Seismic Analysis of Structures
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Lecture - 02
Seismology (Contd.)

In the last lecture, we covered tectonic plates, various kinds of zoological processes that take place at the boundaries of the plate in the fault lines. Then tectonic theory of earthquake elastic rebound theory, then seismic waves and it is characteristics. Today will cover earthquake parameters.

As the waves come to the surface from the rock bed filtered through the soil mass, the waves pass on the surface as a surface wave. These surface waves cause motions of the ground. And these motions can be measured with the help of an equipment called seismograph. The stresses from the seismograph can be used to quantify the size of the earthquake. Also the size of the earthquake can be quantified with the help of some visual observations.

So, the kinds of parameters that are used to quantify or determine the size of the earthquake are known as earthquake parameters.

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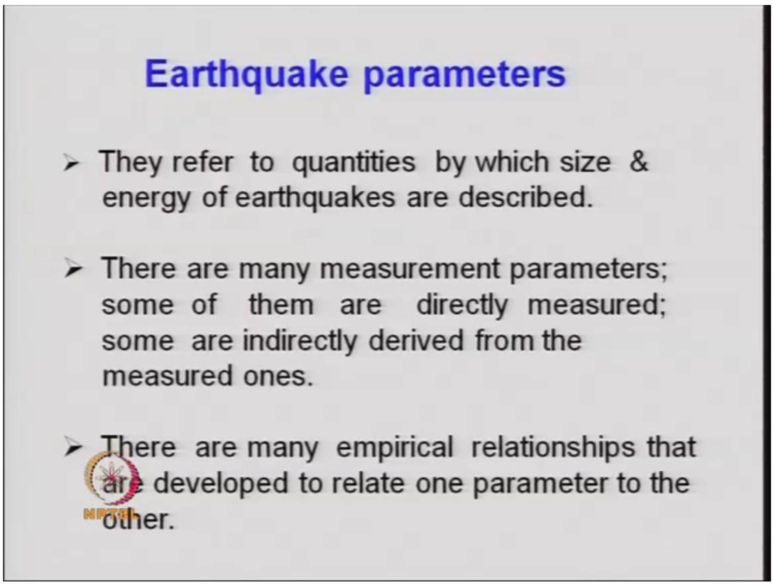

These earthquake parameters also describe the energy which is released by the earthquake. There are many measurement parameters. Some of them are directly measured some are indirectly derived from the measured ones. There are many empirical relationships that are developed to relate one parameter with the other.

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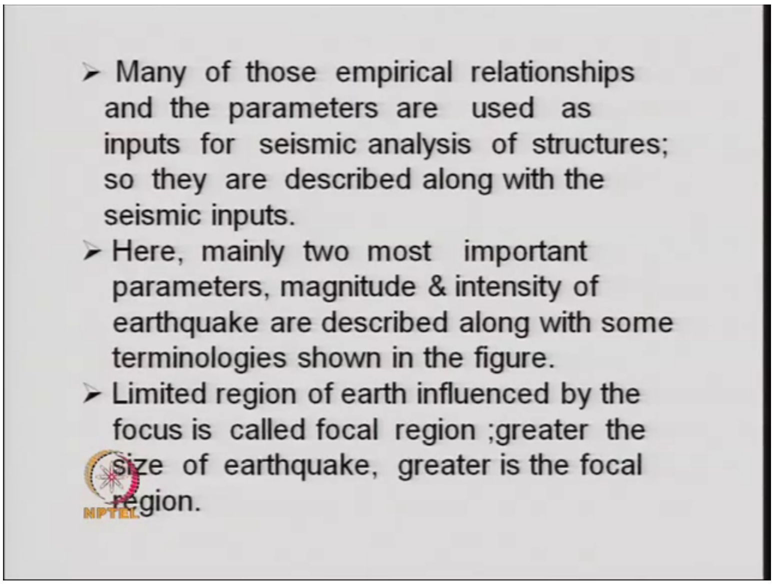

Many of those empirical relationships and the parameters are used as inputs for seismic analysis of structures. So, they will be taken up mostly along with seismic inputs.

Here mainly will talk of 2 most important parameters, magnitude and intensity of earthquake. And also we will describe some frequently used terminologies in the earthquake literature.

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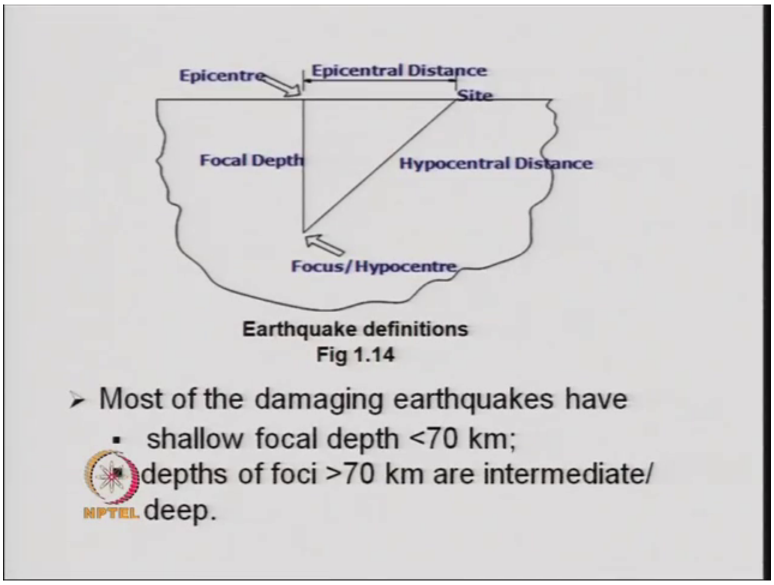

The figure here shows the different terminologies rather important terminologies which are used in the earthquake literature. The region which is mostly affected by the earthquake inside the earth is known as the focal region. At the center of the focal region is the origin of the earthquake and this is known as focus. Just above the focus on the surface of the ground, we have the epicenter of the earthquake.

The site is a place where the local effects of earthquake are of importance to us. The distance between the site and the epicenter measured on the surface of the earth is called the epicentral distance. The inclined distance between the site and the focus is called the hypo central distance. And the vertical distance between the epicenter and the focus is called the focal depth. The epicentral distance will be represented by sometimes small r sometimes capital R also delta is used to represent the epicentral distance.

Focal depth will be represented mostly by small h. The most of the damaging earthquakes have shallow depth that is a depth less than 70 kilometer depth of the foci greater than 70 kilometer are categorized under intermediate or deep earthquakes.

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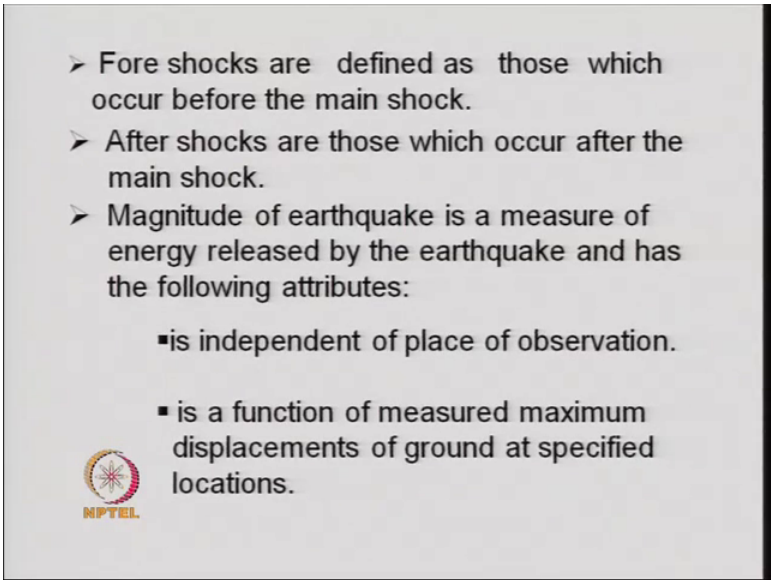

There are two more important phenomena which are quite often talked about, one is the fore shocks and the other one is aftershocks. Fore shocks are defined as those which occur before the main shock. And aftershocks are those which occur after the main shock is over.

Mostly we observed that after the major shock or major earthquake is over. Then there are certain minor trimmers or minor shocks that it experienced after the earthquake. So, they are typically the aftershocks. Now let us try to define the magnitude and intensity of earthquake. These are the two important parameters which will be dealing with here. The magnitude of earthquake is a measure of energy released by earthquake and has the following attributes. It is independent of place of observation. It is a function of measured maximum displacements of ground at a specified location.

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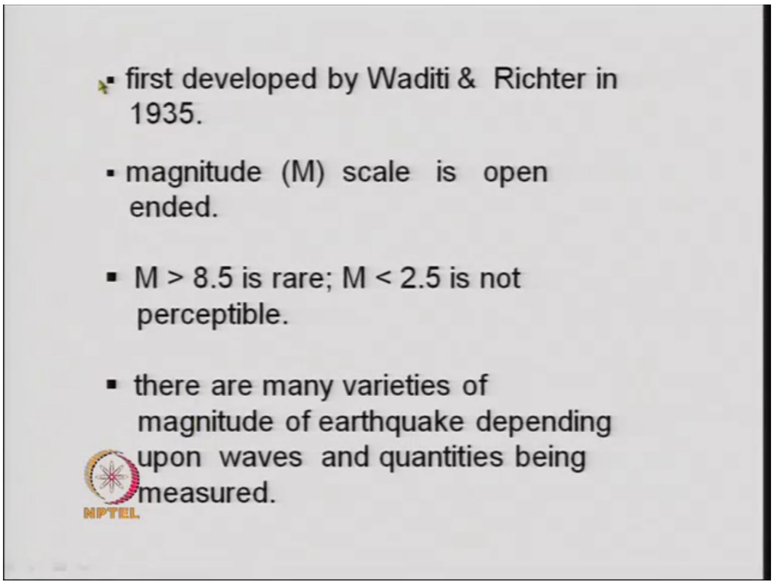

It was first developed by Waditi and Richter in 1935 magnitude M scale is open ended. Magnitude greater than 8.5 is rare magnitude less than 2.5 is not perceptible.

There are many varieties of magnitude of earthquake depending upon waves and quantities being.

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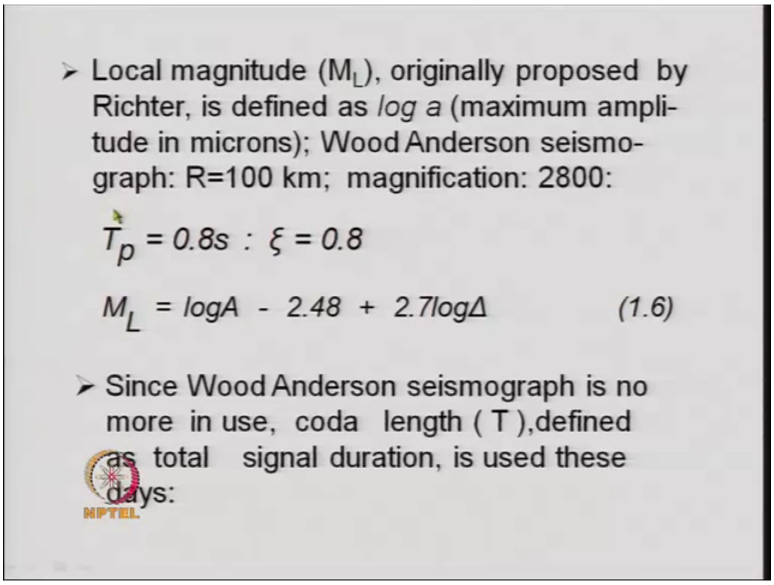

Measured local magnitude was originally proposed by Richter and is defined as log of the maximum amplitude measured in microns. For measuring this maximum amplitude, Wood Anderson seismograph is used it is placed at a distance of 100 kilometers from the epicenter magnification of the Wood Anderson seismograph is 2800 it is period is 0.8 second and it has a damping coefficient of 0.8 the relationship. That exist between the local magnitude and the amplitude of the ground motion is given by this equation. In this delta represents the epicentral distance.

Since Wood Anderson seismograph is no more in use, because it is a very old type of equipment coda length called T defined as total signal distance used these days.

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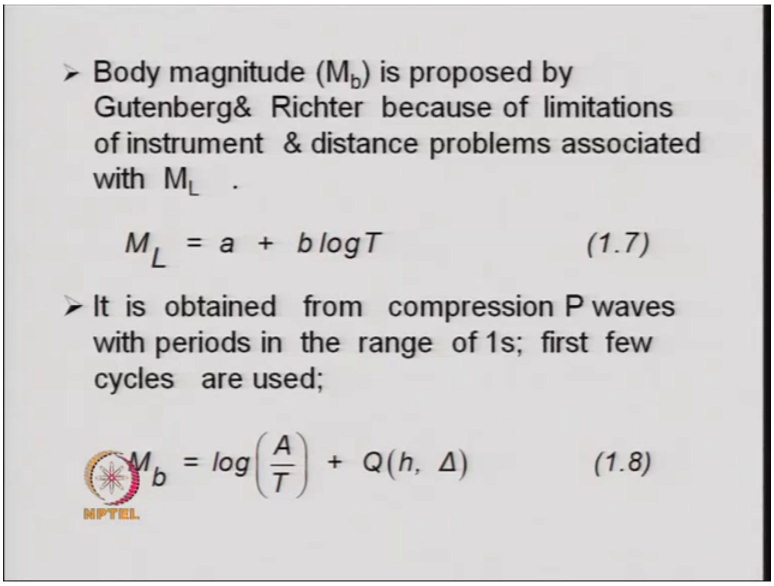

Equation 1.7 shows the relationship between the magnitude of earthquake that is a local magnitude of earthquake and a coda length that is T. And it has 2 constants A and B they are obtained from the study of the local region. The body magnitude called Mb is proposed by Gutenberg and Richter, because of limitation of instrument and distance problems associated with local magnitude.

It is obtained from compression P waves with periods in the range of one second. First few cycles are used to obtain the body magnitude. The relationship between the body magnitude and the amplitude of the ground displacement is given by this equation.

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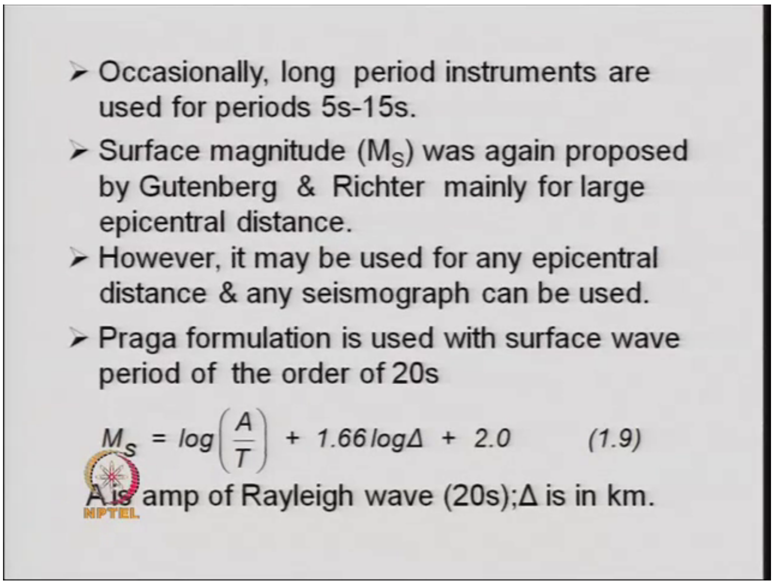

In this equation T is the period of the wave and delta is the epicentral distance and h is the focal depth. Occasionally long period instruments are used for periods 5 seconds to 15 seconds.

Surface magnitude Ms was again proposed by Gutenberg and Richter mainly for large epicentral distance; however, it may be used for any epicentral distance and any seismograph can be used for this purpose. Praga formulation is used with surface wave period of the order of 20 second to determine the surface magnitude. And the relationship of between the surface magnitude and the amplitude of the ground motion is given by the equation. Again here T represents the period of wave and delta represents the epicentral distance in kilometer.

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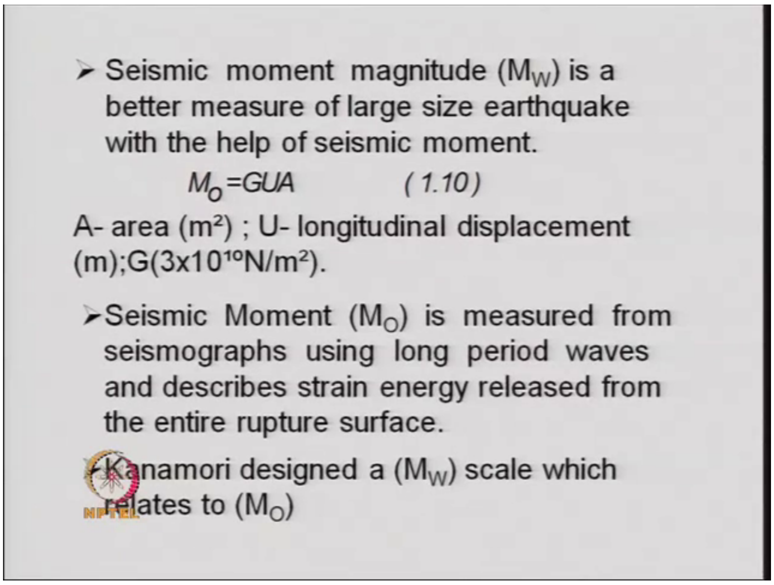

The period is typically of the order of 20 second. Next is the seismic moment magnitude Mw it is considered to be a better measure for large size earthquake, with the help of seismic moment which is defined in this equation. M 0 is the seismic moment is equal to GUA where U is the longitudinal displacement at the fault line, A is the area of rapture and G is the modulus shear modulus of rigidity.

So, with the help of this equation, the seismic moment is calculated. Then the seismic moment is related to the Mw that is a seismic moment magnitude. Seismic moment is measured from seismographs using long period waves and describes strain energy released from the entire rapture surface. Kanamori designed a Mw scale which relates to the seismic moment.

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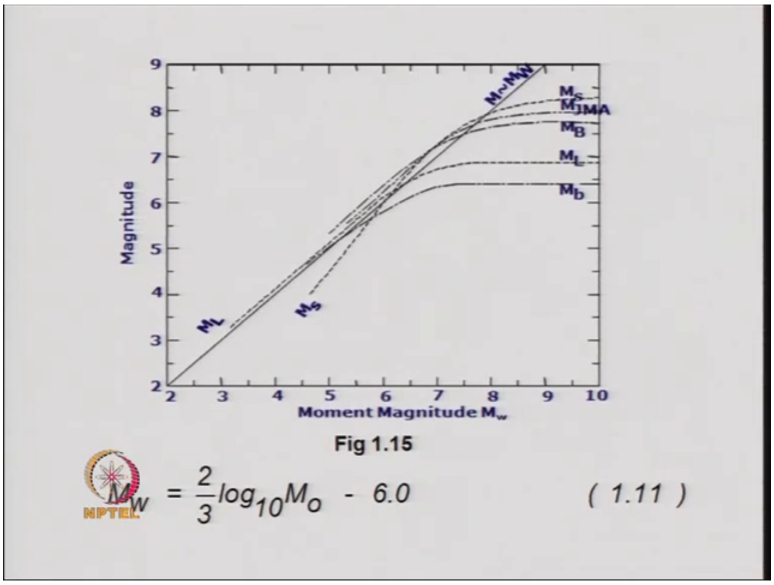

Equation 1.11 gives the relationship between the moment magnitude and M 0; the here the constant 6.0 that is obtained from the regional characteristics. This figure shows the relationship between different magnitudes or different types of magnitudes that I have described with the moment magnitude Mw.

One can see that up to a moment magnitude of 6; the magnitude which is defined as body magnitude surface magnitude local magnitude. They are all same as Mw. After a magnitude of 6 as Mw, be there is a lot of difference between M b M L M s etcetera and differs significantly from that of Mw. Therefore, for large size earthquake one has to specify what kind of magnitude people are talking about, whether this is Ml Mb Ms mostly for large magnitude earthquake these days.

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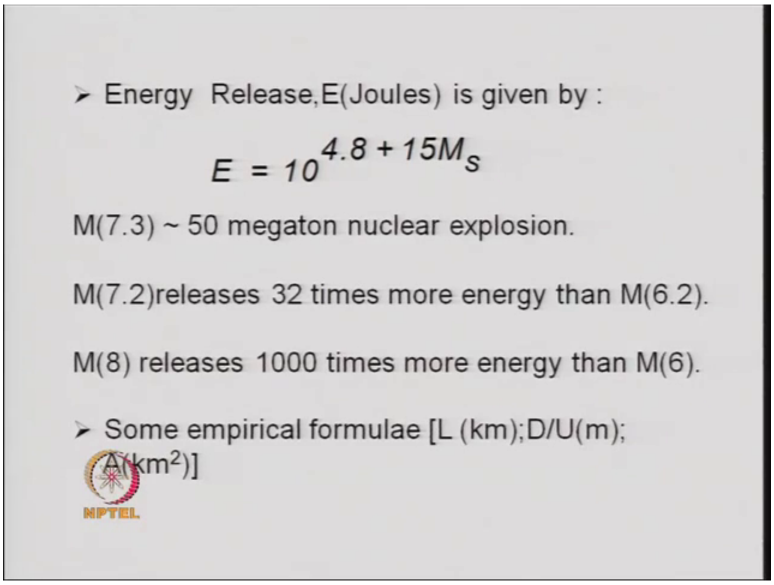

We use the moment magnitude Mw the energy released in an earthquake is related to the magnitude from several observations. The equation here gives the relationship between the surface magnitude and the energy released. Energy release is measured in joules a magnitude of 7.3 is equivalent to a release of 50 megaton nuclear explosion. Because of the log relationship that exist between the magnitude of earthquake and the amplitude of ground motion, magnitude 7.2 releases 32 times more energy than a magnitude of 6.2. Magnitude of 8 releases about 1000 times more energy than magnitude 6.

Thus we see that although in the in times of the values a magnitude of M is equal to 6 and magnitude of M is equal to 8 may not look to be of great difference, but the energy released between these 2 earthquakes are off completely different order. Some empirical formula which have been developed for the rapture length, ruptured area and the displacement in the fault lines are obtained from different data that have been collected.

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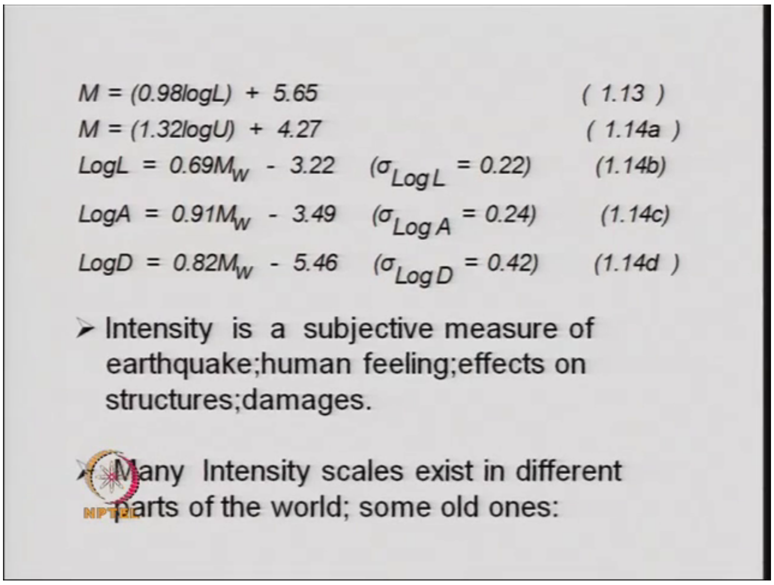

These relationships are developed for different magnitude of earthquake. For example, the first equation shows that the magnitude of earthquake and the rapture length is related by a log relationship.

Similarly, the second equation shows that the magnitude of earth quake is related again to the displacement at the fault line again with the help of a log relationship. The other 3 equations they represent the relationship that exists between the rapture length rapture area and the displacement at the fault line with Mw. These equations provide the mean value of the quantities. And these mean values have a meaning in the sense that the L is considered as a random variable therefore, we talk of the mean value. And the equation provides for a given magnitude of Mw. The average value of the rapture length is given by this equation. And there is a standard deviation for this measurement which is represented over here.

In the same way the other 2 quantities are also considered as a random variable given a particular value of M w. And therefore, the they also provide the mean value of the area and the displacement respectively in this 2 equations. And they are also associated with certain standard deviations. Next we talk of the intensity of earthquake. Intensity is a subjective measure of earthquake is a human feeling, effects of structures damages that are observed. From these we try to scale the size of the earthquake in terms of some intensity.

Thus intensity has a scale like magnitude as a scale. And we provide the size of the earthquake or try to define the size of the earthquake using the intensity scale. There are many intensity scales that exists in different parts of the world.

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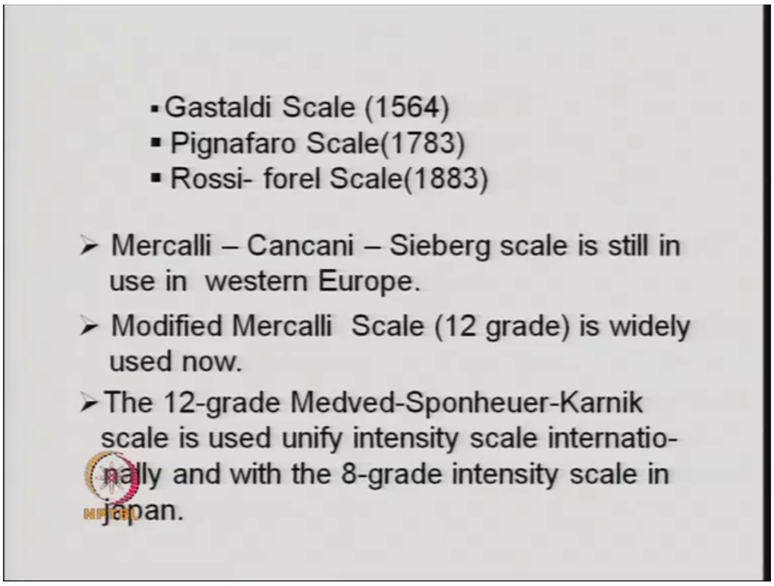

Some of the old scales which no more in use are Gastaldi scale, which was used in 1564. Pignafaro scale which was used in 1783. Rossi Forrel scale it used to be in 1883. Mercelli cancani Sieberg scale is still in use in Western Europe this is again one of the oldest scales. The modified Marcella scale in 12-grade is widely used now. The 12 grade Medved Sponheuer Karnik scale is used to unify intensity scale internationally and with the 8 grade intensity scale in japan.

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Intensity	Evaluation	Description	Magnitude (Richter Scale)
I	Insignificant	Only detected by instruments	1 – 1.9
II	Very Light	Only felt by sensitive persons; oscillation of hanging objects	2 – 2.9
III	Light	Small vibratory motion	3 – 3.9
IV	Moderate	Felt inside building; noise produced by moving objects	4 – 4.9
V	Slightly Strong	Felt by most persons; some panic; minor damages	
VI	Strong	Damage to non-seismic resistance structures	5 – 5.9
VII	Very Strong	People running; some damages in seismic resistant structures and serious damage to un-reinforced masonry structures	
VIII	Destructive	Serious damage to structures in general	
IX	Ruinous	Serious damage to well built structures; almost total destruction of non-seismic resistant structures	6 – 6.9
X	Disastrous	Only seismic resistant structures remain standing	7 – 7.9
XI	Disastrous in Extreme	General panic; almost total destruction; the ground cracks and opens	
XII	Catastrophic	Total destruction	8 – 8.9

This table shows the intensity of different sizes that is intensity 1 2 3 4 5 and so on, and how they are evaluated, and then the description of the damages or other effects that are observed which are associated with that intensity. And then on the right hand side the associated magnitude in the Richter scale. So, the first now the intensity 1, it is evaluated as insignificant only detected by instruments, but it is not generally felt; the magnitude associated with this is 1 to 1.9. Intensity 2 is evaluated as very light. It is only felt by sensitive persons oscillations of hanging objects are seen. The magnitude is about 2 to 2.9. Intensity 3 this is evaluated as light.

These are small vibratory motions the associated magnitude is from 3 to approximately 4. The intensity 4 this is evaluated as moderate. It is felt inside the building some kinds of noises are produced by moving objects. The associated magnitude is 4 to 4.9. Intensity 5 this is evaluated at slightly strong felt by most persons. Some panic is created minor damages are observed. The intensity 6 is evaluated as strong, damages to non seismic resistant structures that are observed. Slightly strong and strong that is intensity 5 and 6 they are related to a magnitude between 5 to 6.

The intensity 7 is evaluated at very strong. People run out of their houses, some damages in seismic resistance structures and serious damages to unreinforced machinery structures are observed. Intensity 8 is evaluated as destructive and serious damages to structures in general are observed. And intensity 9 is evaluated to injurious. This serious damage to wild build structures almost total destruction of non seismic resistant structures are observed. The intensity scales 7 8 and 9, they have an associated magnitude of 6 to 7.

The intensity scale of 10, the things that are observed are that the only seismic resistant structures remain standing. Other structures do fail this is evaluated as disastrous and associated magnitude is 7 to 7.9. The intensity 11 and 12 are categorized under disastrous or catastrophic events. There is a general panic almost total destruction of the structures. The ground cracks are observed and many other kinds of phenomenon are observed near the epicenter, like the hot water springs coming out there is a large scale rapture of the ground etcetera.

So, this is related to a magnitude between 8 to 9.

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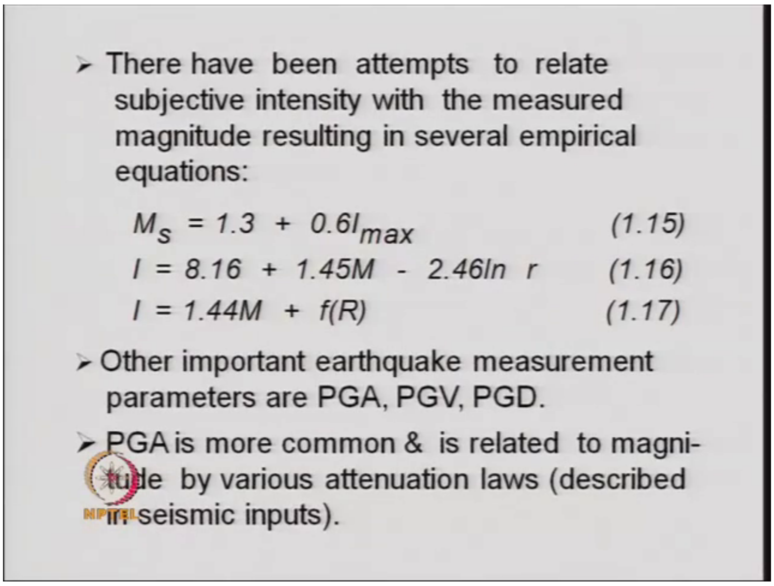

This table shows that; obviously, there have been attempts to relate subjective intensity with the measured magnitude resulting in several empirical equations. In fact, these empirical equations are quite often used in the seismic risk analysis of structures or determining the seismic risk of a region. These are these relationships are shown in these equations. The first equation relates the surface magnitude with the maximum intensity. The other 2 equations relate the intensity with the magnitude of earthquake. Here the there is an variable which is the epicentral distance rather a parameter which is called the epicentral distance and this is a function of epicentral distance.

Therefore, this relationship is valid for a place to place depending upon this epicentral distance, whereas the first equation is independent of r. The other important earthquake measurement parameters are peak ground acceleration, peak ground velocity, peak ground displacement. Peak ground acceleration is more common and is related to magnitude by various attenuation laws which would be describing in seismic inputs.

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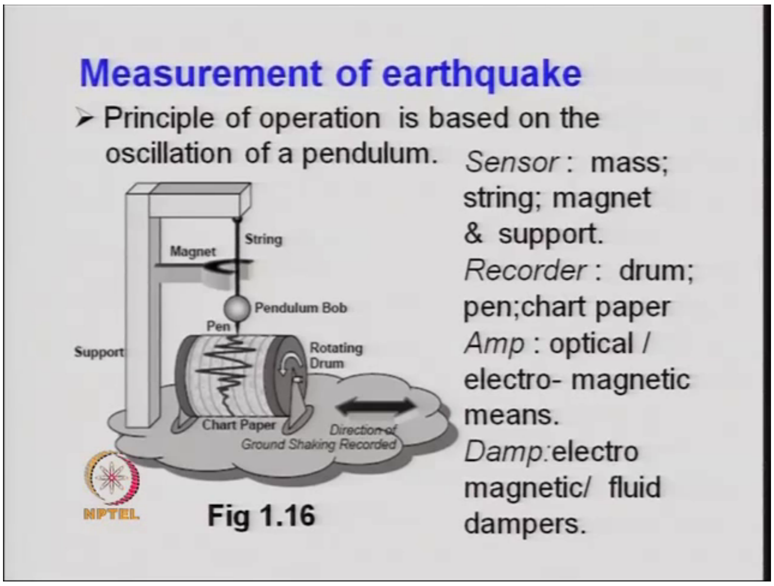

Next we come to the measurement of earthquake. The earthquakes are measured with the help of an instrument called seismograph. Better to say that the seismograph measure the ground motions that takes place due to the earthquake. The principle operation of the measurement earthquake is described over here.

This figure shows a wooden platform. In the wooden platform a bracket is mounted. From the bracket a pendulum hangs with the help of a string. So, there is a magnet surrounding the string. At the end of the pendulum there is a pen. This is a chart paper over which the traces of the earthquake are obtained. The chart paper is wound around a drum. And the drum is rotated at some constant speed.

The different components of this setup are sensor which is the mass that is the pendulum, the string, magnet and support the recorder that is the drum pen and a chart paper, amplification of the stress that is achieved through optical or electromagnetic devices and the damping that is provided by the electromagnet over here or fluid dampers. Now as there is an earthquake these, entire platform moves in the direction shown by the arrow. The entire system in figure one 0.1 6 oscillates in the direction of the arrow which is shown. And the bob now undergoes and oscillation. And because of this oscillation an inertia force is generated in the bob. And the bob starts moving or oscillating about the top point or about the point where it is fixed to the bracket.

Because of this relative movement between the bob and this entire set up, the pen attest to the bob makes a stress on this chart paper, of the movement of the ground. Since the chart paper is wound around the drum and the drum is rotated at some constant speed the a stress of the movement of the ground with time is obtained in this chart paper. So, this is the principle behind all seismographs, but these days these kinds of old systems are no more in use. We have very sophisticated kinds of equipments electronic equipments and other kinds of seismographs, but the principle based on which this measurement takes place is explained here.

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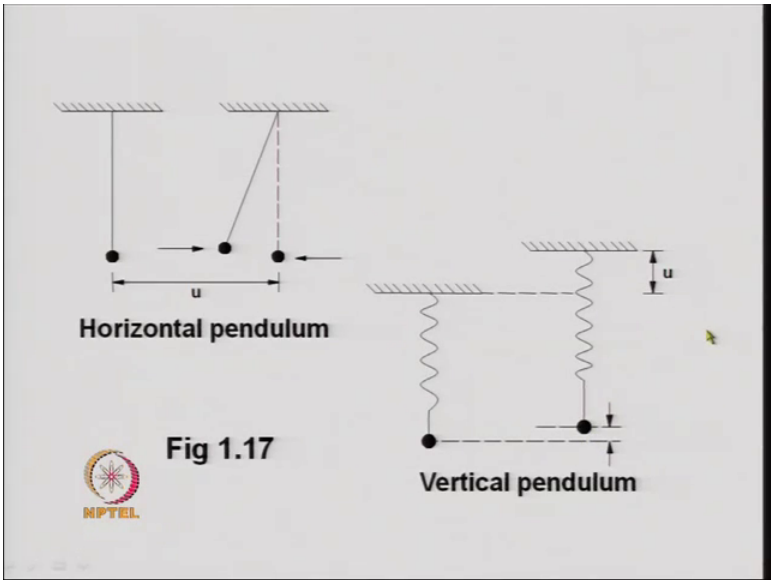

Fig 1.17

If the horizontal ground motion is measured, then the bob acts as a inverted pendulum in the horizontal direction.

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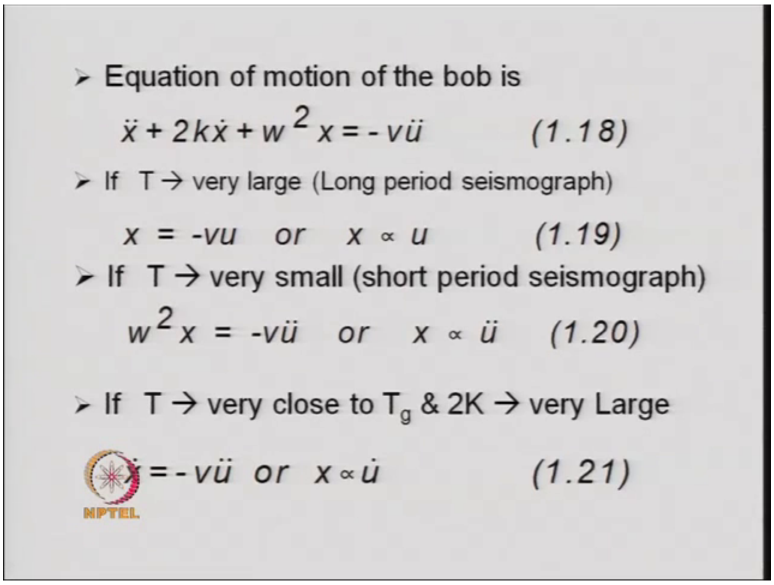

If the vertical movement of the ground motion is measured, then the entire setup can be thought to be a vertical pendulum. One can write down the equation of motion for the bob and that is a fundamental equation of a single degree of freedom system. And I presume that all of you know all of you have some exposure to the structural dynamics. So, this is a the equation of the bob. These v is a multiplying factor, u double dot is the ground acceleration, x is the is the relative displacement. That is measured on the chart paper.

Now there are 3 kinds of seismograph that you can have. One is a long period seismograph. In that the T that is the time period is very large. As a result of that the omega square term becomes very small. Then the acceleration becomes directly proportional to the ground acceleration. And therefore, one can write that the ground displacement will be directly proportional. Or rather the ground displacement will be directly proportional to the measured displacement. So, this will straightaway provide the measure of the ground displacement. If T is very small, then it is called a short period seismograph.

In that case the omega square x term predominates. And then the seismograph will record directly the ground acceleration. Under a special case where the time period of the bob is very close to the predominant time period of the ground, and if the damping is also very large then in that case the measured quantity on the chart paper or the stress count in the chart paper will be proportional to the ground velocity. So, these 3 kinds of measurements can be obtained by playing with the period of the bob and by playing with the damping of the system. However, these days there are many equipments which can measure all the 3 quantities together.

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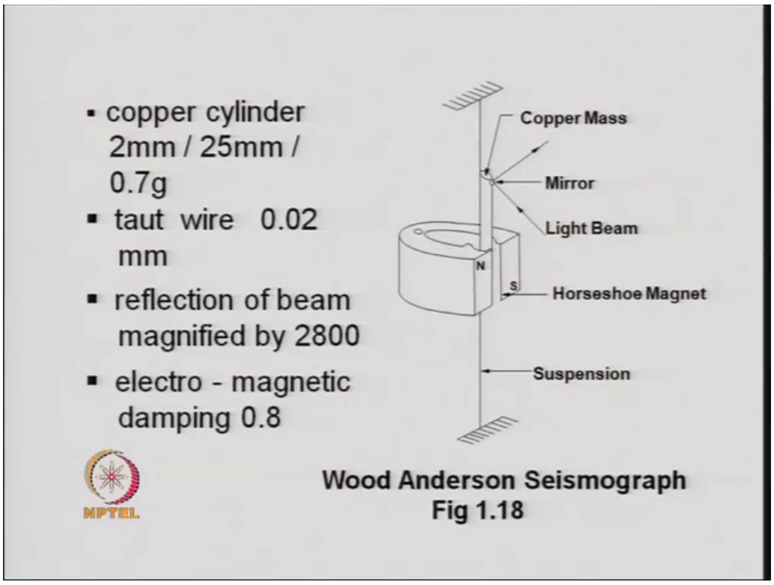

Wood Anderson Seismograph
Fig 1.18

Since we can talk about the Wood Anderson seismograph, let us have a look at the features of these Wood Anderson seismographs. This consists of a string or a wire which is tensioned wire. These are the cylinder which is a copper cylinder.

Then there is a magnet there is a mirror and a light beam a light of beam that is reflected on the mirror. The copper cylinder has a 2 millimeter diameter it is 25 millimeter long. This has a weight of 0.7 g. Then this is the wire is a taut wire and this has a diameter of 0.02 millimeter. The reflection of the beam is magnified by 2800 time. And this magnet provides a damping of 0.8.

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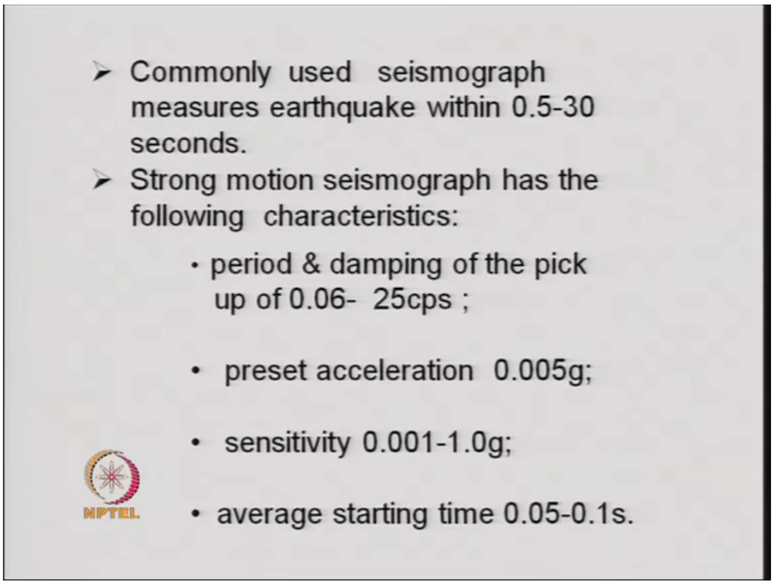

Commonly used seismograph measures earthquake within 0.5 to 30 seconds; the strong motion seismograph has the following characteristics. Period and damping of the peak up is 25 cycles per second. And 0.06 preset acceleration is 0.005 g. Sensitivity is of the order of 0.001 to 1.0 g. The average starting time is from 0.05 to 0.1 second.

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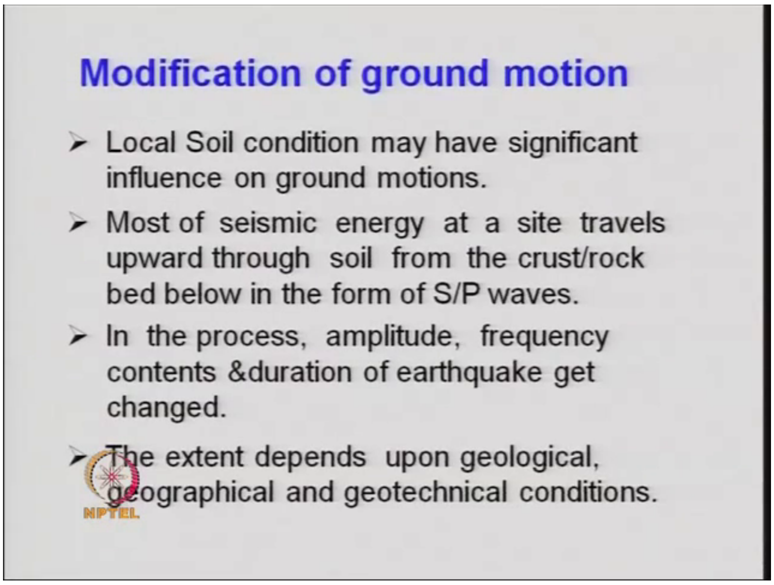

That is about the earthquake measurement parameters and the earthquake measuring equipments.

Now, let us look at a very important aspect of the seismic waves passing through the ground motion passing through the soil. This has a great relevance to the geotechnical earthquake engineers and also to structural engineers. The seismic waves as they passed through the soil and comes to the surface of the earth. A modification of the nature of the waves takes place. This modification depends upon the local soil condition and may have a significant effect on the ground motions that are recorded.

Most of the seismic energy at a site as we know travels upwards through soil from the crust or the rock bed below in the form of S or P waves. In the process amplitude frequency contents and duration of earthquake get changed. The extent depends upon geological geographical geotechnical conditions.

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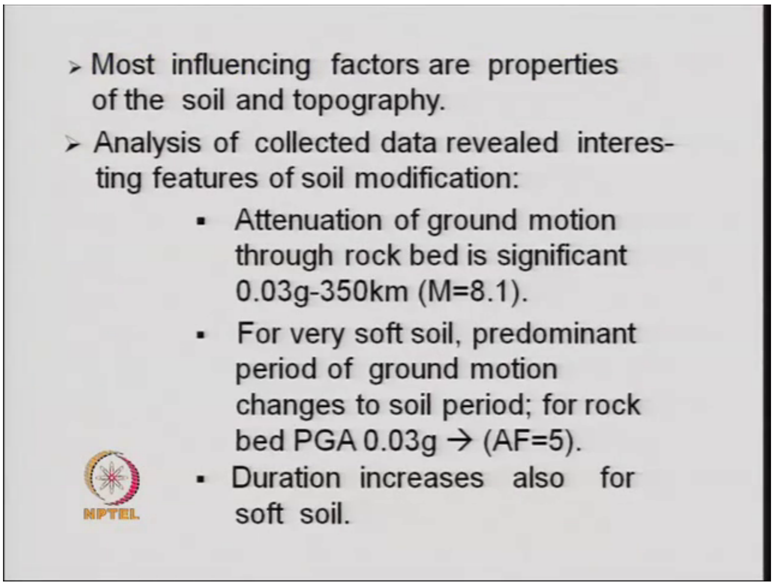

Most influencing factors or properties of the soil and topography analysis of collected data reveal interesting features of soil modification. The first was that the attenuation of ground motion through rock bed is significant. It was seen that for a magnitude of earthquake 8.1 the ground acceleration or the rock bed acceleration is of the order of 0.03 g at a distance of 350 kilo meter.

Therefore, we can see that at a very large distance, the large magnitude earthquake can produce a very small peak ground accelerations. The second thing that was observed was for very soft soil predominant period of ground motion changes to soil period. And there is a large amplification of the ground motion. For a rock bed peak ground acceleration of

0.03 g the amplification of the amplitude of ground motion was seen to be of the order of 5. Next thing that was observed was duration increases also for soft soil.

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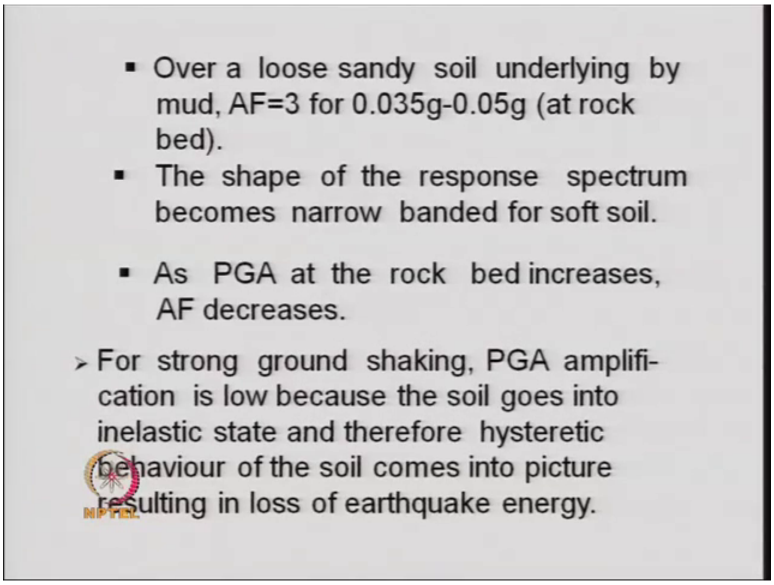

Over a loose sandy soil underlying by mud the amplification factor was of the order of 3 for a ground acceleration at the rock bed of the order of 0.035 g to 0.05 g.

The shape of the response spectrum became narrow banded for soft soil. And finally, it was observed that peak ground acceleration at the rock bed. If it increases, then the amplification factor decreases. This is due to the fact that the soil undergoes a inelastic hysteretic behavior under strong shaking at the rock bed. And therefore, there is a tremendous amount of loss of energy while the seismic waves travel to the soil resulting in a low value of the amplification factor.

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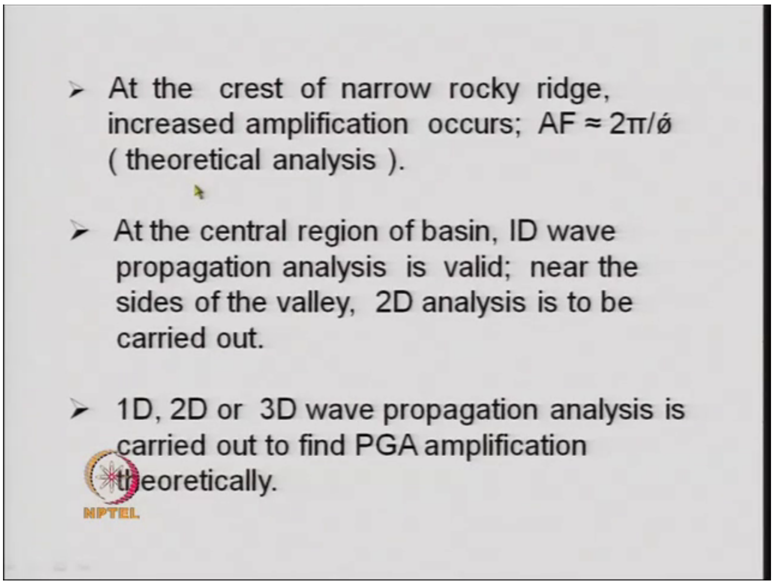

At the crest of narrow rocky ridge, increased amplification was observed. The amplification is of the order of 2 pi by phi, where phi is the included angle of the ditch.

The amplifications that were observed or the ground amplification that were observed from the collected data was later on verified by the wave propagation analysis. And a wave propagation analysis showed that, the observations that were made from the different records are quite valid. In the sense that the seismic wave propagation analysis gives a more or less the expected amplification factors; 3 types of seismic wave analysis can be carried out 1 dimensional 2 dimensional or 3 dimensional. 1 dimensional wave propagation analysis is valid at the central region of a basin. Near the sides of the valley one d wave propagation analysis is no more valid 2 d analysis is to be carried out. And under complex situation one may have to go for a 3 d seismic wave propagation analysis.

So, let me summarize now that what we have discussed today. We started with the earthquake measurement parameters. There are many earthquake measurement parameters out of that. We mainly discussed the magnitude of earthquake and the intensity of earthquake. Intensity of earthquake is a subjectic measure and is generally measured on a 12 scale whereas magnitude of earthquake is as a measured quantity; that means, it is obtained from the measured ground displacement. The scale is open ended, but generally the magnitude of earthquake greater than 8.5 is very rare. There have been attempts to relate the subjective scale of intensity I to the magnitude of earthquake. There is not only one type of magnitude of earthquake that is described. There are different types of magnitude of earthquake those magnitudes of earthquake again can be related with one another.

And it was seen that upto a moment magnitude of 6 all definitions of the magnitude of earthquake are the same or provide the same value. After a moment magnitude of 6, there is a wide variation. Therefore, for defining the earthquake more than 6 magnitudes one has to be very cautious in stating what kind of magnitude he is talking off. Then we discussed about the earthquake measurement equipment called seismograph. We discussed the principle based on which all the seismograph operates. And also shown the oldest seismograph that is a Wood Anderson seismograph along with it is properties.

And finally, we looked at the modification of the ground motion due to soil condition, which is a very important thing to both structural engineers as well as the geotechnical earthquake engineers. The soil modification can create a large amplification of ground motion. You can also change the frequency contents of the ground motion. And the ground motion can be all together changed if there is a plastification which can take place within the soil as the ground as the motion moves up to the surface.

So, for a strong ground motion, the amplification that is observed at the surface is of a smaller order, because of the reason that the pastification takes away much of the seismic energy.