Geotechnical Earthquake Engineering

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Module - 3

Lecture - 6

Engineering Seismology (Contd…)

Let us start our today's lecture on our course geotechnical earthquake engineering. We were going through this module three of geotechnical earthquake engineering course, that is, on engineering seismology.

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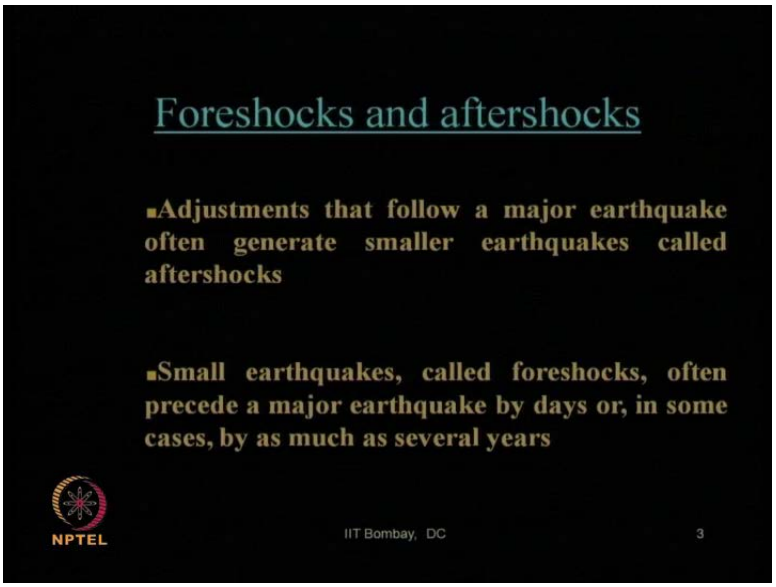

A quick recap, what we have studied in the previous lecture, like what are foreshocks and aftershocks of main earthquake or major earthquake, we have seen.

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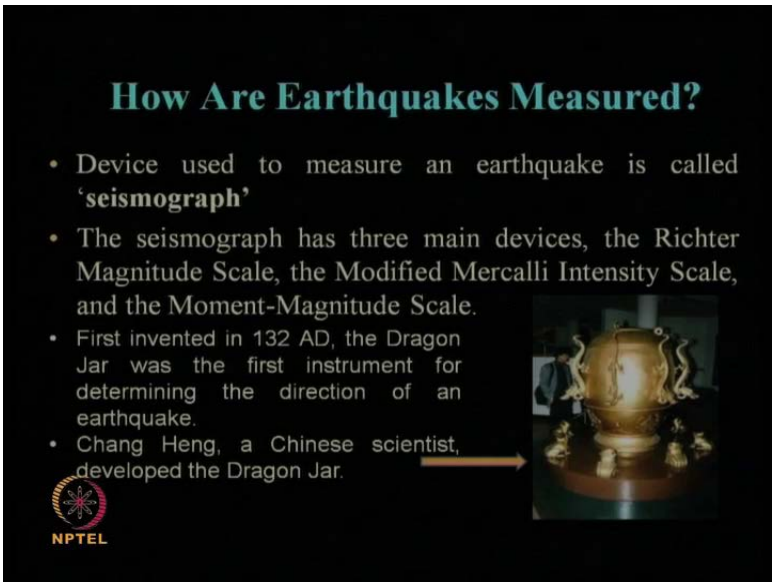

Then, we have seen how to measure the earthquake quantitatively through the use of seismograph, and the olden day's seismograph is nothing but the first one is the Dragon Jar type seismograph, which was invented by Chinese scientist, as shown in this picture. And we have also learned that there are three major devices by which we can estimate the earthquake, one is by Richter magnitude scale, another modified Mercalli intensity scale, and another is Moment-Magnitude scale. Truly speaking, we can divide this measurement of earthquake in two major categories, one is the quantitative measurement through some magnitude scale and another is through the intensity scale.

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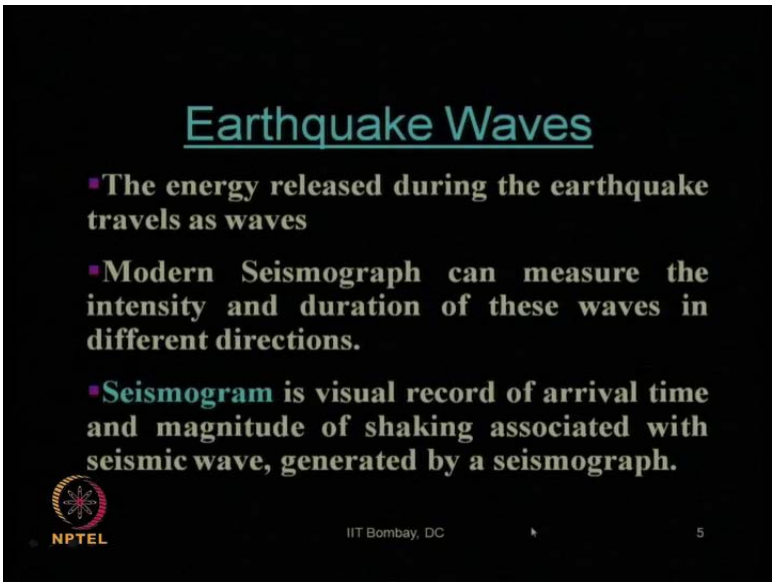

Then, we have also learned that during the earthquake, when energy gets released it travels as waves, and the modern days seismograph can measure the intensity, as well as duration of all the different types of waves, which are getting generated or released during this process of energy release of an earthquake. And seismographs records this travel of wave during and after an earthquake, and seismogram is the visual record of the arrival time and the magnitude of that shaking, which are associated with that seismic waves.

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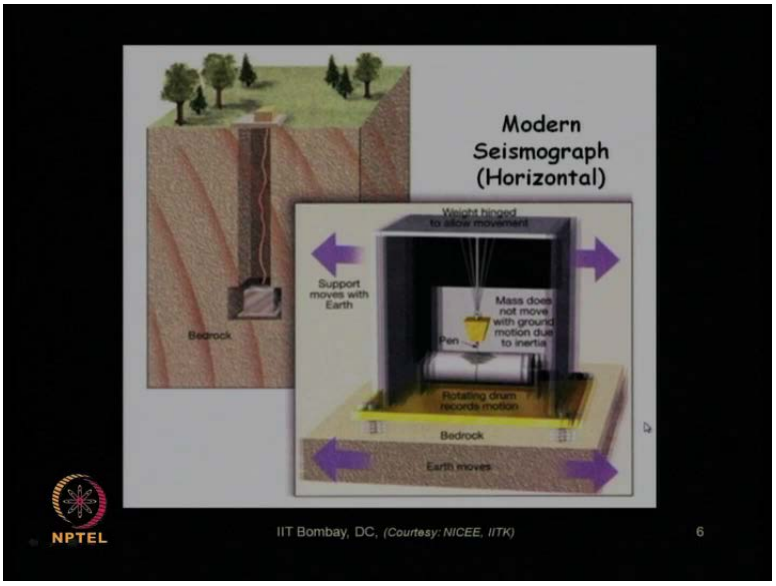

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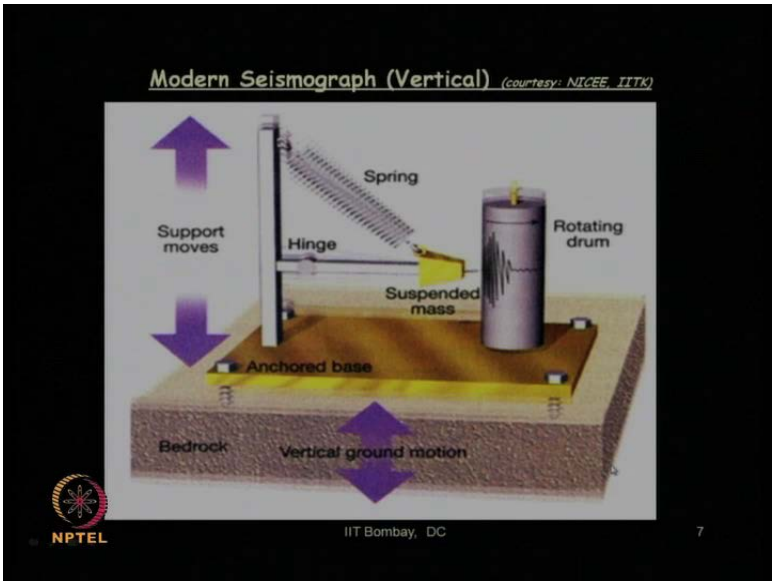

So, in modern day's seismograph we have seen how it looks like for the measurement of the horizontal directional waves. This is the way, the modern day seismograph records the vibration or the seismic waves in the horizontal direction, as well as, we have seen the modern seismograph, which records the movement in the vertical direction in this fashion.

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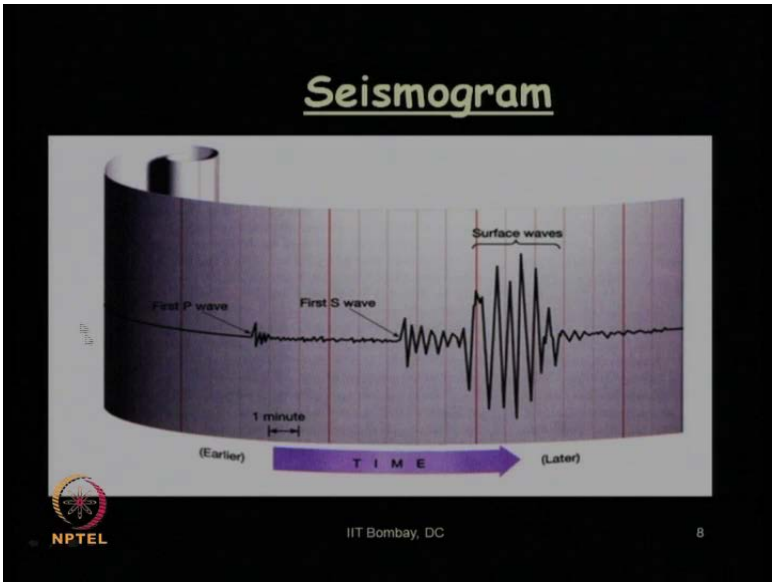

And then, a seismogram looks like this that is, with respect to time on that paper, what we have seen on the seismograph that records all the arrival time of these different types of waves, like P wave, S wave and surface wave.

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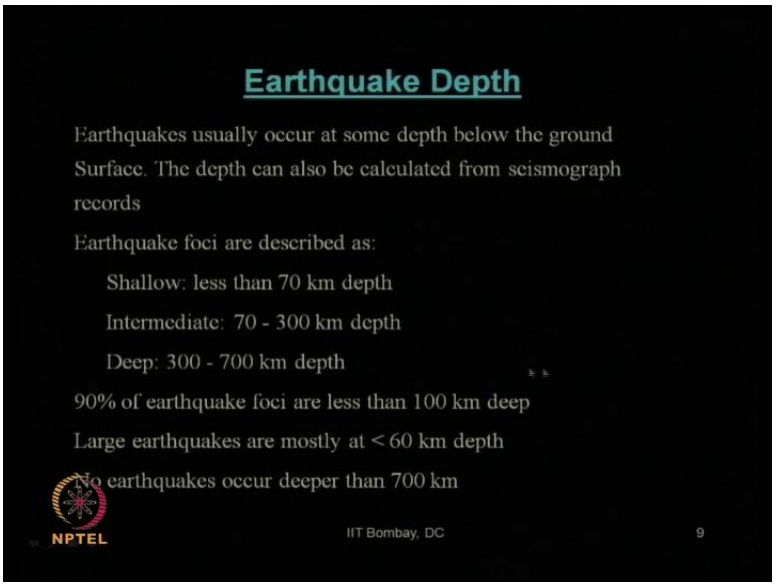

Then, we have also discussed about the depth of an earthquake and with respect to depth we have seen, that earthquake can be categorized into three major categories. One is called shallow earthquake when the depth of earthquake is less than 70 kilometer from ground surface, intermediate earthquake when earthquake focus is within 70 to 300 kilometer from the ground surface and deep earthquake when the earthquake focus is within the depth of 300 to 700 kilometer from the ground surface.

And also we have seen, as can be expected, 90 percent of the major earthquake or more larger magnitude of earthquake are all shallow earthquake, which is quite obvious because closer to the ground surface, more will be its devastating effects.

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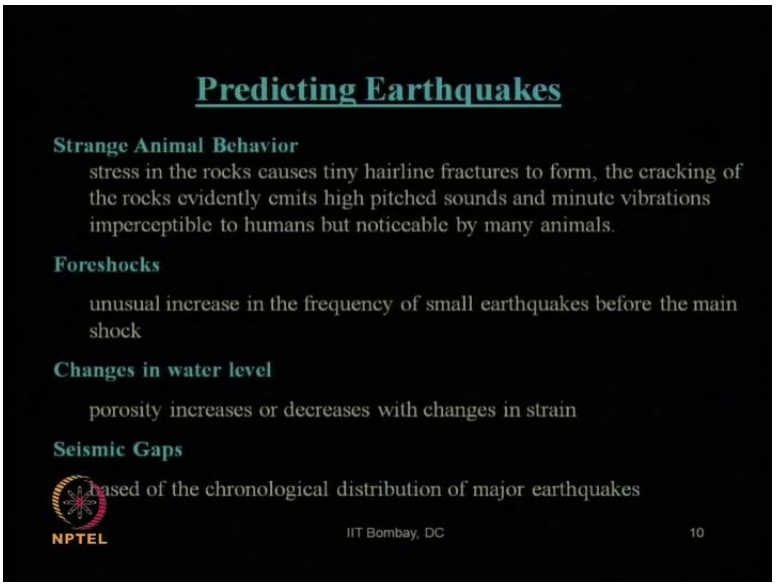

Then, the topic, which we are starting today, like whether we can predict earthquake or not, so regarding the predicting of earthquake people say different categories, like strange animal behavior, like whenever there are stresses in the rocks, which causes this tiny hairline crack during the earthquake process, that is, the rocks get ruptured or whenever there is a plate tectonic moment. If there is a breakage between the two boundaries of the plates or movements or there is a breakage in the rocks, then the tiny hairline fracture, they create a sound, which is of high pitch, that cannot be imperceptible to the human audibility range, but it may be noticeable to animals.

But we also can say, that many animals behave erratically during any changes of the nature, like whenever there is some eclipse, mainly the solar eclipse, that time also, suddenly during day time when the sun vanishes or getting covered during the solar eclipse, that time also animals, like birds, etcetera, behave erratically. So, any kind of natural disturbances, even a big storm is coming, that sound also the animals can record, which is imperceptible to human audibility range to a certain extent. That is why, we cannot strictly say, that using the strange animal behavior we can predict earthquake. It is just a kind of behavior, which does not give us the exact date or time of a future earthquake.

Whereas, if we take the example of foreshocks, like there can be unusual increase in the frequency of small magnitude earthquake before a main or major earthquake arrives at a

particular station that can be an indication, that one major earthquake is going to occur. But again, in this case also we cannot say what is the exact future date of an earthquake and magnitude of an earthquake.

Also, changes in the water level, like porosity increases or decreases with changes in the strain and the seismic gaps, that is based on the chronological distribution of major earthquake people can say a range of earthquake, which is expected to occur, but not the exact one.

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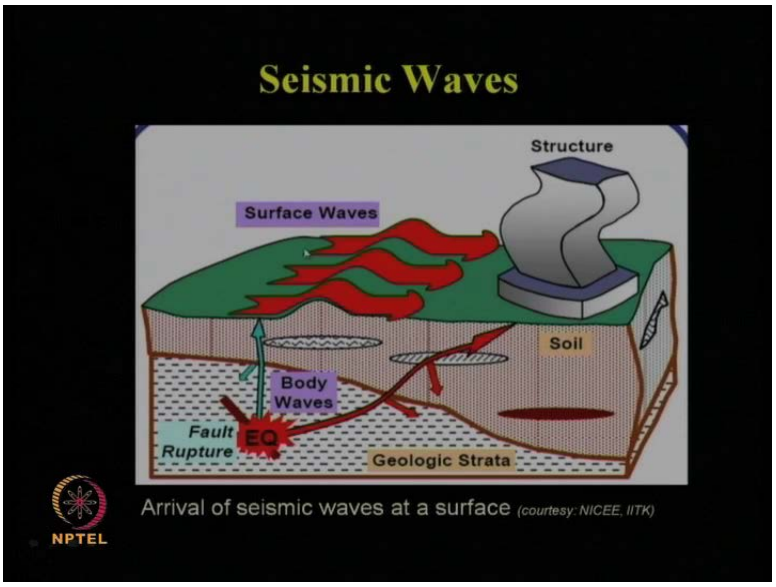

So, during earthquake, we have already learned this, that arrival of seismic wave at surface occurs in this way, like whenever the earthquake energy gets released at a particular depth below the ground surface that is the focus of the earthquake. So, from that point during the energy released through this fault rupture various seismic waves get form, so they travel in all the directions and finally, they arrive at the ground surface. So, the seismic waves, which travel through this interior of the earth, these are nothing, but called body waves and the waves, which travel through the surface of the ground or close to the ground surface, those are called surface waves. So, these are two basic types of seismic waves, which get created or travelled during, and after an earthquake, one is body wave, another is surface wave. And you can see, it may pass through various geologic strata, as well as, the soil below the ground and finally, it affects the super structure resting on the ground.

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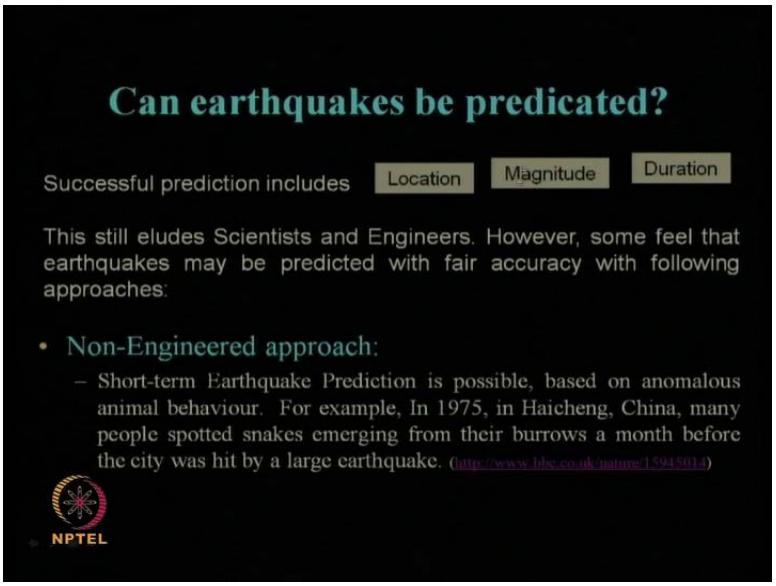

Now, let us come back to that issue, whether the earthquakes can be predicted or not. What do we understand by this term, that earthquake prediction, if we want to predict an earthquake successfully, then what are the things we require to obtain? Like, for a correct prediction of an earthquake one must know these three important things, location of the future earthquake, magnitude of the future earthquake and duration of the future earthquake. So, these three are the important parameters, which must be known if we say, that we want to make a successful prediction of an earthquake.

But this still eludes scientist and engineers. However, some people feel that earthquakes may be predicted with fair accuracy with the following approaches, maybe it is not yet proved by scientist and engineers. So, there can be two major approaches by which people can think about a successful prediction of earthquake, let us see what are those two approaches. One is non-engineered approach, like short term prediction of earthquake is possible based on anomalous animal behavior, as we have discussed just now.

There is an example, like in 1975 in China many people spotted snakes emerging from there burrows a month before the city was hit by a large earthquake. So, this report is available in this site, but still if you see or look at the scientific background of this prediction, it is not a purely scientific one, that is why it is says it is a non-engineered approach. It may be because of some other reason also, snakes may come out of the

ground because of several other natural changes or changes in the nature; earthquake can be one of the reasons. So, it is not necessary, that snakes coming out of the ground will always indicate, that a future earthquake is going to occur, maybe another type of disaster is going to occur. So, it, we cannot say, that this is a successful prediction of an earthquake.

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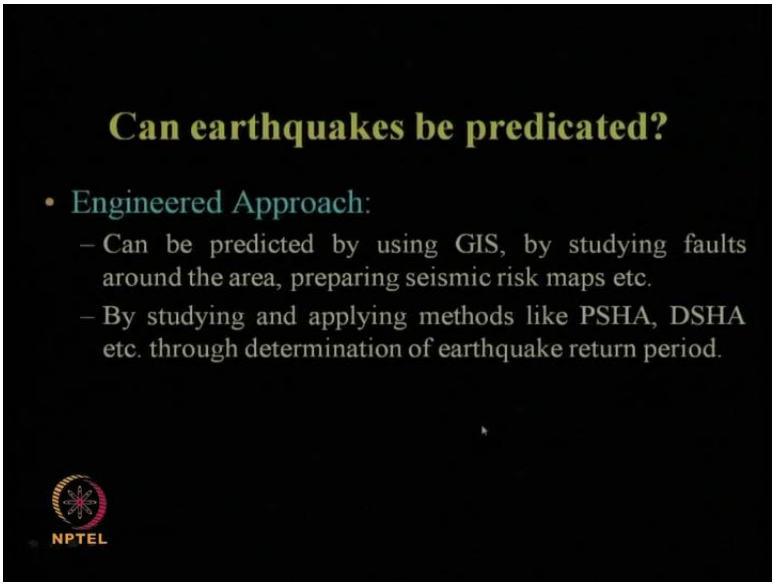

Whereas, there is another methodology, which we called engineered approach. So, how, using the scientific or engineered approach, whether we can predict earthquake or not, let us see. So, it says, it can be predicted to certain extent, not fully, by using GIS, by studying the faults around a particular area, preparing the seismic risk maps, etcetera. And in connection by studying and applying methods, like probabilistic seismic hazard analysis, in short we call that PSHA, and deterministic seismic hazard analysis, in short we call DSHA, etcetera, through determination of earthquake return period.

So, these are basically the mathematical or scientific or engineer procedure by using the concept of probability distribution by which using the historical earthquake data, the fault map and other relevant input parameters we can estimate what can be earthquake return period, that is, after how many years or how many months a particular magnitude of earthquake is expected to arrive at that particular location. Again, I am telling, this is a probabilistic estimation, so always there is a chance that it may happen or may not happen with a certain amount of probability. We can never say that hundred percent

probabilities will be there, that this magnitude of earthquake can occur at this site on this date. So, that exact classification or estimation of a future earthquake date with its magnitude and duration is not yet possible scientifically. We can only give; I have probability, that is, chances of occurrence of a particular magnitude or range of magnitude at a particular site for a particular range of dates or months or even a year. It depends on how well probabilistic distribution you are using for your analysis. Now, let us learn the few basic things, which is necessary for us to save ourselves during and soon after the earthquake.

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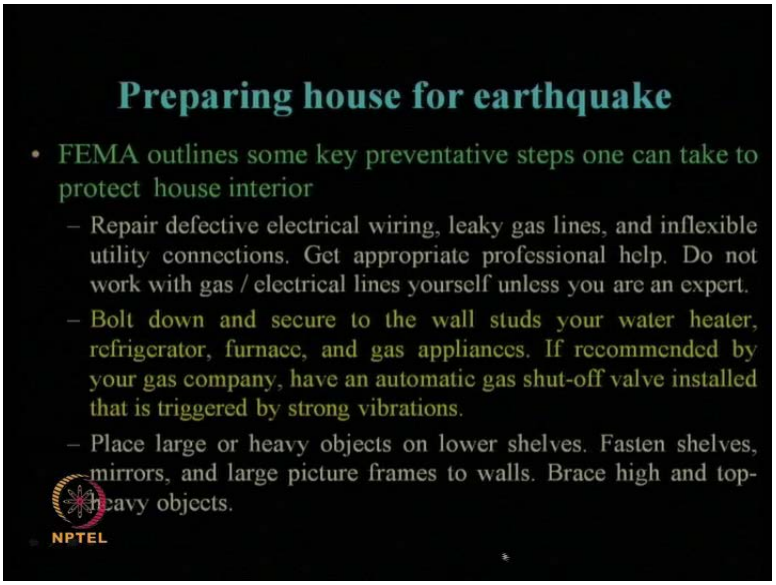

So, let us look at here, that is, preparing house for earthquake, how to handle this issue when we face ourselves the earthquake because as an earthquake engineer or whether you are a geotechnical earthquake engineer or structural earthquake engineer, we must know how to save first of all ourselves during the earthquake. And soon after the earthquake from the damages also we should know, that how to save other people those who got trapped during the earthquake.

So, FEMA outlines some key preventive steps, which one can take to protect the house interior during an earthquake, like repair. Always repair the defective electrical wiring because if you have a defective electrical wiring, some electrical lines, etcetera, cables are hanging just abruptly, during the earthquake process when any damage, everything occurs, those are the first things to gets effected or fall down and there is a high chance,

that electrical short circuiting from those hanging connections, etcetera, may create a severe damage. So, that is why, repair the defective electrical wiring. Then, leaky gas lines, if there are any chances of leakage through your gas line, of course, you must repair that one because again, it may create fire hazard after the earthquake due to large breakage of various structures, etcetera.

And inflexible utility connections, that is, those are inflexible or not properly connected, fixing and features in your inside the house during an earthquake of shaking process, those are the things, which are going to fall first. Suppose if you have a piping system inside your house, if it is not properly fixed, those are going to fall first and it can hit you and other people staying in the house. So, those have to be fixed properly.

Now, get appropriate professional help, that is, wherever it is required, get the professional help appropriately to fix all those things and do not work with gas or electrical lines by yourself unless you are an expert, which is quite obvious, that is, we must not work with this gas system, electrical line system during an earthquake process. If you we are not an expert, then bolt down and secure to the wall studs your water heater, refrigerator, furnace and gas appliances, that is, all this utilities must be fixed properly with the wall, so that if they are not properly connected, there will be always a chance, that these things can fall during the shaking process of an earthquake. It recommends, if recommended by your gas company have an automatic gas shut off valve instead that is triggered by strong vibrations.

So, in large earthquake prone regions like California, etcetera, they have automatic shut-off valve installed in the gas pipe line. Whenever it records certain amount of vibrations, so beyond a certain level of vibrations if the automatic shut-off valve is connected to your gas line, it will get automatically disconnected, which will save the further damages during the earthquake process.

Place large or heavy objects on lower shelves, that means, never keep the heavy items or large items at a higher level because chances of following those large objects during an earthquake process. If it falls, obviously, those are going to damage more those who are staying inside the house. So, try to keep the heavy and large objects as low as possible close to your floor level. Then, fasten the shelves, mirrors and large picture frames to the

walls. So, these things should be connected properly and brace high and top heavy objects. So, everything should be connected in a proper manner.

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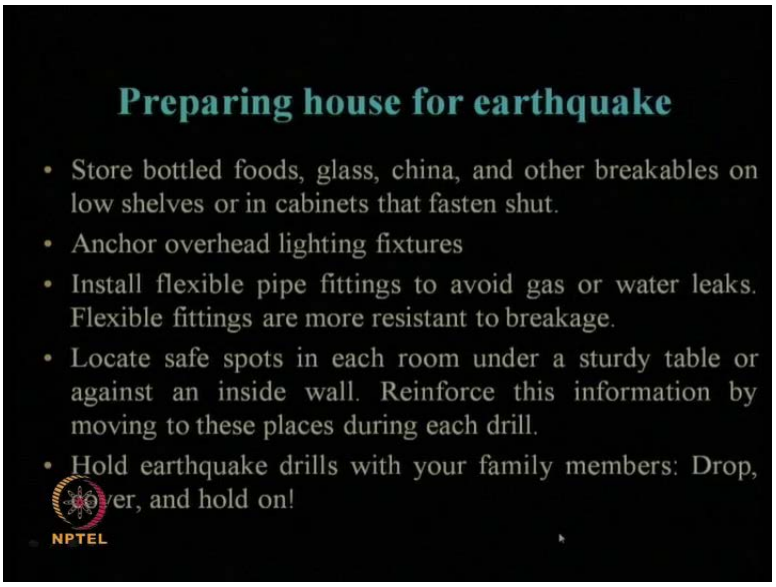

Next, like store bottled foods, glass, china and other breakables items on lower shelves or in the cabinets, that has been fastened properly. That means, all the glass items, bottled items, that is, which are easily breakable items, those things you should also keep them at a lower height as possible, that is, close to your floor level because if you keep them at a higher level, during the earthquake shaking process there is a chance, that this glass objects and breakable objects may fall very easily and that can create the damage and chaos inside the house.

Anchor overhead lighting fixtures, as I have already mentioned, all the electrical fixtures should be fixed properly. So, it includes your lighting fixtures, which are typically on the overhead. Even in our Indian condition, like ceiling fans, etcetera, needs to be fixed properly, so that during the shaking process it can always feel or see the earthquake or whenever earthquake is coming, the ceiling fan from the overhead will try to swing because it will start to act like a pendulum system. So, there is a high chance that it can fall or come down if the connection is not proper. So, to avoid that one must connect that overhead lighting fixture system and this ceiling fan, etcetera, properly to the top.

Now, install flexible pipe fittings to avoid gas or water leaks. Flexible fittings are more resistant to breakage, that is, instead of rigid fittings to this pipe and water connections

you use the flexible fittings because flexible fitting can take a certain amount of displacement during the earthquake process, which will still hold those pipe lines and water lines etcetera, but will not break. But if it is a rigid connection there is a high chance, that it will be broken during the vibration process or shaking process.

Now, locate safe spots in each room, under a sturdy table or against an inside wall. Reinforce this information by moving to these places during each drill. That means, inside the room always you should have a place, which is more safer than the other place, that is typically below a sturdy table or close to a sturdy table where chances of falling objects are minimum and things are pretty strong or restrained properly, so that if necessary, during a large magnitude earthquake one can take a shelter below that sturdy table, etcetera. A strong shelter, which itself will not move much and also it will protect from other objects, which are falling during the vibration or shaking process. Now, hold earthquake drills with your family members, that is, drop, cover and hold on this earthquake drills.

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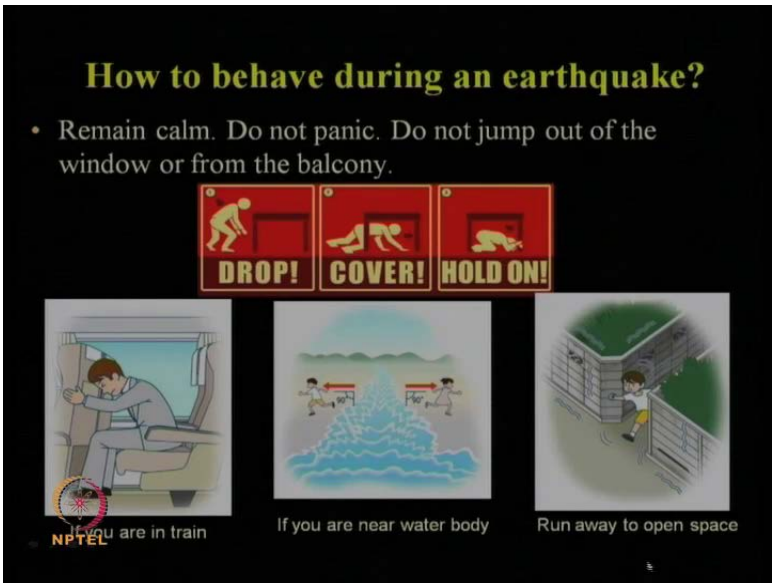

So, this picture clearly shows how to behave during an earthquake because obviously, when any disaster comes, generally people try to get scared and because of their erratic behaviour many damages will occur. So, to avoid that this is a guideline, which says how to behave during an earthquake, so that you can protect yourself and also other people from the large damages during earthquake?

First thing is to remain calm, which is very difficult, of course, when a large disaster or large earthquake occurs, but one must remain calm because then only they can utilize their brain properly to how to react to that event. Do not panic and do not jump out of the window or from the balcony because when large amount of vibration or shaking occurs during an earthquake, to get out of the room because it is always advisable to go to an open ground than inside a house because if the house, various parts of the building, etcetera is going to collapse, soon you may get trapped or even killed due to the process of the breakage or damage of the building. So, that is why, it is advisable to move out of the house and go to a open ground. But during that process you should not try to reach to that open ground by jumping out from windows or balconies, then there itself you are going to hit yourself with a severe damage, maybe.

So, that is why, these are the steps, you can see as I was mentioning, find out a typical shelter point in your house. Always get ready in the very large earthquake prone areas, you drop down below this, then cover yourself and hold on that relatively stable structure during the process, so that falling objects, etcetera, will protect you from that event and also, this will give you some kind of a shelter.

Now, during earthquake if you are travelling in the train the best thing is to hold the relatively stiffer or the fixed seats in front of you, like this. Now, if you are near water body, you must move out from the water body because there will be hydrodynamic waves gets generated and also, there may be a chance to get tsunami wave generated, if there is a condition, which can create tsunami during the earthquake. We have already learned that only few type of earthquake can generate tsunami, not all, so always it is better to move out from the water body during the process of an earthquake. And the best thing is run away to an open space, that is, instead of any structural boundary or building, etcetera, you try to move out from those places and go to an open space during a major earthquake.

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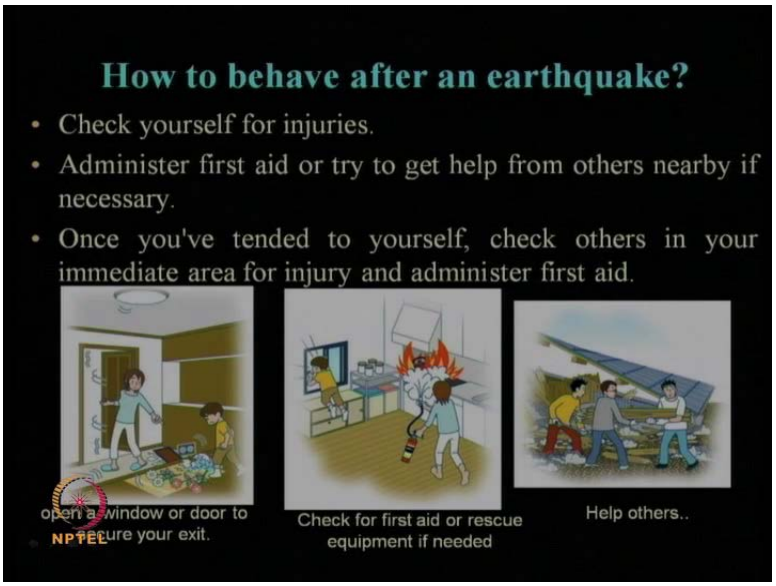

Some more facts, how to behave during an earthquake? You must check yourself for injuries, that is, you have to protect yourself, then only you can protect others as well. Administer first aid or try to get help from others nearby if necessary, that is, first aid should be readily available in the nearby places and if, at your house also you should keep the first aid closest to that stable corner. And once you have tended to yourself, then check for others in your immediate area for injury and administer first aid help to them.

So, see here, it shows open a window or door to secure your exit, so that during the earthquake process if you feel, do not worry about the household items, etcetera, you can move out of the house very easily. Check for first aid or rescue equipment is needed, like fire extinguisher if there is a fire damage, etcetera. You have to keep these items readily available in those earthquake prone areas. And once you are secured by yourself, then help for others, those who got trapped in that process.

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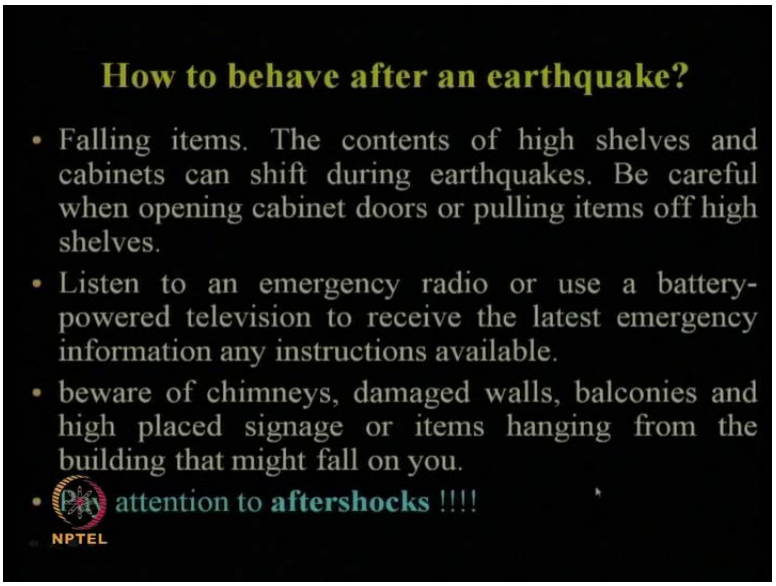

Now, you have to be careful about the falling items. The contents of high shelves and cabinets can shift during the earthquake, so you have to be very careful when you are trying to open any cabinet door or pulling items off the high shelves. It may have shifted from its position and there is high chance when you are opening the cabinet door everything can fall on you and can damage you. So, you have to be very careful about that.

Now, listen to an emergency radio or use a battery powered television to receive the latest emergency information and instructions, whichever is available at the place because many a times at large earthquake prone areas, government or various NGOs, they try to give information, that is, which are the places to avoid, where you should go, where you can get help, medical help, etcetera, rescue team and all other details. So, you have to listen to this emergency radio and for that a battery operated because you cannot expect that power line will be working properly. So, the battery operated television or radio you should use to get all the information.

And beware of chimneys, the damaged walls, balconies and high placed signage or items hanging from the building that might fall on you. So, all these structures you have to be very careful. You should not stand in the balcony because those overhang part are always more susceptible to damages during the earthquake process. So, those places have to be avoided during an earthquake.

And most importantly, you must pay attention to aftershocks. You may feel that I have saved myself from an earthquake, but there may be some more shocks are coming very soon or within couple of days and even months also. So, you have to be very careful and get ready for that aftershocks. You should never take in account, that I have already faced a big earthquake, so nothing is going to happen very soon, it is not. So, there may be a chance of, about this aftershocks also and these are also sometimes more dangerous because maybe, their magnitude may be less than your main earthquake or major earthquake, but already the damages, which has partially occurred during your major earthquake, those will now fully fall down. That is, suppose inside your interior house some part got damaged, got cracked etcetera, but had not fallen during the major earthquake, during the aftershock there is a high chance that those parts will fall down. So, one has to pay attention to this aftershocks of earthquake.

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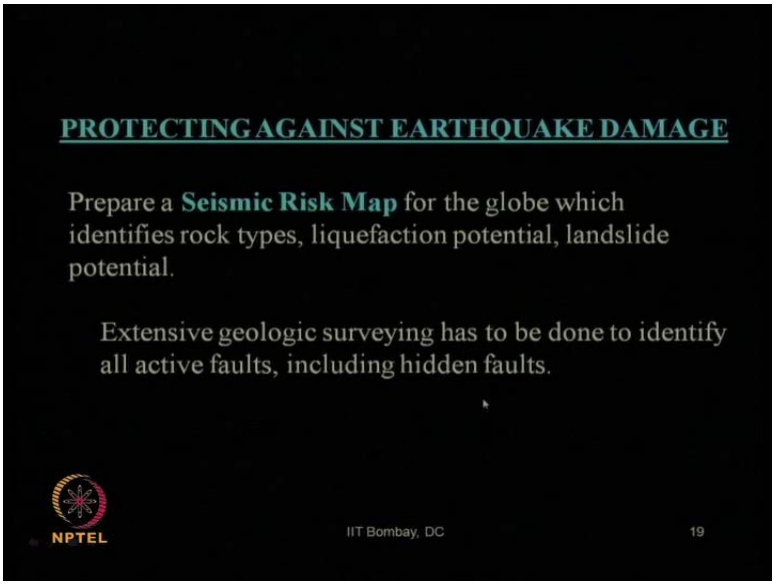

So, protecting against the earthquake damage, as I said, that engineering way to protect ourselves is to first step is prepare a seismic risk map, that is, at a place how much hazard, earthquake hazard is going to come. That can be two different ways, one deterministically, one probabilistically we can find out. Once you get the hazard map you need to find out the risk map that takes care of the vulnerability of an area, that is, how much people, how many people, what are the different structures are getting exposed to that exposure effect, etcetera, and altogether will give you the seismic risk map of a particular locality. So, once you know the seismic risk map of a particular site or

particular locality that will help you for further protection of your structures in that vicinity. So, it, for which, globe identifies rock types, liquefaction potential, landslide potential, etcetera.

So, extensive geologic surveying has to be done to identify the all active faults, that is, whatever faults can be subjected to earthquake in future, those are active faults we have to find out including the hidden faults, that is, the faults, which are not appearing to the ground surface, probably they got lost with another fault plane inside the ground surface itself, those hidden faults also has to be identified through geology investigation or geology survey.

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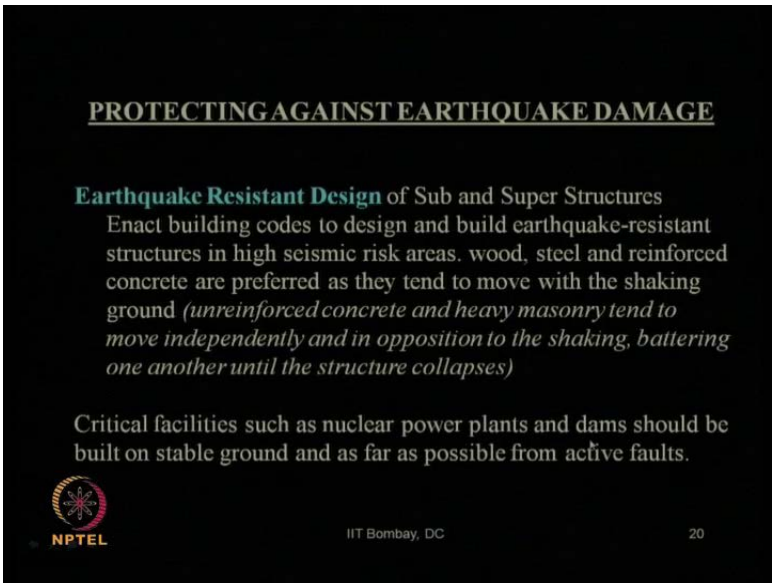

And next step, for the protection against earthquake damages, of course, earthquake resistant design and construction. So, for earthquake resistant design and construction of both sub structure, that is, underground structures, as well as, the super structures or above ground structures. So, enact the building codes to design and build earthquake-resistant structure in high seismic risk areas.

That is, in the first step what you are doing? You are finding out the seismic risk map, that is, you are dividing various locality of an area or a country or a state or a city with respect to the seismic hazard, vulnerability, exposure, all these things taking into consideration. Once you have that seismic risk map available with you, now whenever you are going to a particular high risk zone and for a construction of a building or any

structure with its foundation and sub structure, we have to be automatically careful, that for high risk what are the extra measures should be taken for the earthquake resistant design and construction of a particular building or structure at that locality compared to another zone where earthquake hazard may be or earthquake risk may be minimum or lower.

So, like wood, steel, reinforced concrete are preferred as they tend to move with the shaking ground, whereas unreinforced concrete and heavy masonry tend to move independently and in opposition to the shaking, battering one another until the structure collapses. So, in single words, in high seismic risk area it is better to avoid unreinforced concrete and masonry building. You should go for either wooden building, steel structures or reinforced concrete structures, which are preferred, that is, they can take more amount of movement during the shaking compared to unreinforced concrete and masonry building.

But of course, for that you need to design these structures, whether RCC or steel or wood structure, properly to take care of all the clauses of design codes and the issues involved with super structure and underground structures of during that earthquake resistant design process and the construction process. Whereas, some critical facilities, critical are very important facilities, for example, like nuclear power plants, dams, concrete dams or earthen dams, etcetera, should be built on a stable ground as far as possible from this active faults, why? Because damage of a building is always not expected to occur, of course, we should design the building accordingly. But it is more so for important structures, like nuclear power plant and dams, why?

Because damage of these structures are associated with more severe damage afterwards, that is, if your nuclear power plant fails it creates the problem of several other coincidental events of, say, radiation problems, like what happened during the Tohoku earthquake of 2011 in Japan. That is, after the breakage of nuclear power plant, severe radiation start occurring and that does not create problem only in that locality, but it creates problem spread over worldwide also, like, that is why we have seen during that, after Tohoku earthquake, the major damage of that nuclear power plant of Japan, that created the problem far away up to the Hawaii island because of the movement of the air direction, etcetera.

So, we have to be very careful while we are designing such important structure because breaking of those structures not only creates problem in that locality or that place, it creates sometimes even a global problem, same for the dams. If a dam fails, then it creates a huge problem in the downstream of the dam. The entire downstream may get flooded, washed away, damaged, everything, right. So, that is the reason these are called very critical structures or important structures where extra measures have to be taken, like of course, we do not want buildings also to collapse, bridges also to collapse, but for dams, nuclear power plant, we never ever will design such a structure, which can fail in an earthquake. So extra measure, extra factor of safety, extra things needs to be taken care of for these important or critical structures. Now, let us come to the next subtopic, that is, plate tectonics.

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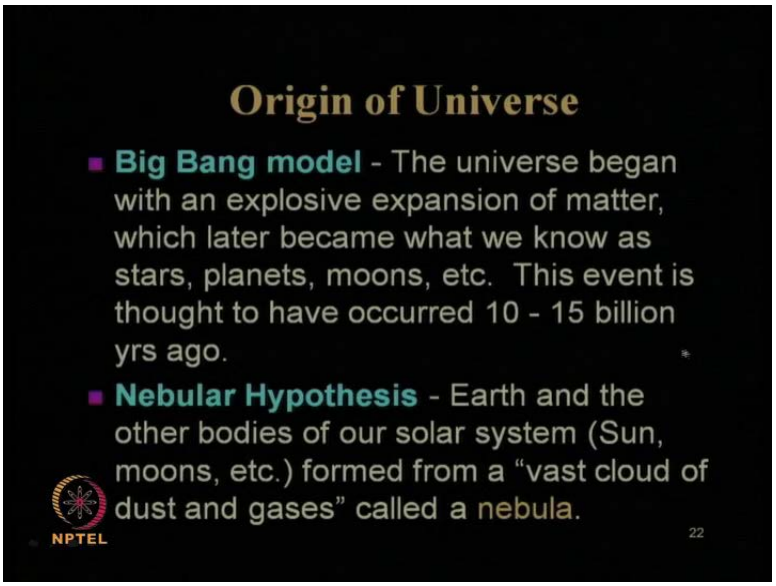

So, before we understand the plate tectonics let us discuss how the universe were found, that is, origin of the universe, which all of us must have learnt in our basic high school geography or other related courses, geology courses, like there are two basic theory or hypothesis, which I believed behind the origin of universe.

The one is called Big Bang model and this model says, that the universe began with an explosive expansion of matter, which later became what we know as present day stars, planets, moons, etcetera. Now, this event of big bang is thought to have occurred about 10 to 15 billion years ago. So, this is one theory or one hypothesis or one module, which

is thought of behind the origin of universe. The second hypothesis says, it is called nebular hypothesis. It says that earth and the other bodies of our solar system, like sun, moon and other planets, etcetera. They were formed from a vast cloud of dust and gases, which are called as nebula that is why, it is called nebular hypothesis.

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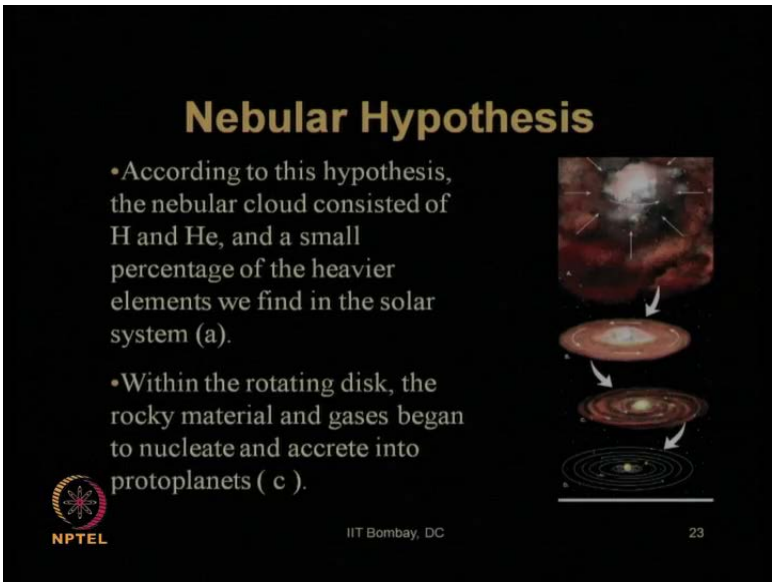

Let us see further, like nebular hypothesis, as you can see, full of dust and cloud through, that through the process of rotation the different, different parts of this solar system got created like the heavy or larger or major portion, like sun get into the center and other planets starts moving around this.

So, according to this nebular hypothesis, the nebular, that is, the cloud consisted of hydrogen and helium and a small percentage of the heavier elements, we find in that solar system a. So, this is a. So, within the rotating disk, within this rotating disk the rocky material and gases began to nucleate and accrete into the protoplanets; this is the protoplanets. So, these rocky materials, they nucleate from a nuclear type of thing, which finally gets created in the formation of the planets of protoplanets that is the belief behind this nebular hypothesis.

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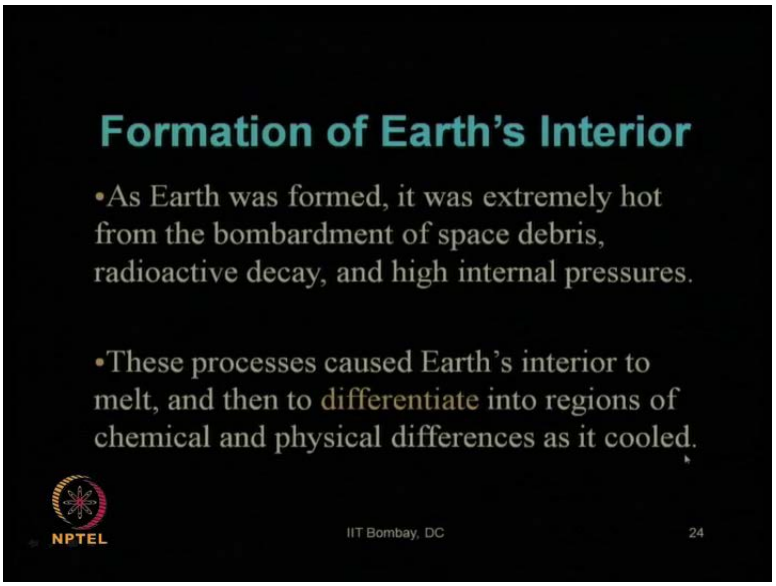

Now, how our earth's interior was formed, like when earth was formed through that nebular hypothesis process as it is believed, it was extremely hot from the bombardment of the space debris, like big rocky materials, etcetera, and the radioactive decay and high internal pressure and these processes caused earth interior to melt and then, to differentiate into the regions of chemical and physical differences as it cooled down with time. So, the inner part of the earth interior is hot and larger specific gravity or weight and as you go out or come close to the ground surface they become cooler and cooler and a lighter weight material as it is spins.

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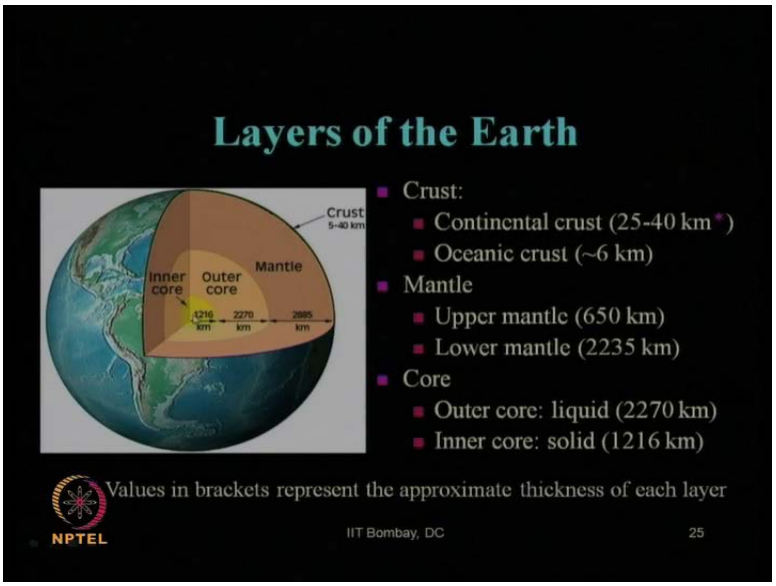

So, the various layers of earthquake, various layers of the earth are defined in three major categories, one is called crust, another is called mantle and another is called core of the earth. Now, crust can be subdivided into two different types, one is called continental crust. The thickness of the continental crust is typically about 25 to 40 kilometer from the ground surface. So, you can see, from this ground surface crust is from 5 to 40 kilometer to cover all the ranges of crust. So, continents, that is present in the crust, which are of thickness about 25 to 40 kilometer, whereas the oceans, the oceanic crust is the thickness of about 6, 5 to 6 kilometer, these are typical ranges. So, that is why, you can see a thickness of entire crustal plate or crust thickness of earth is about 5 to 40 kilometer.

Next part of earth's interior is called mantle and mantle also can be subdivided into two parts, one is called upper mantle, which is having a thickness of about 650 kilometer and next part is called lower mantle, which is having a thickness of about 2235 kilometer. So, that is why, altogether the thickness of the mantle, you can see approximately, about 2885 kilometer or so.

So, upper mantle is the portion close to this crust and lower mantle is the portion close to this earth interior or next layer, which is called core of the earth. So, next part of earth's interior is core. In this core we again can subdivide it into two parts, one is called outer core, outer core is nothing, but full of liquid, that is, it is in the fluidized state, it is not in the solid state. And thickness of that layer is typically about 2270 kilometer and the inner core is heavy solid material, which typically is having a thickness of about 1216 kilometer.

So, you can see in this picture, after mantle, then the inner part is outer core, which is of this thickness, which is fully in the molten state or fluidized state and the inner core, which is heavy solidic material, that is of this thickness here. So, you can see, as we go deeper and deeper the unit weight and specific gravity of material increases. Also, there is an increase in the temperature drastically from the ground surface to the inner of the earth.

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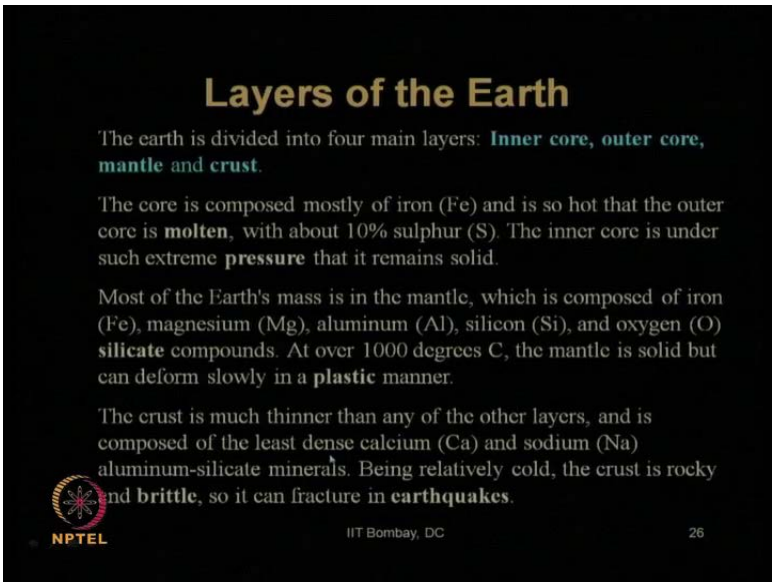

So, the layers of the earth, as we have just now seen major four main layers, we can say inner core, outer core because they are of different types of material, one is fluid, another is heavy solid. So, inner core, heavy solid outer core is fluidic material, then mantle and then crust. The core is composed mostly of iron and is so hot, that the outer core is molten. That is why we mentioned just now it is in the fluid state with about 10 percent of sulphur. The inner core is under such extreme pressure, that it always remains solid because the inner part of the earth is always under the heavy pressure of outer layers, so that remains always under the solid state, but outer core is in the molten state.

So, most of earth's mass is in the mantle, that is, majority of the earth's weight or mass is located in this mantle region, which is composed of iron, magnesium, aluminum, silicon and oxygen silicate compounds at over 1000 degree centigrade. So, you can see the amount of temperature compared to the ground surface, very, very high temperature. The mantle is solid, but can deform slowly in a plastic manner, that is, it is in a fully solid state, but it is under huge pressure, as well as, at a very high temperature. So, it can behave in a plastic manner, that is, it can be deformed in a plastic manner, whereas the crust is much thinner compared to the other thickness.

We have seen all are in the order of thousands, whereas this crust is just in the order of tens. So, much thinner than the other layers and it is composed of the least dense material. There is lightweight material, which is calcium, sodium, aluminum silicate,

etcetera, these minerals are predominant in the crustal level and being close to the outer surface or the air, they are relatively cold and the crust is rocky and brittle. So, they can be broken into parts very easily because they are brittle and so that is why, it can get easily fractured creating these earthquakes. Is it clear why the earthquake can get generated from the crustal plates, etcetera?

And if you have noticed carefully, let us see over here what we have said. Typically, the earthquake, shallow earthquake, they occur within the depth from the ground surface, about 70 kilometer, which is shallow earthquake, which is essentially the earthquake occurring in the crustal plate or in the thickness of the crust mostly, and the intermediate and deep earthquake.

The maximum depth of earthquake the seismology is mentioned is up to 700 kilometer. So, you can see, at this thickness you can add the crustal thickness to that. What does it mean? That earthquakes can occur up to a depth of that upper mantle layer, that is, layer close to that crust, beyond that there will be no chance of getting earthquake, why? Because energy getting released from that layer to reach to ground surface is quite unusual because of its thickness by that process, it gets dissipated fully, is that clear?

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So, with this that what are the various layers of earth and the composition of various parts of the earth's interior, we come to the close of this session. We will start again in the next lecture.