Maintenance and Repair of Concrete Structures
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Lecture - 26
Structural Strengthening & Stabilization (Load Effects and Introduction to S&S)

This module is on structural strengthening and stabilization. There are 4 lectures planned in this. The first one is on load effects and introduction to strengthening and stabilization.

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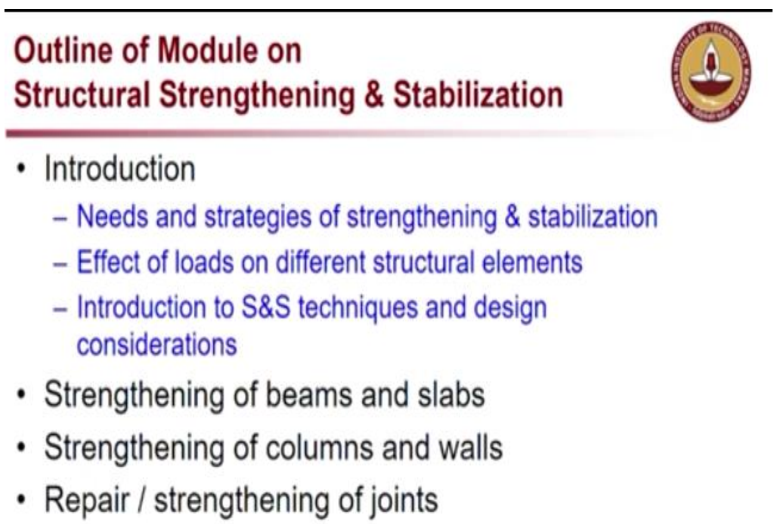

This is the outline. In this lecture, we will look at needs and strategies of strengthening and stabilization. Why do we need to strengthen and stabilize these structures and also we will look at what are the various effects of loads on different structural members or different type of loads, which are acting. And then we will look briefly various strengthening and stabilization techniques and also some general design considerations in this lecture.

The remaining 3 lectures will focus on strengthening of beams and slabs and strengthening of columns and walls and then we will look at how the joints and connections are or can be strengthened in the next coming 3 lectures.

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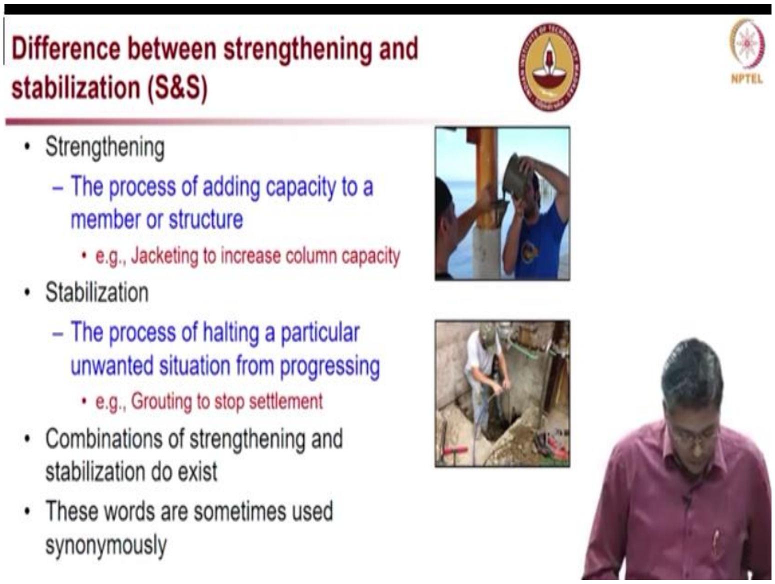

Now let's look at first what is the difference between strengthening and stabilization. Strengthening is the process of adding capacity to a member of a structure. Now one easily recognizable example is jacketing of concrete columns to increase its axial capacity. What is stabilization? It is the process of halting or preventing a particular unwanted situation from progressing.

For example, if you have a crack and if you want to prevent that crack from growing, then we usually say that process by which we prevent that crack from growing is stabilization. A good example of stabilization is grouting to stop settlement, so that the cracks, which are forming due to settlement can be stopped from further growth. And also there are a lot of projects, which involve both strengthening and stabilization and sometimes people also use these two words synonymously.

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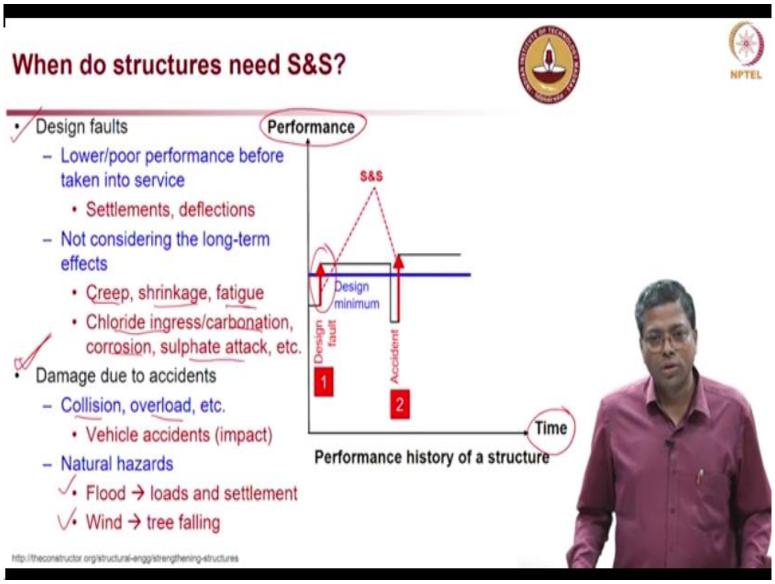

When do structures need strengthening and stabilization? Now structures need strengthening and stabilization mainly because of four reasons. The first one is fault in the design, then damage due to accidents, and then material deterioration and increase in demand.

So, let's first look at design faults and damage due to accidents. So design fault is lower or poor performance before even the structure is taken into service. So let's, first we look at this graph here or the chart. Where you have time on the abscissa and the performance level on the ordinate. In the first point, which is design fault, we are talking here (indicated on the chart). So if we find the blue line is the design minimum or minimum performance, which is expected from this structure.

And if you find that there is a faulty design even before the structure is put in service, then we have to do something so that the performance level can be enhanced or strengthened, and brought to the point, which is above the blue line or above the minimum expected performance level. So that's indicated by this first arrow here, first arrow here.

Why this faulty design happens? One reason is that may be sometimes people don't consider the long term effects. For example, creep or shrinkage, fatigue, etc. the problems because of these will show up or start manifesting not necessarily in the very first week or so, but may be after some time, may be sometimes even months also and in case of fatigue, it might come many years later and chloride ingress, carbonation, corrosion, sulphate all these deterioration mechanisms also can play a role or can be counted as a design fault. And when I say that the design fault, I mean not only the structural design fault, but also the durability based design fault or because of not considering some of the material parameters.

The second point is damage due to accidents. So first we covered design faults, second is damage due to accidents and when I say accident, this is something which we don't really expect, but happens.

So collision or overload, typically vehicle accidents, if we are talking about a bridge, there are many cases, where the bridge columns are hit by vehicles, incoming vehicles or even sometimes you might see that the girders, if you have an overpass, you will see that the girders are hit laterally by the vehicles coming, if the height of the vehicle is more than what is allowed. Even though they are not expected, but it happens in some cases and the natural hazards, flood, wind, etc., all these will also can lead to an impact load or additional load to the structure.

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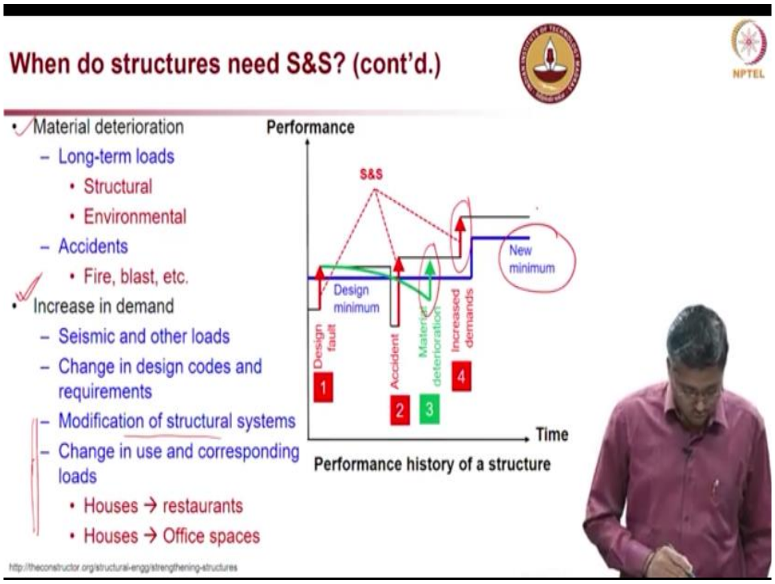

Now let's look at the next point, which is material deterioration. Typically, these are associated with the long-term loads and when I say long term load, it's both structural and environmental loads, and also accidents come into the picture. The accidents which lead to degradation of the property of the material. For example, fire or blast load, these might induce some micro cracks in the concrete system and that might affect the overall behavior or the material properties, of the concrete.

And then, so that is shown here in this sketch by green curve, the performance level is slowly degrading and then going below the design minimum and at one point of time, we go for enhancement, which is indicated by the green arrow, vertical and then, we raise the performance level to a point above the design minimum.

Now increase in demand is the fourth point. Increase in demand is shown here on the right end, right here and what are the typical scenario where there is an increase in the demand. First one, we can think of a seismic or any other excessive loading. Typically, if you go for a repair of a structure, which was built before the seismic code revision in 2003. So if you go to repair a structure, which were designed and built before that and now if you go and repair, you will have to actually meet the new design condition or criteria.

So that will give you increase in demand or in other words, we can call it as a retrofitting process. And other case is change in design code requirement, already mentioned, then the modification of structural systems. Maybe some structures, they were not meant for the change in the loads, which are being experienced by the structure, because of a change in the functionality of the building or because of a change in the structural systems itself.

So those are these two points here. So these are the main major reasons, like seismic or any other changes in the loading conditions or change in the codal requirement or modification of the structural system and also modification in the load pattern because of the change in the functionality of the structure. In such cases also, we go for something called retrofitting, which I will cover later, what is the difference in these terminologies.

So that is the fourth arrow, which you see on the right end. So again, you have a new minimum performance criteria, and so you have to maintain the structure at a performance level, which is more than the new minimum.

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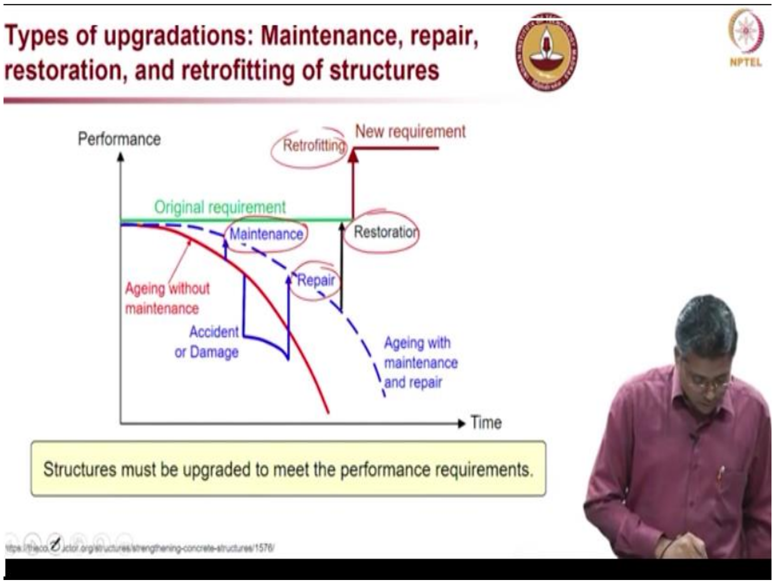

Now what are the type of upgradations, which we talk about. Now first maintenance, repair, restoration and retrofitting, so we will talk about these four, when they come into action and what is the difference between these three. Similar to the previous slide, we also are looking at here, time versus performance level and let's first look at the red curve, which is how the structure would behave if there is no maintenance.

So, you can see that the performance level keeps going down or keep decreasing as a function of time. Now, maybe if we perform some maintenance activity, then I am talking about this point here, then from that red curve, there is a blue vertical arrow, that kind of during that maintenance activity, the performance level is slightly enhanced, that is we have here and then the structure will follow the dotted or dash line or dash curve and that is basically aging with maintenance and repair.

One more possibility which will happen is, let's say, if your structure is either maintained or without maintenance, if there is an accident, then the performance level decreases significantly at one point of time, immediate reduction in the performance level and then if accident happens, there may be some time period during which you may not do anything, you may not really repair the structure immediately. So that is this time lag, which we are talking here.

And then you repair the structure and then bring back the performance level to higher level not necessarily to the original requirement, so that is when we call repair or typically these are all cosmetic repairs and then, the structure experiences further degradation in the property and at one point of time, the safety level might be very low or something. So we tend to decide to restore the structure to its original performance level or originally expected performance level or the original requirement.

So, you get the performance level to that point. Then, if there is another reason for retrofitting to increase the capacity or performance level to a point which is more than the original requirement, then we go for this arrow here or we enhance the strength further, so that you can get higher capacity and that is when we call retrofitting. So basically, you start with original requirement.

If you perform some maintenance and some repair and then restoration to reach to the original level again and if there is a code changes or functionality changes or load conditions are increasing, then you go for a new requirement, which is higher than the original requirement and in such case, we call retrofitting. So, I think just these four words are very important to know and then how different they are, it is very important. So, we are talking about maintenance, repair, restoration and retrofitting. Structures must be upgraded to meet the performance requirement as and when it changes.

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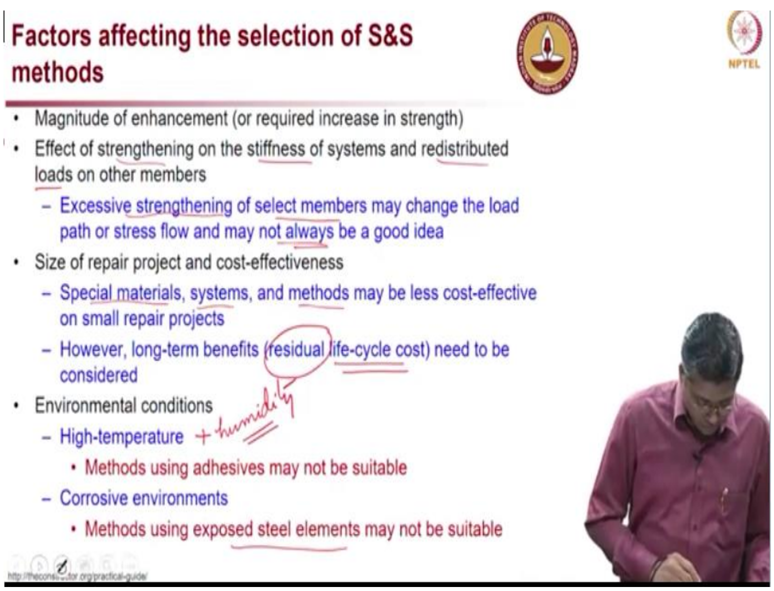

Now factors affecting the selection of strengthening and stabilization methods or techniques. So first thing is magnitude of enhancement, how much enhancement is required? That depends on the original design, original requirement, and what is the current strength of the system and what is the retrofitting action, or what is the new requirement.

Now the effect of strengthening on the stiffness of the systems and redistributed loads on to the other members. That is also very important factor which needs to be considered while selecting a stabilization or a strengthening method. Now excessive strengthening of selected members may change the load path or the stress flow and hence it may not always be a good idea. In general, it might feel that it is good, but not necessarily always.

For example, if you are putting too much of steel reinforcement than what is required, then you might actually convert an under-reinforced structure system to an over-reinforced structural system, which is not good idea. Sometimes there is a tendency for the on-site personal to just change the type of reinforcement from a lower grade to a higher grade based on the availability without really consulting the structural engineers.

These things happen, so it is very important to make sure that such things are not happening and whatever is the grade of the steel, which is recommended by the engineers that must be used and if in case you want to change it, it should be checked again for the brittleness and all the structural behavioral aspects. Now size of repair project and cost effectiveness, that is also something very, very important, special material, systems and methods may be less cost effective on smaller repair projects.

Some technique, which might work very well and very cost effective effectively for a larger project may not be the best possible repair methodology or the repair system for a small project. So, for the specific project you are talking about, you have to analyze how is the cost effectiveness, but at the same time when you talk about cost effectiveness, it is not the cost effective the capital effectiveness of the capital investment. When I say capital here, it is for the repair not the original construction.

What we need to look at is, what is the impact of that on the residual life cycle cost? Residual life cycle cost, So whatever happened, happened, we cannot do anything about it, but at least for the rest of the life of the structure, we can think about going for a best repair methodology, which will give you the minimum life cycle cost. Now environmental conditions are also very, very important to consider.

For example, if you look at high temperature or even humidity; humidity is another important aspect; temperature, humidity and we have to look at; for example, if you are talking about an adhesive which is used for repair procedure that adhesive should work even at high temperature or whatever is the temperature condition prevailing and whatever is the moisture condition, which is prevailing, it should work in that condition.

So the selection of materials should definitely be depending on the environmental conditions and if you have corrosive chemical environment for example, if you are talking about repair of a chemical plant, a structure in a chemical plant, so what are the fumes of chemicals around must be considered while deciding on the type of material, which will be used, materials and systems. So, let’s say you are having very corrosive environment and if you are having repair systems which have exposed steel elements, then that may not be a good idea to go for.

You will tend to have more frequent repairs. So all these must be looked through, so that we will have minimum repair, maximum life for the repair, which we are doing and at the same time cost effectiveness and when I say cost effectiveness, what I am meaning is residual life cycle cost, not just the one time investment.

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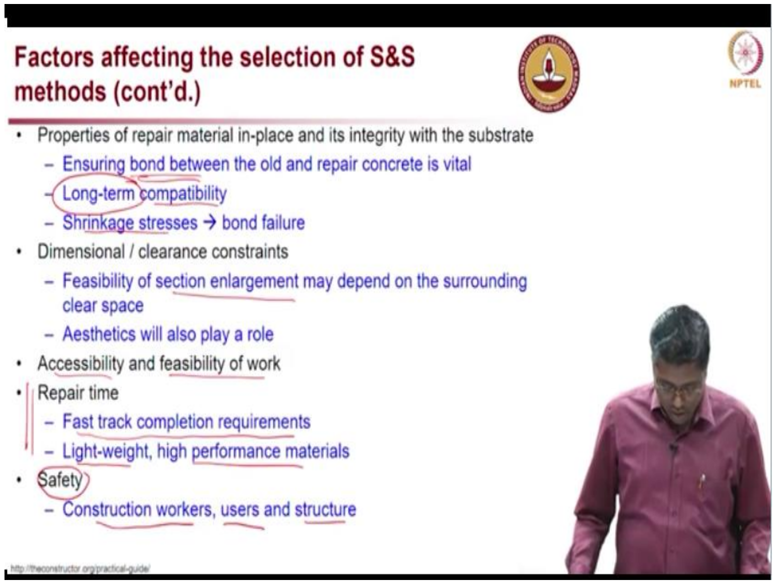

Now we will see factors which affect the selection of stabilization and strengthening techniques. Properties of the repair material in place and its integrity with the substrate. The bond is very, very important. How compatible this repair material (long term) is with the existing or the substrate material. So compatibility and not only the short term compatibility, but also the long term compatibility. For whatever life, the structure needs to last, so for that entire time period how compatible the repair material and the existing or the substrate will be.

And typically, shrinkage stresses, creep and all that will lead to bond failure, which need to be thought through. Now dimensional or clearance constraints. Feasibility of section enlargement, this is relatively simple procedure maybe, but you have to think what its impact on the available space, whether you can really afford to loose such spaces or not, or you should go for a more sophisticated or another technique.

I will explain all those techniques later, so I don't want to introduce those techniques right now. But depending on the different type of techniques we use, each technique has its own advantages and disadvantages. So we have to look at what technique is the best suitable for the particular problem, which you have at hand.

Now aesthetics will also play role, because if you go for, section enlargement, one example is increasing the size of a column or increasing the cross section of a beam, so they might influence the aesthetics of the structure. So that is something very important to look through or to look at. Now accessibility and feasibility of the work. Some of the repair techniques may not be very easy to implement at every locations on a particular structure. So you have to see, if you are talking about a high rise building, something which can be done very easily on a ground floor level may not be that easy to do on wall element, which is at a particular height.

So accessibility and feasibility are very, very important to think through before deciding the technique to be used. And also the time taken for the repair work or the strengthening work, that is also very important, fast track completion. Nowadays, everything we want to be done very fast, and also light weight and high-performance materials are preferred. Why? because if you go for light weight and high performance, typically the chances are that you will still get not much changes in the shape or size of the structure and so you would not even know that a repair was done, if it is high performance material. Most often case by case it differs, but in general we can say and at the same time, when you go for lightweight materials, you will not add more weight to the structure.

So in other word, the dead load of the structure will still remain more or less similar, not much changes might happen and high performance means again durability is something which is thought through and also structural performance. Then, safety very, very important and not only for the structure, when we say safety, it should be for safety of construction workers, whoever is the users, and the structure.

So workers who actually perform the repair work, how safe they are, is also very important to think through and after the work is over, then the users of that structure, how safe they would be.

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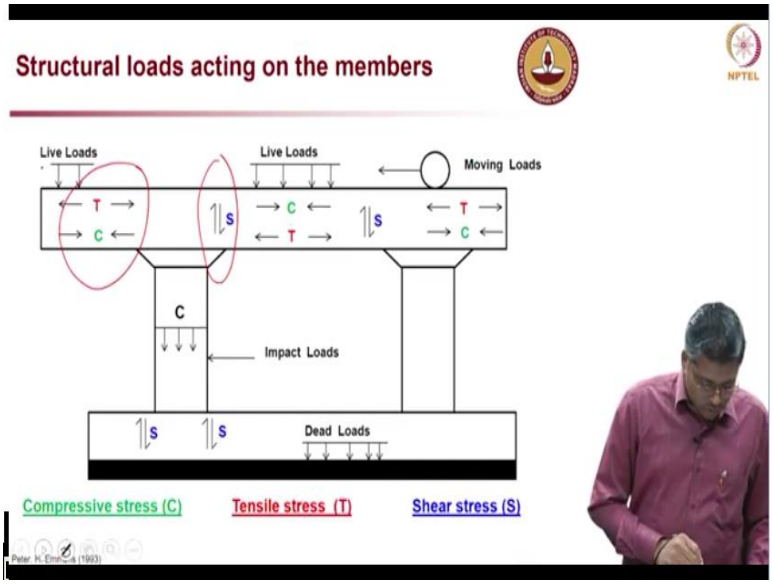

Now let's look at what are the various type of loads, which act on the structural members. So here you can see three letters mainly T, C, and S. T stands for tensile stress and S stands for shear stress, and the compressive stress is C. So if you are talking about let's say this particular structural system, where you have, here you can see that, that is like a cantilever section where on the top side you have a tensile stress and bottom portion is experiencing compressive stress and right here near the support here, you have shear stress.

So like that, different types of stresses are acting at different parts of the structural system. Why this is important is, it is very important for us to know what type of stresses are acting and which will help us to understand the failure mechanism and which will then help us to understand or to suggest more suitable repair or strengthening techniques. So understanding what type of stresses are acting is very, very important. So that we can really come up with a strengthening technique, which is very useful, which will really work.

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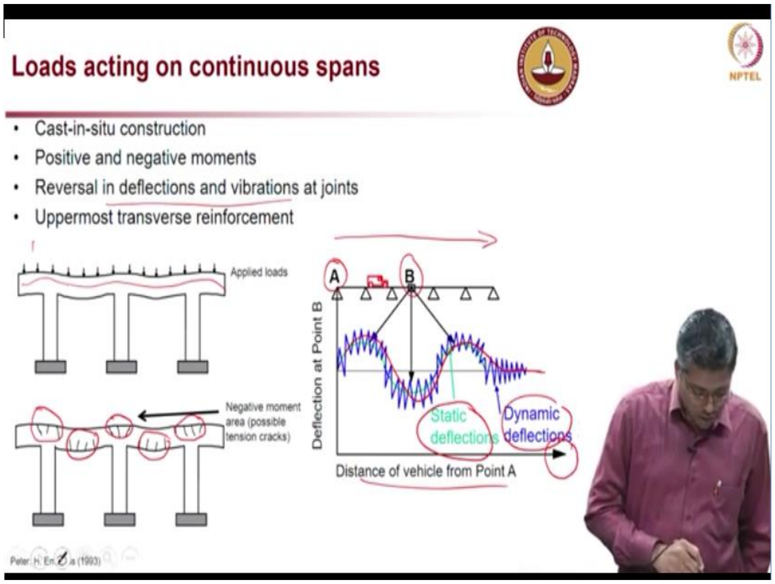

And at the same time, if we know that a particular portion of a member will only experience compressive stress, in that portion, you don't need provide something, which is designed for taking tensile loads. So this way, we can actually optimize the amount of repair material used and the amount of repair work, which is being done, instead of just doing everything everywhere, that will add to the cost of work also.

So these kind of optimization will help in saving money and material, so you can really have a sustainable approach, especially these are important when we talk about very large structural repairs. I am not saying that for the small repair, you don't need to think about it, but that is up to your choice, but on large projects, it becomes much more important to think about such things, so that you can save money and material and also time.

Now loads acting on continuous spans, if you are talking about a continuous span like what is shown in the sketch on the left side. You can see continuous load is acting. So the deflected shape is kind of shown here. Now because of this kind of load, which is acting and the type of the structure, continuous span, you can see that the crack at the top because of the negative moment and then cracking here and cracking here. So there is a typical pattern.

These are not anything new, which you don't know, but just thought of refresh your memory on all these things. Now this type of cracks, so we know what is the reason for that type of crack and then address or come up with a strengthening technique. Now reversal in deflections and vibrations can also happen. For example, on the right side graph, on the abscissa you have the distance of vehicle from point A.

Point A is here and what is the deflection at point B. That is this graph is indicating the deflection at point B, when the vehicle, the point B, when A to B is the or when the vehicle is at any point. so now here, let me just restate this. So here the abscissa indicates the distance of vehicle from point A, that is point A is here. Now as the vehicle is moving towards the point B and then past point B,

So you can see that the type of load, which is experienced by the material at point B is different. Initially, if you say it is compression and then it becomes tension, let's say looking at the bottom fiber of the girder. So initially it might be compression, then tension and then compression, tension, compression, tension and then it fades away as the vehicle is very far away from the point B, then there is no much load acting.

And also we have to think about static and dynamic deflections, because based on this, these needs to be considered to decide on the property of the material, which have to be used and the strengthening technique.

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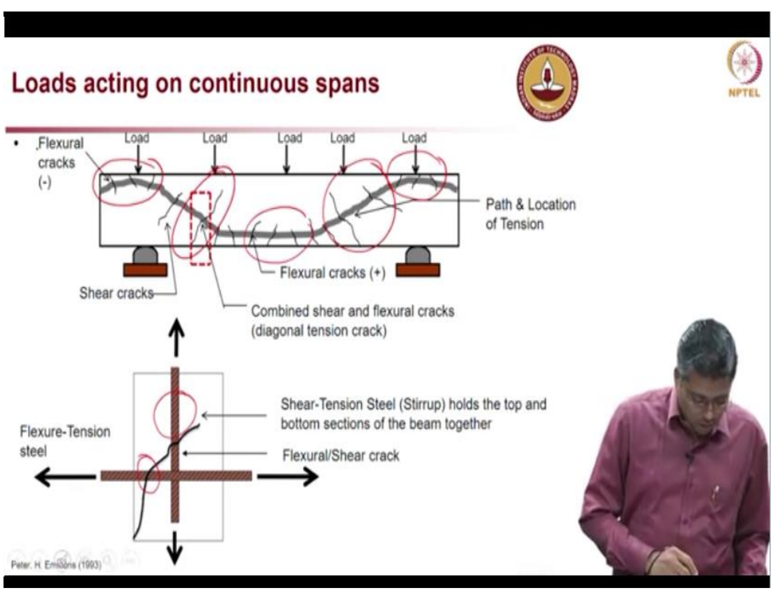

Now loads acting on continuous spans, we just little bit zooming in on the sketch, which was shown in the previous slide. So you can see here, these are the flexural cracks, because of the negative bending moment and these are the flexural cracks because of the positive bending moment, like this here and then similar negative bending moment cracks and then we also have shear cracks, combined flexure shear cracks here.

So these are different type of cracks and based on the type of cracks visible, we can decide and we can identify, what is the problem or why the crack is happening and so what type of resistance need to be enhanced at various points on the structural system. For example, looking at the bottom sketch, if you have a crack which goes like this, if I want to handle this problem, I have to provide a vertical reinforcement.

If I have to handle this crack, then I have to provide a horizontal reinforcement. So we can decide, you know by looking at manifestations of crack, how to handle or how to address those issues.

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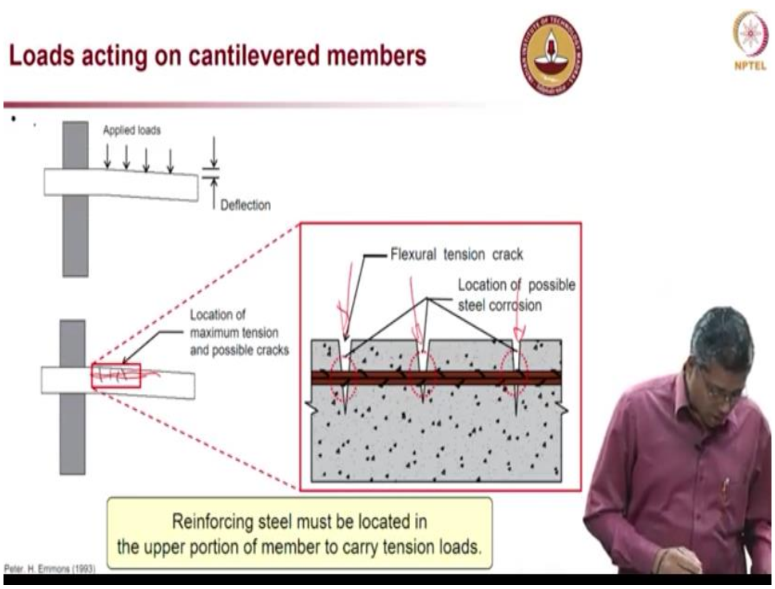

Now loads acting on a cantilevered member, again if you see cracks on the top portion of the cantilever near the support, we know that what is the reason for that, because it is a flexural crack and due to the negative bending moment acting in that region. Now what is the problem with this? If you zoom in and let's say imagine, you have reinforcement, which goes like this, Imagine, you have reinforcement at the top portion and if they are going through the crack, the zoomed in version is shown on the right side.

You can see that reinforcement are actually exposed now because of these cracks, or if moisture or anything can easily go through these cracks and attack the steel rebars. So one thing is the reinforcing steel must be located in the upper portion to carry the tension load. Why I mention this here is I have heard many cases, where without really understanding how the load path is or sometimes it is also that the mistakes are done at the site, may not be based on the structural drawing, but at the site.

Structural drawings might be good, but at the site, people make mistakes and where there need to be a tension reinforcement, they don't provide the tension reinforcement, instead that goes to the bottom surface or bottom location. So all these can happen and then will help us in understanding the problem and then address the issue anyway. The point is steel is good for tension or it is meant for taking tension. So wherever tensile loads are acting, that is where you have to provide steel and not in the other places. I mean, unless the load reversal is not considered, that is a different story.

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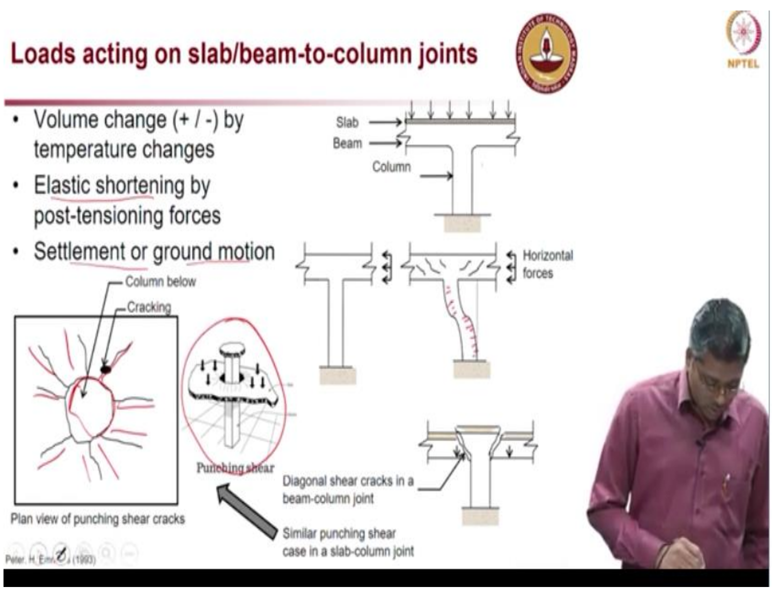

Now loads acting on slab or beam to column joints. Now volume change might be possible when there are changes in temperature from one point on the element to the other point on the element or if there is an overall change in the temperature also, but these might lead to differential stress, lead to generation of stresses at various points on the structural members and also elastic shortening can lead to some stresses.

And because of the elastic shortening, it might pull some other members because of post tensioning forces. So you have to look at how the different elements are interacting each other also. Now settlement or ground motion is another thing which lead to stresses. So let's see all these how through the sketches over here. Now on the top right, you see a slab and a beam and a column joint and now I am looking here, this sketch here.

So you can see that if there is a horizontal force, let's say take an example of temperature variation. Let's say the element over here is expanding for some reason and it is pushing the whole column towards the left side. If that is happening, so if it is expanding, that can push the column to the left side which might eventually lead to some cracking on this portion of the column and maybe also here depending on how the stress levels are.

But you can see on which side of the column the cracks and where they are. So these all can help us in identifying the root cause. And also, there may be a possibility of shear cracks, diagonal shear cracks in a beam column joint because of the heavy load or some movement in the ground. For example, in this case, assume that the other columns in this structure are actually settling, which might induce a downward force on the girders, eventually leading to shear crack.

And also, there are possibilities of punching shear, as you can see here in this sketch. Punching shear here, which will lead to cracks like this (you can see on the picture on the left side). So there are different types of loads acting at the joints between a slab and a column or between a beam and a column and we have to identify what type of loads are acting and based on the manifestation of the type of cracks, based on the analysis of the type of cracks, we can identify what is the reason for it.

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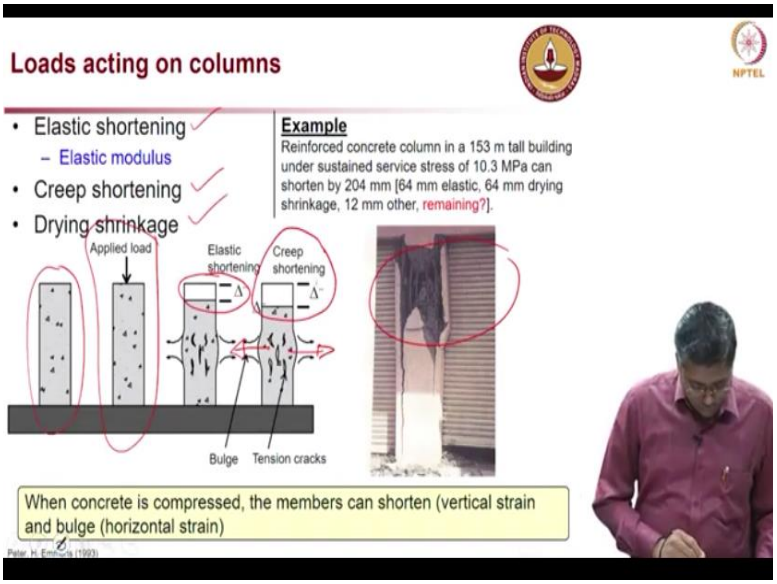

And if you are looking at just a column, what is the type of loads acting on a column, elastic shortening definitely, because it is under axial compression and creep shortening, which is an effect of a long term behavior and drying shrinkage also. So especially when you talk about large columns, you can have very significant problems because of creep and drying shrinkage and elastic shortening is something, which happens immediately. So let's go through the sketch here.

So the column is constructed and then load is applied and as soon as the load is applied, whether it is prestressed or other gravity loads, then you can expect an elastic shortening, that is elastic in nature, so it is immediate effect and after some time maybe months or years, you can have creep shortening also and drying shrinkage also will add to that. So you can see that the delta or the change in height because of elastic shortening and then further reduction because of the creep or drying shrinkage shortening.

So just what will be end effect of this when there is a shortening happening? Because there is a load acting in the axial direction that might also because of the Poisson's effect, that might lead to a lateral expansion or laterally outward forces, which might tend to crack the concrete and the reinforcement also might tend to bulge out and which will push the concrete cover, so that is kind of demonstrated in this picture here. So this is something, which is possible if you overload the concrete element.

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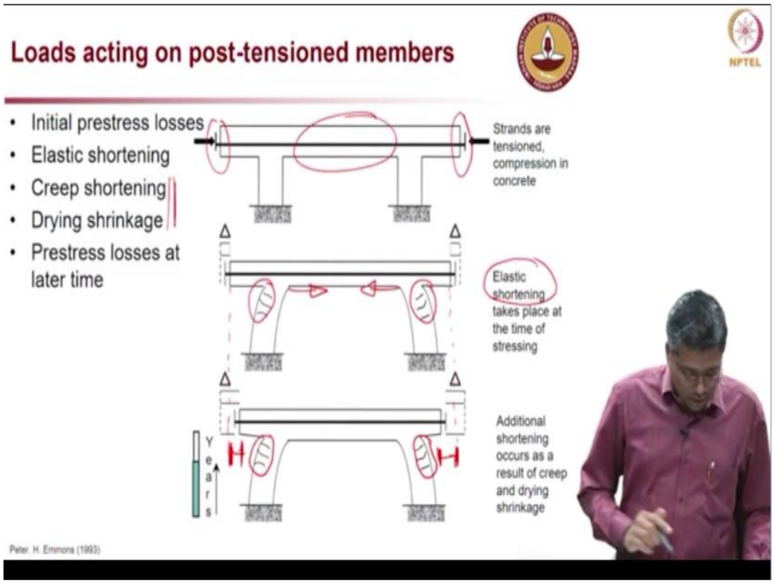

The types of crack, here again we can very clearly say that whether this is due to an excessive overloading or due to a lateral load which is acting. So that is where these understandings are very important so that you can design for those forces. Now if you are talking about a post tensioned member, initial prestress loss, I mean, maybe we can think about seating loss as one example, strands are tensioned and concrete experiences compression. So this tension, so this whole concrete here is under compression and the strand is in tension. So, first thing which happens immediately, in the previous slide, we talked about a column, here we are talking about a girder. So immediately what happens, elastic shortening. As soon as the prestress is applied, the concrete experiences a shortening. So the elastic shortening happens.

At that process these columns are also pulled towards each other. Because of this, it is possible that you can develop some cracks on the outside surface of the columns. Now if it is continuing for long term, then again, creep, shortening and drying shrinkage might continue to happen.

So this much is the extra shortening, which happened and here also this much is the extra shortening which happens (bottom picture). So this is additional shortening due to the long term effects such as creep and drying shrinkage and prestress losses can also happen because when there is a creep and shrinkage happening, the length of the strand is also decreasing. When the length of the strand is decreasing, that means that there will be a loss in prestress.

So all these factors will have to be considered and then the type of cracks can tell us what is really happening in the structure. So that is the idea. We should be able to make visual observations and from those visual observations, we should be able to identify the damage mechanism or what is happening in the structure. So that we can design suitable strengthening techniques or strengthening methods.

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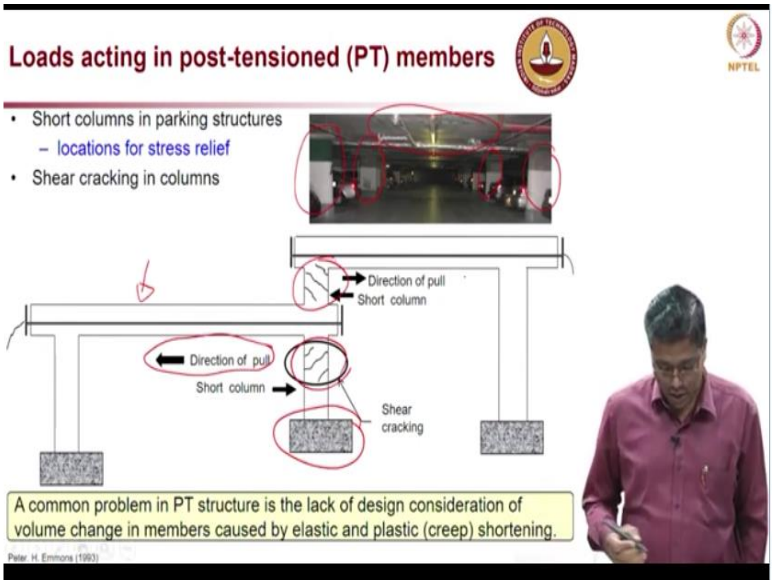

Now more on the loads acting on post tension members. You can see here if you are talking about parking garage for example, usually they have very short column, because these are not really a high bay structure. Imagine this whole roof element here is post tension, a PT slab. A post tension slab and short columns, this is combination is what we are talking.

Now if the prestress or post tensioning is too much, then there will be a pull. I am talking about this column here that there will be a pull to the right direction from the top slab, whereas the bottom slab is pulling the short column to the left direction. This is indicated by these two black arrows. So direction of the pull to the right and then short column is trying to resist that.

And that will lead to inclined cracks like this. Now, short column is trying to resist, but at the same time, there is also a possibility that the bottom slab is pulling the short column to the left side. So whichever reason, the type of cracks you can look at what is the angle or direction of the cracks and that will tell us which force is actually creating this crack or reasons for these cracks.

Now let's look at the bottom column here, bottom portion of the column. Again, the crack direction is opposite. It is going in the 45 degrees in the opposite and there the reason is there is a leftward pull by this slab or that post tensioning element and the short column is trying to resist because it is sitting on ground. So it tries to resist and then it leads to the inclined cracks like that.

So different type of cracks, you can see the top portion or this region is experiencing the crack in one direction and whereas this region is experiencing the crack in the opposite direction. But both are in 45 degree angle. So there is something to do with the shear resistance.

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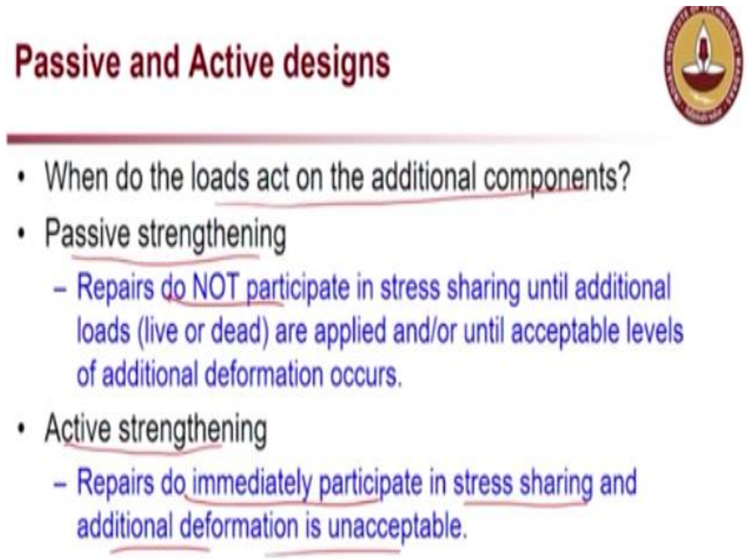

Two types of strengthening designs, one is passive and another one is active. When do the loads act on the additional components? That is how we tell whether a particular design is a passive design or an active design. Now when you talk about passive strengthening, they are the type of repairs or strengthening elements, which don't take part in the stress sharing until additional loads or live load are applied and/or until acceptable levels of additional deformation occurs.

So they don't take part in the beginning, whereas the active strengthening they immediately take part. In the first case, the passive strengthening they don't take part until either the load level increases or there is a significant deformation whereas in the active strengthening, the strengthening elements will take part immediately after they are installed. They will take part in stress sharing and no additional deformation is acceptable in the active strengthening designs.

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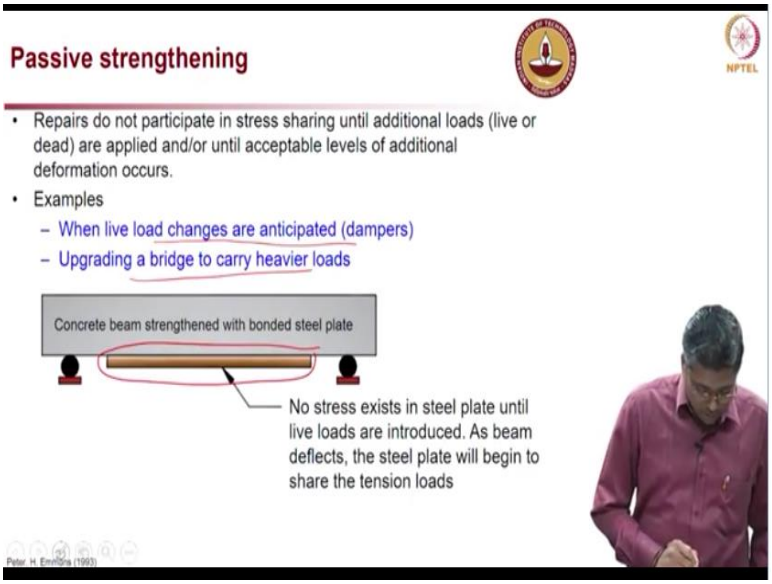

I will show you one example of each of this. So passive strengthening is when live load changes are anticipated. One example is dampers. The dampers, let's say, if you have dampers to resist earthquakes, magnetorheological dampers, for example, they actually start functioning when there is an earthquake. Until that moment the dampers don't really have a role. They are there, but they come in to action when there is a significant load.

And then upgrading of a bridge to carry heavier loads. When a bridge is to carry heavier load, but it is not necessary that always the bridge will experience that heavier load. So when there is the heavier load, at that time the passive strengthening elements will come in to action. In the case of dampers when there is an earthquake or when there is heavier lateral loads or something, at that time the dampers will come in to action, So these are just extreme cases.

Or in other word, structures are designed for the extreme cases. So when that extreme load condition occur, at that time these elements will come in to action. Now example is here (picture in the slide). You can see a beam with a plate something below and a plate element is below, which is not prestress. So this plate element will come in to action only when there is a significant deformation or a significant loading. Until then it just stays there.

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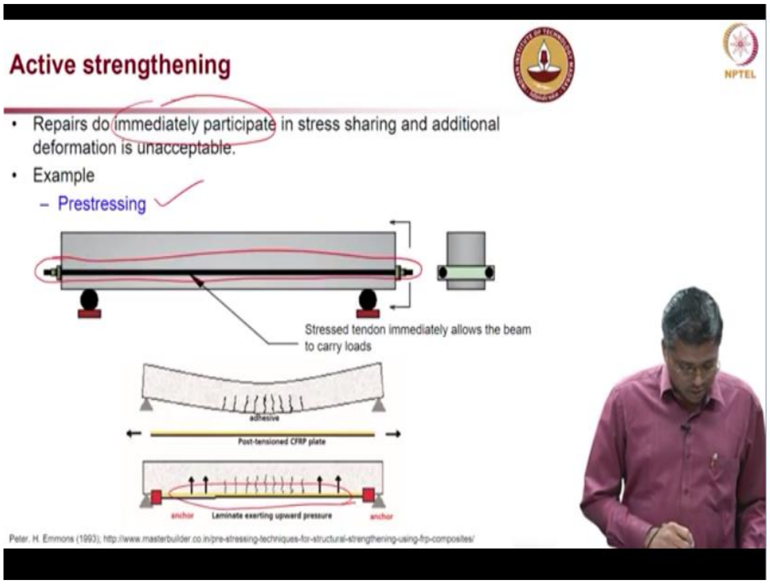

As opposed to that, there is an active strengthening system, which immediately participates; example is prestressing. If you have plate element like in the bottom image, you can see a laminate, CFRP laminate here or any prestress element; in the top one you can see a prestressing or external post tensioning unit, which is under stress and it takes the load as soon as it is in place. One example on the top is the external post tensioning and that the bottom is external post tensioning using a laminate. Both kind of functionality is very similar. So both will take the load as soon as they are installed. They don't wait for that excessive loading to come. In other words, they start taking the loads as soon as they are installed.

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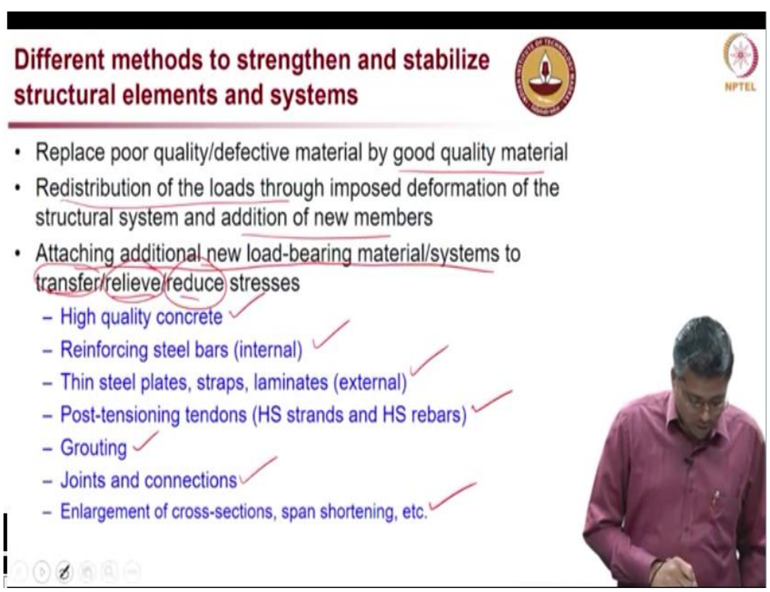

Now different methods to strengthen and stabilize structural elements and system. One is replacing, first thing to do is replace all that is bad or replace poor quality or defective material. Poor quality means the material properties are poor. Defective means they might have been good in the beginning, but something happened and then it got degraded. So replace them by using good quality materials and then redistribution of the loads through imposed deformation.

You allow some deformation to happen, so that the stresses are not really happening the way which is harmful. So redistribution of the loads through imposed deformation of structural system and at the same time sometimes we can add new members, which will take this additional load and then other methodology is attaching new load bearing materials or systems to transfer, relieve or reduce the stresses.

Three things, one is if there is a stress generation somewhere, if it need to be transferred it need to be transferred. If it does not need to be transferred, there are in some cases where we will try to relieve the stress or have some space available so that the stress does not get transferred to the next element like expansion joints. Another way is to reduce the stress by having a system, which will distribute and then reduce and stress on the members.

All these we will cover in the coming 2, 3 lectures, but the idea here is just to give you an introduction. So three terms to be remembered here is transfer, relieve and reduce the stresses. Now how we do all these? By using high quality concrete, by using reinforcing bar internally maybe by drilling an extra hole in the concrete and then providing a bar inside and also some times by thin plates or thin steel plates or non-metallic or FRP fibre-based straps and some laminates, which are usually placed as an external member. They are glued to the concrete surface.

And then post tensioning tendons, which are external, but not in direct contact. So they are post tensioned with some anchorage points and deviator points. I will discuss all that also later. And grouting is done usually to stabilize the structure, so that there is a proper load transfer, and then proper joints and connections, which will help in transferring the load in the way which we want or sometimes to not to transfer the load, which we want.

Now enlargement of cross section, span shortening, these are all kind of different techniques by which we can control the, stresses and that way minimize the damage on the structures.

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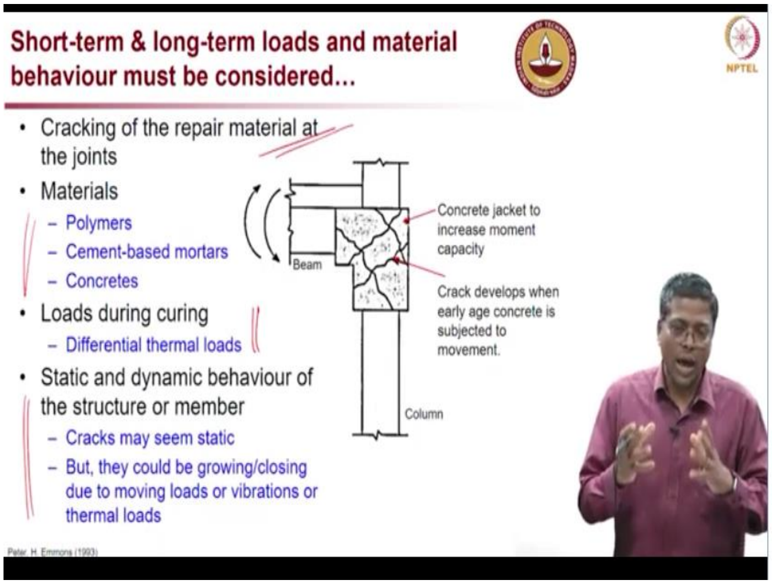

And above all one very important thing is we must think about short term and long term loads, not only the short term loads, because even if a system works very good for a short term load condition, it might not really work for long term load condition and in the such case usually it is the material properties, which are very, very important. You should think about how the material property can degrade over the time and make sure that the material, which we use don't degrade over time.

So whatever assumptions you have on material properties at the time of construction should remain like that during entire life of the structure. So cracking of repair material at joint, definitely that must be prevented by providing enough time for that material to build enough strength and stability or stiffness, so that crack don't really happen. Now different type of materials used are polymers, cement-based mortars, concretes.

You have to see which type of material is good considering finance also, which type of material is economically feasible and technically feasible and then use such material. It is not necessary that always you have to use something, which is available in the market, I mean something, which is widely used. So sometimes you will see that in many places, people use unnecessary material and waste money.

So judicious decisions have to be made, so that you can optimize both the technical aspects and at the same time the economic aspects. Now loads during curing, this is what I just briefly mentioned earlier. How the material will behave the curing period? So in other words, you have to ensure that the material get cured properly and build sufficient strength and mechanical properties, so that it can actually take the load at a later time.

Now static and dynamic behavior should be looked at. If some crack is there, it might look like that crack is not growing, but it may actually be growing or it may actually be closing and opening in case of fatigue loads. So all these have to be thought through and the material selection is very, very important. It is not only the structural system designs, but the materials, which we use should actually take those loads also.

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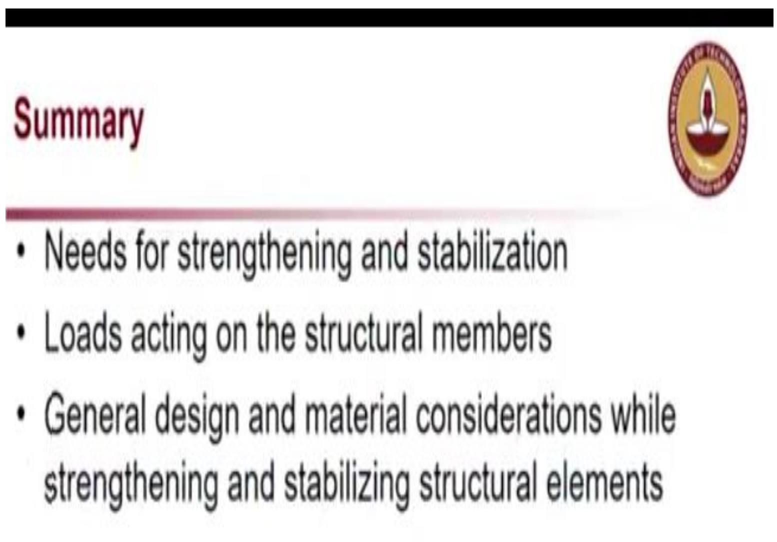

So I am going to summarize this lecture. We talked about the need of strengthening and stabilization. We looked at different strengthening, like different terms like maintenance, repair, restoration, and retrofitting, what this difference between them and also looked at different type of loads acting on structural members and also talked about general design consideration, material consideration, while selecting a strengthening and stabilization techniques.

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These are the various references which we used in this lecture. So in the next lecture, we will talk about how to go for strengthening of beams and slabs. Thank you.