Geotechnical Earthquake Engineering
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Lecture - 1
Introduction to Geotechnical Earthquake Engineering

Welcome to the NPTEL video course on Geotechnical Earthquake Engineering. My name is Deepankar Choudhury.

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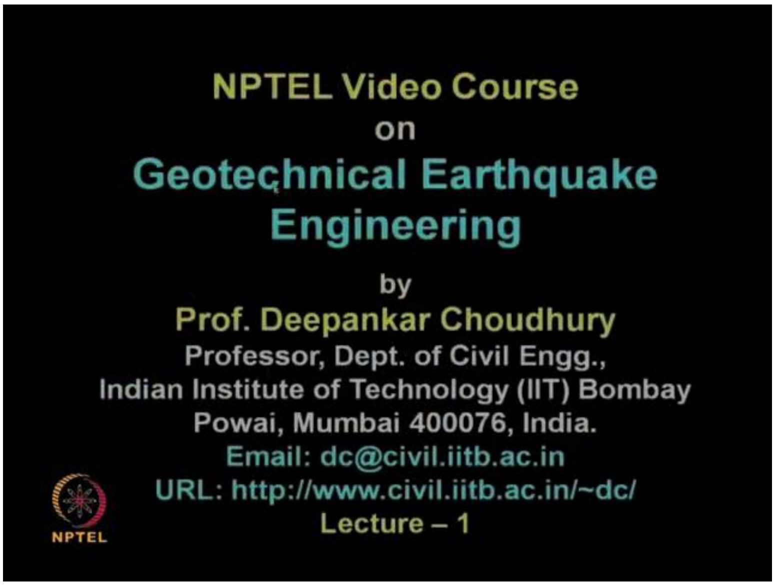

Let us look at the slide here. As I have mentioned just now, we are starting our NPTEL video course on the topic - Geotechnical Earthquake Engineering. My name is Deepankar Choudhury. I am a professor at Department of Civil Engineering at Indian Institute of Technology, that is, IIT, Bombay located at Powai in Mumbai. This is the pincode of Mumbai city of Powai, IIT Bombay campus in India. If anybody is interested, you can contact me by email to this email address, that is, d c at the rate c i v i l – civil dot i i t b dot a c dot i n. And if you are interested to know about my research areas, research publications, projects, students, all other academic details, you can go through this URL, which is available at IIT Bombay, civil engineering official website link, that is, h t t p w w w dot civil dot i i t b dot a c dot i n slash tilde d c.

We are starting our lecture number one of Geotechnical Earthquake Engineering. Let us first see what are the course details and course contents for this Geotechnical Earthquake Engineering video course.

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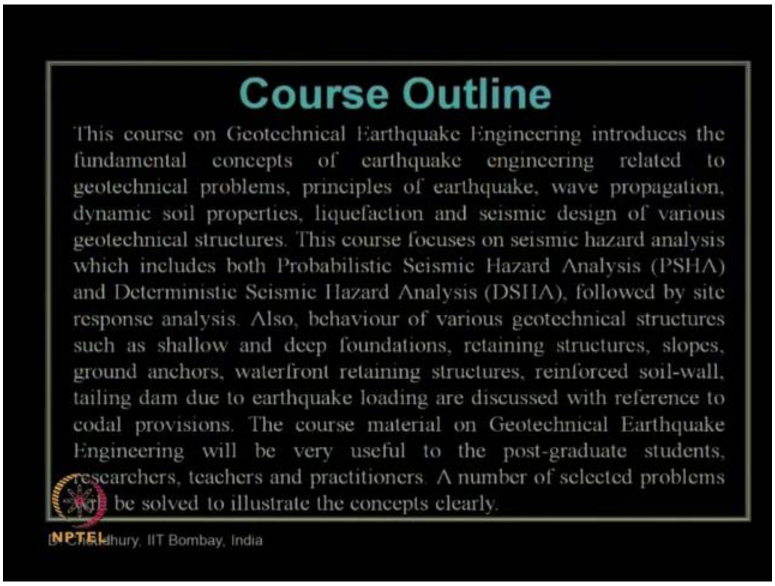

This is the course outline in total. This course on Geotechnical Earthquake Engineering - it introduces the fundamental concepts of earthquake engineering, which are related to our geotechnical engineering problems. Principles of earthquake, wave propagation, dynamic soil properties, liquefaction and various seismic designs of different geotechnical structures like retaining walls, waterfront retaining structures, foundations, piles, slopes, anchors, landfills, etcetera. So, this course focuses on also the seismic hazard analysis, which includes both the probabilistic seismic hazard analysis, which is commonly known as PSHA and deterministic seismic hazard analysis, which is commonly known as DSHA followed by the site response analysis, site specific ground response analysis I should say. And also the behavior of various geotechnical structures as I have just mentioned like for shallow and deep foundations, for the retaining structures for slopes, for ground anchors, waterfront retaining structures, reinforced soil wall, tailing dams due to earthquake loading are to be discussed with reference to the various seismic design codal provisions.

We will be discussing about our Indian seismic design code provision as well as other country design code provisions like the euro code, nihar, US code, etcetera. The course material on geotechnical earthquake engineering will be very useful to the post-graduate students, researchers, teachers, practitioners, etcetera. And a number of selected problems will be solved to illustrate the concept of this entire course very clearly. So, with that course outline, let us see, what are the basic course contents, which we will be covering in this Geotechnical Earthquake Engineering course.

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This is the basic course contents; like first, it will start with the introduction to the topic; then, basic vibration theory will be covered; engineering seismology, strong ground motion, wave propagation, dynamic soil properties, seismic hazard analysis, site response analysis, dynamic soil structure interaction, and applications of earthquake engineering to various geotechnical engineering problems or design related issues for retaining walls, foundations, anchors, piles, tailing dams, landfills, slopes, waterfront retaining walls or sea walls, reinforced soil-walls; then, liquefaction criteria and various seismic hazard mapping, etcetera, will be discussed in this course on Geotechnical Earthquake Engineering.

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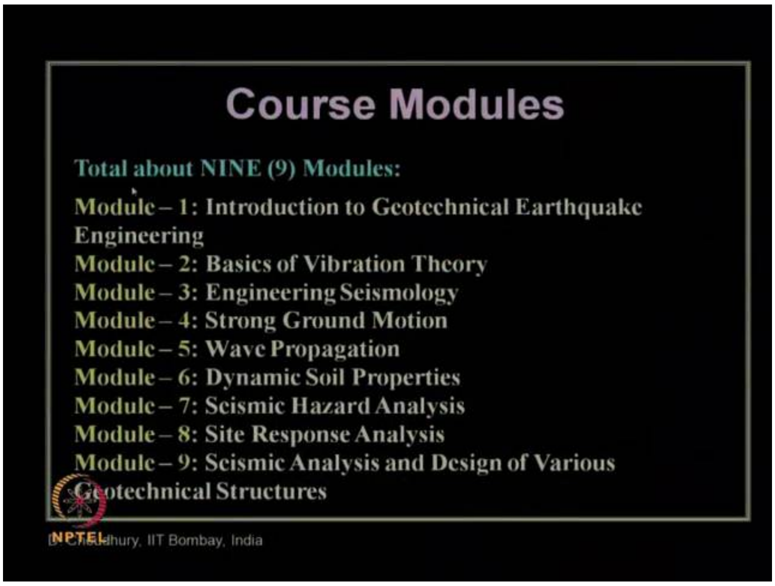

Now, let us see how we have divided this course in various modules; that is, the entire course – this entire video course on Geotechnical Earthquake Engineering, we have subdivided it in various numbers of modules. And, total about nine modules have been created for this course. Let us see what are those modules contents for this video course. So, total nine modules. Module 1 - we will be covering the introduction to geotechnical earthquake engineering; then, module 2 - we will discuss about the basics of the vibration theory; in module 3, we will be talking about engineering seismology; module 4 - we will discuss about the strong ground motion; module 5 - about wave propagation; in module 6, we will talk about the dynamic soil properties; in module 7, seismic hazard analysis; in module 8, site response analysis; and, the last one - module 9 - with seismic analysis and design of various geotechnical structures.

Let us remember that each of this module will also comprise of several numbers of lectures; and we will cover several number of subtopics. Let us see what is the pre-requisite before going through this lecture or before taking this lecture.

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Let us look at the slide here pre-requisite for this course is soil mechanics or the geotechnical engineering; that is, the basic knowledge of the soil mechanics subject or the geotechnical engineering subject is necessary. So, it is a mandatory pre-requisite. And, another video course, which I have developed for NPTEL, that is, on soil dynamics, that is another pre-requisite, but this can be kept as optional. So, suppose if somebody has gone through that soil dynamics course, I will suggest that they will be in a better position to understand this geotechnical earthquake engineering course in a easier manner or in a more simpler way. So, that is why I kept it though optional, but it is always preferred that somebody, who is listening to this geotechnical earthquake engineering video course, before going through this geotechnical earthquake engineering course, they will go through the NPTEL video course on this soil dynamics to clear or to clarify the basic dynamics related to the soil mechanics problem.

And, who will be the audience for this course on geotechnical earthquake engineering? As I have listed over here, like post-graduate students. When I am talking about post-graduate students, I am also including the very high caliber bachelor students as well; those who are interested to know about this geotechnical earthquake engineering, which is a very modern topic compared to other conventional subjects in this area. So, those who are interested in their fourth year of engineering in the bachelor’s degree, they can also go through this course; also the master students those who are doing masters in geotechnical engineering; and, those who are doing masters in structural engineering -

they also can go through this geotechnical earthquake engineering, because after all, for earthquake resistant design of any structure in civil engineering, we need to know not only the superstructure behaviour during an earthquake, but also the substructure behaviour, because ultimately, their structures will be located or it will be standing on a firm foundation. So, unless we know the behaviour of those foundations and the surrounding soil media in which the structure standing, then it will be very difficult or it will not be a complete design against the earthquake. So, that is why, for the structural engineering students also, this is the compulsory course or this is a better course to understand the geotechnical earthquake engineering problems.

Now, let us look at the slide over here. Other audiences for this course can be the teachers of various engineering colleges, those who are dealing with this subject; then, various practitioners in the field, those who are doing the design of various foundations, retaining structures, slopes, etcetera and relating the liquefaction related problem, etcetera, they need to go through this course to understand the basics of the subject, so that they can apply in practice; also, the designers, who are going to design the various cross sections of foundations and several other geotechnical structures or substructures, they should also go through this course; various academicians, who are related with this course.

And, I will mention that decision makers, that is, those who are taking decision not only to implement it in the seismic design codal provisions or the code which a country supposed to follow, they should also go through this course to know or update the seismic design codes of various countries including our Indian design code to incorporate the latest findings of all around the world on this topic, so that the earthquake resistant geotechnical structures can be constructed. And, that will automatically reduce the amount of devastation or distraction due to earthquake related to this geotechnical engineering or the foundation engineering problems. So, that is why, decision makers are also invited to go through this course. Not only that, even the various NGOs or political decision makers, those who will be taking decision to give a priority of a particular area for future construction, etcetera, should also go through this course, because we should know before constructing a particular building, a particular structure, particular house, etcetera of national importance, etcetera. We should locate the site properly. And, for that location of the site, we should know about the geotechnical aspects of the area or of the region. So, that is why, this course will be very useful for them as well.

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Now, let us see what are the major references we will be following for this course; that is, various books I have listed over here. These are the major references I have listed. There are several other references as well, but these are main references; like the book by Steven L. Kramer - this is one of the very finest book on this topic of Geotechnical Earthquake Engineering from Prentice Hall publication. That was originally published in 1996. And, later on, several other Indian editions as well are available; till 2007 version also is available. So, this Steven L. Kramer's book is one of the basic fundamental books on this topic of Geotechnical Earthquake Engineering, which is used worldwide. So, also for our course at several lectures, later on, we will see that we have taken several material or information from this book. So, this is the one major reference for our course on Geotechnical Earthquake Engineering, that is, the book by Steven L. Kramer.

Then, next another important reference is the Geotechnical Earthquake Engineering Handbook, which talks about various simple design aspects incorporating the Geotechnical Earthquake Engineering by Robert W. Day; that Robert W. Days book, which was originally published in 2002 from McGraw Hill in New York - that can also be considered as one reference book for this course. Next important reference book for this course is authored by Professor Ikuo Towhata. Ikuo Towhata had written the book on this Geotechnical Earthquake Engineering, which came out from the publisher Springer in Heidelberg, Germany. So, that book is also a very good reference for this course on Geotechnical Earthquake Engineering. Then, another book authored by Kenji Ishihara - Professor Kenji Ishihara has written this book on Soil Behaviour in Earthquake Geotechnics, which is published by Oxford University Press. So, that is another important reference book for this course.

Of course, another important reference for this course can be considered as the book on Soil Dynamics written by Professor Shamsher Prakash; that Shamsher Prakash's Soil Dynamics - originally, it was written in 1981 and it was published by McGraw Hill company. So, that can be used for the basic concept of the design and pseudo-static design, which we will discuss later on for this course. Then, this booklet by Milutin and Srbulov - Geotechnical Earthquake Engineering: Simplified Analyses with Case Studies and Examples, which is published by the Springer; that also can be considered as a reference material, reference book for this course on Geotechnical Earthquake Engineering. And in reference, I must mention that our Indian Standard design code, that is, IS 1893 - it is having five parts; that is, all the five parts from part 1, part 2, part 3, part 4 and part 5 and in different years, the latest revisions or latest versions are available. So, Indian Standard Criteria for earthquake resistant design of structures - that also will be one major reference material, which we will be discussing about the design concept, seismic zonation, etcetera for this course throughout.

But, these books or design course are not only the limited references, there are many others. I will suggest the listeners to this video course to go through several other references. And mainly, as I have highlighted over here, additional reading, which is a must; those are the journal and conference papers. Very recent journal and conference papers will give us the idea of the latest development in this area of geotechnical earthquake engineering, because as I have already mentioned, this geotechnical earthquake engineering is ever evolving and still it is a very new concept in the domain of our learning compared to other courses or conventional other engineering courses. So, that is why, its development is very fast.

So, unless we go through the latest journal and conference papers, which discusses about various latest developments on this geotechnical earthquake engineering topics - various topics, then we cannot update ourselves. So, that is why, that updation is a must for this course. So, additional reading as I have mentioned over here, I will also go through in my course several journal papers and conference papers, which I will be highlighting and discussing, which are dealing with this geotechnical earthquake engineering as a whole.

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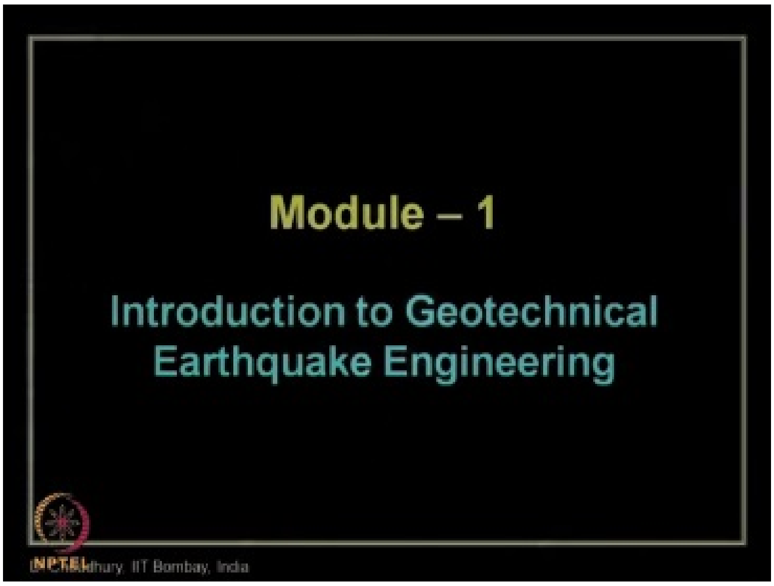

Now, let us start our course with our first module, that is, module number 1, which is Introduction to Geotechnical Earthquake Engineering. This is the first module. In this first module, let us first go through what are the basics of this geotechnical earthquake engineering or why we should take this course; what is the need for taking this course; what are the basics behind it. Let us go through quickly.

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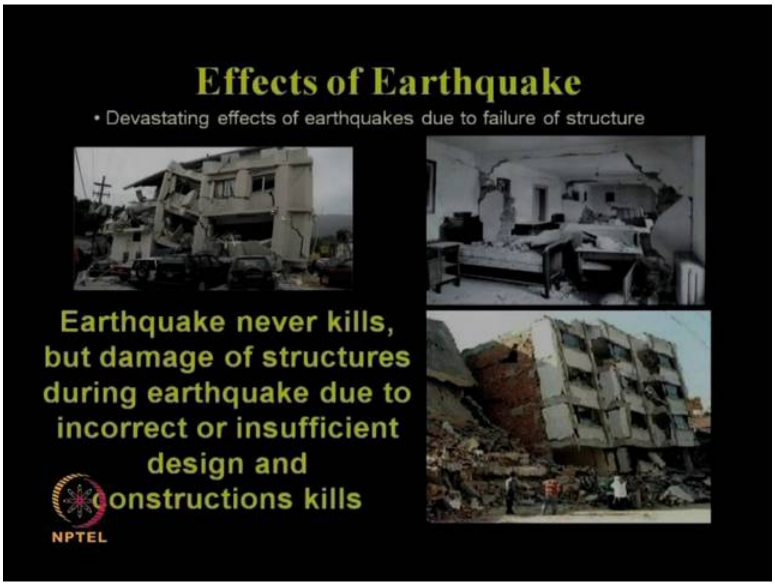

If we see the effects of earthquake, which is known to all of us that, these are the several pictures, which I have taken from various sites, which shows the devastating effects of earthquake due to failure of the structures. You can see over here after the earthquake, this total building has collapsed completely. This is interior of a building has been shown, which has also been collapsed during the earthquake. This is the total collapse of another building during the earthquake. But, we should always remember one important aspect that this earthquake never kills, because suppose the earthquake - if it occurs in a desert, where there is no human being is living, that is, in an open area, then obviously, there is no chance of getting damaged of any structure, because at those locations, there is no structure at all. So, we cannot say that earthquake kills human being or other living animals, etcetera.

But, what kills the people? This is the damage of this structure, which occurs during this earthquake due to either incorrect or due to the insufficient design and construction, which kills the human being or people those who are staying in those houses or buildings or related to those structures. So, this collapse of this structure, why it occurs during an earthquake? One reason is either it was incorrectly designed or insufficiently designed and constructed. So, it is not only can be said due to the design or due to the construction, it can be and/or situation; that is, either design can be incorrect or construction or materials can be incorrect or the combination of them can be the reason, which makes the structures to collapse during an earthquake, which finally, creates this severe damage or devastating effect or kills the human being and loss of life.

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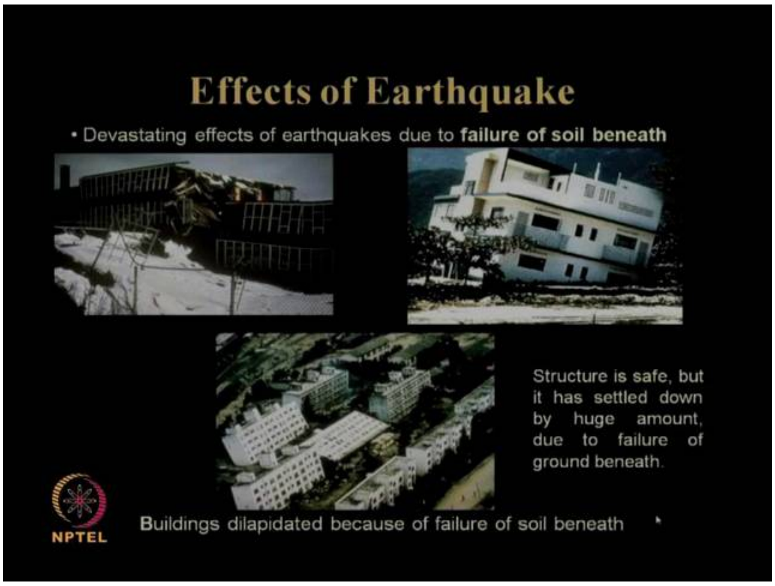

This is another picture, which shows the devastating effects of earthquake due to failure of soil below the ground. So, this is the failure of the soil, which finally make the structure standing on that soil to collapse. This is another picture you can see. This is the soil fail during the earthquake process. So, though the superstructure, which was very correctly designed, but due to the failure in the soil, it tilted and settled enormously. So, it took a final shape like this. So, this type of problem is related to our geotechnical earthquake engineering, because here the superstructure was designed properly, but not the foundation considering the behaviour of the soil during this earthquake.

This is another picture of building, which are dilapidated because of failure of the soil beneath. You can see over here there are row of houses; few rows - they are standing properly; but, the same similar houses in just behind row – they have collapsed here completely, here tilted partially, etcetera. So, these are because of the local regional soil, which is very important to characterize during the earthquake process. So, the structure is safe, but it has settled down by huge amount due to the failure of the ground beneath. As I have already mentioned, you can look here also; this superstructure of the building above the ground is intact; there is hardly major damage. Same thing for this picture as well; there is hardly any major damage in the superstructure. But the soil below this structure that has failed or the foundation with soil has failed. That is the reason of the total collapse of the building or the settlement, huge settlement.

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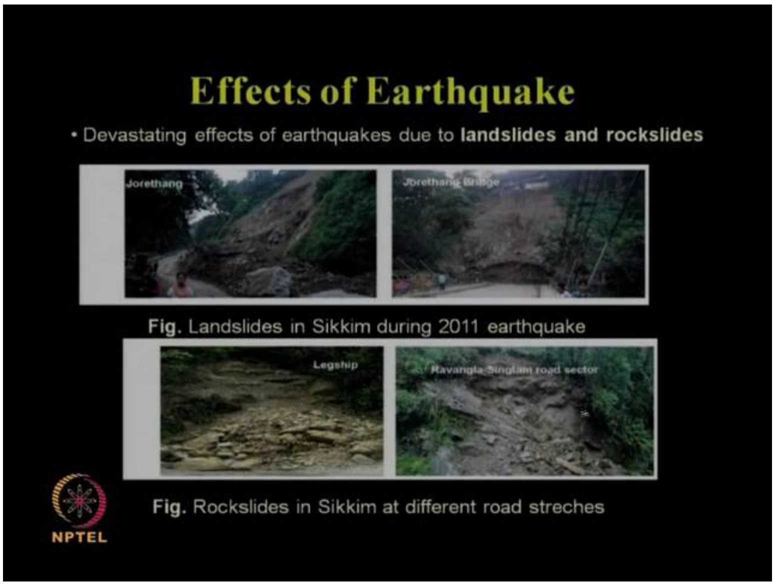

Then, we can see some other effects of the devastating nature of the earthquake due to the landslide and a rockslide. You can see over here. This is the landslide; this is another landslide. This picture during the Sikkim earthquake of 2011 in September; in India, we have seen several such damages at various roadways, etcetera - on the way to Gangtok. So, these are the failures, which caused or which are related to the soil and rock. So, these problems can be addressed by this Geotechnical Earthquake Engineering course.

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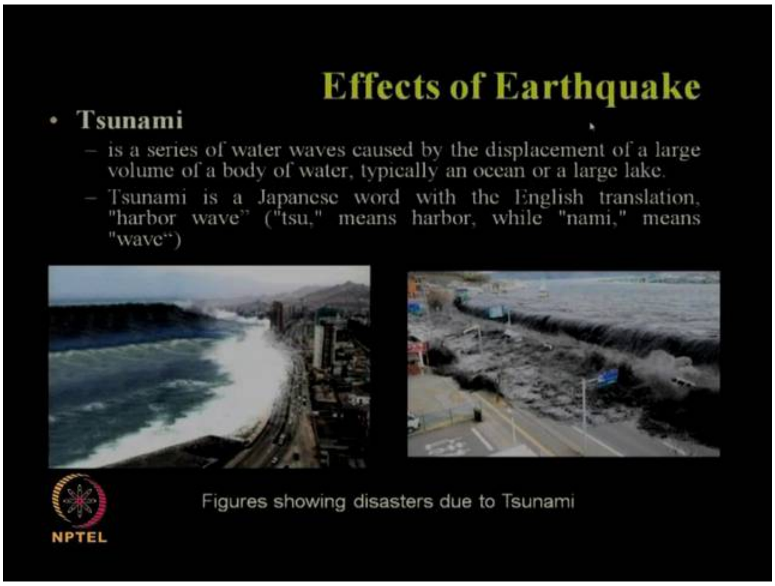

Now, another effect of earthquake can be named as tsunami. What is tsunami? Let us first understand this word. This picture shows what is the disaster of a tsunami. It is a series of water waves caused by the displacement of a large volume of a body of water, typically in an ocean or in a large lake. So, it occurs in a large water body either it can be an ocean or sea or a very large lake. Tsunami is a Japanese word with the English translation as harbor wave, because this word tsunami can be broken in two parts tsu - t s u - tsu means harbor; and name - n a m i - nami means wave. So, that is why, it can be called as harbor wave. You can see the picture of a tsunami waves coming from the sea in this location. So, it is trashing on the shore and it is washing out entire area or this road, cars, buildings, etcetera, whatever is located close to this sea.

You can see this picture. This is a very well-documented picture nowadays, because this tsunami picture, which is shown on this portion of the slide is taken from the 2011 Japan Tohoku earthquake in March. So, after that earthquake, we all know a devastating tsunami also occurred in Japan. So, this is the amount of large height of the wave. You can easily compare to this vehicle height. These are the vehicles you can see; compared to that height of the vehicle, this tsunami wave height is much higher than that. And, this is washing out totally the entire area cars and whatever buildings or structures well-located in this shore.

This tsunami maybe a cause of earthquake sometimes, why I am using the word maybe? Because it is not necessarily that all earthquake in ocean or in sea or in a big water body has to create tsunami, because we will see later on, when an earthquake occurs, typically, two plates or two falls -they move with respect to each other in different combination. They can move horizontally side by side like this. They can move vertically up and down two plates like this during an earthquake while they are going to release the energy; or, they can move inclined way like this, which will have a vertical component as well a horizontal component. So, two plates movement can occur, which are nothing but the crustal plates, etcetera. It will be an oceanic plate, because we have seen, to create a tsunami, it has to create from a large water body. So, what happens?

Suppose there is an up and down movement between the two plates, then the equilibrium of the water standing above that plate will get disturbed. And, once it get disturbs, it generates tsunami, because of the displacing equilibrium of the water body above that moved plate. But, for that vertical movement of the plate or a vertical component of the movement, if the movement is oblique, then there can be a vertical component as well as a horizontal component. So, the vertical component of the movement can create a tsunami. But, if two plates - they move side by side like this, when there is a horizontal movement between the two plates, no vertical movement. So, there will not be any disturbed equilibrium in the water standing on top of that plate. That will not create any tsunami though the earthquake can take place at that region or in that ocean or deep sea or in the large water body. That is why I have mentioned in this picture that it is not necessary that tsunami will always get created whenever any earthquake comes in the sea or ocean; it may come or may not come depends on the amount of fault movement and their relative displacement, etcetera There are various other cases, which we will discuss in due course of time on this course.

Another important aspect I want to highlight here. It is not necessarily that tsunami will be created only due to earthquake. There are instances or examples available that tsunami may get created due to the vertical movement of ocean floor or sea floor by… that is, if there is a disturbance between the seabed, above top of which water is standing, if that vertical equilibrium of standing water on the plate is disturbed in some way, that may create a tsunami. For example, in the sea, whenever there is a big submarine or anything get crashed suppose due to a collision with a iceberg or something, this kind of phenomenon commonly occurs in say north sea area and those regions in which area Norwegian geotechnical institute (NGI) - they also do research - they have found out that there can be several other reasons other than earthquake like collapse of a submarine or the damage or movement of the sea floor due to mud flow and slope movement within a seabed.

That also can create a vertical movement between the two portions of a sea. One portion can go down; another remains here. So, that is why that also disturbs the water, which is standing on top of that seabed or the floor of the horizontal bed of the sea. That may also create the tsunami. So, that is why, I wanted to highlight through this slide that, one of the effect of earthquake may be a tsunami. It is not necessarily that in ocean or in water body whenever earthquake occurs, it can create tsunami; it may occurs tsunami. But, if tsunami occurs, there are several other additional distractions I will say, including the distractions due to earthquake. So, we need to address this aspect as well related to our geotechnical engineering when we are trying to construct any kind of foundations or the retaining structures or which we call as a sea wall, which protects the shore from the sea once the wave comes and hits this shoreline. So, we generally provide the sea wall. So, how to design those sea walls or the waterfront retaining walls, we have to be careful to consider these aspects of earthquake and tsunami, which we will be discussing in this course of Geotechnical Earthquake Engineering.

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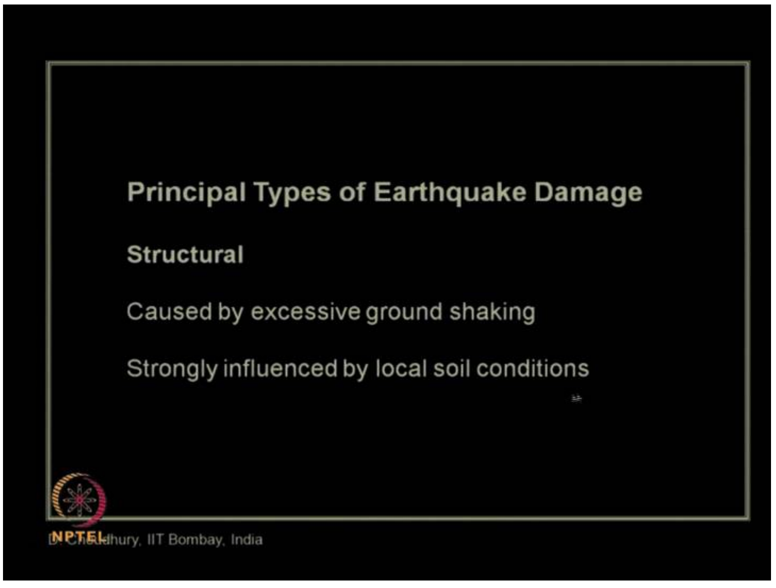

Now, let us see what are the various principle damages of earthquake. If we categorize the principle types of earthquake damage, there can be a structural damage, which can be caused by excessive ground shaking or it can be strongly influenced by the local soil conditions.

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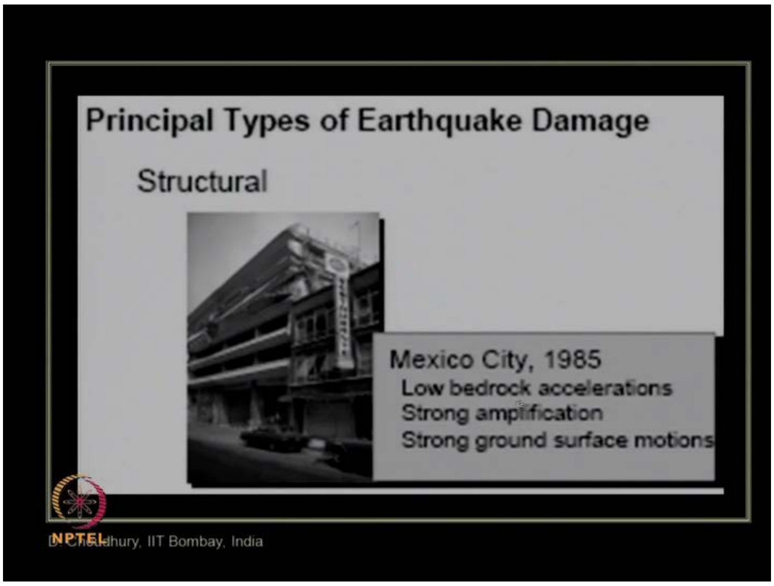

How this local soil condition also influence on the structural damage? Let us see the few examples - historical examples like structural damage occurred during the Mexico city earthquake, which is a very well-documented earthquake, which occurred in 1985 in the Mexico city in the country Mexico. In that earthquake, actually, at rock level, whatever earthquake acceleration hit at the site, that was a pretty low bedrock acceleration; that is the earthquake acceleration at bedrock level; that is, far below the ground surface was pretty low. Obvious reason people thought that it probably may not make much of a structural damage or the damage of the building, which is standing on the ground, because the original seismic acceleration or earthquake acceleration was pretty low.

But, in this case, the local soil condition influence or it amplifies, which is known as strong amplification; that is, these small accelerations get increased or get amplified when they reach on the ground surface. And, because of that reason, the high value of seismic acceleration make the structures to collapse. So, finally, a huge earthquake damage occurred after this Mexico city earthquake though the basic input acceleration was pretty low. So, very strong surface ground motions – finally, those things create the entire damage to the Mexico city earthquake after this 1985 Mexico city earthquake.

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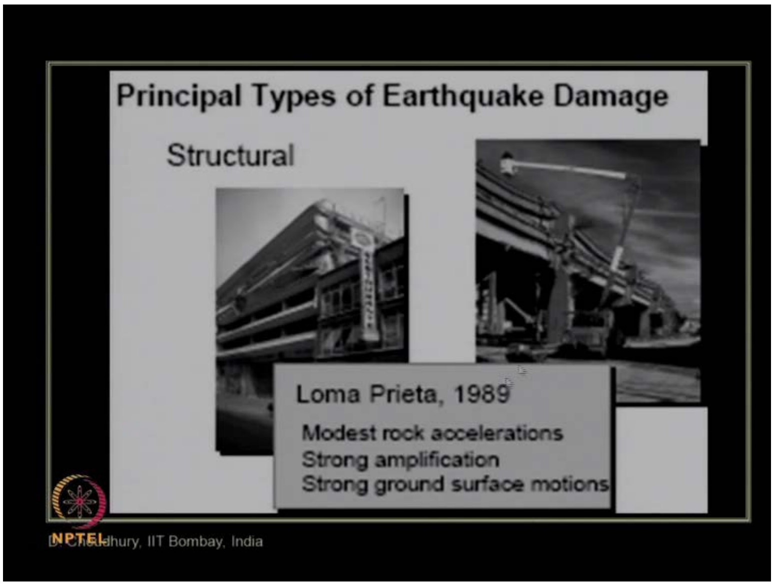

Another example of the geotechnical problems or the soil-related problems of a local site at a particular place, which caused the structural damage during an earthquake, is the Loma Prieta earthquake in 1989. This Loma Prieta earthquake, which has shown the damage over here; in that case also, the basic input or the bedrock level seismic or earthquake acceleration was a modest value or a not so large value, which can cause a serious damage or major damage to the structures on the ground. But, again, at the soil condition was majorly responsible to create a strong amplification, which increased the basic input bedrock at a seismic acceleration to a larger value, which finally creates a damage to the structure. So, that strong ground surface motion also created the damage in this Loma Prieta 1989 earthquake.

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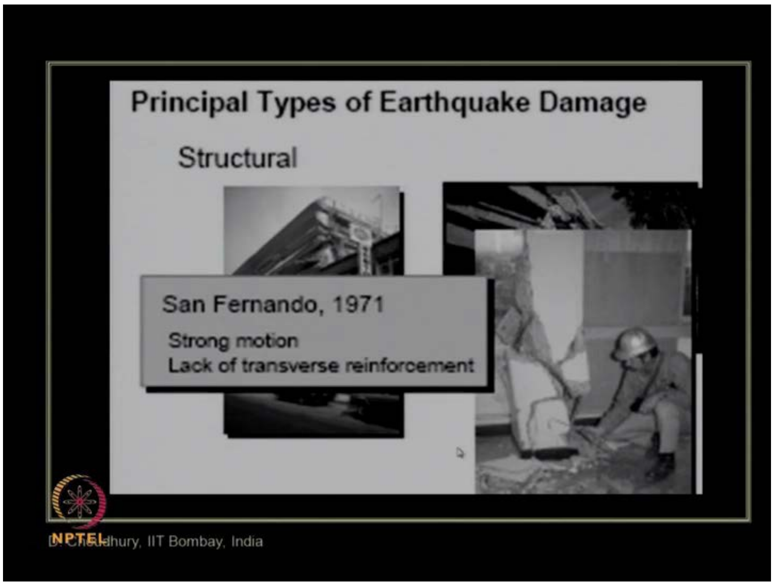

Then, another example of structural damage occurred during the San Fernando earthquake, 1971. You can see the picture of the structural damage. That was because of the strong motion. Strong earthquake motion was the reason. And, there was a lack of transverse reinforcement; like unless we put the transverse reinforcement properly in the design, it can also create a major structural damage in terms of earthquake-related issues, which occurred in San Fernando, 1971 earthquake.

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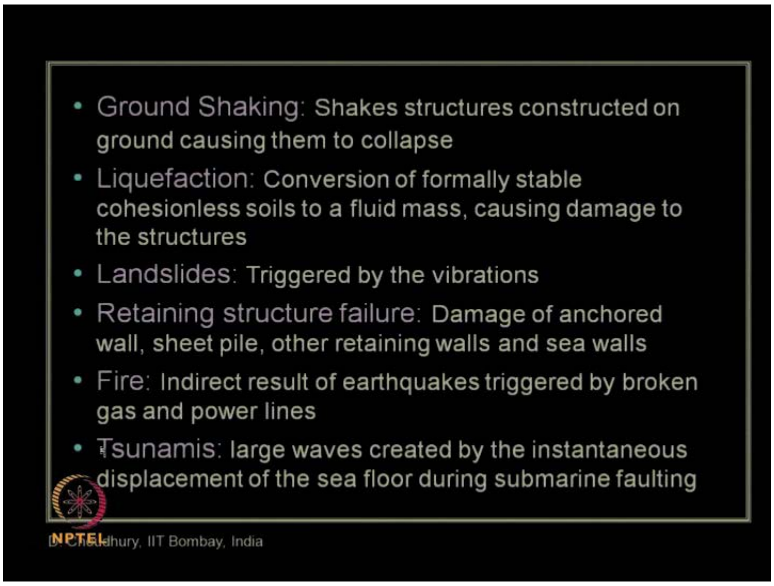

Let us see what are the various points, which we need to discuss during this course of Geotechnical Earthquake Engineering; like ground shaking is one important aspect, because it shakes the structures, which are constructed on the ground and finally they are causing the structures to collapse. So, ground shaking is an important criterion, which we have to look into. Then, as a geotechnical engineer, we have to go through this criteria, which is called liquefaction. What is liquefaction? In a common man terminology, it is nothing but a conversion of a formally stable cohensionless soil to a fluid mass. So, it is causing the damage to the structures. So, as I have mentioned in this sentence, what happens, a cohensionless soil typically below the water table - that will start flowing as if it is a fluid or liquid. So, there is no effect of the solid grains, which can stand the structure or foundation standing on that soil. So, obviously, if during an earthquake, the soil gets liquefied, the entire damage of the structure can be expected.

Then, landslide is another problem, which is addressed by the geotechnical earthquake engineers, which can be… This landslide can also be triggered by vibrations; and, one of the sources of vibration can be the earthquake. Then, retaining structure failure like damage of the anchored wall, which are anchored retaining wall or anchored sheet pile wall and various other types of retaining wall like the gravity type, cantilever type retaining walls and sea walls, as I said the waterfront retaining walls, etcetera; including the reinforced soil wall, those structures how do they behave under the earthquake condition? That needs to be addressed by this Geotechnical Earthquake Engineering course.

Another aspect of earthquake engineering or I will say the sub-effect or the indirect effect of earthquake damage is the fire-related damage. So, it is the indirect result of earthquakes, which triggered by broken gas and power lines, because what happens during this earthquake, if the pipe lines or gas lines and power lines, the structure, which are holding or supporting those pipe lines, are broken or damages, then obviously, entire system of the gas pipe line system or power pipe line system may collapse and damage. That can create automatically the trigger, the fire induction in that area or in that locality, which finally, creates a huge disaster in a particular size. So, that fire-related hazard is indirect result of earthquake, which may occur due to this broken gas and power lines. This actually comes under another topic of earthquake engineering, which is called life line earthquake engineering, which also discuss about the various indirect damages due to earthquake. And, fire is one of them.

Like tsunami - as I have already mentioned, large waves created by the instantaneous displacement of the sea floor during the submarine faulting or the earthquake induced faulting effect. So, if there is a vertical movement, instantaneous displacement of that floor bed of the sea or ocean or the large water body, then these large waves get created, which finally, reaches at the shore and they can be called as tsunami or a harbor wave as we have seen just now. So, this can be another sub-effect of earthquake, which also needs to be addressed to design this sea walls and waterfront structures by the geotechnical earthquake engineers.

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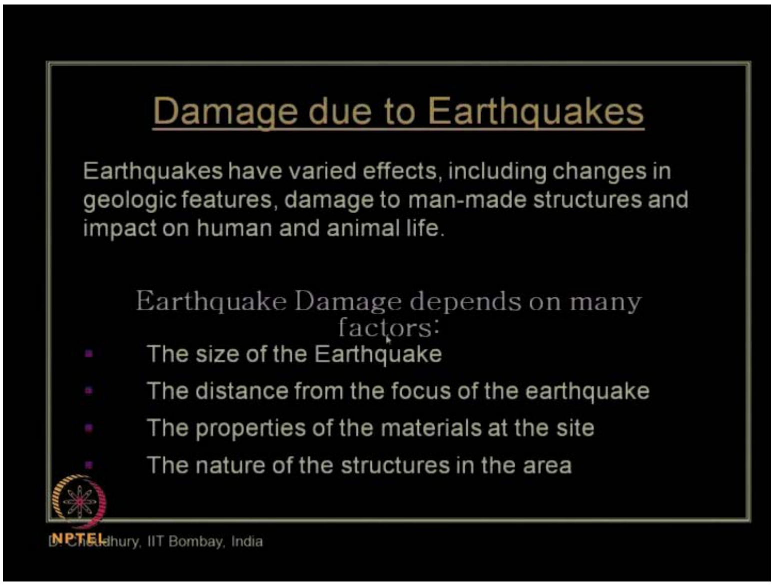

When we are discussing about the damages due to earthquake, let us see, what the various effects are. Earthquakes have varied effects including changes in geologic features, damage to man-made structures and impact on human as well as an animal life. So, earthquake damage depends on many factors. These four are the major factors, which can be listed as the reasons for earthquake damage. First important factor is of course the size of the earthquake; that is, how big an earthquake is. If earthquake is of a bigger magnitude, in quite a common way, we can say that, probably, it will create a large damage. Why I am telling probably? Because there are various other parameters also involved with this. We will go through this course and we will learn that, not only the magnitude or amplitude, which it matters; it also matters how long that magnitude or that earthquake duration is lasting; that is, duration is also important; and, how much frequency it contains during the earthquake. So, these are also important parameters we will see during the discussion on this course in other lectures. So, size of an earthquake overall matters a lot when we are talking about earthquake damages.

The distance from the focus of the earthquake to the site of your interest; that is, wherever you are planning to design or construct a new structure, how far is that site from the focus point or the epicenter point or the hypocenter point of a particular earthquake or older earthquakes - that distance also matters to estimate the earthquake damage-related issues. The properties of the materials at the site; that means, what type of soil, what type of rock and their characterization under the dynamic conditions, etcetera - that matters a lot how much earthquake damages going to occur.

Suppose as I have already given the example of Mexico city, it was located on a soft soil deposits; that Mexico city, all the ground structures - they are located mostly on the soft soil deposit. And, the bedrock acceleration at large depth from the ground surface - that was pretty low in the magnitude, which was not supposed to cause major earthquake damage, because size of the earthquake was pretty less. And also, the distance from the epicenter of that earthquake during that Mexico city earthquake was far away from the site of the concern of that Mexico city. But, still huge damage occurs, because of the property of the material at the site; that is, the local soil condition is very important. That is one of the major necessity, which tells us that the geotechnical exploration, soil exploration or the soil classification compared to the dynamic properties is a must before we design any building or any structure and before constructing it. And also, the nature of the structures in that area is also an important factor, which decides about the amount of earthquake damage.

For example, suppose in an area, we have more number of mud houses or the non-engineered structures, that is, say masonry structure, which are not having beam, columns, etcetera. In that case, if earthquake occurs at that site, then major damage will occur compared to say, in the same site, we have a better engineered construction with reinforced column, then reinforced beam, slab, etcetera - properly designed building; then, that will go through a lesser amount of damage or no damage during an earthquake at the same site. So, that is why, as I have mentioned over here, it is also important that what type of structure is located at that area to decide on how much amount of earthquake damage will be created at that site.

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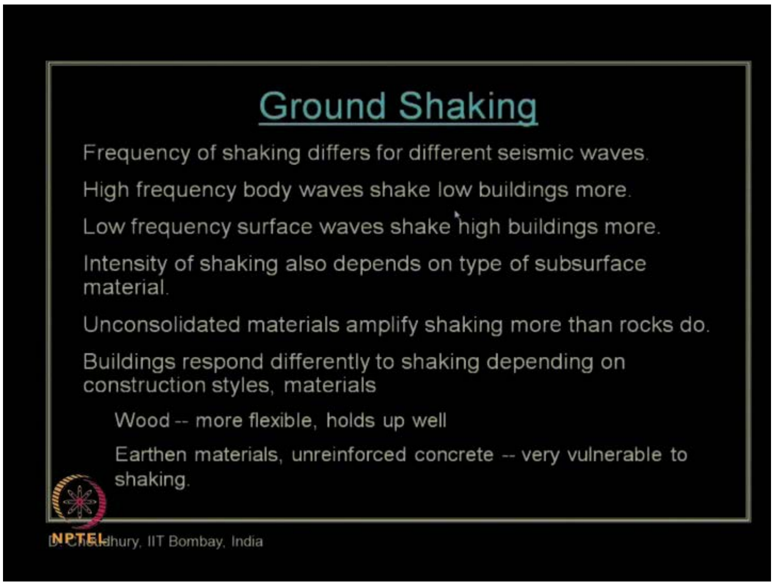

Now, let us discuss about the ground shaking. Ground shaking – as we can see over the here that, frequency of shaking… Let us look at the slide. Frequency of shaking differs for different seismic waves; that is, we will see later that during an earthquake, when earthquake energy get released from the hypocenter or the focus of the earthquake, that is, the origin of the earthquake energy released point, various seismic waves starts travelling in the media - in the rock or soil, whatever media it gets generated through. So, that seismic waves are having various amount of frequency. So, that frequency of shaking - that differs for different seismic wave.

And typically, it has been found that high frequency body waves. Body waves are those waves, which goes through a body or a media; body in the sense, the soil or rock media much below the ground surface, not close to the free surface or ground surface. So, those are body waves; like primary wave and secondary wave. So, they shake the low buildings more; that is, low raised building or the shorter buildings like single storey or one storey building. Whereas, the low frequency surface waves… Surface waves are those seismic waves, which travels close to the ground surface like rally wave and love wave. We will discuss about these types of waves in due course of time for this course. If they have a low frequency, it has been found that they shake typically high buildings more; that is, high raised building, very tall buildings more. There are reasons, etcetera. The technical reason - we will give mathematically later on during the course of this subject. So, these are the typical behaviour of effect of frequency variation of various waves on different types of building.

That automatically tells us that the layman idea or common understanding is typically, the tall buildings will be more vulnerable or more getting damaged during an earthquake. But, single storey or one storey building are safe during an earthquake. So, it is not a correct theory or it is not a correct belief I will say. As I have shown here, the correct observation that, it depends on what is the input frequency of the earthquake. If it is a high frequency, then the low raised building are getting more damaged; if it is a low frequency, then tall buildings or high raised buildings are getting more damaged.

Then, intensity of shaking also depends on the type of subsurface material. As I have just mentioned, type of subsurface material like whether it is a soil or rock; if it is a soil, whether it is a stiff soil or a soft soil or a loose condition or a dense condition. All these different criteria will decide how much intensity of that ground shaking is going to occur at a particular site. Then, unconsolidated materials – they amplify shaking more than the rocks do. What does it mean? Unconsolidated means the material, which has not consolidated or settled completely. For example, like very soft clay material, which are in unconsolidated state, they will amplify the ground shaking much more than the rocks what they will do. So, rock – they generally do not amplify much the input ground or base level ground shaking. But, this unconsolidated material or the soft soil material will amplify or increase their acceleration – seismic acceleration, etcetera when they pass through this unconsolidated material. So, that is why, we have to be very careful about the soft material or unconsolidated material if anything is existing below our site of concern, where we are going to construct any new structure.

Buildings respond differently to shaking depending on construction styles as well as materials. Like for example, if somebody has used wood as a formation of the house; wood are more flexible and they holds up well during an earthquake shaking or ground shaking. So, that is why, you will see, in the earthquake-prone regions or the hilly terrains, mostly, there the wooden houses or wooden constructions are preferred; whereas, earthen materials and unreinforced concrete - they are very vulnerable to the shaking. So, as I have already mentioned, like mud house or the masonry structure or the unreinforced wherever the reinforcement is not provided in the concrete, those structures are very much vulnerable during this ground shaking.

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This is a picture, which shows the complete collapse of a building during an earthquake.

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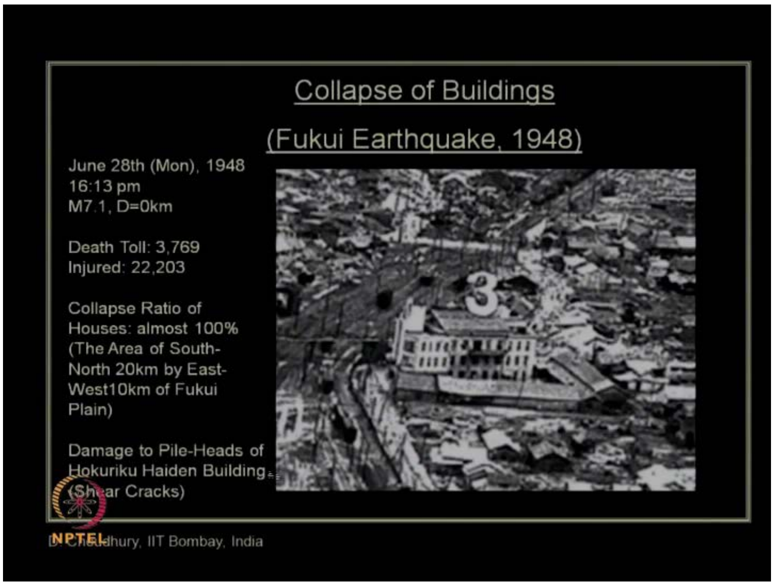

Some more pictures of collapse of buildings you can see over here. This is the picture after the Fukui earthquake in 1948. This Fukui earthquake occurred on June 28th on a Monday, 1948 at 16:13 pm in local time at Japan. And, local magnitude was 7.1; and, the distance from the epicenter was 0 kilometer. So, it was located at that site itself. Number of death during that earthquake - Fukui earthquake in 1948 - it was more than 3500; and, injured was more than 20000. So, you can see in those days, how much damage it occurred. So, collapse ratio of houses - almost 100 percent; that means, almost all houses got collapsed - the area of the South-North 20 kilometer by East-West 10 kilometer of the Fukui plain. So, from this epicentral point, these are the distances in the South-North direction by 20 kilometer and East-West direction by 10 kilometer. In entire area, all the houses, which were located there, 100 percent got collapsed due to the earthquake. So, the damage to pile-heads of this Hokuriku Haiden building or the Shear Cracks occurred - this is related to our geotechnical earthquake engineering. When we are going to design a pile foundation, we should get learnt from these previous experiences of the damages of these foundations, so that we can incorporate the proper steps to design these things.

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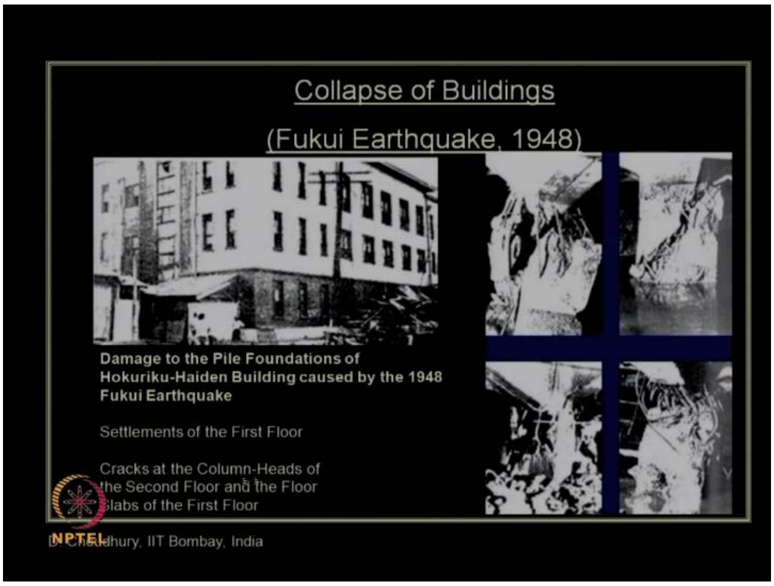

Some other pictures of that Fukui earthquake collapse of building in 1948. This damage to the pile foundations of Hokuriku Haiden building caused by this 1948 Fukui earthquake - you can see here the damage of the piles, the shear cracks. These are the severe damage of these file foundations. So, settlement of the first floor occurs. So, entire first floor got settled and entered and became a ground floor. Cracks at the column-heads - you can see at the column-heads, crack; heads of the second floor and the floor slabs of the first floor. So, that is what a huge damage occurred during this Fukui earthquake.

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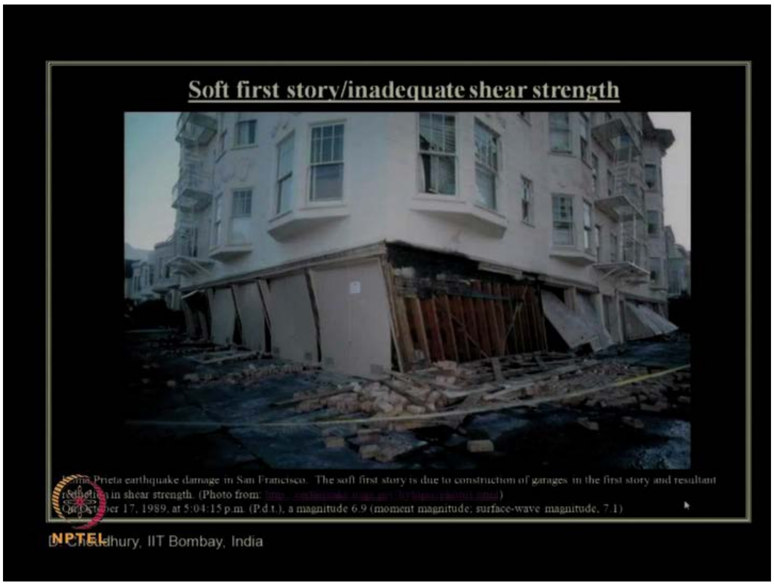

This is another effect of soft first story or inadequate shear strength effect. Generally, in earthquake engineering, we say, we must avoid this soft first story; that is the ground floor generally we use for the basement - open basement. If we use that, the soft first story creates maximum collapse when a major earthquake occurs in that site, because of no bonding or no adequate connections between the members. So, it is always preferred to provide some blessing system or some connection system to avoid this first soft story effect. So, this is called soft story. That is where there is no in fill of wall or there is no in between columns and etcetera. So, that is what to avoid this soft story effect, we always should provide some blessing members or some connections, so that the place can be still further used as a parking lot or the basement area, which can be used for parking purposes or open activity purposes, but still there has to be some (( )) kind of connection, which will avoid this soft story effect. This is the picture after the Loma Prieta earthquake in San Francisco. The soft first story is due to the construction of garages in the first story and resultant reduction in the shear strength. So, this is the photo taken from this site on this date. With this, we will stop our lecture today. We will continue further in the next class.