Dynamics of Structures
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Seismic isolation
Lecture - 28
Concept of Seismic Isolation

Welcome back everyone. In today’s class, we are going to discuss about the application of Structural Dynamics to field called Seismic Isolation. So, as the name suggests, seismic isolation is a technology to basically isolate a structure from the seismic effects of an earthquake.

So, we are going to see first, what is the basic idea behind seismic isolation, and we are also going to discuss in a subsequent lecture the structural dynamics of a seismically isolated building. So, let us get started.

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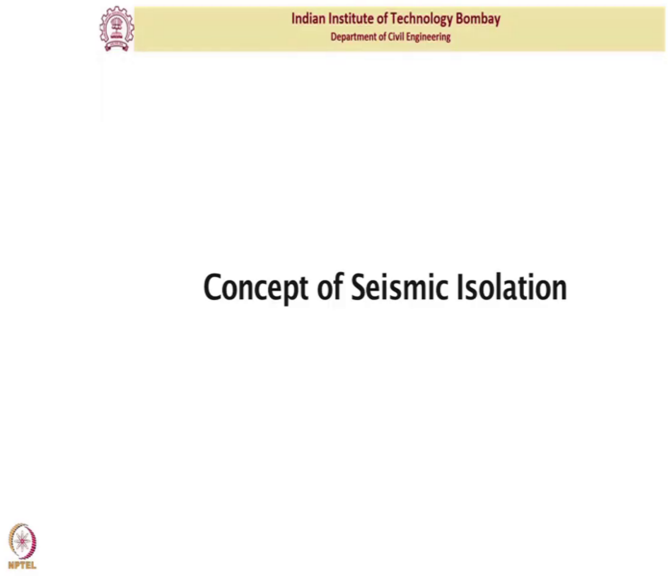

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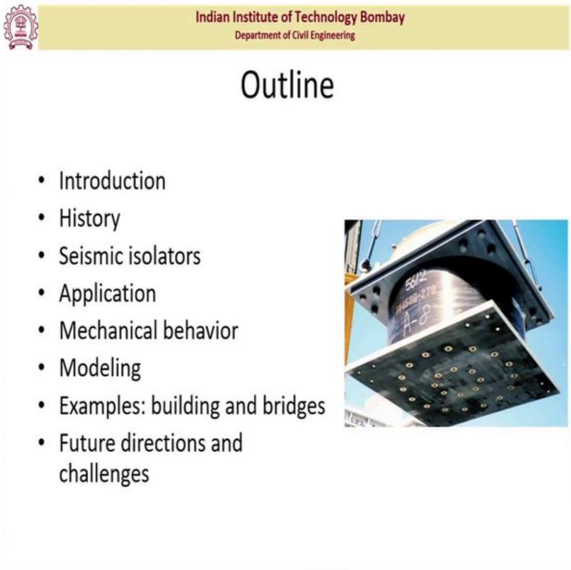

So, now we are going to discuss the principle of seismic isolation. First, I would be introducing to the overall idea and then discussing about some type of seismic isolator application, mechanical behavior and modeling. But as part of this course I would mostly be focusing on the basic idea behind the seismic isolation and giving you some of the structures that have been famously isolated using different type of isolators.

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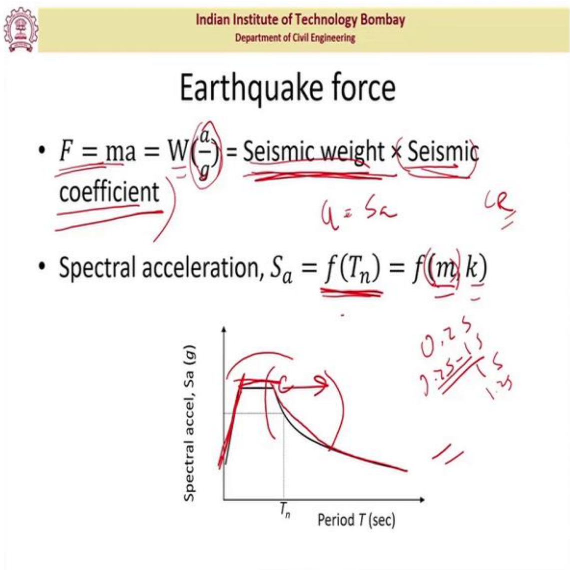

Now, before I get into the idea of seismic isolation first, let us get into idea of seismic force or earthquake force and then see how we incorporate the idea of seismic isolation into it.

Now, as a very simple formula, we know that the total force on any structure can approximately be written as mass of the structure times acceleration. If you write mass of that structure as W/g and combine g with a, I can further write it as this here.

Now, this W is what is called the seismic weight and you would have come across this term, if you would have doing seismic design and everything. This is the seismic weight. Now, you might come across this term many times, but let me just discuss what is the idea behind the seismic weight. What is the dead weight of a structure and you might estimate, what are the live load acting on the structure?

Seismic weight is typically defined as the weight that might be present during an event or an earthquake event for which the structure has been designed. So, it would include the deadweight of the structure, plus certain portion of live load.

Because you typically consider live load for the extreme scenario in which you consider the structure to be fully loaded and then you determine or estimate the live load, but during the normal operation. It is unlikely that your structure would be greater the capacity of the full live load.

So, we typically take 25 percent or 50 percent of the live load. So, deadweight plus, let us say 50 percent of the live load is basically considered or included in the seismic weight of the structure. This a/g, which is the acceleration of the structure, not the ground motion as such. This is the acceleration of the structure, the a/g is called seismic coefficient.

Now, most of the seismic analysis procedure like, linear static procedure or response spectrum procedure. As per Indian codes, the seismic codes and the outside code, they give you procedure how to calculate the seismic coefficient here.

There you have, remember this factor you might see it as CR or other places this factor is written with some other notation, but basically this is the seismic coefficient through which if you multiply with the seismic weight you get the lateral load that is being applied on the structure.

Now, this is basically the earthquake force or the lateral earthquake force. Now, this *a* which is the acceleration of the structure, I can also say this is the *Sa* or the spectral acceleration let us say.

Now, we know that spectral acceleration of any structure is a function of time period of that structure. Time period in turn is a function of mass of the structure and the stiffness of the structure. Of course, what I am writing here is valid for single degree of freedom system, but we can extend this same concept for multi degree of freedom system as well.

Now, if you look at the design spectra and this is the typical shape of a design spectra. Due to an earthquake or at a particular location of a building or a structure, you initially have a increasing spectral acceleration with time period. Then there is a constant phase and then, there is decrease. Now, most of the structure, if it is a rigid structure, it would have typical time period of around 2 second.

If it is moment frame building, you know tall building then you can go it can go up to 1 second or even 1.2 second and further up, but typically we say that a typical structure is in range of 0.25 second to 1 second, which on the response spectra falls in this zone. Now, let us say I have a technology, or I want to reduce the force transferred to the system.

So, what should we do? I know that the seismic weight of the structure is fixed. So, that cannot be changed. Similarly, the mass of the structure is fixed. So, that cannot be changed. The only thing that I can tinker with or I can change time period and how would I change the time period? Mass or stiffness?

Typically, mass of a structure in the design is fixed. It is determined by weight of the infill, beam and column weight, live weight and those things does not depend on the structure. Basically, I mean it depends somewhat on the structural properties; the geometric properties, but overall, there is not much you can do about the mass, but what you can do is about the stiffness.

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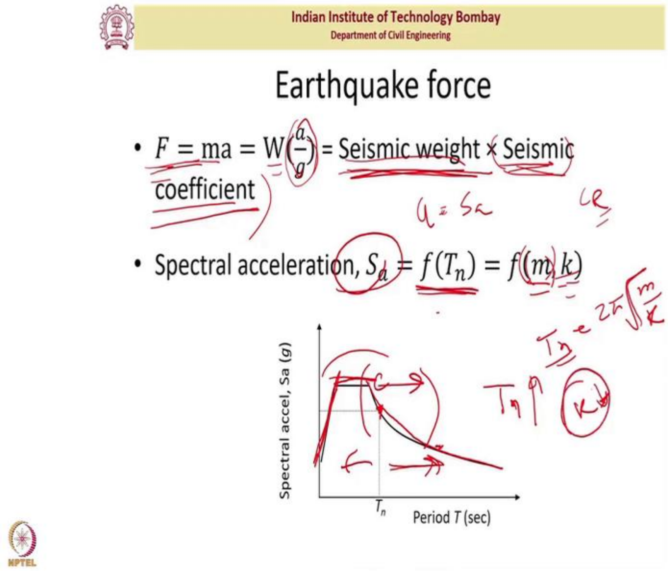

I know that time period is nothing but $2\pi\sqrt{m/k}$ and I know that if I want to reduce the seismic force, I would need to reduce the seismic coefficient or spectral acceleration. How do I reduce that? Let us say initially my structure was here, if I want to reduce that then I must go in this range, not this because there is not decrease in that part. So, I need to come along on this part of the response spectra.

Now, if I do that, that means, I need to increase the time period and I know time period is $2\pi\sqrt{m/k}$. To decrease the T_n, what can I, to increase the time period what can I do? So, basically our goal is to decrease the stiffness. So, we have found out one conclusion, that if I want to reduce seismic force on a structure, we should have a system or the structural system which has low stiffness.

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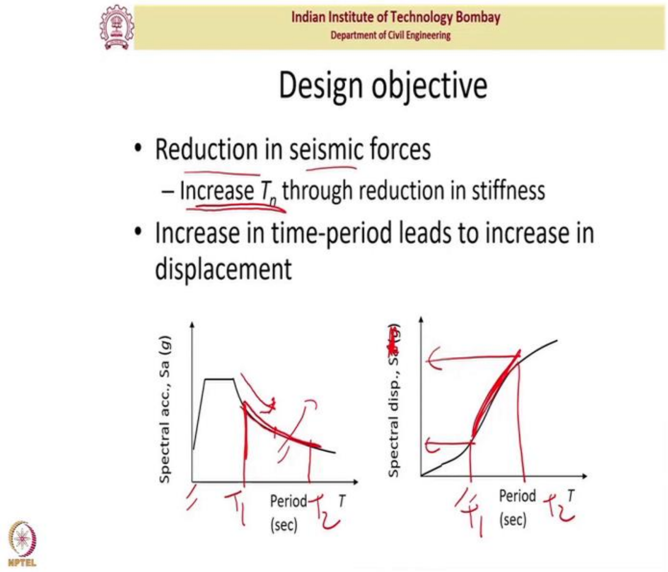

So, the design objective for a seismic design is basically a reduction in seismic forces. So, increase T_n through reduction in stiffness. Now, increase the time, now remember if this is your acceleration response spectra, there is also displacement response spectra. So, for a typical acceleration response spectrum, a deformation response spectrum, I have drawn on the right-hand side.

So, what happens as you decrease or as you increase the time period and decrease the forces, what happens to the spectral displacement? Let us say initially I was here T_1, I increased the time period so that my forces decreased. So, let us say initially I was here and then T_2, I was here. So, my force or the acceleration is decreasing, but what is happening to the displacement here? My displacement and this should be S_d here it is incorrectly written as S_a.

So, this is S_d, which is the displacement. Displacement is increasing and that might be a matter of concern especially if you consider closely spaced building in a dense urban environment. So, we need to control displacement as well. Now, we know by increasing the time periods, we can decrease the force. But increasing the time period is creating a problem for me, because it is going to increase the displacement. So, I need to address that issue.

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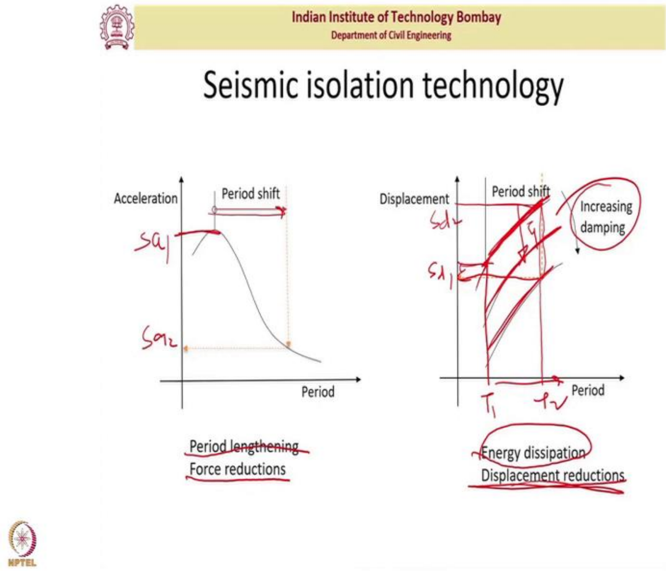

So, let us see how we do that. So, as I discussed, if I increase the time period, it would lead to decrease in the acceleration and subsequently decrease in the forces. So, initially if this was acceleration S_{a1}, it becomes S_{a2}, when S_{a2} is much smaller than S_{a1}. However, initially I was here, my displacement and this was S_{d1}. As I increase the time period from T_1 to T_2, remember this is the spectra I have. I increased the displacement from S_{d1} to S_{d2}.

So, in order to control that displacement, what do we need to do? We need to increase the damping in the system. Now what does damping do? It decreases the displacement and my response spectra, the displacement response spectra that I was having it here. By increasing the damping, I can reduce it to here. Now, if I do that then I am able to bring my displacement down either below the initial level or maybe control the displacement to an extent that it is not detrimental to my structure anymore.

So, period lengthening lead to force reduction and if we provide damping, which is energy dissipation, it leads to displacement reduction. Through these two, we control the response of the structure. That is why at many places you will also see that seismic isolation is studied as a part of seismic response control or seismic control of the structures.

There are other technologies also involved in seismic control, like you can have viscous damper or other type of tuned mass damper or you can have other technologies. But, seismic response control means applying technologies so that I can control the response of the structure to a desired value.

So, if you increase the mass, it will increase the time period, but consider a typical example. Let us say if you have a concrete building and if you want to design it, can you do much about the mass of the building that you are designing. These structures are more suitable for seismic isolation rather than light structure.

So, basically you would not apply seismic isolation to a wood structure. I have not come across any application like that. Although many of the houses outside are made up of wood structure, because wood structure itself is very light and the stiffness is very low.

They adequately perform during the earthquake as well, but even steel structure, when we apply, we try to stiffen the superstructure. Because the steel structure is also lighter, but for concrete structure seismic isolation is very good. If you have heavy, let us say masonry structure, for that also it can be applied and any type of the structure.

For heavy structure, your seismic isolation is more effective, because you already have mass that helps in increasing the time period of the isolated structure. So, let us say, you estimate some loads and you estimate live load and you know that there is certain uncertainty associated with that.

So, those factors would still need to be there. Because the uncertainty associated with that load is taken into consideration with the load factors and uncertainty associated with the strength of material is taken with the strength factors. That cannot be addressed through seismic isolation, it is an entirely different technology that is more often a statistical and risk perspective. What here is in terms of the technical aspect of it.

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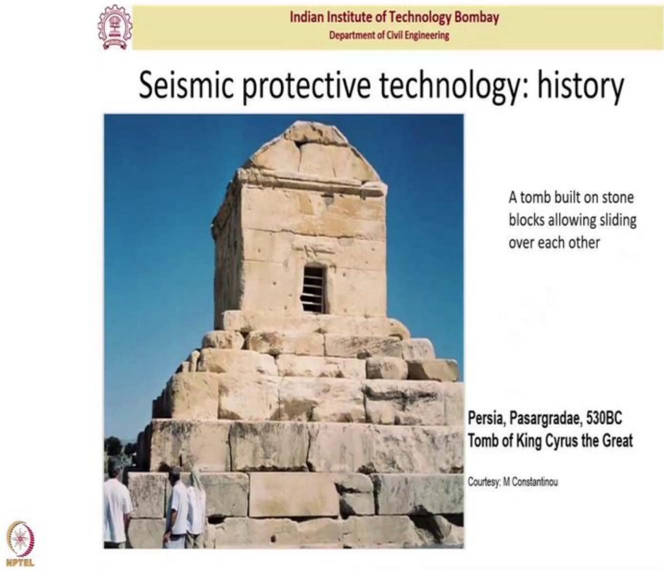

Now, you might think that seismic isolation is a very new technology and you might have seen the recent application, but the overall idea behind seismic isolation technology is not very new.

To support my argument what I am showing you here is a very old structure. It is a tomb built on stone blocks and this is in Persia. As you know that region is very prone to earthquake and see this is like 530 BC, this is the tomb of King Cyrus the great.

Now, this is very big stones being kept over each other and the tomb is kept on the top of the structure. This has survived even though it is there right now. So, you can imagine 2000 and then maybe 22500 years this structure has survived. And how? Now, the idea remains simple. During an earthquake, these stones are not filled with motor and these can slide over each other.

So, when the earthquake comes, it does not allow the transmission of the force from the ground to the tomb and the overall force that is transmitted to the structure is significantly smaller because when this slide over each other, you can assume or you can imagine that it would have very small lateral stiffness. This was built very long time ago.

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Similarly, this is a very famous structure you might have seen in photos, movies or some other place. This is a Parthenon in Athens. It has survived earthquakes for 2100 years. When it was finally damaged, it was not damaged due to an earthquake. It was damaged due to an explosion.

Now, as you know Greece is a very seismically active region, there are lot of earthquakes and over the 2100 years it is a still survived. Now, the design of these structures is very simple. You have modular blocks. So, each of the column contains modular blocks which are kept over each other and then there is a central hole through which you can have, let us say, post tensioning mechanism or you can have a single rod to keep it in place, but effectively it reduces the lateral stiffness significantly.

So, you can see, in all these structures what the engineers at that time did, they simply changed the lateral stiffness of the system. So, that overall stiffness reduces significantly. Now, the stiffness is reduced, the overall force transferred to the structure is also reduced and that is why they have survived for so long.

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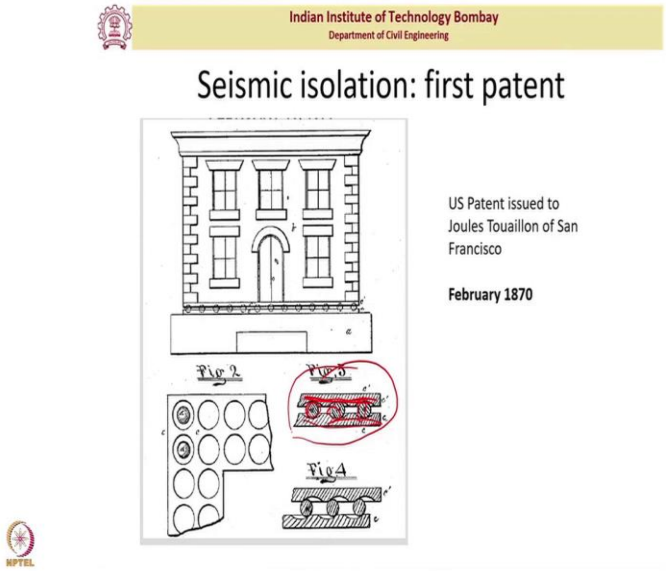

Now, you might ask when was the first patent related to seismic isolation technology created, we do not exactly know because you know there are different type of technologies which look like seismic isolation technology and people file the patent for that.

One of the first known instances is this US patent that was issued to Joules Touaillon of San Francisco and it was issued in February 1870. The figure is from that patent application, if you look at it he has simply shown his schematic of a house and this house is kept on a foundation and if you look at the magnified view here, this is nothing but rollers.

So, you have cylindrical rollers and then you have overall base mat, you can say a new foundation. When the earthquake comes again it, can roll over each other so it provides the restoring force as well as sliding. This was one of the first known instances of patent issued in this area.

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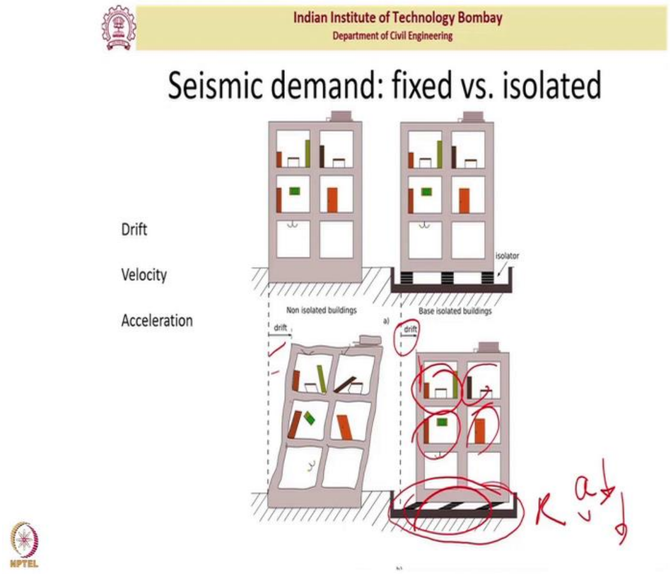

So, let us look at basically seismic demand on a regular structure and base isolated structure. So, what I am showing you here is basically a traditional conventional fixed based building. Now, what you have seen till now, we can achieve seismic isolation if you provide a horizontally flexible layer.

I will show you different type of seismic isolator, but let us for right now, assume that this is an isolation layer. So, on the left-hand side you have a structure that is fixed to the ground and on the right-hand side you have the same structure, but now it is isolated through an isolation layer. Now, what typically happens during an earthquake, the overall seismic demand is accommodated by the superstructure. So, deformation, acceleration and the velocity demands are accommodated by the superstructure.

Because of deformation demand, it leads to deformation in these beams and columns and that leads to cracks development, plastic hinge formation and if the demand is too large may. So, that seismic design technology what it tries to achieve is to provide enough ductility in the system so that it can accommodate such seismic demand in the superstructure.

So, it can go in the non-linear range, but it can still accommodate this much of drift demand without collapse. Basically the performance goal is typically collapse prevention. Now, compare that and that I only talked about in terms of drift or displacement let us say.

Now, if you look at it while you might protect against drift demand what will happen to the objects and machinery and people inside this building? If you look at this and you might think those things might not be expensive.

But just think of hospital building or hospital structure, you know in hospital structure, most of the cost is actually machinery, a typical MRI machine might caught cost north of let us say 10 crores, 15 crores like that and there are several scanning machines. So, those are of much more value that needs to be protected. Now, you might protect it by making the structure very strong, but if you make the structure very strong it would have again large stiffness and acceleration.

So, acceleration is not reduced because if your stiffness is more, then the acceleration would be more. So, you still have the acceleration demand and that would lead to acceleration in the internal components.

So, with the traditional seismic design philosophy, you may be able to protect your structure against the drift demand up to certain extent, but the acceleration demand or the velocity demand might not be accommodate that efficiently as, we would compare with the base isolated structure.

Now, what happens in a base isolated structure? You have this superstructure and this isolator layer. Now, because this is very flexible layer, all of the drift demand is actually accommodated at this isolation level here so right here. Now, isolators have properties that it would have sufficient restoring forces that it can bring back the structure to its original position. It would have sufficient buckling capacity. It would not have any or very minimal permanent damage.

So that those things I can do by designing the isolator like that, but the superstructure there is no drift or very small drift compared to the fixed base. So, there is very less damage to the frames of the superstructure. At the same time, because my stiffness here is very small for this isolation layer, the acceleration is very small. So, the internal components are also actually protected in a base isolated structure. So, you can see the benefit of applying isolation here.

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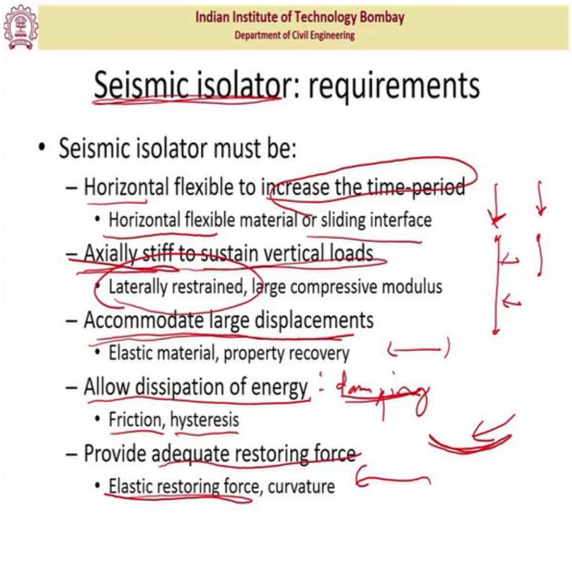

So, now, you have seen some of the structures and examples. What should be the requirement of a seismic isolator? Now, you know that seismic isolator must be horizontally flexible to increase the time period. Because, only with the increase of time period, I would achieve reduction in the seismic forces and reduction in acceleration.

So, through this slide, what I am trying to find out, what should be the requirement of a seismic isolator and then, we will see different type of isolators that satisfy those requirements.

So, to achieve this horizontal flexibility, we can use horizontally flexible material, or we can use sliding surface. When I see one surface is sliding over each other, what I mean in horizontal direction it has very small stiffness or almost negligible stiffness. Now, it needs to be horizontally flexible, but at the same time it needs to be axially stiff or vertically stiff, because see your whole structure is still there.

So, even when it is moving flexibly in horizontal direction, at every point it would still need to sustain the vertical load. So, it needs to be axially stiff. Now, how do we increase the axially stiffness, we will look at later. But the axial, we know that let us say if you have a simple column and if you have line axial load, I know that a shorter column would have higher capacity or higher buckling capacity or if I provide lateral restraint, it would have higher capacity. So, I would need something that is either laterally restrained in terms of axial stiffness or it has large compressive modulus. If I would have those property, then I can accommodate large vertical loads or the total load of structure.

Now, it should also accommodate large displacement, because as I said in the previous slide, when you did not have an isolator, the whole drift demand this much was being accommodated by the superstructure. Now, imagine displacement demand of the similar order, now, need to be accommodated by the isolators.

So, it should be able to carry large displacement. So, it should have elastic property or even if it does not have elastic property, it should have property which should be recoverable. So, some of the materials have that kind of property like recrystallization, especially like a lead rubber bearing. Now, we also want damping because, we do not want too much of displacement otherwise it would lead to pounding effect to the next building or instability.

So, to control the displacement and other response quantity, we basically want some dissipation of energy or I can say damping. Now, there are different ways in which we can achieve damping: one is friction. So, if we have a sliding, surface friction sliding over each other, it leads to generation of heat. Heat cause of friction and ultimately leading to loss of energy and that is what is damping is. You might also dissipate energy through hysteresis.

So, if you have a material, let us say elastic plastic material or bilinear material, it will dissipate synergy that would also allow dissipation of energy. Then at the end what you do not want that, after the earthquake your structure is remaining in the dissipate position because then residual deformation would lead to serviceability issues. So, you want your structure or the isolation layer to have adequate restoring force. So, that it can bring back the structure to its original position.

So, you want either elastic restoring force, let us say with the rubber or you want maybe through a curvature so that structure slides back to its original position. But there should be some adequate restoring force in the base accelerated structure. So, these are the basic requirements from the seismic isolator. Any isolator that satisfy these requirements may be investigated further for application or to be utilized as a seismic isolator.

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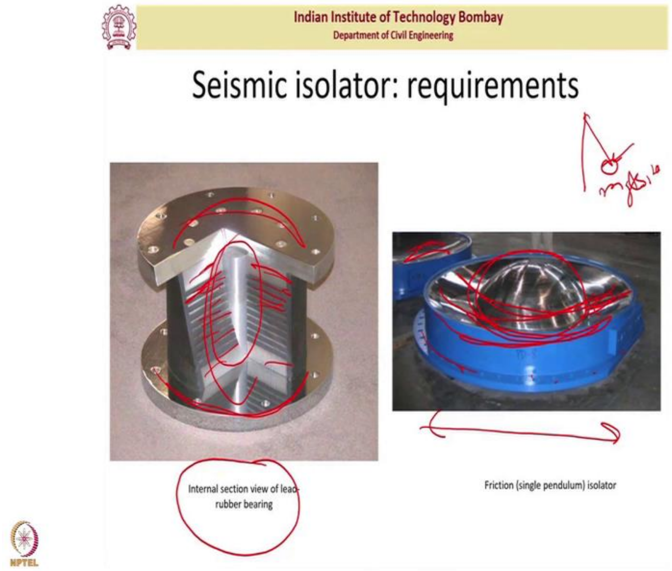

Two of the popular type of isolator and remember these are not only the two type of isolators that are available right now. There are many other isolators as well, but these are very popular because of their reliability and basically application to wide range of structure. The left-hand side what you see here is a cut view. So, this is not overall isolator, what they have done, they have cut it.

So, you are seeing basically the internal section of a lead rubber bearing. Now, what you see here is a multiple layer of rubber constrained by steel shims in between and then, there are bearing plate which is this is the internal bearing plate and then there is a bolted external bearing plate. Now, this bolted external bearing plate is how this is connected to the sub-structure and superstructure.

These rubber layers are the one that provide horizontal flexibility. The role of steel shims here is to provide lateral restraint to the rubber and I will show you why do we need that. The lead here is a very good energy dissipation material. Plus, it recrystallizes when you bring it back to its original position and temperature. So, its properties are recoverable. So, it dissipates energy, but after some time when you leave it, it will acquire its original property back.

So, it is not exactly elastic, but if you bring it back to its original position at molecular level, it recrystallizes and again would give you similar kind of energy dissipation capacity like the one you had before.

So, this is the one of the examples of elastomeric bearing. On the right-hand side, what you have is a sliding bearing and remember this is not again the whole sliding bearing, what you see here is the internal surface on which this block here slides and the top plate is kept in the corner as you can see.

So, this kept on the top of that and again this is bolted. So, it is connected from the top and bottom using these bolts. When the structure comes, it slides over this. Now, this sliding surface provides you very low horizontal stiffness. The curvature provides you restoring force because it is like a pendulum. If you take a pendulum restoring force is $mg \sin\theta$.

Now, these two types of system either rubber based or sliding based elastomeric systems are typically used in today's seismic isolation applications and we will look into these type of systems further.

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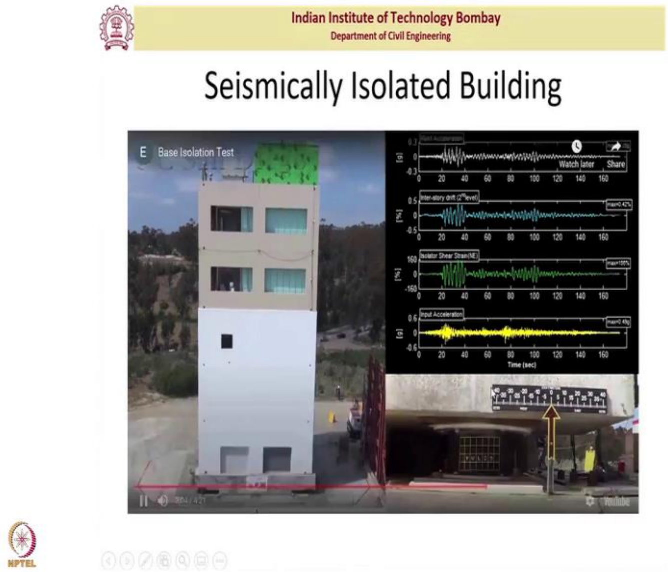

So, what I want to show you here is basically example of a building. It is a full-scale building; I do not know whether you know this or not. This is a shake table facility in university of California San Diego. So, this is one of the biggest shake table facility in the world and what you see here is a structure that is built on top of it. On the base, there is a shake table platform. So, the ground motion is being applied through this shake table platform and this structure is isolated. Now, on the right-hand side, you see the magnified view of the isolator below the base mat. So, here keep an eye here. I will start it the video and then we will see.

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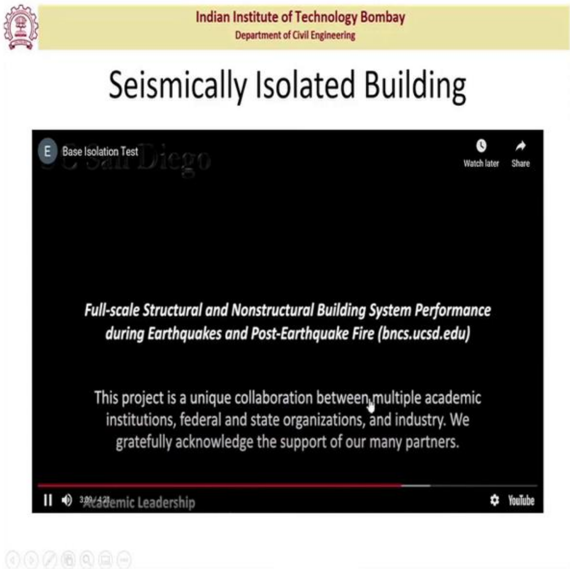

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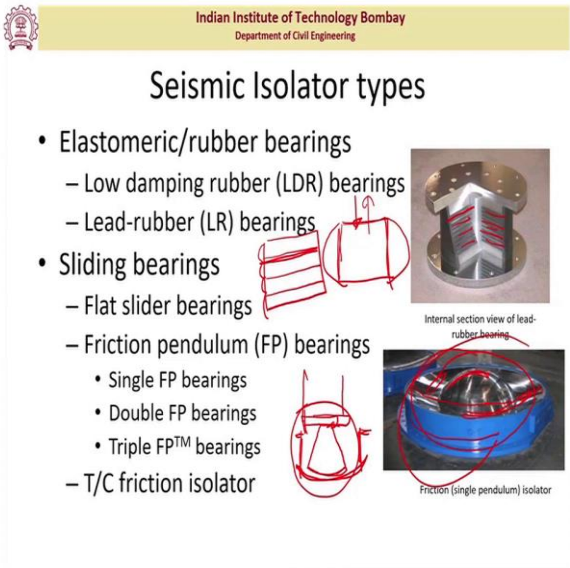

Overall seismic isolators can be broadly characterized like these types. Elastomeric bearings and in the elastomeric you can have low damping rubber bearing or lead rubber bearing.

As we will look at later, low damping and lateral bearings are basically almost same except in lead rubber bearing, you have a lead to allow higher damping or energy dissipation capacity that comes because of the lead. Similarly, you can have sliding bearings. Now, in sliding bearings, you can have a flat slider bearing, you can have friction pendulum bearings. In friction pendulum you can have single or double or triple.

The way we categorize these bearings are the number of sliding surfaces. Based on that we see either these are single sliding surface then single pendulum bearings and then double friction pendulum bearing or triple.

There is also other type of bearing, which is tension and compression friction isolator, but those are not very common. Now, throughout the course I will show you some sliding bearings or friction pendulum bearings, but our focus would be on elastomeric bearings rocker bearings look something like this. You have a surface like this and on this one, you can have column and here a slotted this thing. So, because of this rocker thing, basically it leads to reduction in the horizontal load. If you as a building designer would have to use, would you go for this type of bearing? Then why not go for directly sliding bearings? This would be much more stable; it would provide you enough capacity as well and the force transferred would also be smaller.

Now, if we size for the perspective of seismic isolation, we are mostly utilizing either rubber elastomeric bearings or friction pendulum or sliding bearings. Bridge rocker bearings are little bit different. Those are not seismic isolation bearings. So, in general term, bearings are used at many places like ball bearings. It is also used in mechanical engineering. The rocker bearings that are used for bridges, they are still used. Those are not those are not for seismic isolation application. Like even the neoprene pads. Neoprene pads that are used in bridges, they are not for seismic isolation.

They are only for providing or accommodating expansion joint or accommodating traffic load deformation and those things. For seismic isolation, it needs to accommodate large deformation capacity. Because even for seismic isolation application if you look at it, these steel surfaces, accumulation of dust is a big issue. So, here what they do? They use a cover. So, the overall thing is there is a cover, whole thing is actually covered inside, a closed this thing. This surface here is polished and there is a layer that is applied on this basically a polymer layer.

That is applied on this surface because, change in the value of friction, is a major issue with the sliding bearing. Because let us say you are designing your superstructure for certain load transfer and if your coefficient of friction increases, then the overall load that is being transferred to your structure would also increase and then that becomes a problem. So, to maintain that, they take some counter measures in sliding type bearings by making it very polished and then covering it completely. So, there is no sand or dust accumulation and it is of stainless steel. So, those type of counter measures today, but if you have a single rubber block of this much or if you have same thickness and if you have a steel plates in between, this would have less bulging than this one. This is what you can see here, this is the internal construction of an isolation bearing in which you have intermittent steel plates which are called steel shims.

These are used to prevent that bulging or effectively you can say to increase the vertical load capacity. So, this is done basically in isolation as well and coming to the issue of neoprene longevity basically what happens? Neoprene is basically a synthetic rubber. Now, after 10-15 years you have to keep basically inspecting these neoprene bearings that they are still providing adequate performance, otherwise you need to replace this. In isolation, we are now moving towards natural rubber bearings, what has been seen with natural rubber bearing, that this type of bearings would have less strength degradation or less environmental issue or degradation issue over the time.

So, that is why in US they have almost shifted to natural rubber bearing, in Europe they are still using little bit. But overall natural rubber bearing if you replace neoprene with a natural rubber, it performs much better for seismic isolation of course. Elastomeric bearings have other kind of issues like you have ingress issues in the sliding bearings or change in the coefficient of friction. The problem with rubber is that over the time the property of the rubber changes because of environmental condition like sunlight or it might change because of rubber, which is basically a material that get keeps on getting cured over long amount of time.

So, the shear modulus might change. So, those are issues are there with both. But typically, those are being taken care of in the design itself by estimating that over 15-20 years. The shear modulus is going to increase by 10 percent. So, we do bounding analysis saying that even after changing the property, my structure should still be able to sustain those loads and deformation demand from the earthquake.

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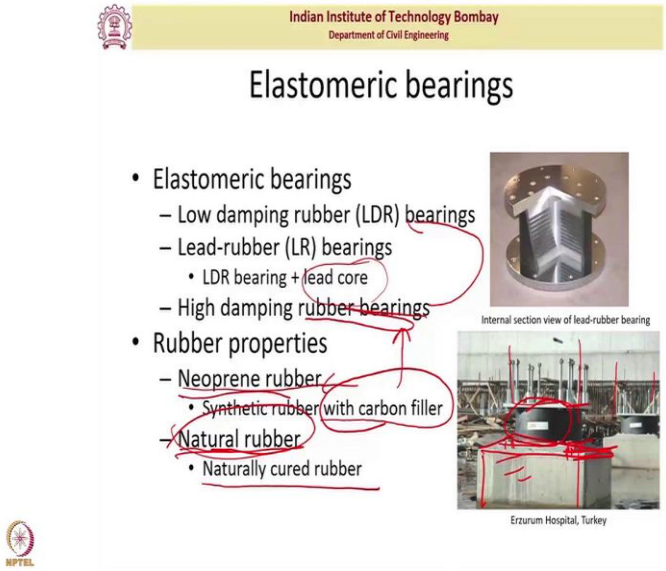

So, let us now discuss elastomeric bearings. Now, as I said in terms of elastomeric bearings, we would be discussing low damping rubber bearings and lead rubber bearings. Lead rubber bearing is nothing, but low damping rubber bearing with a lead core and the role of the lead core here is basically to provide energy dissipation capacity.

And, then there are also other type of bearings, which are high damping rubber bearings. Construction wise high damping rubber bearing system is same as low damping rubber bearing, these do not have lead core. The source of energy dissipation comes from the rubber itself.

So, by changing the composition of the rubber, you can achieve damping properties in high damping rubber bearing. This used to be popular at the beginning, but now people are moving more towards lead rubber bearing and low damping rubber bearings, because what happens? We use basically natural rubber and natural rubber do not have inherent damping capacity as much as neoprene bearing. Because remember natural rubber bearings is naturally cured rubber from the trees.

So, I do not know whether you know the manufacturing process of rubber. Natural rubber is obtained from the trees. If you cut the outer layer of tree and basically from that whatever you get, and you can go ahead and watch some videos. Those rubber are obtained from those trees. Neoprene rubber which is also synthetic rubber can be produced in the lab by changing the composition of the materials and chemicals.

By adding different type of additives, you can increase the damping or decrease the damping. The problem with that is over time, as we talked about the longevity issue, high damping rubber bearing and neoprene rubber bearing have more longevity issue and they over the time degrades more compared to natural rubber which does not have any kind of additives.

Because with the carbon filler, Sulphur or other type of materials that are used to obtain a neoprene rubber. They keep on reacting over the time, over the years.

So, these dormant reactions keep on going over the time and that is why its changing its property. Now, as a designer, if you are designing something that is changing its property over a long time, then you would prefer other type of material, which have less change in the property over the time compared to neoprene which have more change. So, that is why for seismic isolation, we are going with the natural rubber now.

You see you have foundation pedestals here. So, below this you might have a wrap foundation or something else. On the top of that you have this foundation pedestal, which are typically very rigid, and this isolator is connected through these external bearing plates and bolted to this pedestal.

Here and on the top, you again have the same bearing plate and then you can connect to the concrete columns or a steel column as the case may be and you would have several of such bearings in plant.

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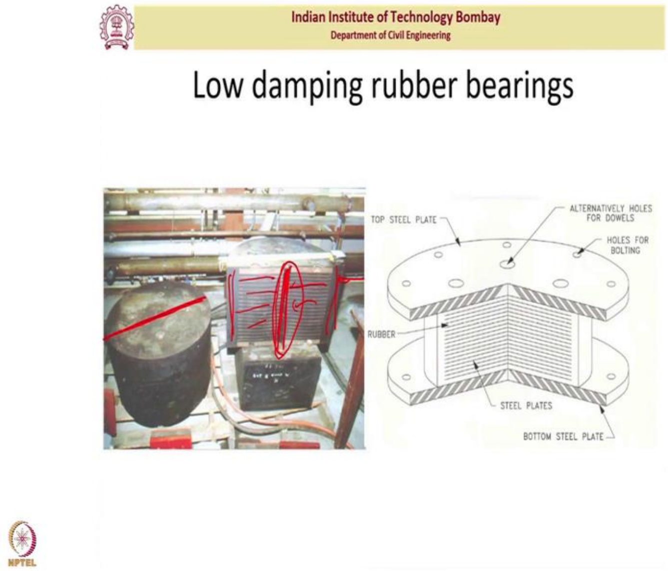

So, let us first show you what is the low damping rubber bearing. Now, what I have shown you, the internal construction of a low damping rubber bearing. There is no lead core here and on the left hand side there is this rubber bearing, which is actually cut in half. So, what you are seeing here, the internal construction multiple rubber bears. Remember in the end what you see here is basically rubber cover. Cover is provided to rubber bearing to protect the bonding at the interfaces.

Because it is very vulnerable at those points and sometimes you might see a central hole, the whole idea behind providing a central hole is from the manufacturing perspective. It allows proper distribution of heat during the vulcanization or curing process. Because, if you have internal hole, basically it allows uniform distribution of heat. So, that it cures properly, and you get good bonding between rubber and steel shims.

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So, this is a low damping rubber bearing. Similar construction you would have damping lead rubber bearing, but now instead of a central hole or without hole, you will have a lead core now. And there are methods through which you can decide what is or how to find out the diameter of the lead core.

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In terms of sliding bearings, you can have a flat sliding bearing, you can have single friction bearing with a single sliding surface, you can have double friction bearing, double FP bearings, which doubles sliding surface as you can see here or you can have triple, in which you have one sliding surface here, one sliding surface here and then one sliding surface here.

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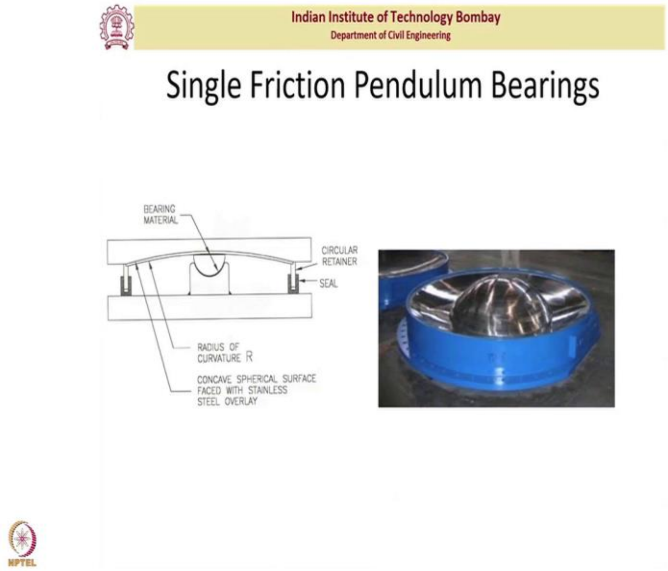

So, this is a magnified view of a single friction bearings where you have single sliding surface.

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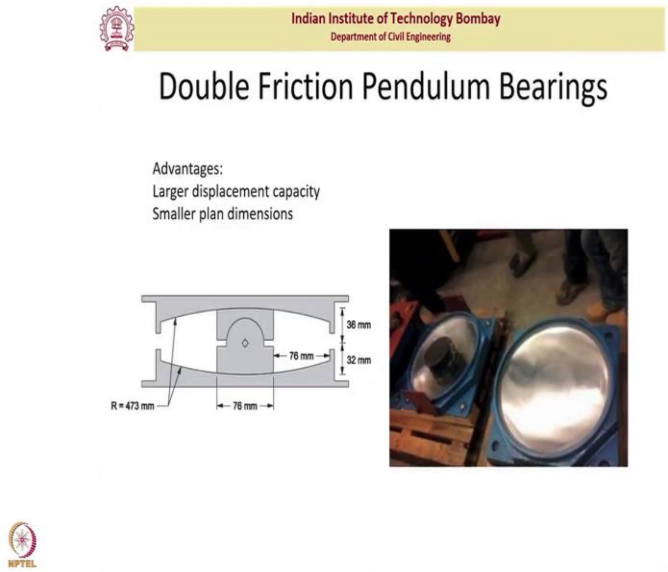

Then this is a double friction pendulum bearings. Now, a question you might ask, why should I go for double friction or triple frictional pendulum bearing anyway? Now, what happens, if you go for double friction or triple friction pendulum bearing, these would provide you enough or larger displacement capacity with similar or smaller footprint.

Because you have multiple sliding surface now, in this case, this would just slide to the end and that is the end of it. But on this one, first this would slide to the end then this can again slide over the top of this one. So, the displacement capacity is actually increased.

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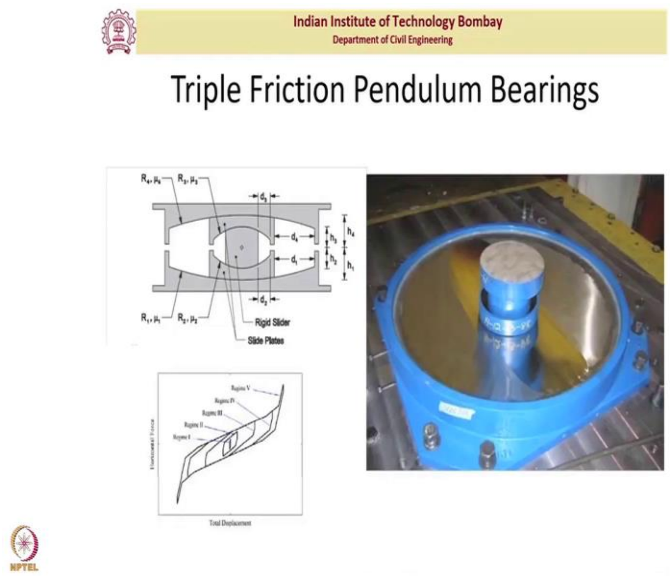

If you increase the number of sliding surfaces further, again your displacement capacity is further increased. So, if the structure, where you want to apply seismic isolation have very small footprint, let us say very small columns and you cannot fit larger bearings, then you can go for triple friction pendulum bearing. Because, it would have smaller footprint or a smaller dimension and it would provide you similar or higher capacity than single friction pendulum bearing or elastomeric bearing.