Maintenance and Repair of Concrete Structures
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Lecture - 28
Structural Strengthening & Stabilization – III (Columns & Walls)

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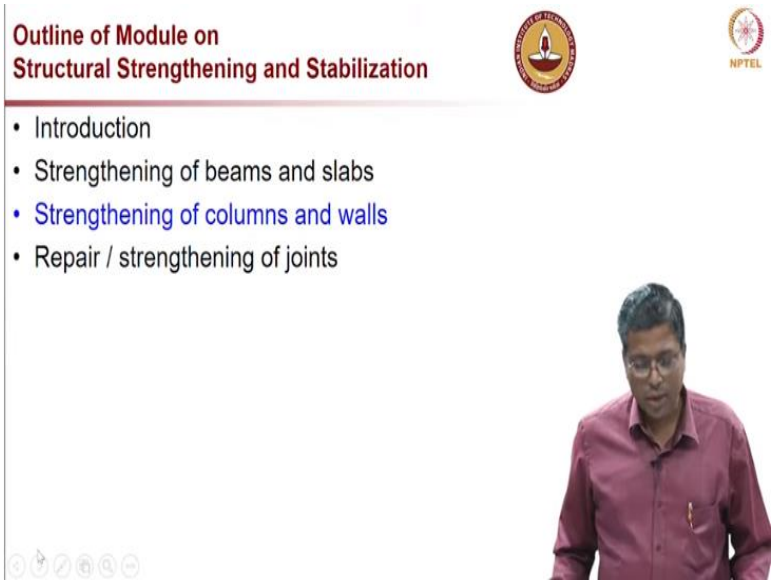

This is the third lecture in this module on Structural Strengthening and Stabilization. In this we will talk about columns and walls and how to strengthen them or stabilize them.

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Let us first look at the three common types of failure with respect to columns. The first one is an example of a compression failure, I mean you can see that there is little bulging of the reinforcement, but let us say that is mainly due to Compression failure, the second one you can very clearly see the bulged out reinforcement which is a Buckling failure, and the third one is a shear failure, very clearly that inclined plane indicates a Shear failure of the entire column or pier.

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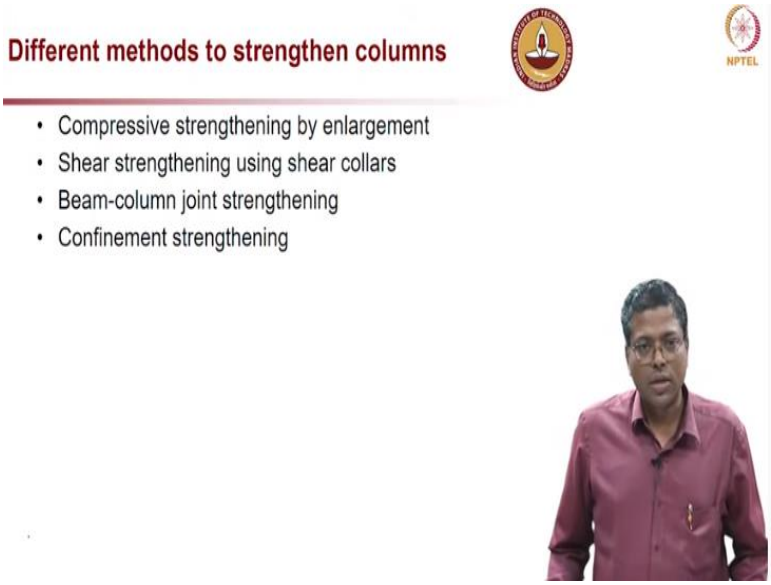

Now, how do we strengthen these columns? There are four major approaches by which we can strengthen them, one is Compressive strengthening by enlargement, the other one is Shear strengthening using shear collars, then Beam-column joint strengthening, mainly the moment resisting capacity of the joint and then the fourth one is Confinement strengthening. So all this you can see it is all different mechanism one is compression, then shear, then flexure and then also looking at confinement.

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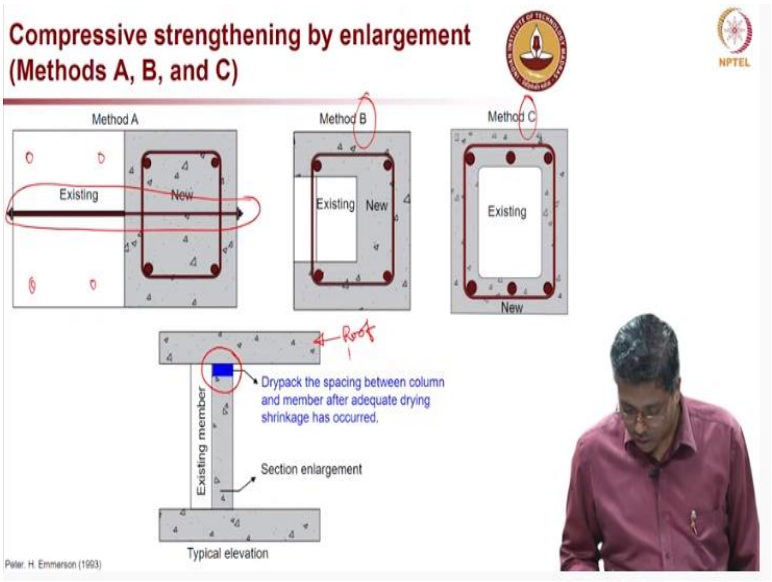

These are the major ways by which we can fix the columns or strengthen the columns. So in case of Compressive strengthening or Compression strengthening by enlargement of the section, there are three major types, we are going to call it method A, B and C. In these drawings here the white region is the existing concrete and the gray shaded region is the new concrete or the repair material.

So you can see under method A where an existing concrete is on the left and then you can see a new concrete with additional stirrups, details on this column is not really provided here to keep it simple, but that will have other reinforcements as well. But now let us see how the new concrete is integrated with the existing concrete is, it is by a post-tensioning tendon. You can see here there is a post-tensioning system which holds the two together. So if you are talking about a column of several feet tall, you can have multiple of these tendons which will hold the entire system together. In method B there is a smaller column which is the white region and then there is a C-shaped or a channel shaped three-sided cover of the new concrete. And the stirrups actually go through the existing concrete, so you will have to drill through and then come up with a full stirrup so that the entire system is again functioning like a single unit. In the method C depending on the cases, the existing column is completely encased by the new concrete which also has additional reinforcement and both primary and stirrups.

The sketch at the bottom is basically showing the elevation of these type of systems where main thing to show is columns are supposed to take the compression loads. So during the compressive action what might happen, or if the new material starts shrinking, what will happen is over a period of time the length of the new material can decrease a little bit and then it will probably get detached from the roof element or the beam below which it is kept. So what we need to do is, to ensure that there is proper continuity or the proper load transfer directly from the roof element or the beam element to the column or the new part of the column, then we can actually fill that space with some dry packed material basically make sure that it is well compacted and there is no space left behind. So that then the load transfer will happen smoothly and uniformly and combinedly the existing member and the new member will take equal load.

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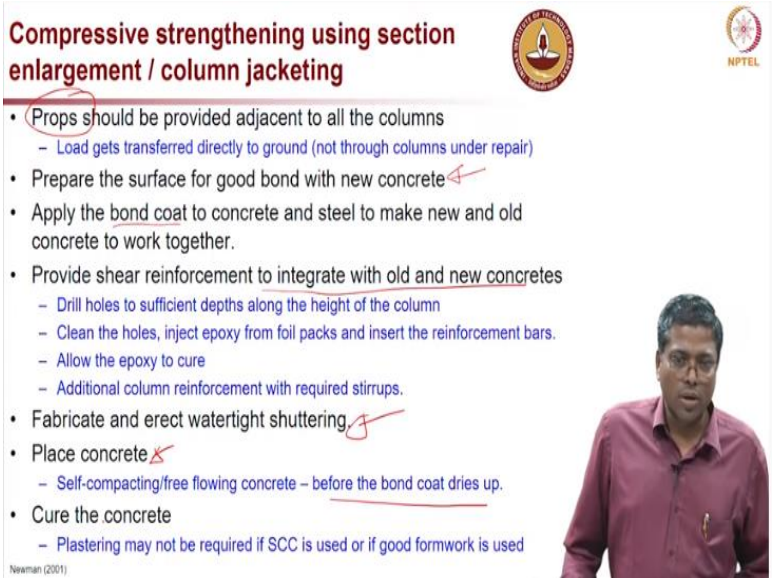

Now we will look at the compressive strengthening using section enlargement, column jacketing, what are the key features or what are the things we should worry about while doing this or we should focus on and how to do things also. So first thing is whenever you talk about column jacketing or section enlargement, the additional material which you are going to put around the existing member is supposed to take the load along with the material of the existing member. So to make this happen, first thing to do is at the time of construction or at the time of repair, there should be no load acting on the existing column or the remaining column element which is there, the load should be directly transferred to the ground from the beam above or the roof above. So

best way to do that or achieve that is to provide props, adjacent to the columns, right on either side of the column you provide props. So that the entire load goes directly to the ground and the column itself does not experience any elastic compression. Whatever permanent deformation has happened, we cannot regain that, but all the elastic shortening can be regained. And so that when the new load is applied, both the existing and the old concrete take the load together. Now other important thing is you have to prepare the surface of the existing concrete very well so that the new material will bond very well with the existing concrete and apply the bond coat or whatever the ways by which you can enhance the bonding of the new concrete to the existing concrete. A bond coat can be provided or shear anchors can be provided, so there are many ways by which we can enhance the bond between the two. Now provide shear reinforcement to integrate with the old and new concrete. This is basically drilling rebars into the existing concrete so that the interface between the old and new concrete does not experience any movement along the phase or there will not be any shear failure.

Now fabricate and erect watertight shuttering, so that while we place the concrete into the formwork water should not come out, if water comes out, it means that there may be an indication of segregation etc., which will eventually lead to the formation of honeycomb also because if all the water goes out then you can have regions where cementitious materials are going to be less. Then place the concrete, self-compacting concrete is very good option in these types of repair work because it flows. Usually the thickness of the jacket will be relatively less and sometimes you may not be able to place your needle vibrator, whatever be the case if you go for self-compacting concrete or free-flowing concrete. Micro concrete nowadays comes with the self-compacting behavior or property, so, that can be used and at the same time this self-compacting concrete it gives very nice smooth finish, so it looks good also after the work is done. Now one thing one important thing is the SCC or the concrete or micro concrete or whatever concrete you use, a repair concrete should be placed before the drying of the bond coat, then only you will have proper grip, or a proper bond will develop. So you should not allow the bond coat to dry completely. Curing is very important but usually people also plaster the concrete surface, but if SCC is used you do not need to plaster because it really gives a very good finish and plastering is not at all required, especially one thing is for example, if you are talking about a round circular column, it is very difficult to get a good circular shape with plaster. So it

is best to go for ready-made formwork and then go for SCC and plastering can be actually avoided.

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So here is an example, a case study on this, in this particular project you can see here the concrete at the bottom portion was found to be corroded. So they removed about one to two meter height portion of the cover concrete. The reinforcement was found to be corroding probably because it is a poor quality concrete, capillary suction, then it keeps that lower portion of the column moist for long period of time and it started and continued to corrode.

Now in this case you can see that, before it was removed, the proper props were provided, the metallic support, you see all these temporary columns which have a truss element on top, so that they really take the entire load and transfer into the ground through the footpath which is provided. So the columns at this moment as you see in the picture, they do not take any load coming from the roof or beam above.

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This is a similar structure, you can see that in some cases we also provide additional reinforcement depending on whether it is a retrofitting work or is it a restoration work or how much amount of steel has already been corroded, all that has to be looked at and then we can decide whether additional reinforcement is required or not. And we can use micro concrete for filling the space in between the existing and the formwork.

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Now this is again another example to show, in the previous one, the support system was not really a heavy-duty support system because that was just a footpath type structure, here you are talking about a huge load where the girders carry heavy loads. So at this moment, as you see in the picture, the column system or the pier is not really experiencing any load, all the load from

the girders are directly transferred through this prop and it directly goes to ground. Here also you can see the load is directly taken and transferred to the ground by these heavy-duty props. So depending on the type of structure you have to decide what type of temporary support system need to be used. And you can see here this is the region which is going to be repaired, a significant amount of area has been removed from the pier and then when the new material is placed that is supposed to share the load with the existing concrete. So this kind of load removal before the application of the repair material is essential when we talk about any column repair or any structural member repair, because the load has to be released, if we are talking about beam then you have to lift the beam so that the beam at the time of repair does not take any load.

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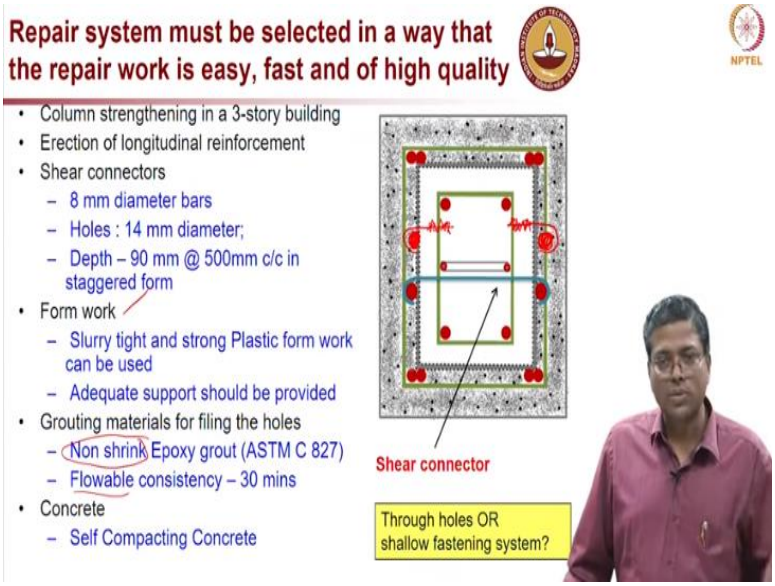

Now let us look at another example here, why I made this slide is to tell you that how to select repair system, because same column can be repaired in multiple ways, but the way you choose should be in a way that the repair work is easy, fast and of high quality. Three things are very important, it should be practically easy for people to actually practice, because most often designers, if they do not go to the site and they do not realize what is the site conditions, the design which comes out might create a lot of trouble for the construction engineers and decision makers at the site or for the workers, also sometimes the construction time will also be very long if the design is not really a good one.

So this is an example of a project, where it is a three storey building, column strengthening work was going on and it involved erection of a longitudinal reinforcement which is this you can see here (big red dots), there are 10 additional longitudinal rebars, the white region is the existing concrete and the shaded region in the periphery is the new concrete. And also there is lot of shear connectors, this blue hook like in the Centre indicates shear connector. The recommendation is actually to drill a hole through the existing concrete and then provide this hook, but when it came to the site, there were a lot of challenges associated with this because even providing and holding this hook you have to really think the practical way of doing this. Let us say you provide the hook on one side of the column but the other side, if this portion is actually bent then you cannot really do this job. So you have to keep one side straight push it through the hole which is drilled once it comes to the other side then you have to bend it as it is on the column. So these are clear examples of how not to do repair or design. This is not a good design, what I am showing is not a good design. Ideally what could have been done is, I am going to draw it a little away from this so that you can understand what I am talking. So if this is another primary bar so you can draw a hook which just goes like this and if you really want to be safe, we can go a little bit in length also and then draw it in the opposite side also and then bond this region. Provide proper bonding agent and then bond that hook to the existing concrete, that will also give sufficient integrity because the system will there are also additional reinforcements. So this is enough, or this kind of design can be conceptually looked at and then design it accordingly whatever the diameter of the hook or length of the hook embedment length, all those can be designed but conceptually. This might be a better practice than expecting the workers to get this hook done as the hook is on the column. So it is important sometimes some designs are not really easy to adopt, or feasibility is not that good.

Now formwork should be slurry tight, there should be no leakage, why this is very important for columns is usually we have seen that it leaks out through these narrow joints and the columns are like very long elements. So the gap between the different parts of the formwork will just leak out and wherever it is leaking there the chance of poor quality concrete is high because the cement paste is leaking out and then you might have honeycombs also. Now adequate support should be provided and grouting materials for filling the holes, the holes means is the holes for the shear connectors, I just gave an example here, but a non-shrink grout is very, very important, that is the

property we have to really look at and then the grout should be also highly flowable. But again let us not go for this through holes for the shear connecters, it is very difficult to practice, we should design something which is something like this and then bond them well into the concrete. As long as you can transfer that stress, that is good enough. Now the type of concrete can be self-compacting. So the main takeaway or the reason why I showed this slide is just to make you think about whether you should go for a through-hole or you should go for a shallow fastening system or some kind of anchor system.

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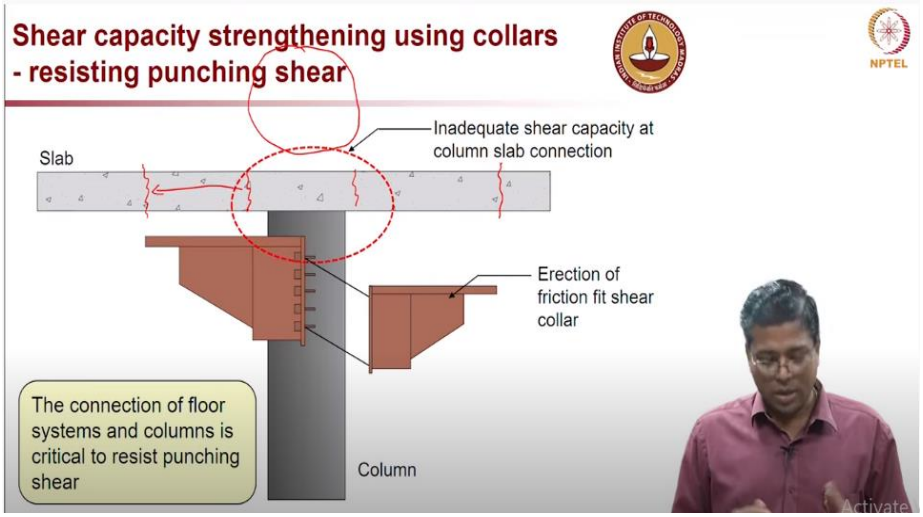
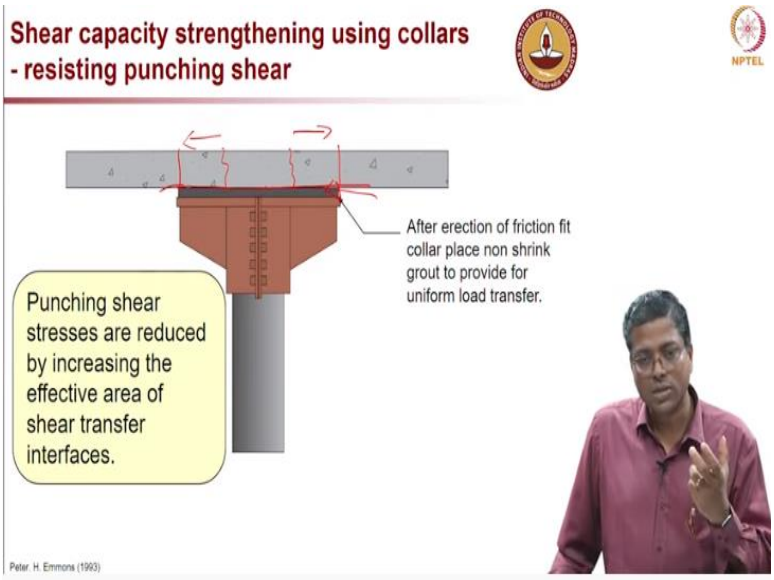


Now the other way of enhancing shear strength is by using collars to resist punching shear. You can see here in this example here, assume that this brown colored collars are not there, so there may be cracks which might happen something like this and something like this (like red line drawn on the sketch) which is kind of an indicator of a punching shear failure. . So if you look at the top view of this it might look something like a circular crack as drawn in the coming slide, So to prevent this what we essentially have to do is increase the area of the circular crack. So how do we do that is you place this collar, so once you place the collar then the shear critical region moves from here to here (from inner vertical red lines drawn to outer vertical lines drawn, as shown by arrow in the sketch). So this becomes the shear critical region and there you have much more the radius of curvature is much more for that region. So you get more surface area and then the punching shear can be avoided. So the shear resistance of the system can be much higher.



So this is how it will look, you can see that this is now the region (outer lines), earlier it used to be here (inner area). So this has moved from here to here, when you go for a larger area there will be no crack. And this gray portion here, this is basically to ensure that the load transfer is happening in a uniform manner, we have to fill that space with either a neoprene pad or something like that or fill that space with a grout a non-shrink grout. Again non-shrink is very important, either non-shrink or shrinkage compensating, basically there should not be any space between the grout and the steel and between the grout and the concrete. Grout and steel, it may not be a problem, because of gravity all the grout will settle down, but you might have a gap between the top flange and the grout. If you have a non-shrink or a shrinkage compensating grout that can be avoided.

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Now another example of different types of these collars, you can see here there is a channel section used with the post-tensioning. So this section over here also and then this is post-tensioned like this, so all the four sides are under compression and then on the right side you can see a capital type structure where you have a little bracket here and a plate and then also another capital here. So basically in the right case probably you can imagine a scenario where capital was designed but that itself was not thick enough. So they went for something like this, an additional steel capital or collar around the column.

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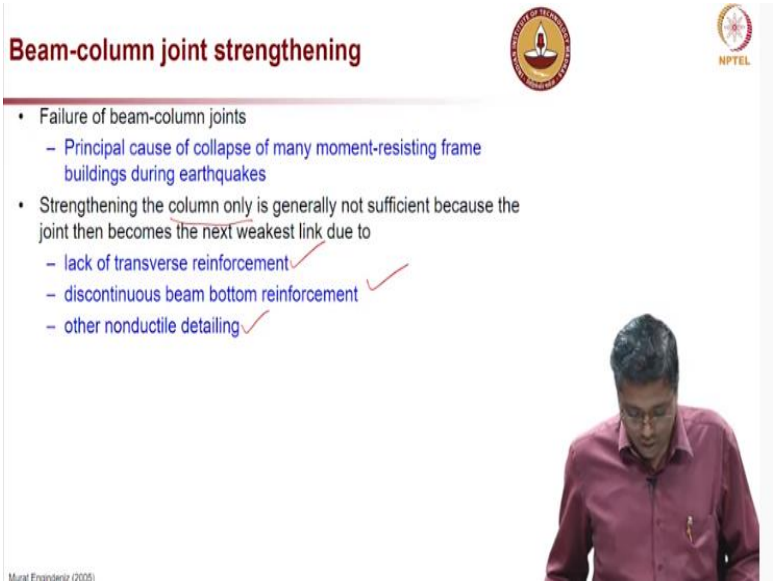

Now we have beam-column joint strengthening. Until now we were talking purely about the column, punching shear and etc., it was all about column. The beam-column joint is the key

failure location for the principle cause of collapse of many moment-resisting frame buildings. Now strengthening of column only is generally not sufficient because the joints then become the next weakest link due to lack of transverse reinforcement, discontinuous bottom reinforcement of the beam and also for lack of adequate ductile reinforcement.

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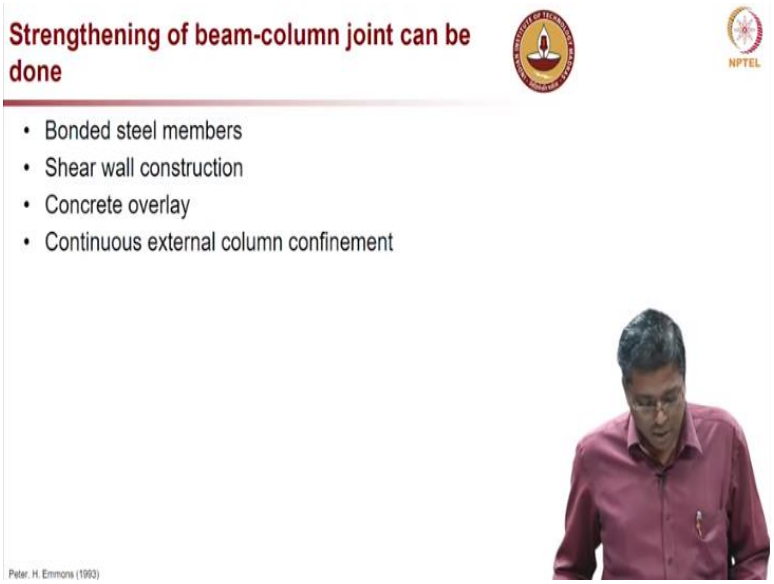

Now how to strengthen this, there are multiple ways, one is by providing a bonded steel member, other is a shear wall construction, concrete overlay can be placed and also, and we can provide a confinement. So these are different ways by which beam-column joint performance can be enhanced.

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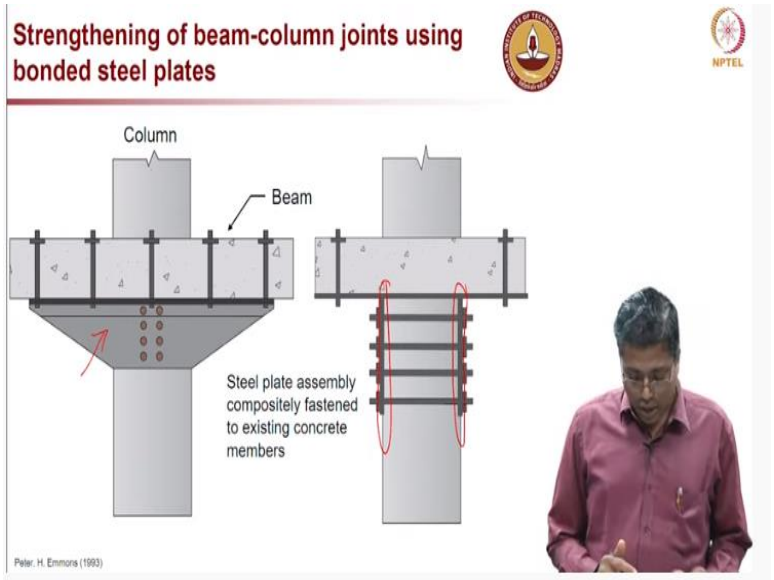

So here it is the bonded steel plate or bonded steel members. What you see here is actually a steel plate and on the right side is the other side view of this, so two steel plates on either side of the column. When I say this works very well for a square shape, if the column is rectangular or square in shape then you can actually provide a steel plate and then this is anchored or fastened to the concrete, you can see there is a nut bolt system here and there is also a horizontal plate. So essentially what you are doing is you are preventing this movement of this beam-column joint or enhancing the strength of the joint itself, not necessarily the strength of the column or strength of the beam but the strength of the joint alone.

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Now if it is very difficult to place steel plates then other option is FRP laminates. So it does not matter whatever the shape of the member or the joint is, you can actually provide very good confinement with the FRP laminate as you see on the left side, a four beam joint. Then all sides can be covered with FRP or confined with FRP, on this right side also this is the joint before repair or yet to be repaired (in yellow color) and this is a joint which is repaired (white color), a nice job, so this is also possible with FRP laminates.

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And the strengthening punching shear and moment capacity of beam column joints, you can see here how the capital can be added there like a column capital. And so here how it is done, I want to also talk about the way in which it is constructed, you can see that a first a formwork is made, it is completely sealed formwork with just an opening for an inlet and air outlet. So you see this is the inlet (person pumping through the inlet), so the SCC is pumped into it and then this space is provided, so that the air can be released and then you can see a similar setup on this formwork on the right side where you can see this is the inlet for the pipe and for the pump. So also it has heavy reinforcement, I am showing this picture on the right side to show that there is also additional reinforcement in this or drop panels.

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Now other way of increasing the bending moment of the joints is by providing additional reinforcement and because it is done on the top of the floor you do not want these things to be projecting above the floor level because then it will be a falling hazard. So what they do is they actually cut grooves like this all along and then inserts these plates or additional reinforcement into the grooves so that after the work is done it can be flushed with the concrete surface. There is a huge negative bending moment acting here, so this is supposed to take care of that negative bending moment or enhance the resistance of the structure against that negative bending moment.

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Now a problem with lack of sufficient confinement, this is what is going to happen if your concrete column does not have enough confinement. This is again a very rare case where the entire bridge deck was lifted and then dropped down with an impact load so that the column became something like a flower. This happens very rarely but this is something which we have to avoid in our infrastructure system. So it is not something which we should neglect, it is very, very important, because infrastructure development it means huge investments. In this particular case, when it happened, they had all this concrete rebar everything got damaged, rebars might have been recycled but the concrete might have just gone as waste. So that is something we would do not want structures to fail.

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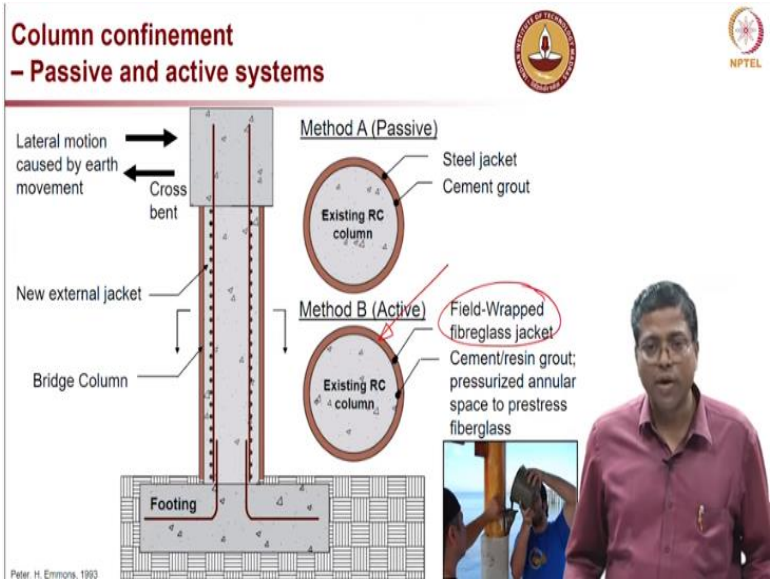

Now how to confine the column? Passive and active systems exist. Method A, on the left side you see the column, on the right side there is a passive system and an active system, both look very similar in the drawings. However, one thing to note is, let us say this brown circles are the steel jackets and then you place the cement grout, but if the cement grout is pressurized or let us say we use some expansive agent in the cement grout, once they are placed in between the RC column and the steel plate, if they have an expansive nature, they will try to fill the space and be under pre-stress or it will provide that stress to the system. So in the active case usually we go for a fiberglass system, not a steel system steel pipe in the case of passive system we usually go for steel jacket. So in the second case you provide a fiberglass system and then provide a cement or

resin grout which can actually exert some pressure onto the jacket and that way the jacket will immediately come into action and it will function like an active system.

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So here is an example, on the left side you see a passive system and on the right side you see an active system. So on the left side, before the repair this was a rectangular column and then after repair it became a circular column, so you provide a circular ring or a steel jacket and then fill the space between the steel jacket and the concrete column with cement or concrete or whatever the system, need not be something which has an expansive nature. But on the center you have a pre-stressed system, you can see here there is a straps which are prestressing and the straps are always under tension which gives very good confinement to the concrete inside. And on the right end the third photograph, is an application of an FRP laminate, they are just wrapping around the column and here like I mentioned earlier in the previous lecture, it should be make sure that the corners are round in shape so that the fiber does not get torn. Otherwise if this is a sharp 90 degree corner then the fibers might get torn and they may not slip which is necessary to ensure that the uniform load transfer.

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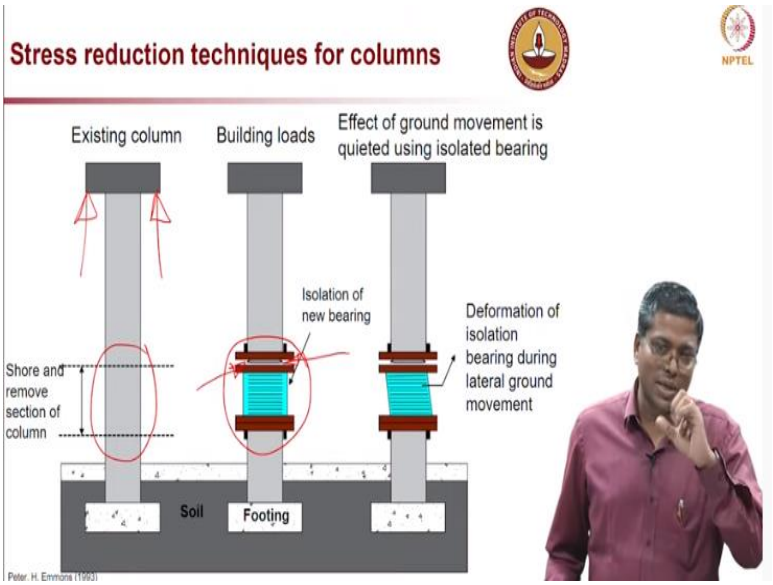

Let us talk about stress reduction technique for columns, especially when we talk about earthquake there may be a lot of lateral loads which comes into the picture and then because of this lateral load the columns might move and then if there is a lateral load, the column will fail, they will try to bend. So the idea is to prevent this bending but at the same time allow that movement to some extent.

So what we do is this is the region which has to be removed (left image) and then replaced with this new bearing system. So how do we replace? When you cut something like this, you have to provide shoring otherwise the column will fall down, so the shoring is provided first or no load will be acting on the column while the strengthening work is going on. Once it is done then you cut and remove and then place this isolation bearing system and then what you do is there provide a flat Jack like you can see in the center picture, provide the flat jack in between the bearing and the bottom face of the concrete, the hanging portion of the column. Flat jack provided because once you put in there may still be some space available and then a proper load transfer may not occur. So for making sure that proper load transfer is happening, we provide a flat jack kind of system and inflate it and then keep it under tight or some other mechanism based on which you can ensure that there is a uniform and continuous load transfer. You can even provide a cementitious system which has some expansive property so that there is no space and then there is a proper load transfer between the top portion of the column and to the bottom portion of the column. And this is showing (right picture) how it will be like during the

earthquake, the bearing will take the lateral load, it will not allow the bending of the column. So the columns will still stay straight, so this portion will still stay relatively vertical.

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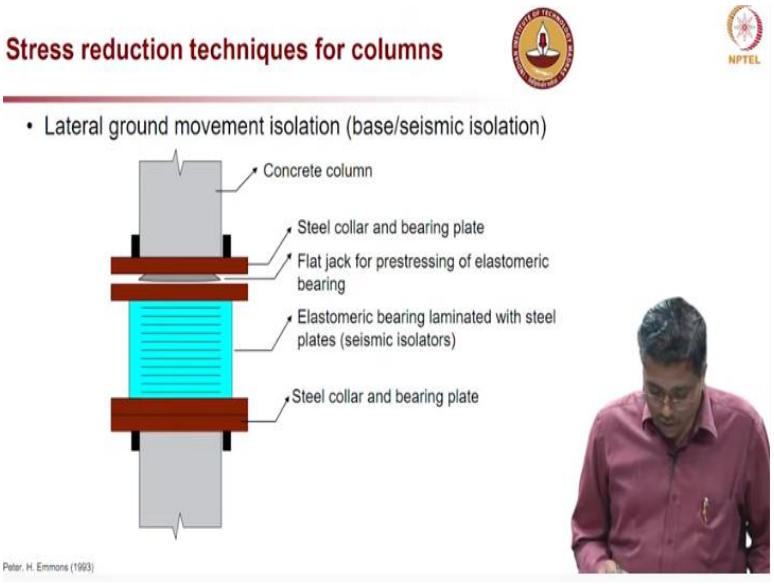

So this is more detailed sketch, if you want to look closer. So this is the flat Jack, but we can provide other systems also, the point is there should not be any air gap or there should be proper load transfer from there to here.

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This is an example in the airport in Turkey. This is for a new construction anyway, I just wanted to show a photograph on how these systems look like, you can see this is the system we are talking about.

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And this is for same airport, you can see here short columns where it is actually support and then you want to completely isolate the portions above this bearing. So even if there is an earthquake there will be no movement above the bearing or the portions above the bearing will stay straight while the ground can move laterally and then that way the resulting movements or stress generated in the portions above the bearing is very limited.

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Another building in Tokyo, you can see similar system where the rollers are in the perpendicular directions. So you can see the roller at this level and the roller and in this level are in the perpendicular direction so depending on whichever direction the lateral movements are the

system will adjust to the same and will it will not allow that force to be transferred to the structural members above.

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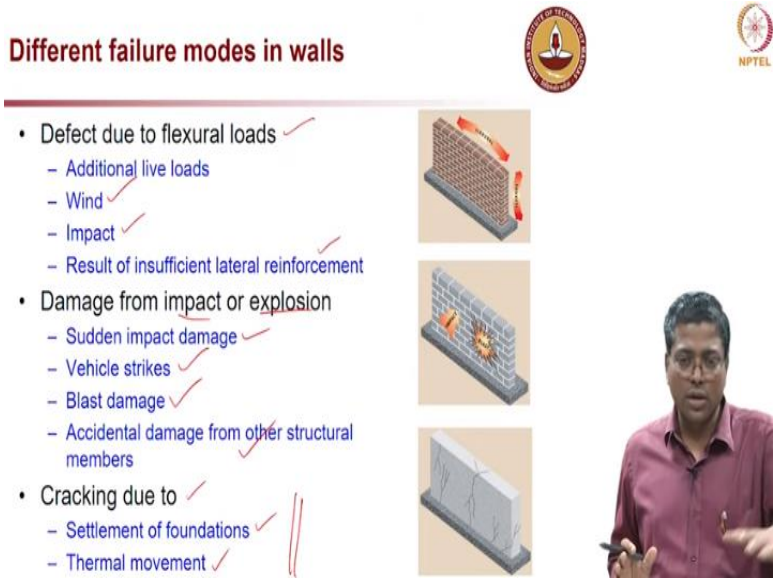

Now let us look at a little bit on how to repair or strengthen the walls, different failure modes we look at first. First is mainly due to the flexure, when additional live load is acting. Because of additional live load or wind or impact, or an insufficient lateral reinforcement, all these can lead to a flexural failure of the wall system.

If the walls are experiencing a impact or explosion then also there could be major failure. So sudden impact damage, vehicle hitting or striking, blast accidental damage, from some other structural members like if a member is falling onto some something like that can lead to failure. Sudden loading conditions, cracking due to settlement of foundation and thermal movement these are also can cause significant stress and these are very important. Nowadays we have lot of structures with entire shear wall system, or wall frame structures where shear walls or in other words the entire wall system is made out of concrete reinforced concrete of course, but there could be significant thermal movement which will generate stresses in which, if one member expands that will generate stresses to the apply stress on to the other members. So this is probably something to look at.

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Now, how to strengthen the walls? So here is an example where you can see a steel plate attached, so retrofitting by steel sections, coupled steel plate shear walls. So you have shear steel plate on this side and on the other side of the wall also and then that is bonded well to the existing wall. So that is one way of enhancing.

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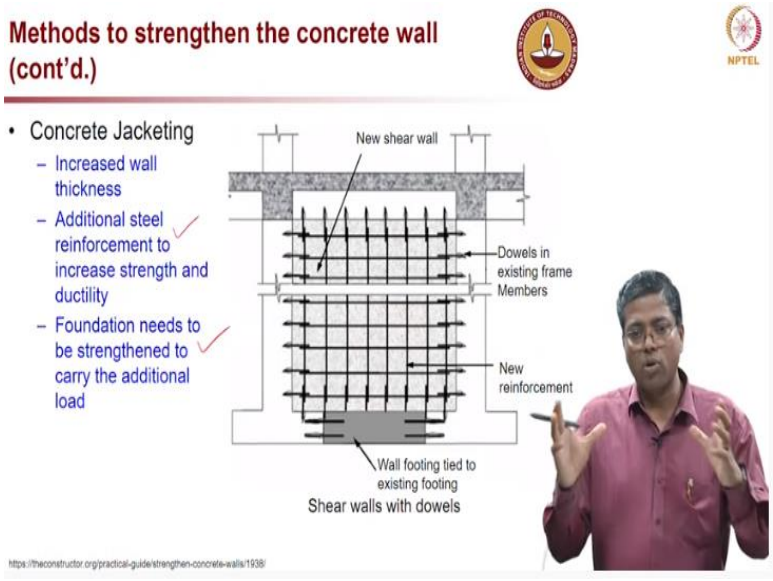

The other way is providing additional reinforcement and reinforced concrete that is concrete jacketing. So the problem with this is the thickness of the wall will significantly increase as compared to the steel plate system. An additional steel reinforcement is used to increase the strength and ductility, which is also case with the other one, but then foundation need to be strengthened to carry the additional load. If more weight is going to come, we have to also think

about, both in this case and the previous case, the when the more dead load you put onto the structure, you have to ensure that the that load is also taken into consideration and we have to check whether the foundation is were design sufficiently for that or not.

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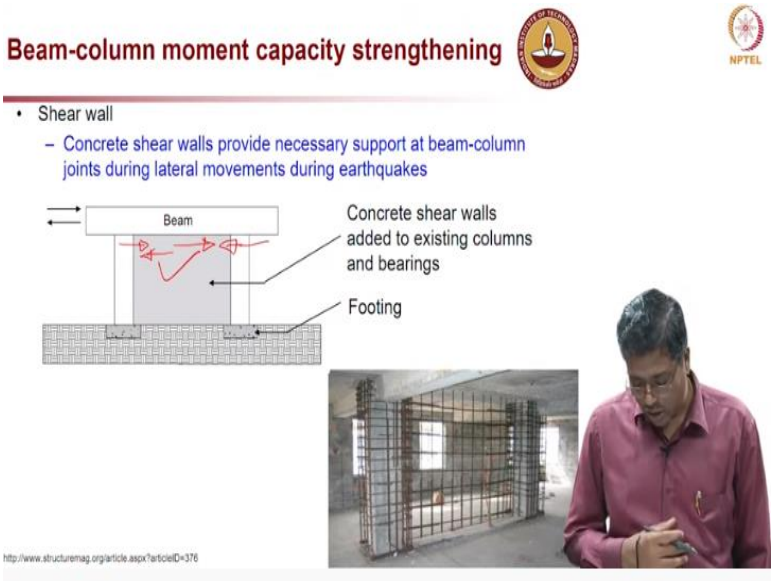

Now concrete shear walls provide necessary support at beam column joints. See nowadays there are lot of structures where ground floor is typically taken as parking lots or something and what we are having is stilt wall construction, one floor essentially is very weak. So in such cases, those structures might be very vulnerable to failure during the earthquakes and one way to enhance their resistance is by filling the space between the beams and columns by additional wall elements.

So this gray region in this drawing here is essentially resisting, for example if this column on the right side is trying to move to the left then the wall will actually resist that. Similarly if the column on the left side is trying to move to the right then the wall will actually resist that movement. So it is very good approach to enhance the earthquake resistance of many of our buildings. Especially the parking lots if you have ground floor parking lot think about this problem and then see if some of the space between the concrete columns can be filled with walls so that even if there is an earthquake your structure can be safe, and you can be safe.

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Now other examples, this is a school building where you can see here the mesh is provided, you can see the mesh structure there, the performance of the wall can be enhanced by providing a mesh and which can be affixed to the existing wall by using any sort of nailing system or some sort of anchoring. In this example they used steel rebars, very small steel rebar with a washer type steel plate or a doughnut shaped and then provide the anchor with grout you place around the washer so that it functions like a big nail. So you can see that this functions like a big nail and then it keeps that mesh on to the concrete the surface. And this is also possible when you talk about fiberglass mesh or steel mesh. So, different type of material usage.

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Now other example is or other procedure by which you can strengthen wall element is by using shotcrete, very widely used for retaining walls. Thought of showing that as an example here, we already discussed the shotcrete in other lectures. And here there is an elevator shaft before and after, you can see this is all region is nicely done with the shotcrete.

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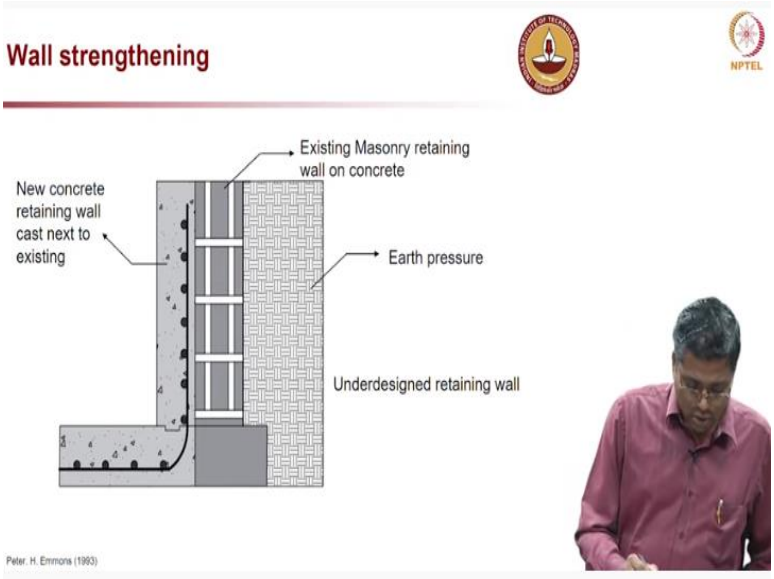

So there are different techniques where essentially it is increasing the thickness and here in this case new concrete wall cast next to the existing one. So this is the existing one and this is the new concrete wall and then you can see reinforcement here and then additional reinforcement of course other details are not shown here but this is something very practical and especially these are very widely adopted for retaining wall structures. Because on the right side you have earth or soil and that is rusting against this wall applying a pressure like this towards the left and then you have to provide something to resist that movement.

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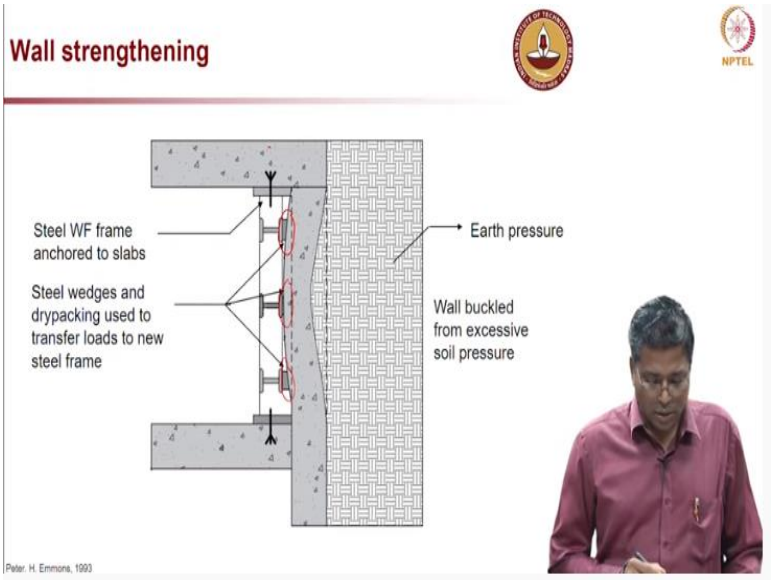

So this again another example where already some deformation has happened, how do we take care of such scenario? Already the element on the vertical element is just bent like this. So you now you look very closely, the height of the three I sections are same, but what they have done is, the gap between the bend concrete element and the I section is filled with different thickness materials so that there is again a direct load transfer possible. Now the after the installation of this, the load is directly taken by the steel frame anchor directly to the slab. So this steel frame will take the entire load right now and then transfer it to the other elements.

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To summarize, we looked at different type of failures in column, mainly compression, buckling and shear type failure and then we also looked at how to strengthen the columns and how to

strengthen the wall elements. We looked at different ways, we also talked about different modes of failure involves with elements and how to fix them also.

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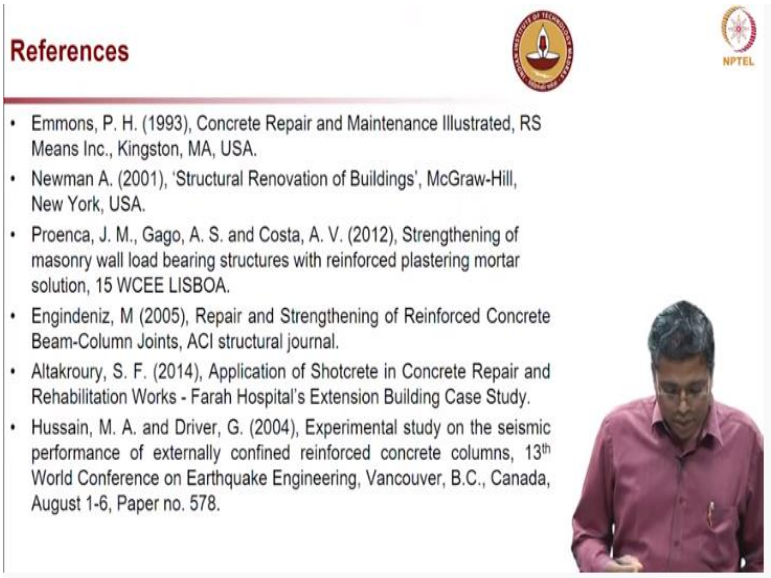

These are the references which we used. Thank you.