Chemical Process Safety
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Lecture 60
Nuclear Disaster-Earthquake

Welcome to this last module of our entire course and earlier we had a discussion about various man-made disasters or hazards, and sometimes nature too play a very vital role in terms of different hazards and these hazards are extremely dangerous with respect to either fatality or injury or sometimes even illness. Now, since all the chemical plants, they are also very much subjected to these kinds of natural hazards, so we thought that we must have at least one module related to the natural hazards.

So, welcome to this Earthquake module. In this earthquake, this is one of the most, you can say dangerous or catastrophic, natural hazard, and this plays a very vital role in terms of number of fatalities, in terms of injuries, et cetera, so let us have an introduction about this type of hazard. This is one of the principal natural hazard from which the process plants worldwide are at risk and in Gujarat various refineries are situated and they are at the risk of this kind of earthquake hazard.

Although there are certain design implications, there are certain structural aspects being implemented to prevent damage those may be attributed towards this natural hazard but still they are at the risk. Now, in India due to its geography and topography, they have a serious large-scale natural disaster, one of them is the major disaster is earthquake, although the flood, cyclone, they are also very vital, but this is having the much gravity compared to the others.

Like in Bengal earthquake, about 3 lakh fatalities took place in year 1737, Kangla earthquake reported about 20,000 fatalities in 1905, Latur earthquake about 7800 fatalities in 2001. So, you can see that there are large number of fatalities those are attributed to this earthquake apart from the property damage, apart from the injuries, et cetera. So in Gujarat 2001, about 25,000 fatalities were there, in Kashmir 2005 about 86,000 fatalities were there including Pakistan and these are some of the major disasters recorded in India.

So, India is having a high risk towards the earthquake, more than 58 percent of India's land area comes under the category of moderate to severe seismic hazard. In past, India has experienced 10 major earthquakes that have resulted in more than 30,000 deaths. So of the

earthquake prone areas, 12 percent is prone to very severe earthquake, 18 percent to severe earthquake and 25 percent to the damageable earthquake.

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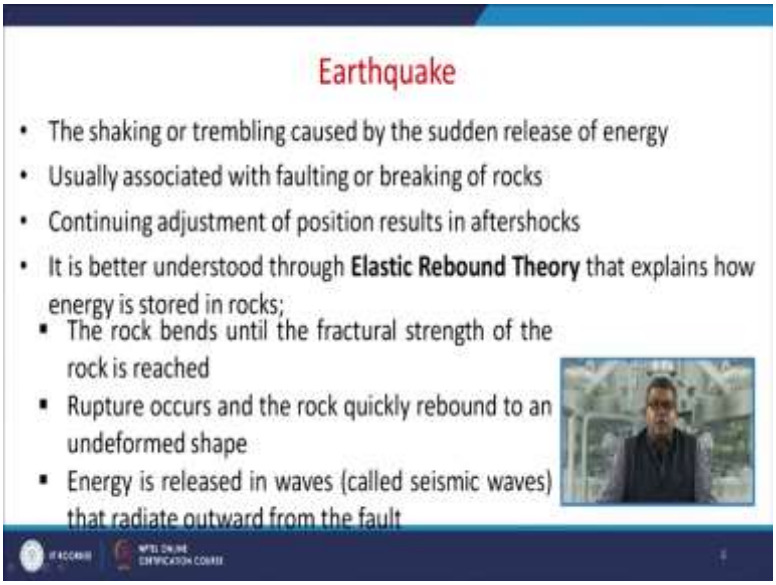

Now, what is earthquake? This is the shaking or trembling caused by the sudden release of energy, and usually associated with the fault or breaking of rocks. Now, continuing adjustment of position results in after-shocks and it is better to understood that through Elastic Rebound Theory that explains how energy is stored in rocks.

So rocks bends until the fractural strength of the Rock is reached and rupture occurs, and the rock quickly rebound to an undeformed shape. So by this movement the energy is released in terms of waves, they are called the seismic waves and that radiates outwards from the fault, so this is the reason why earthquake usually takes place.

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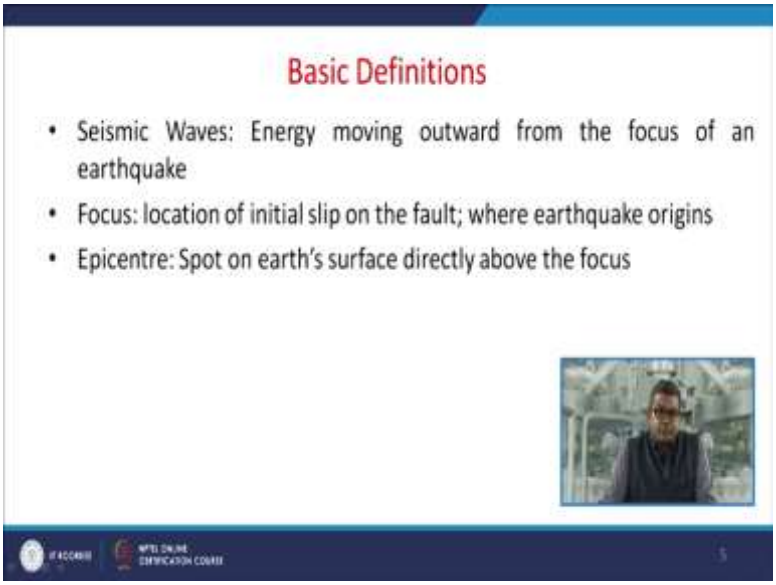

So, in the previous slide we had several words, so it is good to have the basic definition of those words like seismic waves, this is energy moving outwards from the focus of an earth quake. Focus: the location of initial slip on the fault, where the other quick origins. That is the concept of epicentre: spot on earth's surface directly above the focus.

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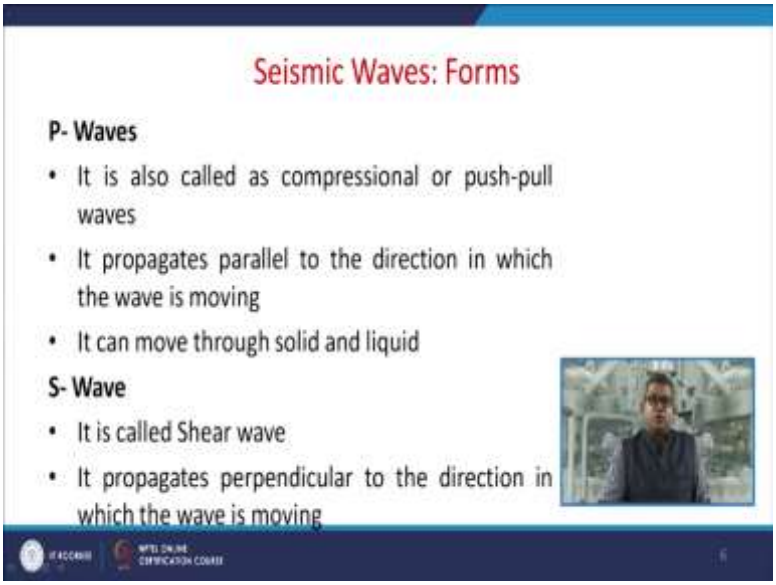

There are various forms of seismic waves, one is the P waves; it is also called the compression or push-pull waves. It propagates parallel to the direction in which the wave is moving and it can move through the solid and liquid. There is S-wave that is called the Shear wave, it propagates perpendicular to the direction in which the wave is moving.

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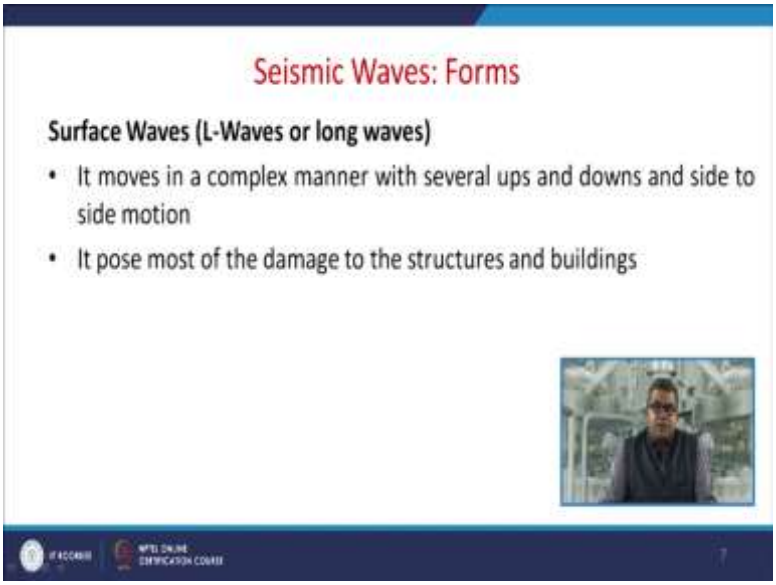

Another is the surface waves sometimes referred as L waves or long wave, so it moves in a complex manner with several ups and downs and side to side motion. Now, it pose most of the damage to the structures and buildings, so while designing any chemical process plant because sometimes it may happen that if you store any flammable material or any toxic material, because of the earthquake if that particular material is released to the atmosphere then the damage or fatalities or injuries may be manifold with respect to the earthquake.

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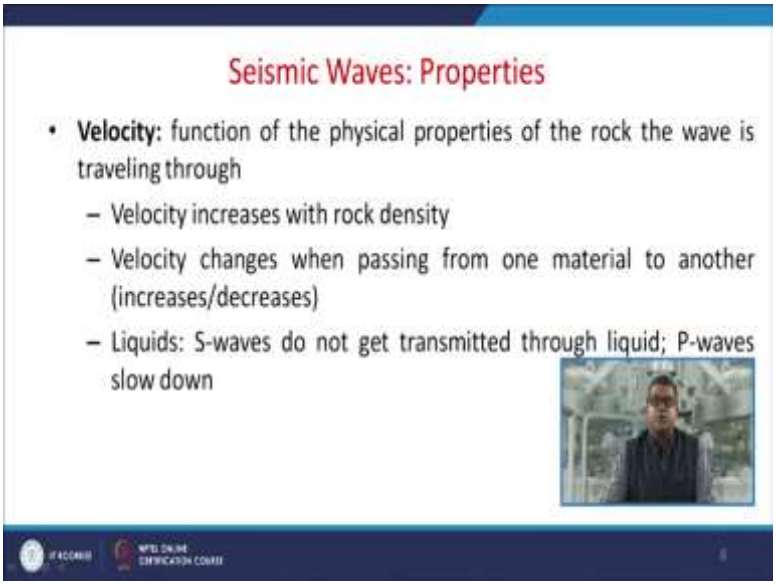

There are certain properties attributed to these seismic waves, like velocity, this is the function of the physical properties of the rock the wave is travelling through. The velocity increases with the rock density, velocity changes when passing from one material to another, may be

increased or decreased. Liquids like S-waves, they do not get transmitted through the liquid and P-waves they are usually slow down. Now, why this is important? If we know the velocity of waves, we can infer the type of rock it travels through and it is how we can map the interior of the Earth so that is why it is extremely important.

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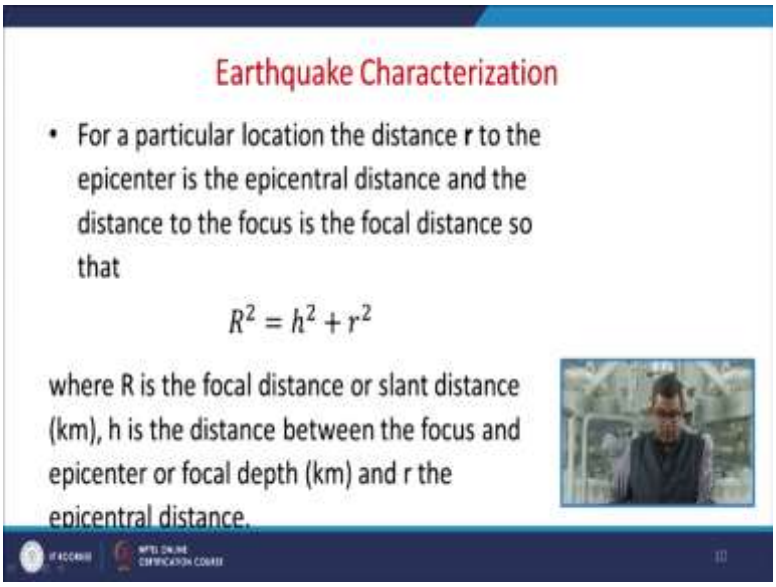

Let us have characterisation aspect of earthquake for a particular location, the distance "r" of epicentre is the epicentral distance and the distance to the focus is the focal distance, so that

$$R^2 = h^2 + r^2$$

Where "R" is the focal distance or slant distance, "h" is the distance between the focus and the epicentre or focal depth and r is the epicentre distance which you have already discussed.

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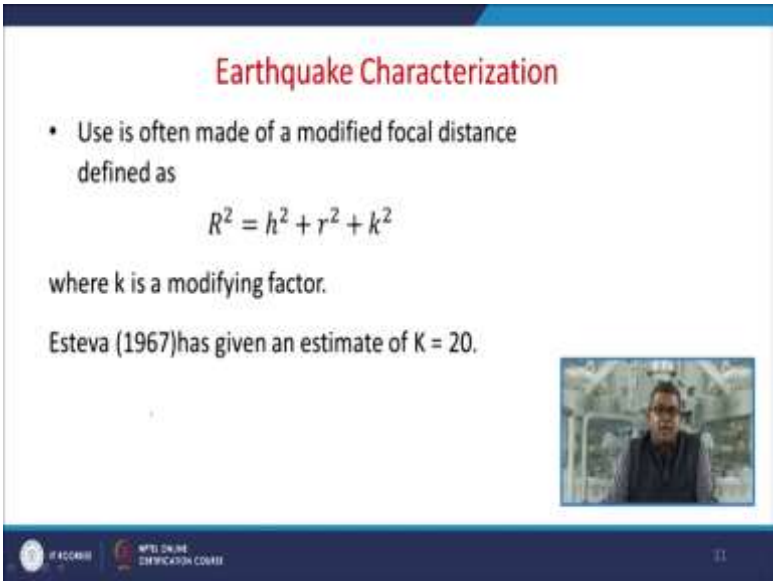

So, the uses of a modified focal distance defined as

$$R^2 = h^2 + r^2 + k^2$$

Where "k" is the modifying factor. Esteva in 1967 has given an estimate of K is equal to 20. Now, another aspect is the magnitude and the magnitude scale, the symmetry of earthquake is defined in terms of its magnitude and intensity. The more objective is the magnitude which is measured by the total energy in the seismic wave. The scale of the representation of the magnitude of an earthquake was devised by the Richter and magnitude is commonly quoted in terms of the values on the Richter scale.

The value is the measure of the ratio of the maximum amplitude recorded for earthquake in question to the maximum amplitude for the standard earthquake with both measurements made on a standard seismograph located at the standard distance from the earthquake and the instruments being Wood-Anderson seismograph of defined characteristics, so this is through which you can measure this magnitude scale.

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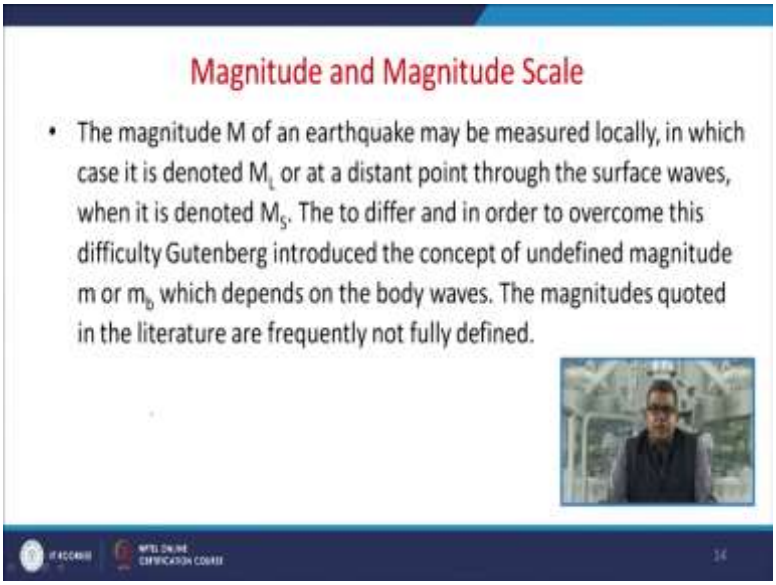

The magnitude M of an earthquake may be measured locally in which the case is denoted by sometimes M_L because L stands for local, or the distance point trough the surface waves when it is denoted by M_s where s is the surface wave. The to differ and in order to overcome this difficulty Gutenberg introduced the concept of undefined magnitude m or m_b, which depends on the body waves, b stands for body waves.

So, the magnitude quoted in the literature are frequently not fully defined. The relation of Richter for the magnitude of local earthquake is given by

$$M_L = log_{10}(A/A_0)$$

Where A is the maximum amplitude in mm and A_0 is the maximum amplitude of the standard earthquake, and M_L is the local magnitude under the standard condition described. So, the value of A_0 that is the standard one assigned to the standard earth quake is 0.001 millimetre.

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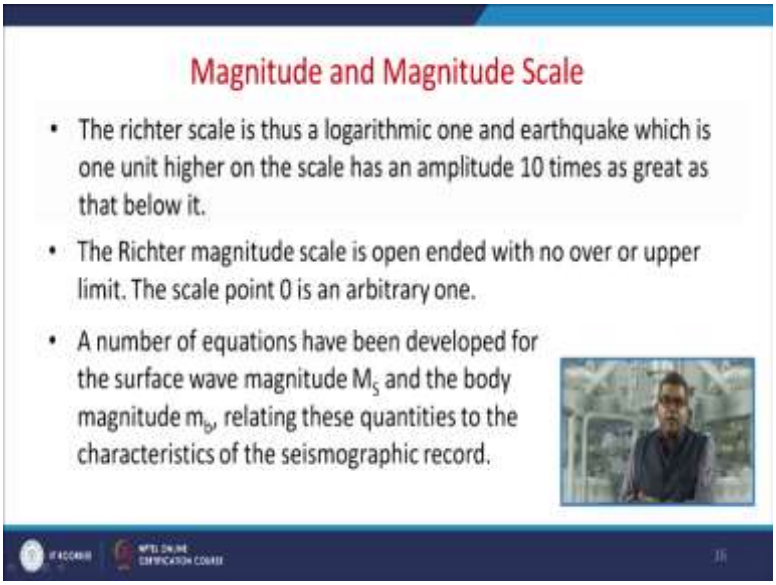

The Richter scale is the logarithmic one and the earthquake which is one unit higher to the scale has an amplitude 10 times as great as that below it. So, the Richter magnitude scale is open ended with no over or upper limit. The scale point 0 is an arbitrary one. So, the number of equations which has been developed for the surface magnitude M_S and the body magnitude m_b, relating these equations or these quantities to the characteristics of the seismographic record. Sometimes it is necessary to convert one type of magnitude to another, and that too widely used approximate relations are those given by.

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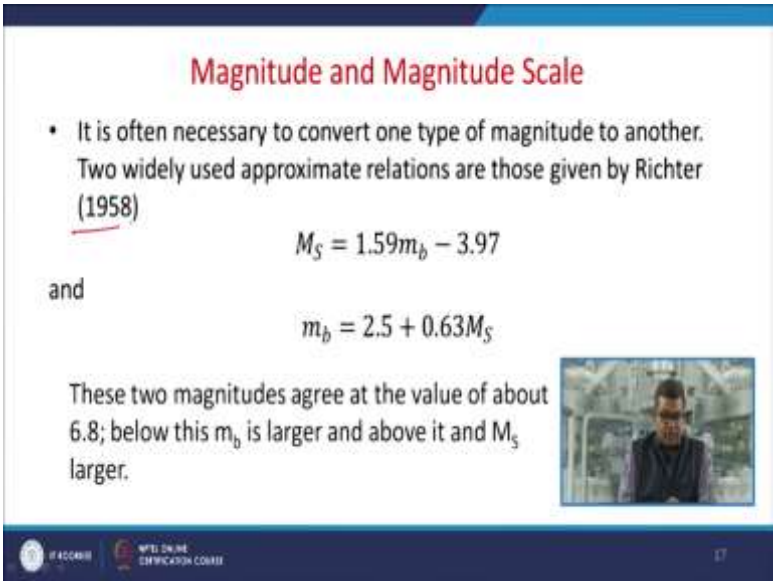

One is given by Richter in 1958 is this one that is

$$M_S = 1.59m_b - 3.97$$

And

$$m_b = 2.5 + 0.63M_S$$

Now these 2 magnitudes agree at the value of about 6.8, below this m_b is larger and above it M_s is larger. Now, this is a very much guiding factor while designing, layouting any kind of chemical plant, so that it falls under specific zone then definitely with the help of this particular equation we can design, so that we can put on more earthquake resistant material design aspect in that particular layout.

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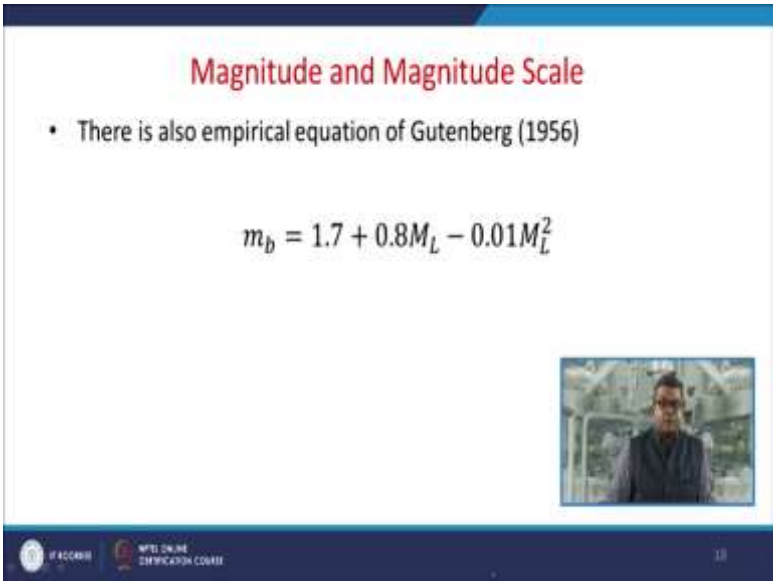

Now, there is also an empirical equation by Gutenberg prescribed in 1956, this is

$$m_b = 1.7 + 0.8M_L - 0.01M_L^2$$

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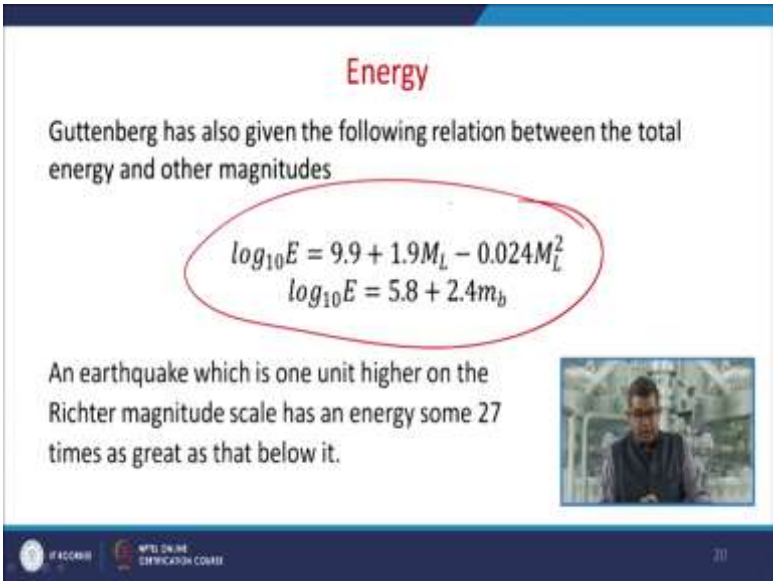

Let us have a look about the energy aspect because this earthquake is attributed to the energy aspect, so the relationship between the total seismic wave energy and the surface wave magnitude was the subject of series of studies by Gutenberg and Richter who produced between 1936 and 1956 and a number of correlations being developed in the due course of time.

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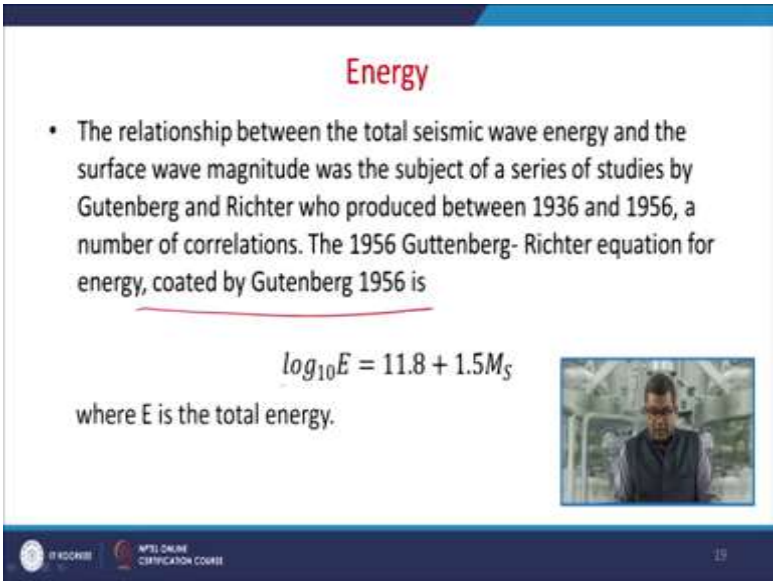

So 1956 Gutenberg-Richter equation for energy quoted by Gutenberg is

$$log_{10}E = 11.8 + 1.5M_S$$

where E is the total energy.

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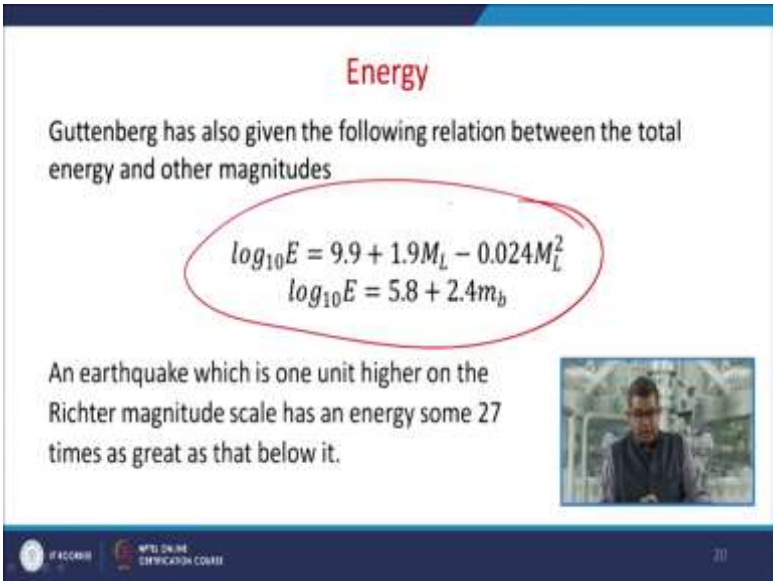

So Gutenberg has also given the relationship between the total energy and other magnitude.

$$log_{10}E = 9.9 + 1.9M_L - 0.024M_L^2$$

$$log_{10}E = 5.8 + 2.4m_b$$

So in this particular equation you can see that there is a relationship between the total energy and other magnitudes like M_L, m_b, etc. So an earthquake which is one unit higher on the Richter magnitude scale has an energy some say 27 times as great as that below it, so you can imagine the magnitude of energy associated with any kind of earthquake.

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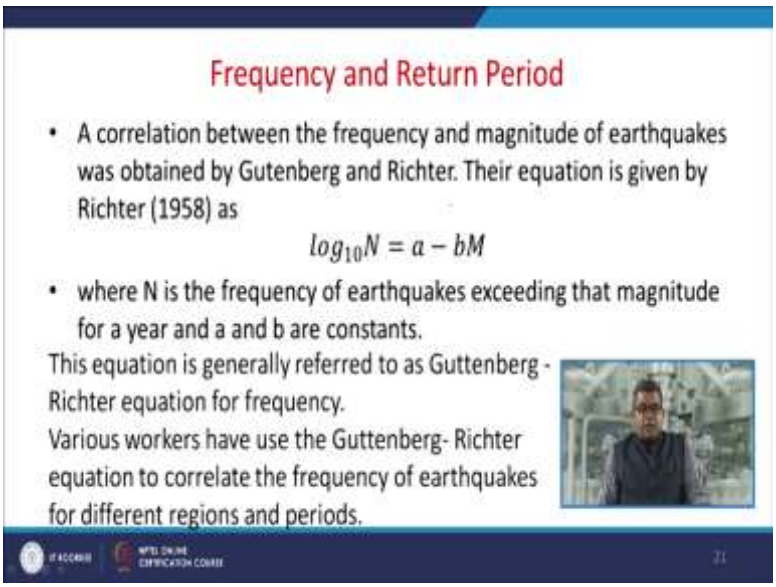

Now, let us have a look about the frequency and return period. So correlation between the frequency and the magnitude of earthquakes was obtained by Gutenberg and Richter. Now, this equation is given by the rector in 1958 as

$$log_{10}N = a - bM$$

where "N" is the frequency of earthquakes exceeding that magnitude for a year and a and b both are constants. So, this equation generally referred as Gutenberg written equation for frequency. So, various workers have used this Gutenberg-Richter equation to correlate the frequency of earthquakes for different regions and period.

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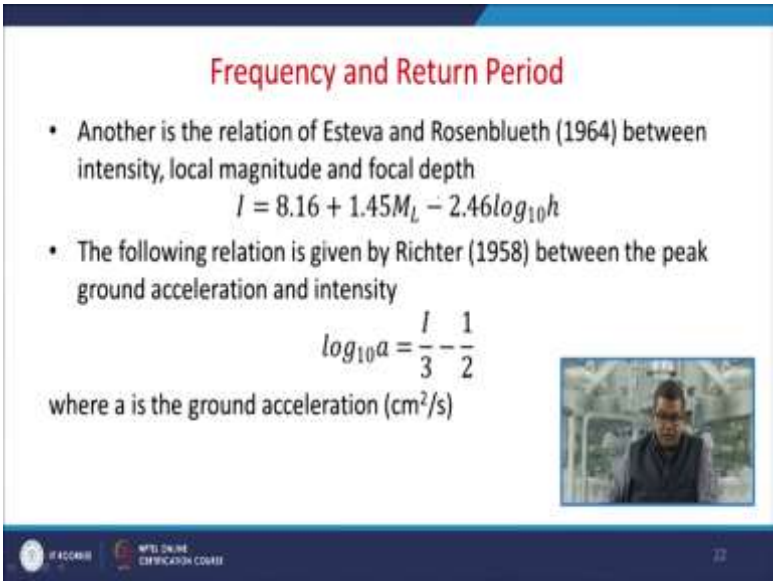

Another is the relation of Esteva and Rosenblueth in 1964 between the intensity and the local magnitude of the focal depth and this equation is given by this correlation.

$$I = 8.16 + 1.45M_L - 2.46log_{10}h$$

Now, this relation is given by the Richter in 1958 between the peak ground acceleration and intensity.

$$log_{10}a = \frac{I}{3} - \frac{1}{2}$$

So here, a is the ground acceleration, which is having the unit square centimetre per second.

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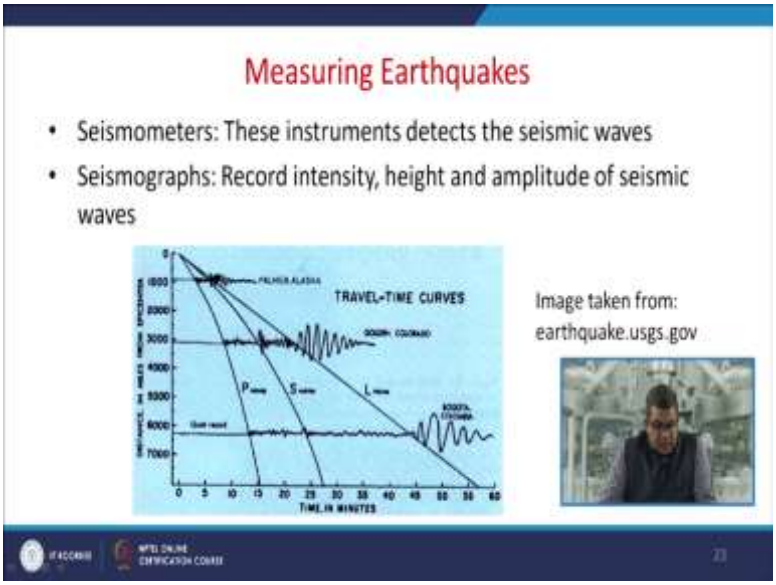

Now, sometimes measuring earthquake is a bit tricky issue and for this, seismometers and seismograph both are being used for measuring the earth quake. Now, seismometers these instruments detects the various seismic waves, whereas the seismograph they records the intensity, height and amplitude of those seismic waves. So you can see this particular graph where you can put the seismograph is given, so you can see that intensity, the reason like Alaska, Golden Colorado, Bogotá so they have recorded different ways, et cetera, so this is the sample example of seismograph.

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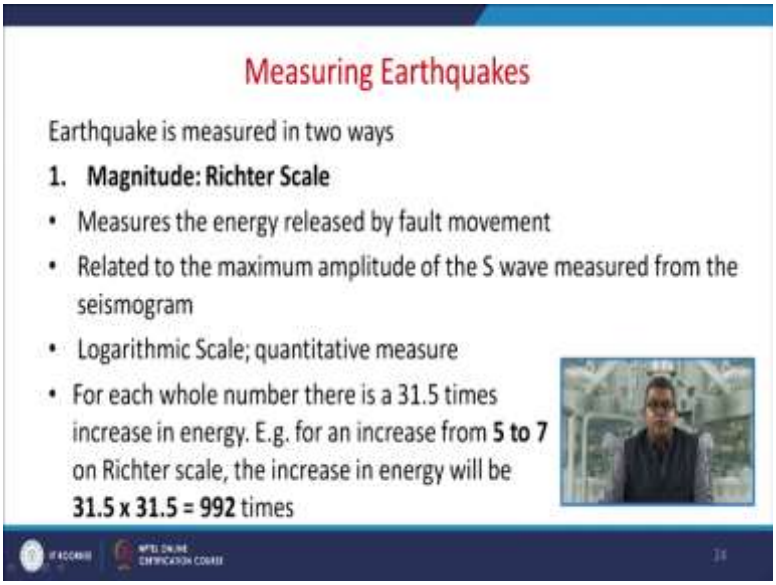

Usually, whenever we are involved in measuring of those earthquakes, earthquake is measured in 2 ways; one is the magnitude with respect to Richter scale. This measures the energy released

by fault movement related to the maximum amplitude of the S waves measured from the seismogram. Logarithmic scale, quantitative measurement is also been taken place. So for each whole numbers there is a 31.5 times increase in the energy. For example, for an increase from 5 to 7 on Richter scale, the increase in energy is given by 31.5 into 31.5 because 5, 6, 7, so it is 992 times, almost 992 times.

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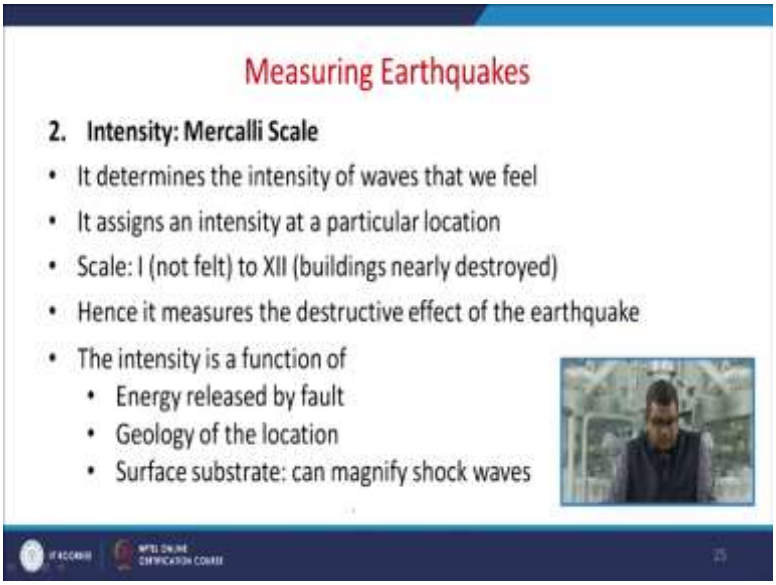

Second aspect is intensity that is related to the Mercalli scale. Now, it determines the intensity of waves that we feel, usually assigns an intensity at a particular location. Now, scale one is when it is not felt to 12 then buildings nearly is destroyed, so hence it measures the destructive effects of an earthquake. The intensity usually is a function of energy released by fault, geology of the location, surface substrate, this can magnify the shockwaves, et cetera.

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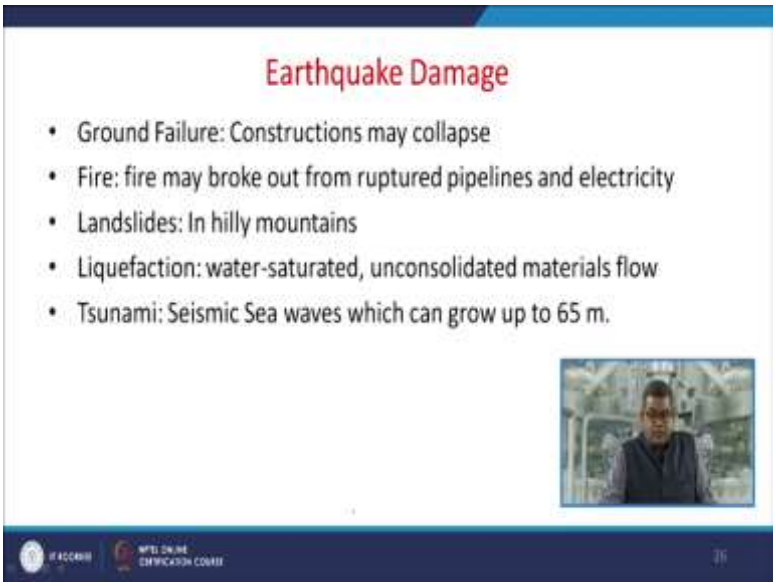

So, let us have a look about the earthquake damage this maybe the ground failure, construction sometimes it may get collapse. Fire may broke out from the ruptured pipelines may be in terms of when these pipelines are subjected to the petroleum product pipeline or sometimes gas pipelines, et cetera, sometimes electricity, etc. so fire may broke up and the results may be

catastrophic. Landslides in the hilly mountain sometimes it may create extremely dangerous and afterwards of earthquake. The liquefaction, the water saturated, unconsolidated materials flow, Tsunami that is seismic sea waves which can grow up to 65 to 70 meters in height.

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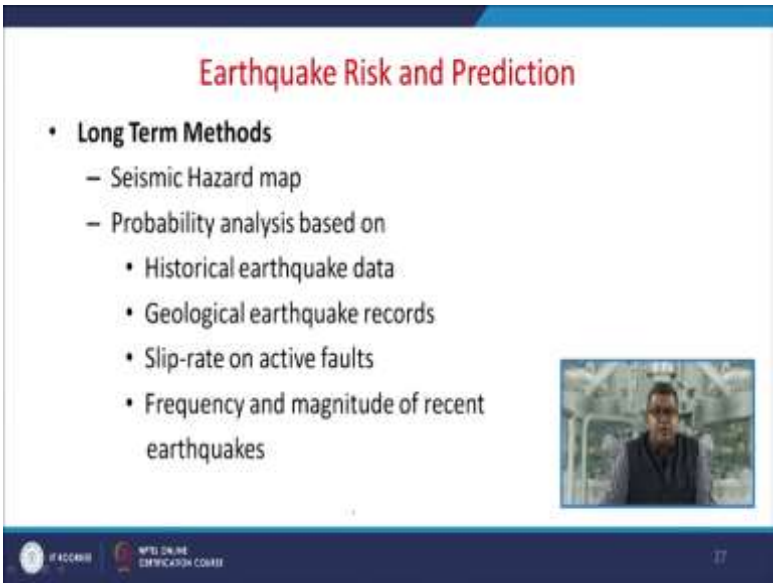

So, let us have a discussion about the earthquake risk and protection. So one is the long-term method that is related to the prevention aspect, you must have seismic hazard map, you may divide different types of seismic zones. The probability analysis sometimes is based on the historical earthquake data, sometimes geographical earthquake records, sometimes slip rates on active faults, frequency and magnitude of recent earthquake also gives proper information related to the long-term methodology.

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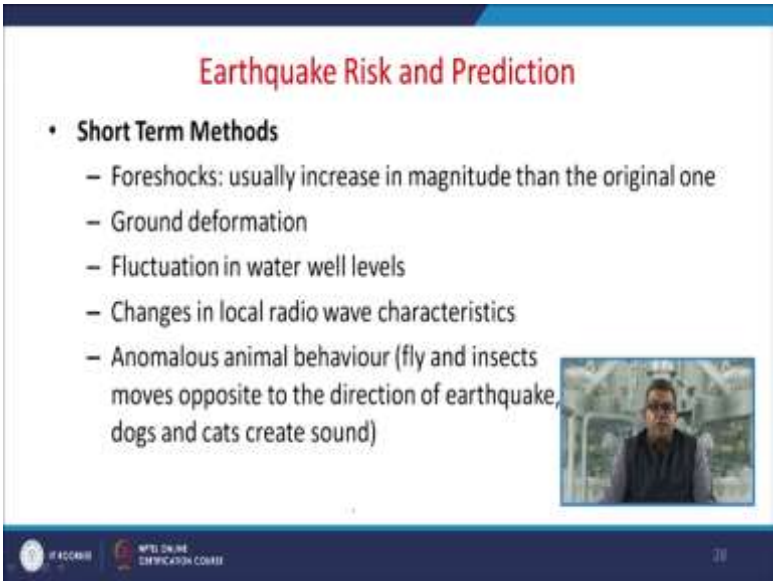

Another one is the short-term one, they are related to the foreshocks usually increase in magnitude than the original one sometimes, the ground deformation sometimes, fluctuation in water well levels, changes in the local radio wave characteristics. Sometimes anomalous animal behaviour like fly, insects move opposite to the direction of the earthquake, dogs and cats they create sounds, et cetera, so they can sensitise about different types of waves coming out from the earth.

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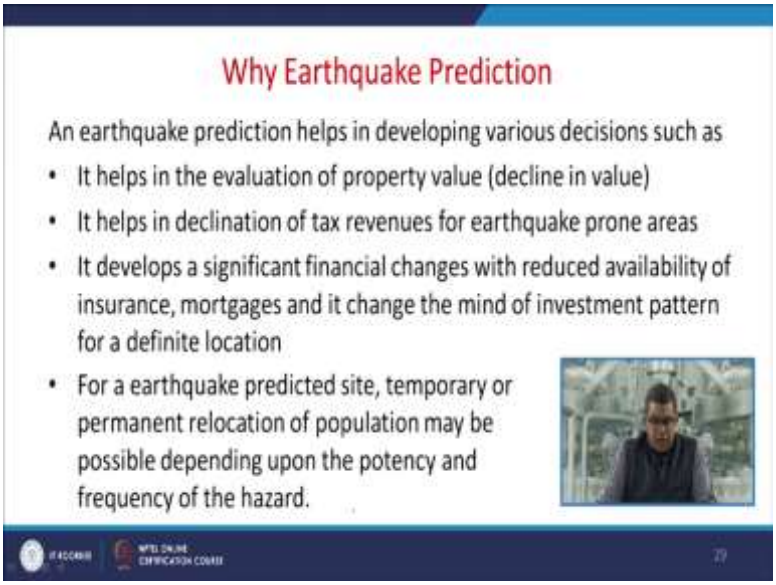

Now, why the earthquake prediction? So, an earthquake prediction helps in developing various decisions like it helps in the evaluation of the property value, sometimes declined value, if your

establishment is in the earthquake free zone then definitely you will see certain appreciation in the value. Now it helps in the declination of the tax revenue for the earthquake prone areas.

It develops a significant financial changes with reduced availability of insurance, mortgages and the changes in the mind of investment pattern for definite locations, et cetera. For earthquake predicted site, temporary or permanent relocation of population may be the possible depending upon the potency and frequency of this hazard. Sometimes those particular area may be avoided under the city plan, sometimes work activities disturbed and can be seized which develops temporary or permanent unemployment for that particular location.

Along with that the level of business activity in those area will also get affected, sometimes periodic trainings and informative session must be provided in every organisation for awareness and developing mitigation strategy for such kind of hazards. Now, let us have a look about the earthquake mitigation. Now most earthquake related injuries, deaths results from collapsing of walls, flying glasses, falling objects, collapse of any kind of storage activities, et cetera.

So it is advisable for a person to move a little as possible to reach the place of safety, now pick a safety place in each room of your house or office or industrial establishment or school, et cetera. This could be furniture such as study table or a desk or against the interior of wall away from any kind of window. Now, brace yourself in and inside corner away from window, move in inner wall or corridor or sometimes door frame of the structural frame or inner core of the building are its strongest points at least likely to collapse.

So they will also back the impact of any falling object that means you are dissipating the energy of those falling objects. So in an apartment building, the safest place is by the Central reinforced core of the building, which is usually located by the elevator wall. You may choose a shelter which shall provide air space if collapses, if your furniture shelter moves stay under it, follow it around the apartment.

Sometimes you know watch the following objects like plaster breaks, light fixtures, pots, fans, et cetera, so usually stay away from the tall shelves, cabinets and other furniture which might slide or topple over. Stay away from the windows, sliding glass doors, mirrors, etc. Grab anything handy, don't be alarmed if the fire alarm or sprinkler go off. If you are outside exterior, if you are in the moving care, stop smoothly and stay in your car.

Now there are certain earthquake resistant buildings, so buildings are designed to withstand vertical forces. So if earthquake only moves the ground vertically then the building might suffer little damage because all structures are designed to withstand vertical forces associated with the gravity. But the rolling waves of an earthquake exert extreme horizontal forces understanding structure. Now, sometimes these forces cause lateral acceleration which scientists measure as G forces.

Now, when the building and the ground shear, the building's natural frequency, they all said to be in resonance. Now resonating amplifies the effect of an earthquake and causing building to suffer more damage so even symmetrical buildings must withstand significant lateral forces. So engineers counteract these forces in both the horizontal and vertical structure systems of the building. These diaphragms are the key components of any kind of horizontal structure so this includes the floors, roofs of level so while designing any kind of establishment you must look into all this aspect.

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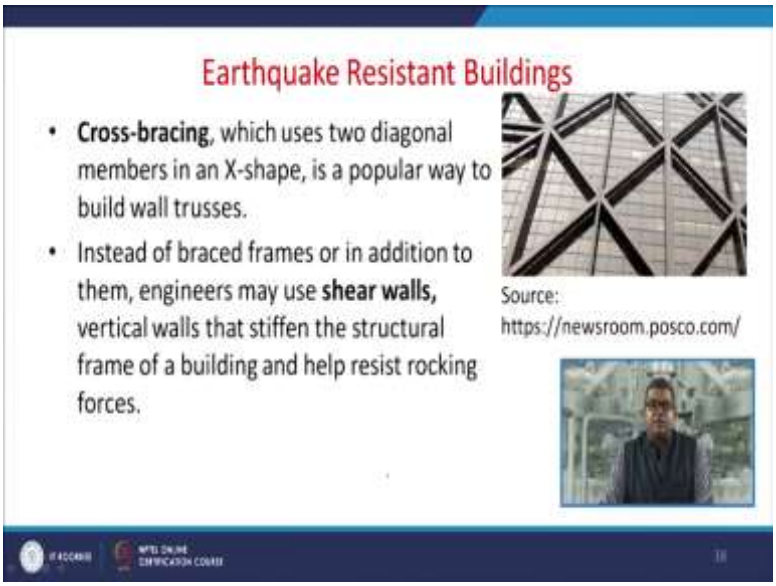

Sometimes the cross-bracing, this uses the 2 diagonals if you see in this particular figure, this cross bracing uses the 2 diagonal members in X-shape like this. This is a popular way to build wall trusses. Now instead of braced frames or in addition to them, engineers may use the shear walls, vertical walls that stiffen the structural frame of a building and help resist the rocking forces.

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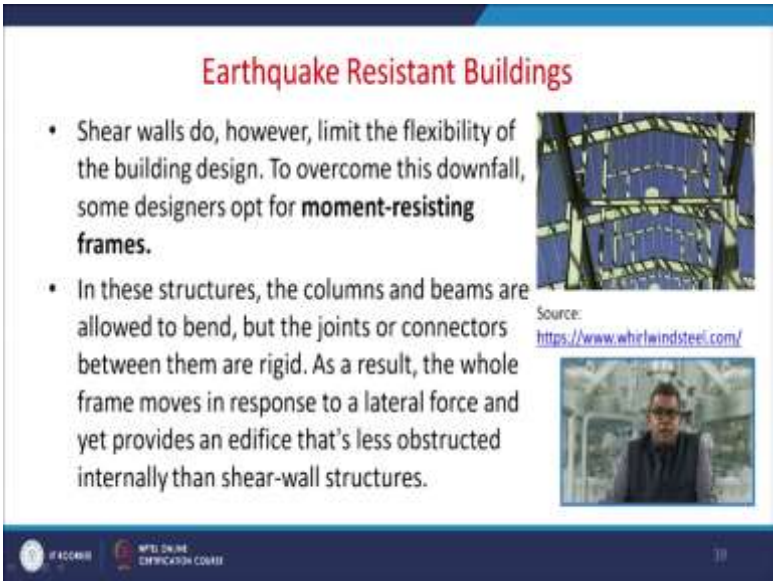

The shear walls do, however limit the flexibility of the building design. Now, to overcome this downfall, some designers opt for the moment resisting frames like this. Now in these structures, the columns and beams are allowed to bend, but the joints or connectors between them are rigid. So as a result, the whole frame moves in response to a lateral force and it provides an edifice that is less obstructed internally then the shear wall structure.

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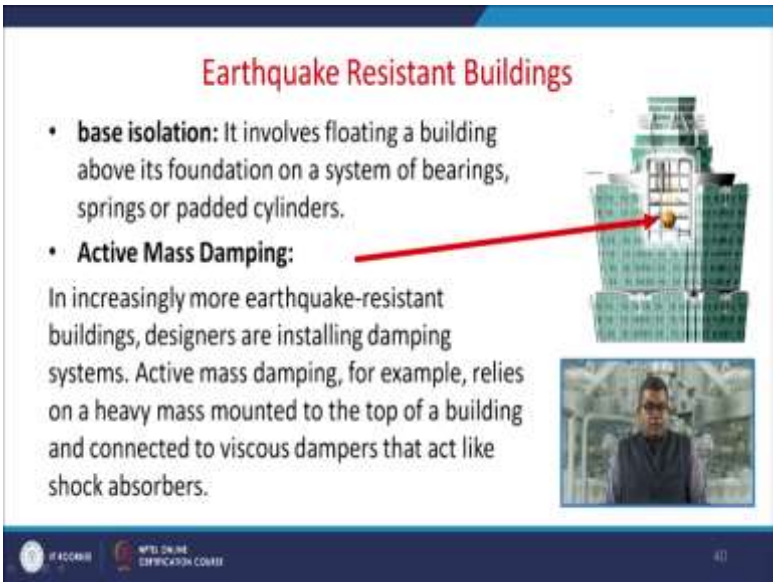

Some base isolation are also there, it involves floating a building above its foundation on our system bearings, springs or padded cylinders, hydraulic movements, et cetera. So, based on this concept, there is a concept of Active Mass Damping. Now, this increasingly more earth quake resistant buildings, designers they are installing these damping systems like high-rise

buildings, et cetera. So this Active mass damping, for example, they rely on the heavy mass mounted on the top of the building and connected to the viscous dampers that act like shock absorbers like in this.

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Now let us have a case study that is the accident took place in Wenchuan earthquake in China 2008. It was the day of May in 2008 2:28 local time. Wenchuan area in Sichuan province that is the heartland of China there was a major earthquake took place and this earthquake killed almost 70,000 people, injured about 3.74 lakh and rendered almost 50 lakh homeless. So the economic loss was attributed to be around 5 million buildings they collapsed while 21 million buildings suffered damage, about 140 billion US dollars was reported in terms of economic losses.

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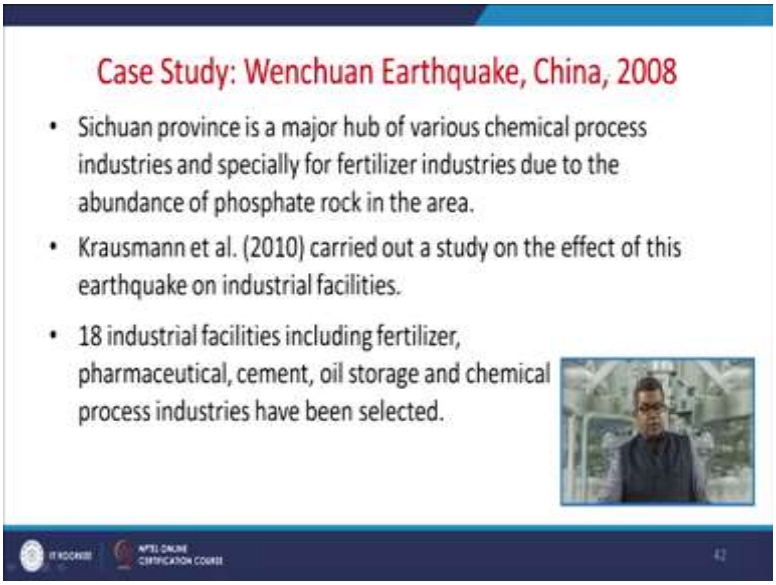

Now, the Sichuan province is a major hub of various chemical process industries and especially for fertiliser industry due to the abundance of phosphate rock in that particular proximity. Now in 2010, a study was carried out to analyse the effect of this earth quake on industrial facility. So 18 industrial facilities including the fertiliser, pharmaceutical, cement, oil storage and chemical process industries have been selected for this one.

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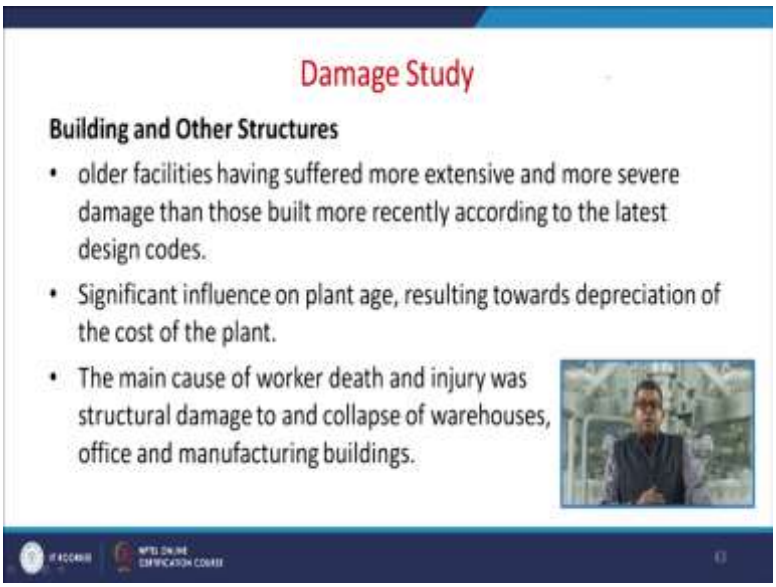

So this study was characterised into different parameters, so one is that building and other structures. So the older facilities having suffered more extensive and more severe damage than those built more recently according to the latest design code. Sometimes government prefers to have these type of design codes and they are modified in C2. Now, the significant influence

on the plant is resulting towards that appreciation of the cost of the plant, the main cause of the workers death and injury was structural damage and collapse of warehouse, office and manufacturing building.

Now falling debris from collapsing buildings and other structures was the main source of equipment damage and the loss. Now the loading by the quick forces like soil liquefaction induced damage was evident in some of the sites. And in one facility numerous silos suffered heavy damage because of the cracks, because of the soil liquefaction. So stack towers made of unreinforced bricks typically they suffer the complete collapse or failure of the upper part where earthquake acceleration was highest.

Another thing related to the pipe and equipment, so much of the loss at the visited chemical facilities comes from the damage to pipes and equipment. And this was caused by the direct loading by the earthquake or indirectly by falling debris from the collapsing building. So one must look into this aspect while designing any kind of piping network in earthquake prone area. Now debris was the main cause for equipment damage and loss as well as for the pipes severing, the crushing the buildings housing machineries.

The shaking load also resulted in breaking of flanges connections between the pipe and equipment. And pipes were also severed, bent or crushed when connected tanks were displaced or building collapsed and often leaving the disconnected pipes hanging in mid-air, et cetera, so this again is a very dangerous aspect. The tanks and vessels, they suffer the damage due to debris, in fact foundation damage or failure or toppling under the influence of earthquake load, so all the material which was there had come out from those tanks.

They studied about the lifeline, so extensive damage to the outage of the electric power, gas, water supply system, forcing maybe industrial plants or interrupted production, et cetera. So the power supply to the most of the affected area was restored within a week of the disaster, the water distribution network suffered badly from the damage to the tanks, reservoirs, numerous (())(30:22) in the water pipeline.

It took around 2 weeks or more to re-establish. Now industrial facilities even if undamaged by the earthquake could only resume operation once the water supply was restored due to the loss of cooling capacity. So in case if they started immediately then something may be more catastrophic.

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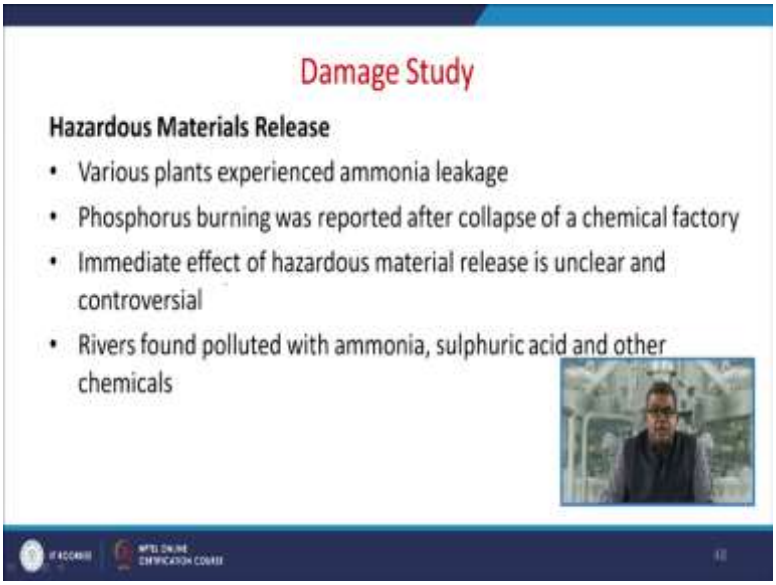

Now let us study about the hazardous material release, so various plants they experienced ammonia leakage, again it was extremely dangerous. The phosphorus burning was also reported after the collapse of a chemical factory, now immediate effect was adult material released is unclear and controversial because sometimes this type of clear data may not be available because it is very difficult when large number of fatalities are at stake so it is very unpredictable find out the actual reason of those hazardous material released.

So rivers found polluted with ammonia, sulphuric acid and other chemicals. So and the last of this particular case study there are a couple of lessons learned like natural disaster can have devastating impact on the industrial facilities, casualties, environmental losses, economic losses in addition to the interaction in business. Newer buildings and constructions of earthquake resistant structures do help in handling of such situations.

Realistic assessment of expected earthquake is the step to mitigate the risk, the collapsed building and debris resulting are the major reason of casualties, so efforts should be made to lessen these situations. Now in this aspect one thing we must remember that the man-made disaster or man-made accidents we can always prevent by proper designing, proper knowledge, proper technical competency, so you can always either prevent or you can minimise but the natural disaster or natural cause we cannot prevent it because it is highly unpredictable in nature, highly uncontrollable.

So this is the thing I mean by this way you can minimise the aspect of danger, you can minimise the aspect of catastrophe by proper designing by proper lay outing, by proper taking care of all

the aspects. So in this particular aspect we have discussed about the earthquake issues. As a reference we have taken with respect to the natural hazards or natural calamities which may pose any chemical plant at the stake.

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If you are interested then you can see different references which we have enlisted in this particular slide. So as we are coming to the end of this particular subject that is Chemical Process Safety So in the particular subject we have studied all the basic aspects of chemical process safety, what are the root causes of Chemical Process Safety, what are the different things which are attributed to safe operation of any chemical plant.

We covered the man-made hazards to the natural hazards, we have gone through different remedial measures, how to prevent fire, how to the prevent explosion, what are the different integral part of any kind of toxic logical studies, et cetera. We have covered various numerical aspects, also we have covered different case studies which are the major hazards or major event in the chemical safety timeline.

So, I hope that this particular subject is very much informative and we have covered all the aspects of this particular subject. With this I am summing up, thank you very much for your patience and thank you very much for your understanding, thanks.