Dynamics of Structures

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Introduction to Dynamics of Structures
Lecture – 01
Introduction to Structural Dynamics

Hello everyone, welcome to this very 1st lecture on the Structural Dynamics. In today's class, I would be just giving you a brief introduction about this course and that will include the concepts that you would be learning as part of this course. Then I will give you a general idea of what is a static loading and what is a dynamic loading and what are the key differences between dynamic and static loading in terms of their effects on a structure.

Then, I would be discussing the problem statement that you would encounter as part of this course. So, what problems to solve and then, different solution methods that we could potentially employ to solve that problem statement. So, let us get started.

In this very 1st lecture of structural dynamics, we are going to discuss about this course, what are the different concepts that we would be going through this course, what are the objective of this course, what is basically a simple difference between a dynamic system and a static system and then, I would be presenting you the problem statement for this course that we would be studying. So, without getting much delay, let us go through this course.

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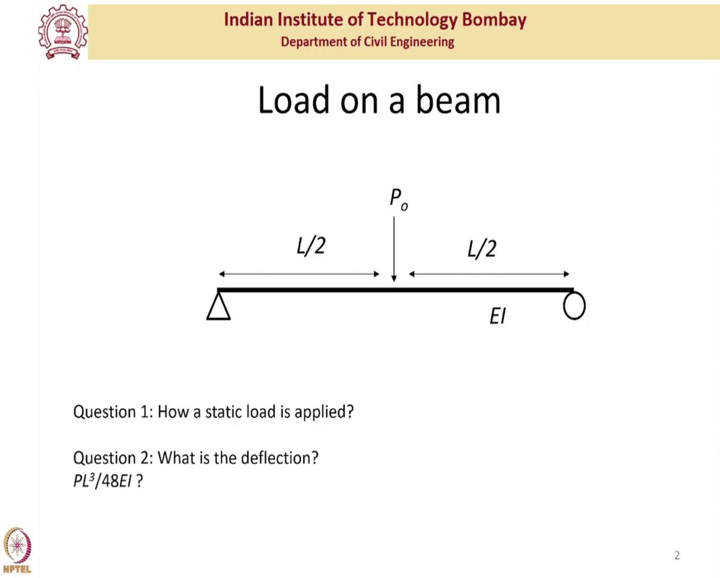

If you remember from your undergraduate knowledge, you use to find out forces and deflection or different response quantities subject to a load say P_0. So, let us say a load P_0 is being applied here on a beam of length L and the modulus of flexure EI.

Now, remember never at any point of time, you were told how the load P_0 is being applied. So, it was just said that a static load of P_0 is being applied on this beam and then, you needed to find out the response quantities such as forces and deflection.

So, my 1st question to you: can you tell me how is this load P_0 is applied? Or let us say, in general how a static load is applied? So, what I mean to say, if you have to apply a static load of P_0 on a structure, what would be the time variation of it? So, that is my 1st question. My 2nd question to you is, what is the deflection of this beam subject to this point load P_0?

Now, you know it from your undergraduate studies, that if the load static load P_0 is being applied, you calculated the deflection at the midpoint as the maximum deflection and the value was $P_0L^3/48EI$. Now, the question is, would this load or would the deflection be always $P_0L^3/48EI$? So, that is my 2nd question.

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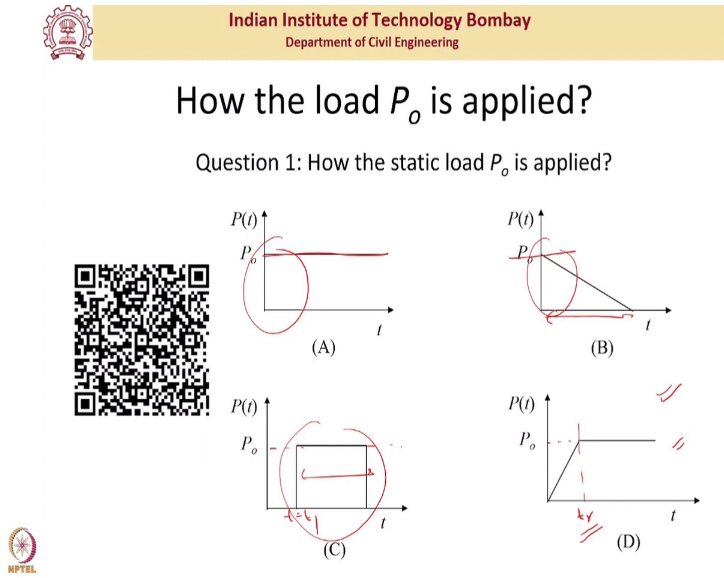

So, the question is how the static load P_0 is applied and I am showing you four options. If you had to represent the time variation of this load P for which the maximum value is P_0, how would you describe this static load?

So, I have shown you four options and you need to select one of these options. If you would like, you can scan this barcode and open up a form, which would show you all the options. Then, you can select the correct answer and that it would show you whether the selected answer is correct or not.

So, let us discuss these four options. In the first option, I have load P_0, which is being applied like this, a constant load P_0. But do you think it is physically possible to apply a load like that? Like it suddenly goes to P_0? We will discuss about that.

In the second figure, you can see, I have a maximum load of P_0 and then it decreases slightly so that it goes to a value of 0 over a certain duration. In third one, I have a load P_0, which starts at certain time t_1, it goes to P_0. It will be maintained over a certain duration of time, then it again goes to 0.

And in the third one, I have a load which is gradually being applied so that it reaches to a maximum value of P_0, after a certain duration, let us say, t_r or the rise time. So, which one do you think can be used so to represent this static load that you have studied till now?

Now, if you think about it, the only load or the load representation could be used is this ramp load here. Because if you try to apply other loads here, you will see from the principle of dynamics that you would study later, they could never have a static load application through any of these representations.

However, if you consider the fourth option here, depending upon the time value of t_r, you might be able to apply a static load and we will come to that, what do you mean by static load and dynamic load? How do you characterize actually? Mathematically, how do you characterize static load and dynamic load?

So, this was the first thing you heard about. You used to do analysis subject to certain kind of load let us say, P_0 is equal to 10 kN or 20 kN and you used to find out the response. But now you need to understand how the load P_0 is applied?

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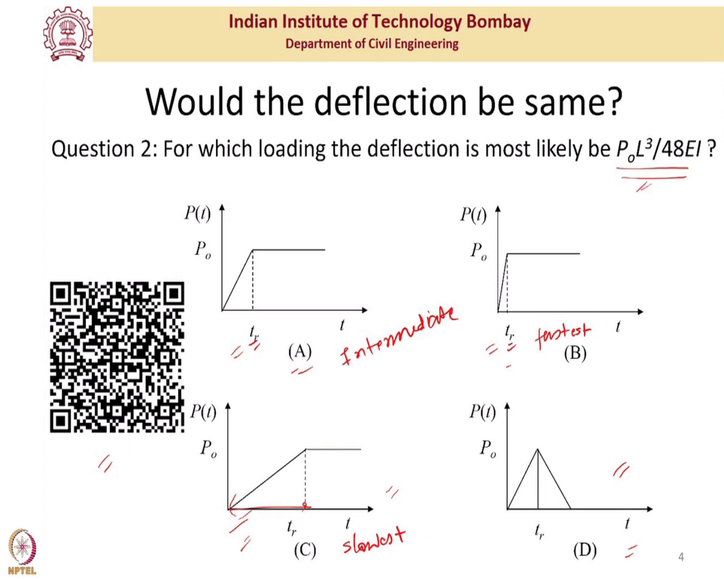

Now, let us come to our 2nd question. So, my 2nd question is, out of these four options or the four load representations that I have shown here, which one would give you a deflection that is most likely to be the value $P_0L^3/48EI$. So, you must select one of these options depending upon the plot of P versus t that is shown here, that would give you a value that is closest to $P_0L^3/48EI$.

Now, again you can scan this barcode using your phone either through an app or through your camera and then, you can submit the answer and see the correct answer right here. Now, let us discuss each of these options that are that have been provided here.

So, the basic difference between these three plots A, B, C, what do you find the basic difference? It is basically the rise time that you see. So, you can see t_r is an intermediate. This first option has an intermediate rise time, the second option is the fastest rise, or I can say like you know the smallest rise time and third is the largest rise time.

So, what I mean by this is that this load is being applied fastest, this slowest and this is somewhere intermediate between these two. Now, I can simply discard this fourth option. This is because this would never produce a value of deflection that is equal to $P_0L^3/48EI$. So, my competition is between these three options here.

So, what you would see that, out of these three, the loading that has the largest rise time would give you a load which is closest to be a static load and we will see why? Mathematically, we will also prove that. But physically, you just need to imagine that if you apply a load very slowly, then load is being applied statically and it does not produce any dynamic effect in the structure. So, this one is most likely to give you the value which is $P_0L^3/48EI$.

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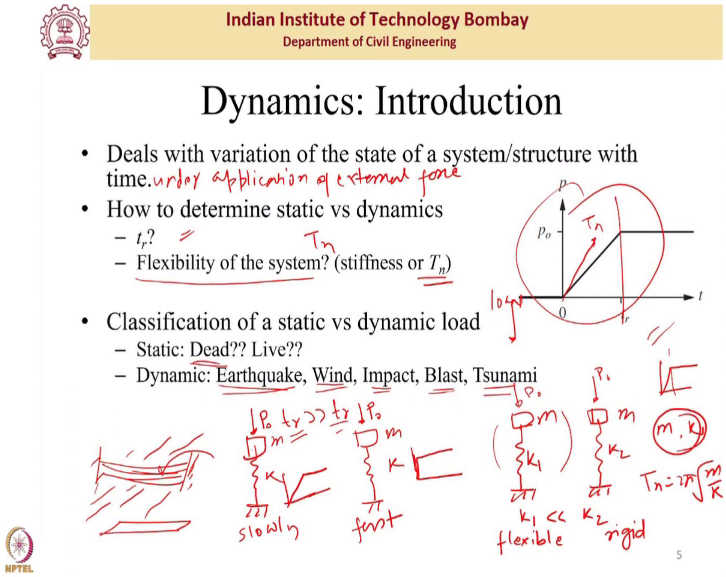

So, now, let us come to what basically defines a dynamic system. So, as we discussed, dynamic system deals with the variation of a state of a system or structure with time under application of external load.

So, again I have shown you that representation, a load representation that can be used to represent a statically applied load of the magnitude P_0. Now, we saw that a parameter to determine whether a system would behave as a static system or a dynamic system under the action of external load is t_r. We saw, in the last slide depending upon how fast or slow you apply, it might behave like a static system or dynamic system.

To demonstrate that, I will give you a simple example. So, let me show you a spring, which has mass m and stiffness k and another spring of same mass. So, both systems have same properties. But now, I am applying load P of final magnitude P_0. Only thing, in this one t_r or the rise time is much greater than t_r in the second one.

So, in this one, load is being applied slowly and in this one load is being applied fast. Now, forget about mathematical formulation, let us just talk about the feel of the system. First develop appreciation from the real-life examples, then we will get into mathematical formulation.

So, in this case, if the systems are same and I applied two loads of final magnitude P_0. However, if one is applied slowly, what will happen? This spring will not vibrate as much as, if you have a load that is being applied suddenly. So, in the first case, load representation is something like this and in the second case, load representation is much more sudden.

So, I can say, t_r plays an important role in determining whether the system would behave as a static load or a dynamic load. Now, can you imagine some other parameter of the system that would determine whether the system is static or dynamic?

For example, again consider a similar example, except in this case, let me keep the mass same, but I have k_1 and k_2. In this case, k_1 is much smaller than k_2, that means, this is a flexible system, and this is a comparatively rigid system. Now, I apply a load which has the same rise time. So, both load of final magnitude P_0 applied over the same duration.

Now, can you imagine, if it is a flexible system, then it would vibrate more and if it is a rigid system, it would vibrate less. I am doing a relative comparison between these two. So, compared to this system, I would see that load P, which is a ramp load, it would lead to more vibration in a flexible system compared to a rigid system.

And I would come to technicality later, what do I mean by more vibration, less vibration in terms of what response parameters. But in Layman terms, you can appreciate this example from a real-life pedestrian bridges for example, *jhula* bridges that you see in some villages, also called suspension bridges.

So, you have, let us say, bridge which is very flexible and supported at the end and then, you have river going over like this. You can imagine, you try to walk very carefully, very slowly here because if you jump, it will start vibrating because this is a flexible system. So, the dynamic effect would be more.

However, if you have a rigid system like a concrete slab bridge, which is much more rigid than this, you do not need to be that careful as you would in the case of a suspension bridge or a hanging bridge. So, the second parameter that determines whether the system would behave statically or dynamically is the flexibility of the system or more appropriately we would see later is the time period, so, it has mass and k.

So, these two parameters and if I represent time period as this, is what determines the second parameter. So, depending upon the values of t_r and T_n, we can decide whether the system would behave as a static or dynamic under the action of an external load. So, this thing you need to keep in mind. We will come back to this later and we will try to do mathematical the derivation of whether the system would act as a static or dynamic.

Now, let us come to classification. So, we saw that we have a ramp load here and if we increase the value of t_r to very large value, then we can represent it as basically a static load. Now, let us consider loads that you have been dealing till now, which were typically dead load or live load. A typical dead load includes a simple load of let us say, 10 kN and we said that is a static load.

Now, can you tell me why the dead load was considered as static load? A self-weight of the structure or anything that is attached to the structure is considered as a dead load and remember that dead load is not applied suddenly to the structures if you are building a structure, you would do it over days or over months. So, slowly you are going to pour concrete and build the structure. So, it is applied over days.

And then, you also have live load. Live load could be the habitants or people that are going to occupy that building or things that could be moved. So, that would be considered as live load even that would be applied slowly.

Of course, we are not considering live load analysis like a vehicle moving on a bridge or something like that. Live loads we are simply considering due to weight of people or things, that could be more during the life the structure.

So, those are the typical static loads that you have encountered till now. Now, in terms of dynamic load, we can consider earthquake load, wind load, impact load, blast load or tsunami load and why do we consider these are dynamic load? If you consider an earthquake load, can you think what is the typical duration of an earthquake?

Maybe let us say 15 second, 30 second, 1 minute something like that. So, structure is applied a very heavy or large horizontal load over a very short duration. So, this t_r is very small and depending upon the time period of that structure, it could lead to dynamic effect.

And then, I can also have wind effect and depending upon at what rate or velocity the wind is flowing. I can have very large dynamic effects in the structure. I could have impact, which is like a sudden impulsive load or I could also have blast which is also like an impulsive load.

And then, I can also have tsunami load which is a sustain load over a little bit larger duration of time than the impact than blast load. So, these types of loads are characterized as dynamic load due to their duration over which they are applied to the structure and the typical time period of the structure. So, keep these things in mind.

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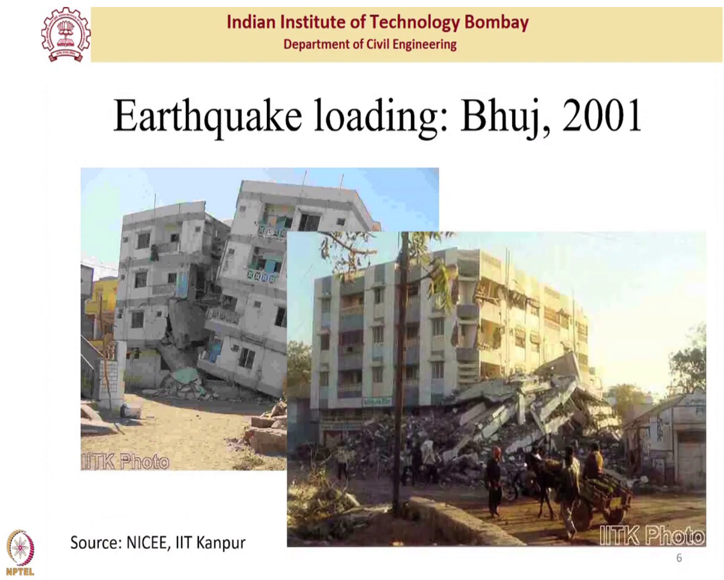

Now, what I am going to do, I am going to show you some videos of the real-life example of different dynamic loads that we have mentioned in the last slide. First, I am going to show you one of the few images of the Bhuj earthquake, that happened in Gujarat and you can see what kind of damage it resulted in.

So, all these building and most of these buildings were designed adequately for vertical loads, but I am not sure whether they were designed appropriately or adequately for horizontal load.

So, earthquake is a horizontal load due to shaking of ground motion. It leads to horizontal load on the structure and because of inadequate seismic design, it led to lot of devastation during the earthquake and loss of precious lives. So, this is the example of what a dynamic load like an earthquake can do to the structure.

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Then, here is a video of Nepal earthquake. You can see, this is a live CCTV video at that time, and I will just show you in a small clip. You can always go to YouTube and see in detail all the clips.

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So, you can see the shaking happening and soon you will see the intensity increasing. You can see that there is a structure that just fell and there are 10 different footages at different places.

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So, you can see another footage is here, I think the structure already collapsed.

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So, you can see the effect of earthquake on this residential house as well. Lot of pots falling around and people coming outside. So, you can go and search on YouTube different type of earthquake loading and the failures on the structures. And you can see what the effects on different structures around the world are for during different earthquakes.

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The second type of dynamic load that we discussed was wind loads. What I am going to show you this is a suspension bridge known as Tacoma Narrows bridge. You can see that, one morning what happened, lot of wind started flowing below the deck and due to pressure differential, it started creating a torsional motion of this deck.

This finally led to failure of the suspension bridge, precisely, the deck of the structure. There are a lot of failure studies which would more accurately describe the failure mechanism and what led to this failure. You can go ahead and look if you are more interested into those studies.

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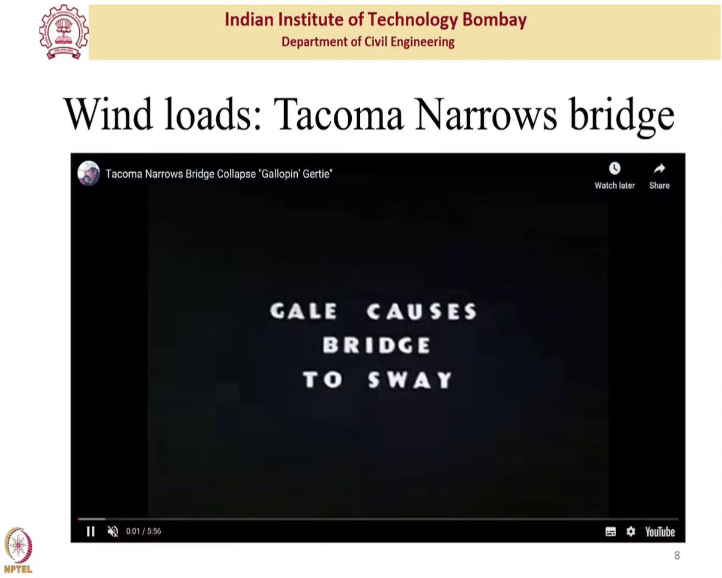

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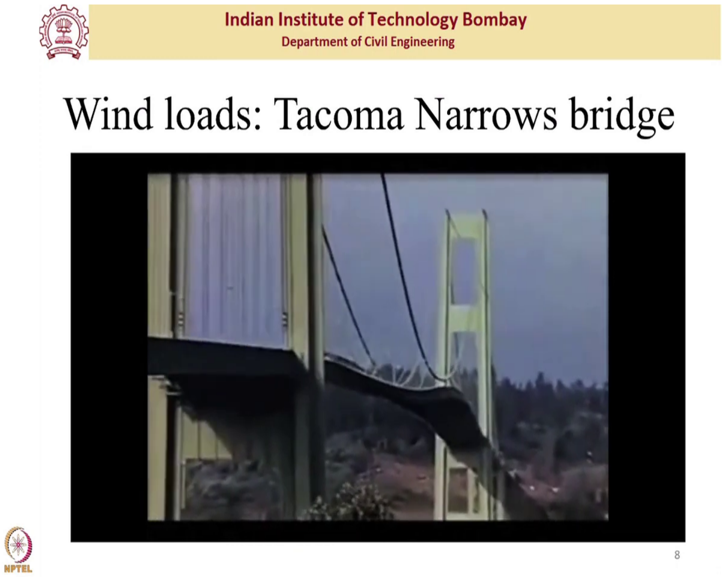

So, you can see this deck of the central span wobbling vigorously and the amplitude keeps on increasing.

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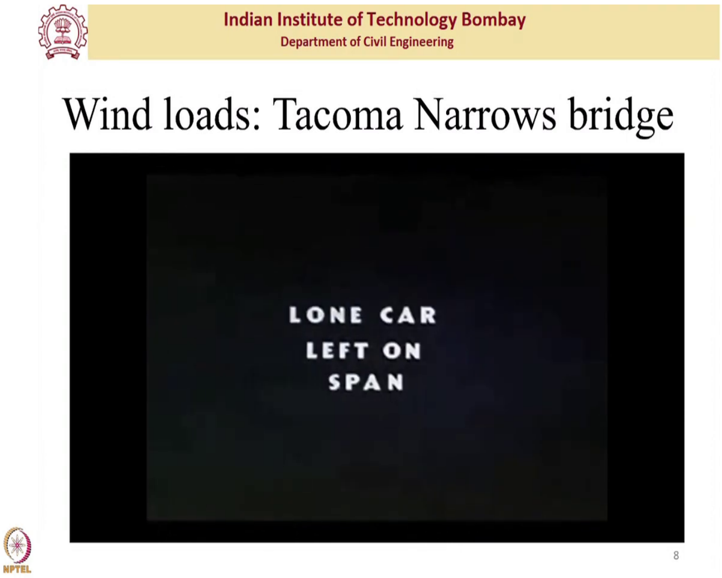

So, I am going to fast forward this video so that I can show you the final failure video of this one.

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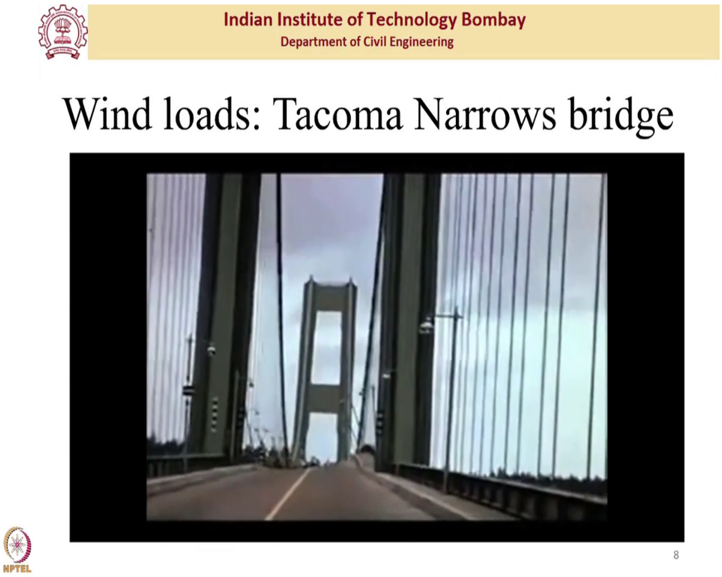

Let me again go here, this is showing the front view.

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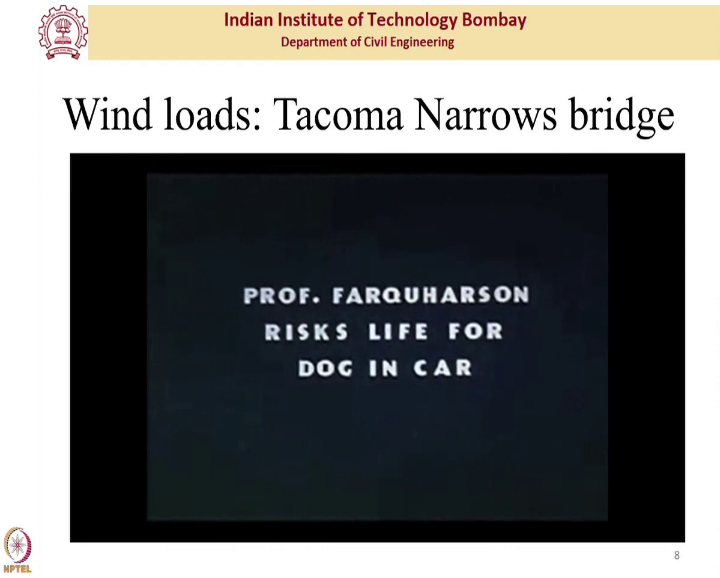

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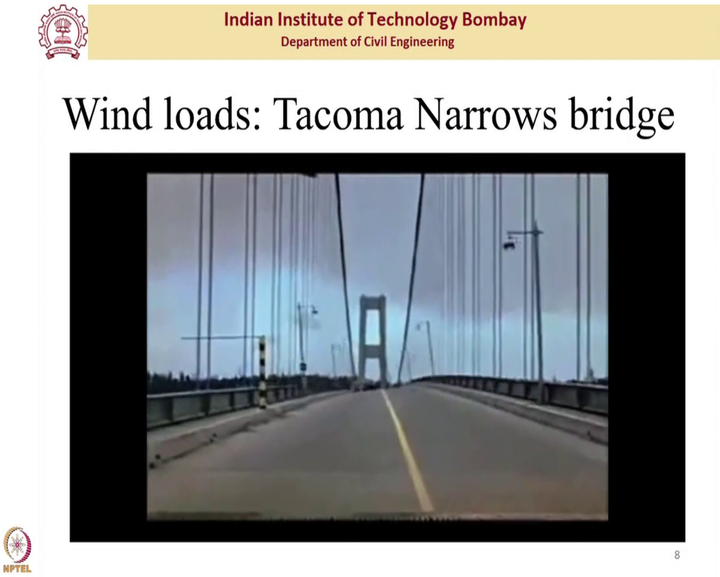

The funny thing happened, one of the dog was left in the car and then, the owner of the dog went ahead and rescued the dog from wobbly deck. You can see that the amplitude is increasing.

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I am again going to fast forward this video.

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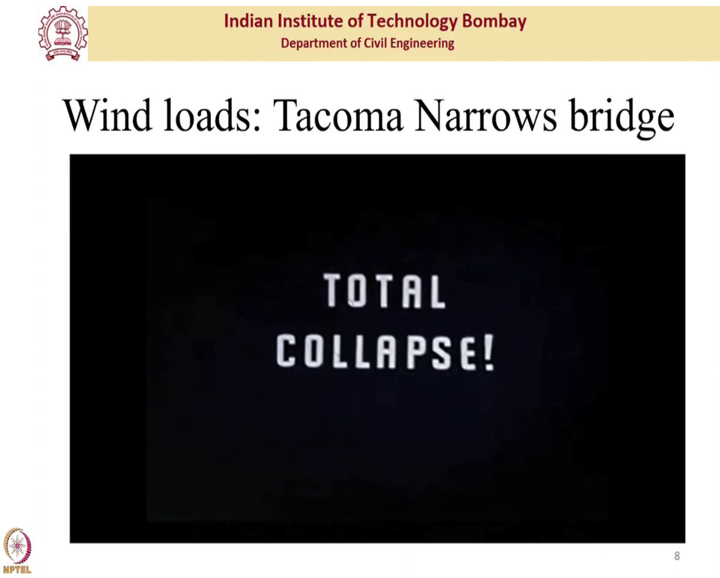

So, we also have a suspension bridge in Bandra-Worli sea link. If you have not gone there, it is a great engineering structure. You can always go there, just to have a look and look carefully at the suspension bridge.

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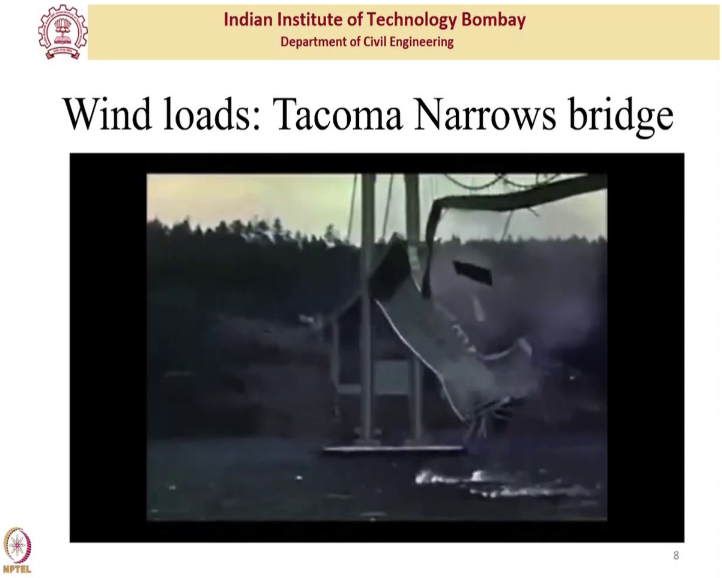

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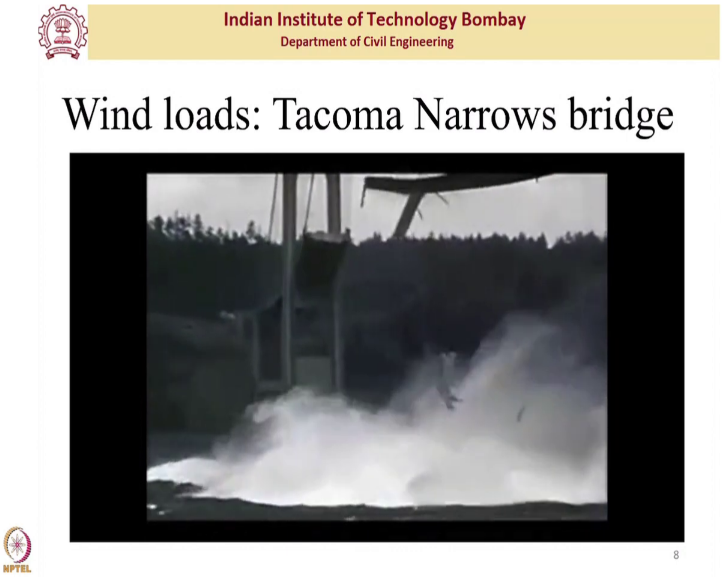

So, you can see that due to increased deflection because of the wind load, it finally, led to the failure of the deck span. So, all these types of structures need to be designed against such wind load. So even if there is a constant energy in fusion due to wind, then there should be some energy dissipation mechanism and which we will learn later, so that it minimizes or trunks or keeps the amplitude within a certain limit, even if there is a constant fusion of energy.

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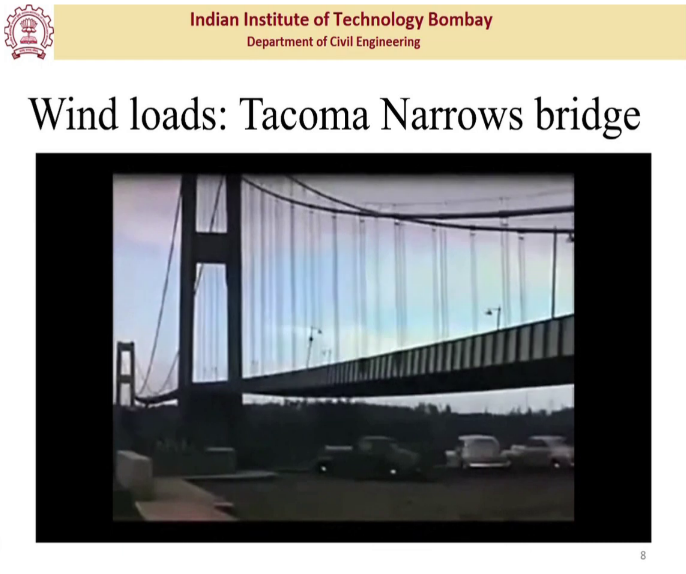

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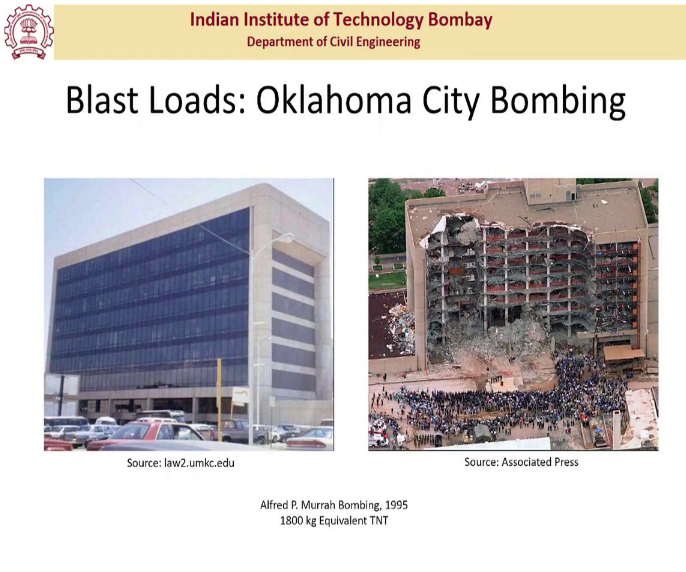

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Now, let us go to the next video. This is a crash test video. The third type of dynamic load that we talked about is the impact load, which is a short duration pulse. So, this is one of the tests that was conducted. Now, you know because of the security threat, many of the structure now need to be designed against aircraft impact. This was one of the experimental tests done, in which a concrete wall was hit with the Phantom F-4 aircraft and then, it was seen whether the aircraft would be able to take that load or not. So, let me just play this video.

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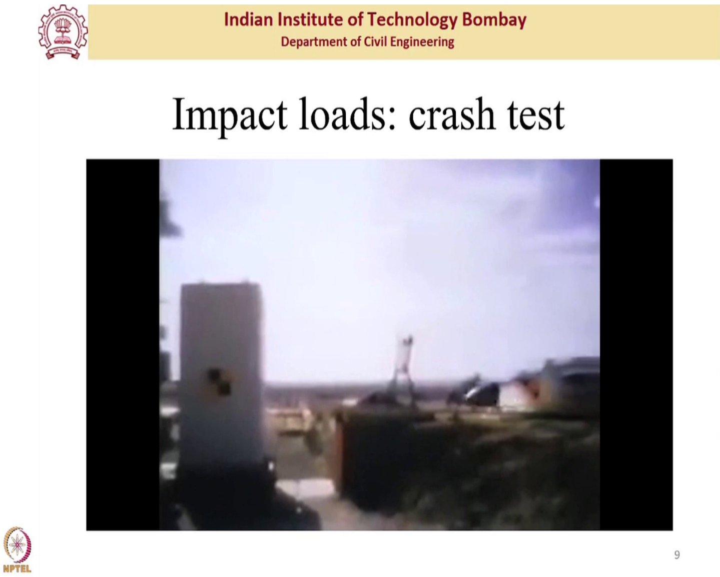

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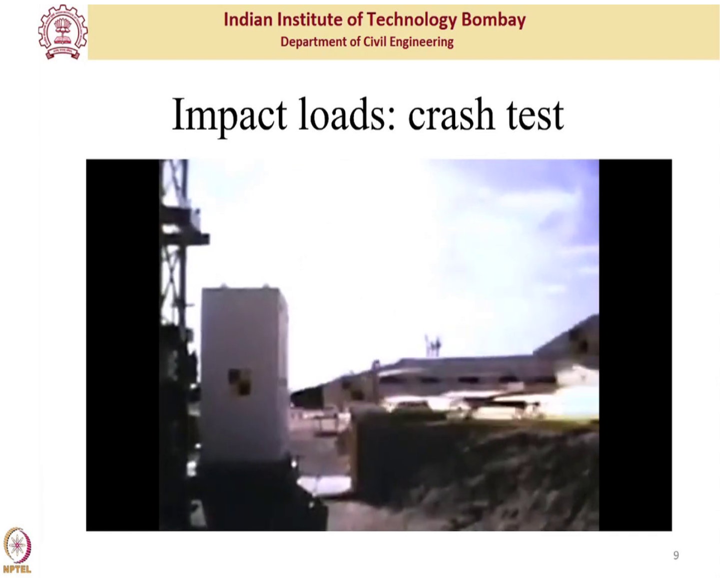

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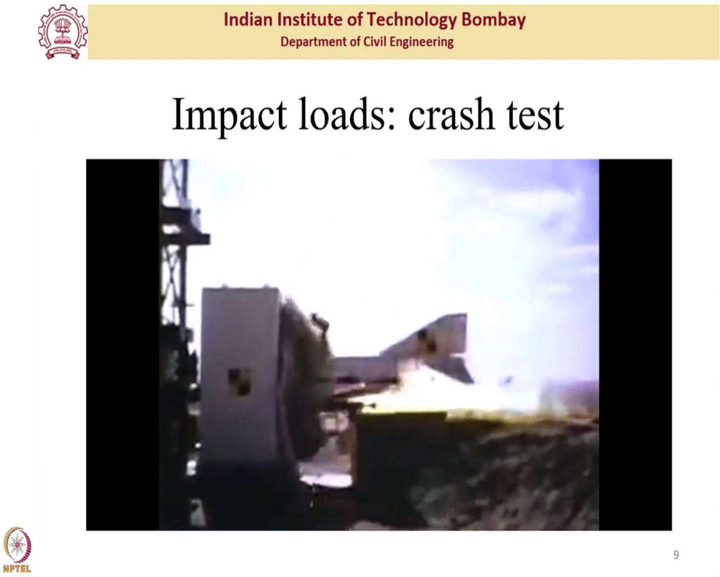

So, what do you think, whether this aircraft did breach the wall or not? Well, it just so happens, even the load was very high, the wall was designed in such a way that there was lot of damage due to this impact. However, there was not a complete breach. That is what these walls were - heavily reinforced concrete walls.

So, I am going to go to the next slide. Next type of dynamic load is a blast load. What I am showing you is a building before and after bombing. This is a federal building called Alfred P

Murrah building, in Oklahoma City and it was bombed in 1995, using explosive kept in a van. The explosive weights were 1800 kg. Due to the blast, it took out the columns here, columns in beam here and it led to the removal of columns here. Then, because of the blast pressure shock wave, there was an upward pressure on these slabs, which they were not designed for. So, due to this, it led to the progressive collapse of the building and finally, what you see here is the building partially collapsed. So, I think a lot of fatalities happened, total number goes around 160 people died in this building.

Now many of the buildings are whether it is critical, like you know, civil building, civil building means like you know for civil purposes, non-military purposes; aircraft structure, aircraft buildings; some operation control centers are being designed for blast loads and also military structure, defense structure have always been designed for these type of loads.

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Next is a very simple but demonstrate the concept of dynamics. It is a vibration due to walking. I do not know whether you know about or somebody would have told you, that when you walk on a bridge whether it is a pedestrian or regular bridge, you should not walk in tandem.

And even forces, military, they are supposed to walk in a tandem or periodic fashion in a normal situation. However, they are advised against walking like that on a bridge because, what happens when you walk in a tandem, you create a walking load frequency. We will see how that looks like walking load.

And that leads to basically a walking load with a certain frequency. If the frequency of that walking load matches with the frequency of the structure on which you are walking, it leads to the failure of building. So, they are asked or requested to break their steps, breaking their steps means walking randomly. So, there are multiple frequencies with very small amplitude. But, not a single frequency periodic load with a large amplitude.

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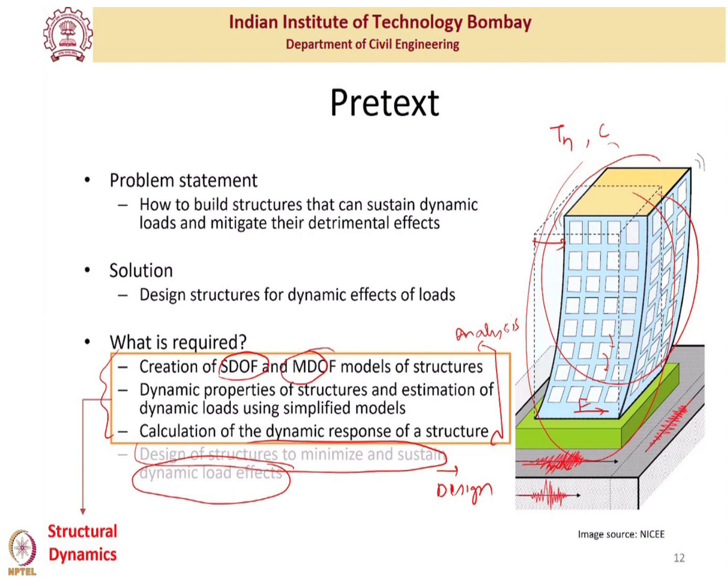

So, let us go to the pretext of this course. What you see here is the problem statement for this course or what we are trying to do here. So, the problem statement is how to build a structure that can sustain those dynamic loads, that we have discussed in previous slides and mitigate their detrimental effect, so that is a larger goal.

And what is the solution for that? Well, the solution for that is to design structure for dynamic effects of load. Very simple but it is not as simple as this statement make it sound. So, what is required to do that? Well, first I am showing you a structure here. This is a building structure here. To obtain and design a structure, first what you need to do is create a numerical model of this structure.

Because you cannot have a numerical model that includes each and every minute detail of any system or structure. So, you need to create a simplified representation, which might be single degree of freedom system or if you need depending upon what is your response quantity of interest, you might create a multiple degree of freedom system.

What is the next step then? Well, once you create a simplified model, you need to find out what are the stiffness, what are the damping properties and then from that, what are the time period of the structure, what is the damping, how it is represented, let us say representing it by viscous damping. So, you need to find that out and then, you need to find out the dynamic loads that are being applied.

So, in this case, I have a horizontal earthquake here. So, I will represent it through some time history function. Then, I have a numerical model and this time history function, the next step is to find out the dynamic response of this structure.

So, response means what are the forces, the base shear, moments in the members, what are the displacement here, those are the typical response quantity. Once we have that, I can design my individual component or overall structure to accommodate those kinds of forces and deflections and the final step, to design the structure, to minimize and sustain those dynamic load effects.

Now, first three steps are analysis steps and the fourth step is a design step. Now, the scope of this course is to study first three analysis steps. So, we are not going to go ahead and design a structure, but we are going to study first three steps.

So, through this structural dynamic course, we are going to analyze system and find out the response. There are other courses that are there, and which will see subsequently that will discuss how to design the structure, once you have the effects of dynamic loads figured out.

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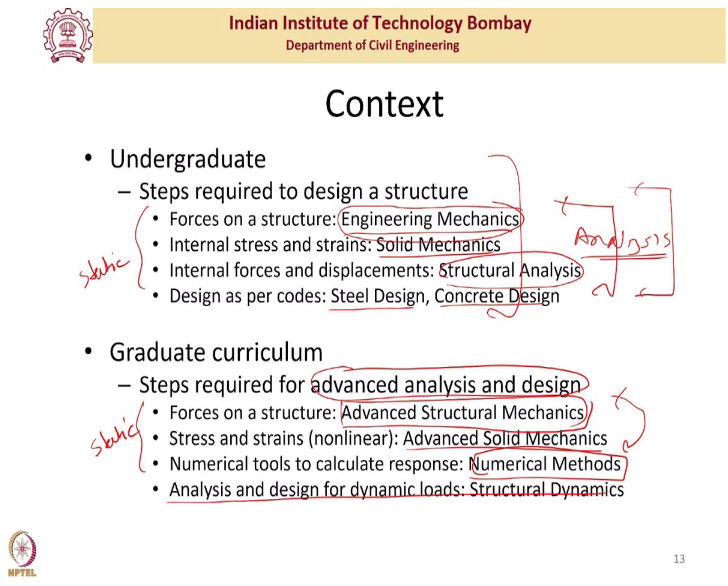

So, that brings us to the context. So, whenever you start a course, the first question you should ask, why I am studying this course? What I am going to achieve through this course and how does it fit into a bigger picture?

So, let us say, if your goal is to become a structural designer or analyst or computational mechanist, you have to first find out what is the utility of those course and how is going to be useful and how does it fit into the bigger picture? Now, let me draw out the whole curriculum.

And then, show you how does this whole thing actually builds up to work towards a greater goal, to equip you with the skills that are required to work towards designing a structure, analyzing a structure and finding out or building safe and economic structure.

Now, in your undergraduate, you would have studied lot of subjects. Let us see where those subjects actually fit into this picture. So, what are the steps required to design a structure as we discussed before? Well, the first step you need: to find out forces on a structure. Which course did you study to find out forces on a structure? Well, it was the first course Engineering Mechanics.

Now, forces might not be enough, because most of the times failure criteria are governed by the stresses not the forces. So, to get the internal stresses and strains you studied Solid

Mechanics. Now, after you studied how to get the stresses and strain, you also needed to find out how to get internal forces and displacements in a structure and what did you study for that: A structure analysis course.

And finally, when you were equipped with all the analysis courses, then you studied specific courses that work for the design of different type of the structures. So, whether it was steel design course and concrete design course and these were at very preliminary or basic level.

Now, at the advanced level in the graduate curriculum, let us see what the courses are and how does this course fit into the bigger picture. So, what are the steps required now for advanced analysis and design? So, you did basic analysis and design in your undergraduate. Let us see, what are the steps required for advanced analysis and design.

So, to find out the same the forces on a structure, now you do advanced structural mechanics, which, discuss advanced methods of analysis and then, you study a course which is called advanced solid mechanics, to find out a stresses and strains. In your undergraduate is you mostly focused on linear stress and strains. However, in a graduate, you might do linear and non-linear both.

Then to obtain forces or stresses and strain, you need some knowledge of numerical methods and to learn those numerical methods, you take, or you are going to take course, which is called numerical methods, which, is part of a curriculum that we our department also has.

And then, till now, whether it is undergraduate curriculum or graduate curriculum, these courses were focused on static. I mean you can do dynamic advanced courses, but the first course that you have, which, deals with the dynamic effect of loads on a structure is this course structural dynamics.

Because most of the loads are actually not static, they are dynamic. Even when you call a load as a static, they are still a dynamic load which has a variation with respect to time but applied very slowly. So, I hope the context of this course is cleared to you.

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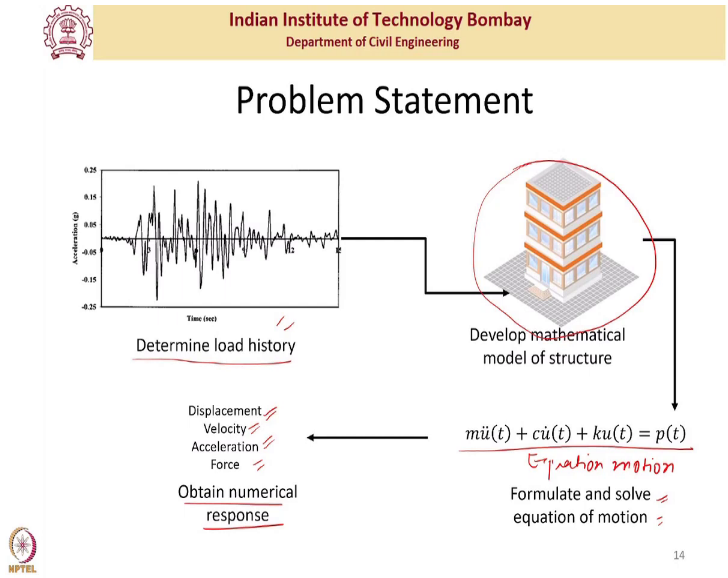

Again, let me come to the problem statement. So, what through this course we would be doing? First, we need to find out what is the load that is being applied on a structure i.e., first we need to determine the load history. The second step is to develop mathematical model of a structure. So, whether it is a building or whether it is a vehicle or whether it is any other type of system, I first need to represent that system or a structure through numerical model or a mathematical model.

Once I have that, with this loading history and the mathematical model of the structure, I would set up what is called equation of motion. So, I would formulate this equation of motion and we would see how to do that for different type of system, and you can extend that to a very simplified as well as complicated systems. So, I need to first set up this equation of motion and then solve this equation of motion.

Now, the after this, once I have the equation of motion setup, I would find out the response quantities. So, obtain numerical response and what are the typical response quantities I am interested is in? They could be this could be displacement, velocity, acceleration and force. So, these are the response quantities I need to find out.

So, this is the the problem statement and basically, through different chapters of this course, we are going to addressing one or multiple steps at a time. So, keep this problem statement in mind when we will go through different chapters.

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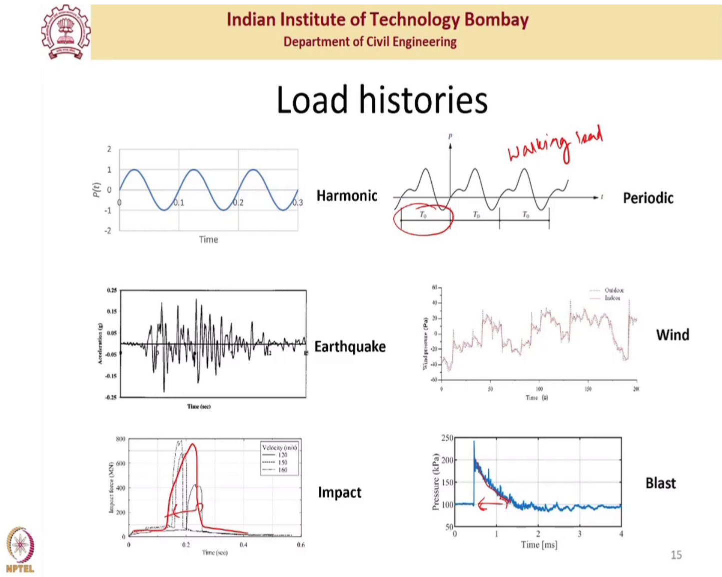

Now, let us look at how do we obtain this load history. What I am going to do, I am going to present in front of you, typical load history that a structure or a system might encounter in real-life. So, the first one is a harmonic loading which might be a sinusoidal or cosine loading.

This type of loading, you can imagine due to some machines on vibration; happening due to machine attached to a floor or other type of harmonic machines, producing harmonic motions. The second could be periodic loading. Now, periodic loading might not be harmonic, but harmonic loading is a periodic loading. So, just keep that distinction in mind.

So, periodic loading is something that repeats after a period, which is T_0 here. So, what I have shown here, is basically a representation of a walking load. Of course, this assume a uniform walking at a fixed pace. But this basically represents a walking load. Then, there could be earthquake load, which, is more like a random excitation. There could be a wind load, which, again could be represented by these random spikes, which, represent the pressure peaks.

There could be impact load, which, is like a sudden spurt of a load for a very small duration of time. There could be a blast load, which, is a sudden spike and then, decreased in this duration, which, is actually very small. So, I have shown you some of the load history that a structure might experience. These are the load histories and typical load scenarios that a structure would experience, while obtaining a dynamic response of a structure.

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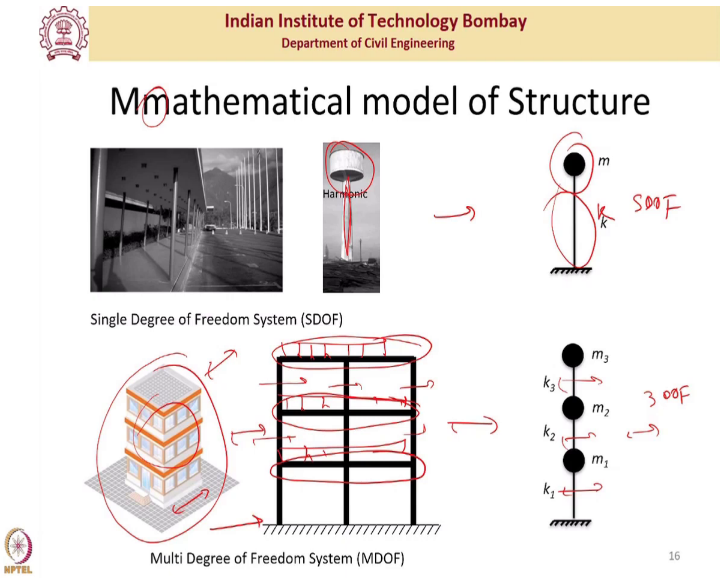

So, once you have the load history, second thing we talked about is mathematical model of the structure. So, in mathematical model of the structure, I can represent my structure using a single degree of freedom system and I will tell you what that means - the degree of freedom - in a later slide.

Let us say I have this pergola type of structure, where, this is like a walkway in which a heavy slab is actually connected or supported through these steel columns or you have a water tank in, which, again a heavy mass is connected through this column. So, this can be simplified through a single mass and then a single stiffness component represented by this column and this is called single degree of freedom system.

Or we could encounter like you know more complicated system in which is a very complicated structure and I might decide to simplify at simple beam columns. Then, applied by loads here so, the slab loads and everything can be applied here and then, horizontal load might be applied here or a vertical load might be applied here and depends.

Now, this is this structure can be further simplified if we assume that all mass of these floors is rigidly connected to each other and the flexibility is basically represented by these columns. So, I can further simplify this system through this 3-degree of freedom system.

Now, you would ask which is the appropriate representation? Well, it depends on your problem and it depends what are you trying to achieve through that problem. So, for some system, even this could be represented by a single degree of freedom system.

If, let us say, your goal is to find out what is the total base shear and not what is happening in the structure above. Or, if your goal is to find out what are the storage shears, then you need to represent it through a shear type building or building like this. So, it depends on what are you trying to find through that problem.

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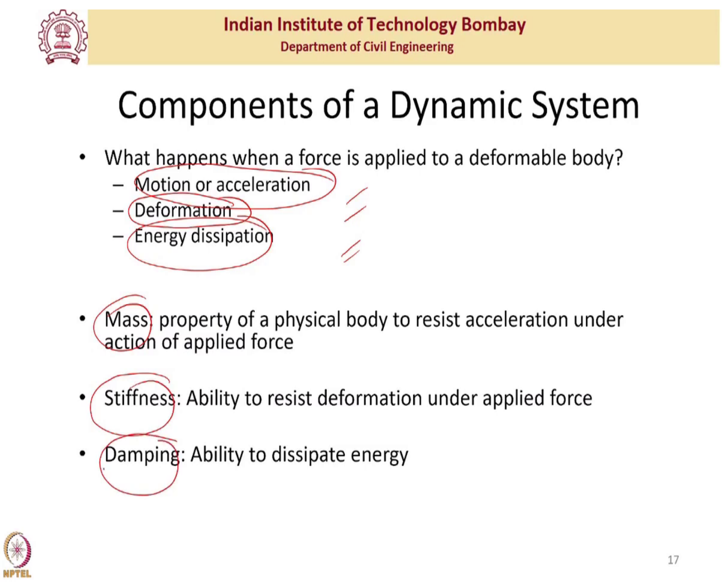

So, coming to what are the different components of a dynamic system, you have to think about what happens when a force is applied to deformable body? Just think that you have a deformable body and then, you apply a force, force rate is varying with time.

So, can I say if you apply a force on a deformable body, then there would be an acceleration; if it is deformable, there would be deformation. And can you imagine if I apply a load to the structure, there would be some sort of energy dissipation.

So, in reality, every system or structure in reality would dissipate some amount of energy when you apply a load, it might be small. So, in some cases, it might be neglected. But for all practical purposes, there is always some energy dissipation. So, the third component is energy dissipation.

So, considering these points in mind, any structure or a dynamic system has three integral properties, which are: mass, which, is basically ability to resist acceleration; then stiffness, which, is ability to resist deformation; and then damping, which, is the ability to dissipate energy.

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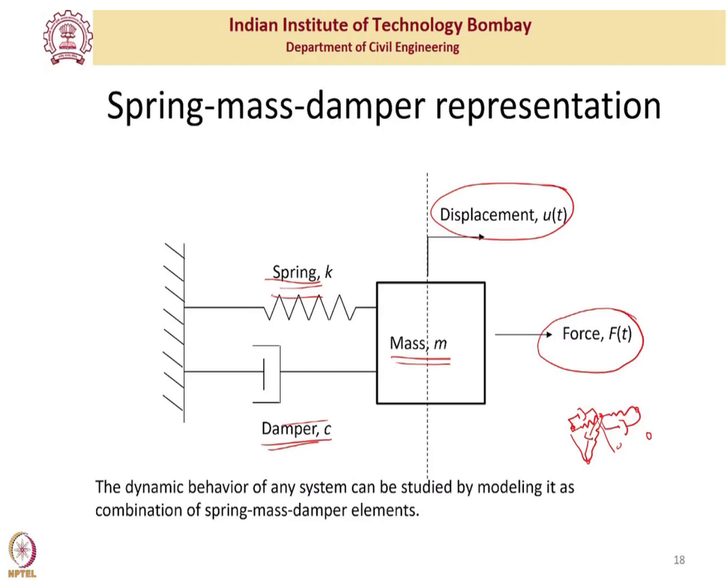

So, a simplest representation of a dynamic system is a spring-mass-damper system and this is called as spring-mass-damper representation. If this spring-mass-damper system is acted upon by an external force $F(t)$, there would be a response, which, is here displacement. So, I can say the dynamic behavior of any system can be studied by modeling it as a combination of spring-mass-damper system.

So, although I have shown you here a single spring-mass-damper system, let us say, even if I have interconnected body, I can lump the masses, connect them with a spring and a damper and each of them can be connected through each other node, depending upon what is the connectivity and through this, any system can be represented by a spring-mass-damper.

So, what I need you to do basically, when you are doing this course, try visualizing every system, what you see around yourself, as a representation of a spring-mass-damper. If you can tell me that to solve this system, I need to represent it with some additional properties, then let me know, because, this I find is the most simplest representation of a dynamic system.

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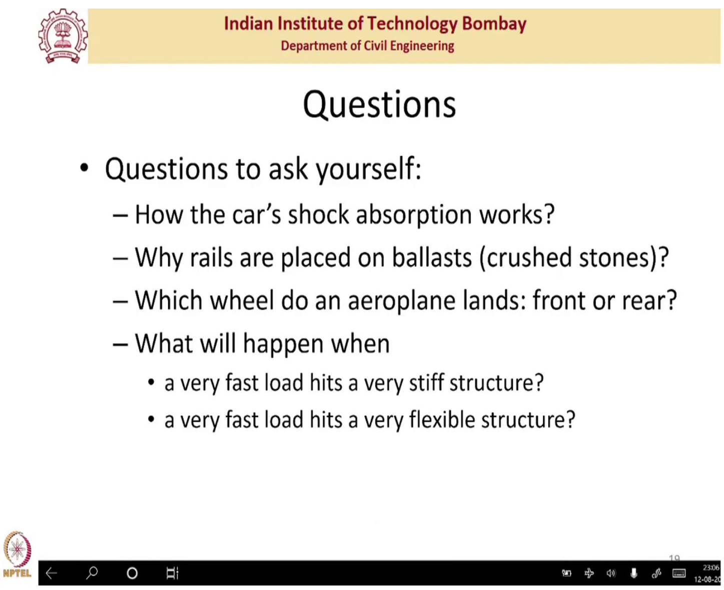

So, what I want you to do, ask yourself few questions at this point a time in this introduction slide. How the car shock absorption works? So, you have cars or any other vehicle and Mumbai or our Indian roads are famous for potholes; and all the cars or any type of vehicles are equipped with shock absorption.

So, you need to imagine how would that work and if somebody has to design that car shock absorption, how would they do it? What would be the critical parameter? Then, what I want you to ask yourself: you guys have traveled by train and you must have seen or the metro;

you must have seen there are blasts or crushed stones below the rails. What is the function of that one? Why cannot I just have rails on the top of concrete slab?

And then, just run vehicle on the top of that. So, what is the utility of that? And then, you might have also traveled by aeroplane, have you ever noticed which wheel the airplane lands on? Whether it is front wheel or the rear wheels?

So, just try to notice that next time and try to find out the reason why the rear wheel or why the front wheel? Then, I need you to ask yourself what will happen if a very fast-moving load hits a very stiff structure? Or a very fast load hits a very flexible structure? So, these questions I want you to leave with. Keep pondering about these questions, because the answers to all these questions would lie or would be answered in future chapters that we study.

So, these questions are just example. Always try to imagine, whenever you see the system surround you-try to visualize why-what is happening and what is the mechanism behind that? How can I explain that? There are so many example of dynamics around you or the structural dynamics around you, that it would become very interesting when you start looking and analyzing those systems in your mind.

So, with these questions, I would leave you. We will come back to these questions in subsequent chapter and I will explain the basic concepts behind those principles as well as the mathematical derivations of those principles or the answer to these questions. So, thank you for your attention and let me just leave you with these questions and we will come back to again in next chapter.

Thank you.