in an earthquake process that can be express mathematical formulation frequency. Fourier spectra, power spectra, and response spectra we will go through these things very soon.

And duration of an earthquake the duration of an earthquake history is somewhat dependent on the magnitude of the earthquake. So, they are correlated sometimes, but you can see what is the various effect of duration on different damages, etcetera on a structure, so why duration is important, what duration we should consider for the design and analysis we will see very soon in sub frequency slides.

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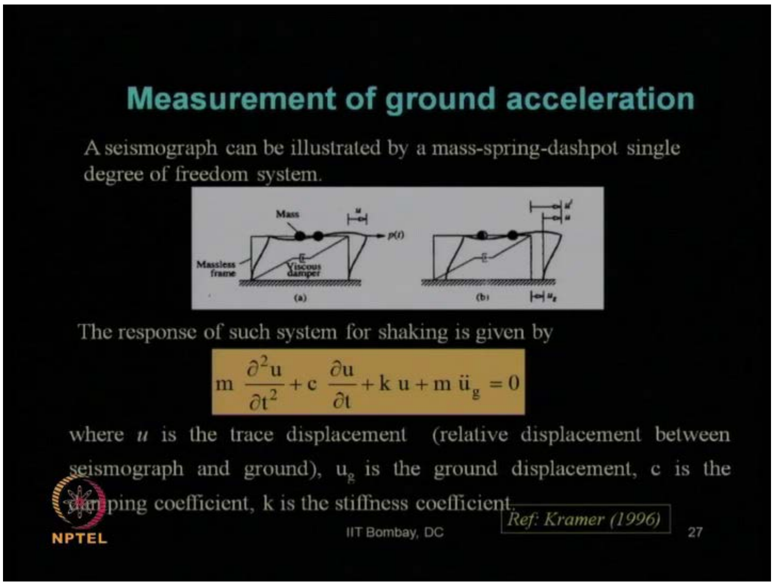

Now, when we talk about the measurement of ground acceleration, this is a typical picture, which shows how a seismograph, it can be illustrated based on the basic model of mass spring dashpot single degree of freedom system. So, this is a single base single to portal frame structure is shown over here and entire mass of that structure is assumed to be concentrated at the floor level considering the weight of the or mass of the beam and slapped together.

And typically columns are considered as mass less they only provide the stiffness k and this is the viscous damper, if an earthquake starts if a dynamic force is acting on this structure, the displacement will be like this. But this is if an externally applied dynamic load is acting on this portal frame, but if there is a ground acceleration or ground motion during an earthquake what is occurring.

This is the behavior as we know, ground will be moved by a certain distance due to the earthquake let us say the ground moment is given by u suffix g and at slab level or beam level. Let us say the total displacement is u t u total and this u denotes the relative displacement between the ground and the slab level or the beam level. So, what we can derive from this we can derive that the mass will be subjected to an inertia force. So, if we write down the variation of different forces which are acting on this like this single degree of portal system.

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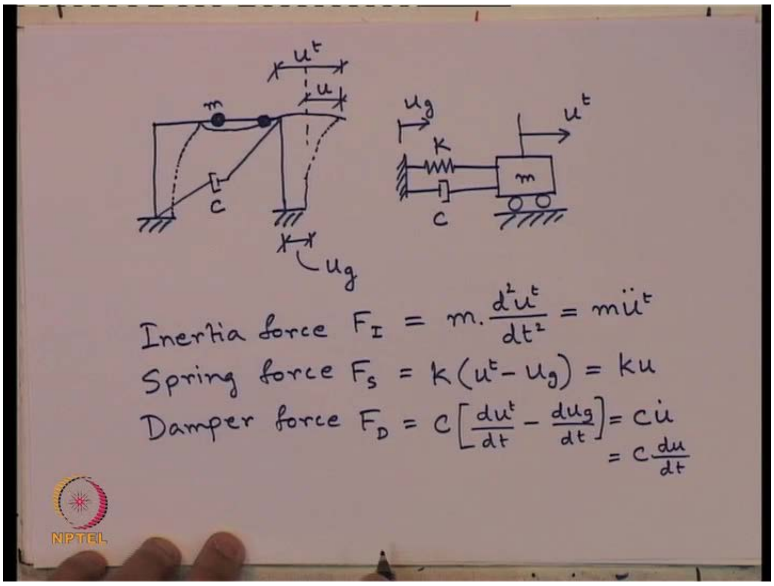

As we have seen the defected shape is something like this. So, we have taken this as u g ground displacement, this we have taken as relative displacement u and this much you have taken u t total displacement. And mass was initially concentrated over here; that has move D to this place and it was connected through a damper originally.

So, we have seen this damper and stiffness is coming from the column that we have seen. So, of we talk about, so if the damping constant is c and k is the stiffness coming from the column writing down the conventional mass spring dashpot system of a single degree of freedom system, what we can show over here mass spring constant damper, this is the single degree of freedom model. In this case what we can see this has moved by u t, mass as moved by u of t, total movement, this ground as also moved by an amount u g.

So, on inertia force, inertia force F I in this case is mass times acceleration, so mass times d 2 u t by d t square, which we can write as mass u t double dot. Now, what is the spring force? Spring force F S is nothing but k times the relative displacement what is relative displacement, u t minus u g which is k times u, u is relative displacement. And what is damper force, the damper force F D is c times the velocity difference, that is relative velocity d u t d t minus du g d t which we can write as c u dot which is nothing but c d u d t now what Deal Embert's principle says that, all the forces will be in equilibrium.

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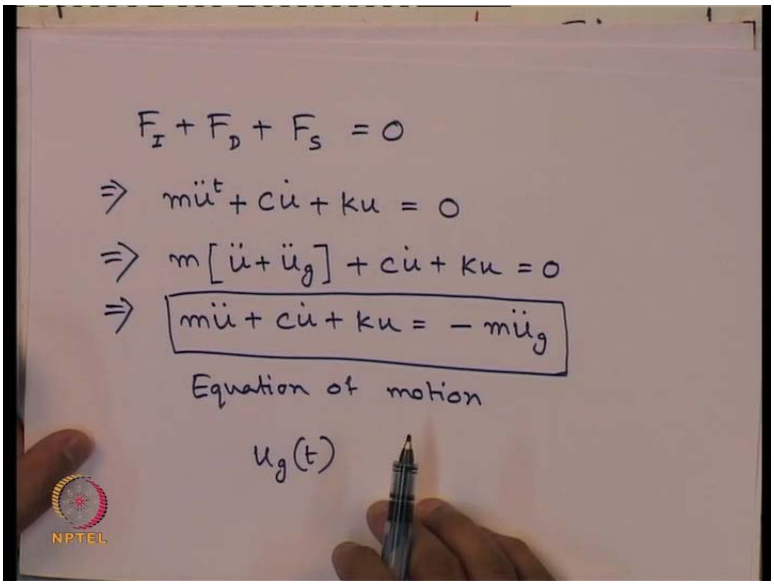

So, if all the forces are in equilibrium we can easily write here that F I plus F D plus F S, that is equals to 0 using Deal Embert's principle, that gives us m u double t acceleration on total displacement plus c u dot plus k u equals to 0. Now, what is u t double dot, that is nothing but u double dot plus u ground double dot am I right am I right, because total displacement is nothing but that relative displacement plus the ground displacement. So, if we differentiate that it can be written like this c u dot plus k u equals to 0. So, mu double dot plus c u dot plus k u equals to minus m u g double dot; that is the basic equation of motion.

So, this is the basic equation of motion for any earthquake, what we can simplify in this form, that is the relative displacement whatever acceleration. It is producing, times mass plus relative velocity times damping constant plus relative displacement times spring constant will be equals to minus sign, this is very important because this is nothing but your earthquake force which is acting on your system. So, that is the reason why it is called a forced vibration, this is the force. So, how much force it is acting, it is nothing but the whatever is your ground displacement remember that, u g is the function of time, u g is actually u g of t it is a function of time. Because during earthquake your ground displacement is keep on changing with respect to time.

So, that whatever acceleration it produces times the mass with a negative sign gives us the total earthquake force, which is acting on any structure or any system. So, this gives us an equation of motion which we know how to solve from our soil dynamics course in the other video course developed for this NPTEL. So, that is why you see over here in this slide that, this u is the relative displacement between the seismograph and the ground u g is the ground displacement and c is the damping coefficient and k is the seismic coefficient this is the equation of motion how it can be derived we have seen that.

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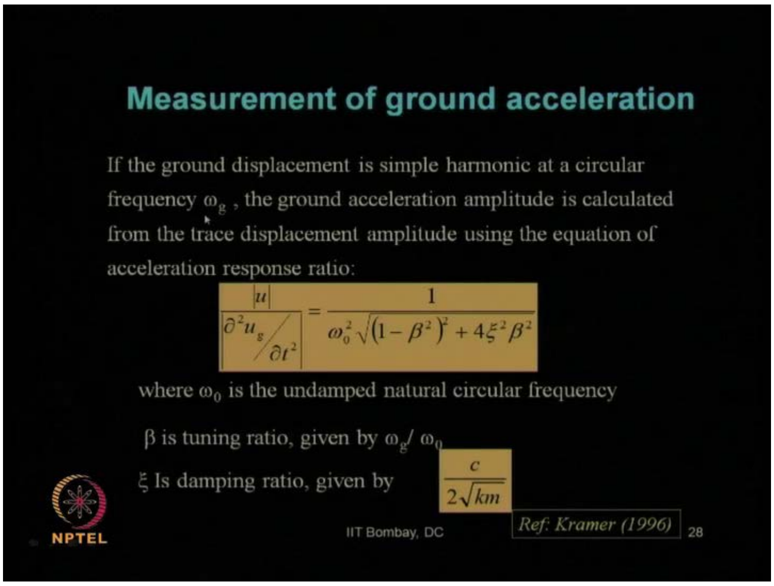

Now, measurement of the ground acceleration in can further continuation, if you solve that equation of motion what we have derived just now. The ground displacement is simple harmonic at a circular frequency of omega g, that is if you assume that your ground displacement which we have considered as u g of t.

If you consider that as a function, which is following a simple harmonic equation with a circular frequency of omega g, then the ground acceleration amplitude is calculated from that relative displacement or trace displacement amplitude using the equation of acceleration response ratio. What is acceleration response ratio? It should be u double dot please note it down, in the slide it has not appeared properly. It will be u double dot modulus4 of that, that is magnitude of relative acceleration divided by magnitude of ground acceleration; that is d 2 u g by dt square is nothing but ground acceleration will be equals to 1 by root over omega naught square root over 1 minus beta square whole square plus 4 eta square beta square. Where from we got it? If you correlate it with our soil dynamics course, you will see we already have derived it there how to obtain the dynamic magnification factor.

This is nothing but the expression of dynamic magnification factor. Similar to that, you can see the dynamic acceleration divided by with respect to your ground acceleration, you can express through this form where this omega naught is nothing but undamped natural circular frequency. And beta is called tuning ratio which is nothing but the ratio between these ground circular frequency by which you have expressed it harmonically that ground displacement, so that omega g by that natural circular frequency of the un-damped system. So, omega g by omega naught, so it is nothing but actually that frequency ratio right.

So, it is called tuning ratio here, and this eta or epsilon whatever you say is nothing but the damping ratio, which can be easily calculated by this expression, that is c damping coefficient divided by 2 times root over k m. k is stiffness constant and m is the mass of the system. So, with this, we have come to the end of today’s lecture, we will continue further in the next lecture.