Structure, From, and Architecture: The Synergy

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Lecture - 38
Highrise Structural Components- Part II

Hello everyone, welcome back again to the online NPTEL course on Structure Form and Architecture: The Synergy. In the last lecture we have discussed about various Structural Component pertaining to the high rise structure and we discussed on the interior structure. In that part what we understand that, mostly the load bearing members, major structural members are placed interior of the building.

Now, we move forward and we will see the different kind of structural element and their mechanism, their property, their association related to the exterior structure. That means, in short in this category all the structural members; like on majority of the structural members are placed at the perimeter of the building of high rise structure and that refer to the exterior structures. So, without further delay, let us start this particular discussion.

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Here also this is a beautiful skyline and always like the reason to start the lecture with this nice photograph, so just get a sense how beautiful it look like; but with this beauty, with this beautiful form aesthetic you know pleasant, we should also know the structural systems, so that we can actually know the mechanism. Even with our further exploration, we can also try this for our design. Now this is again a repetitive slide to start with, I repeat this slide again.

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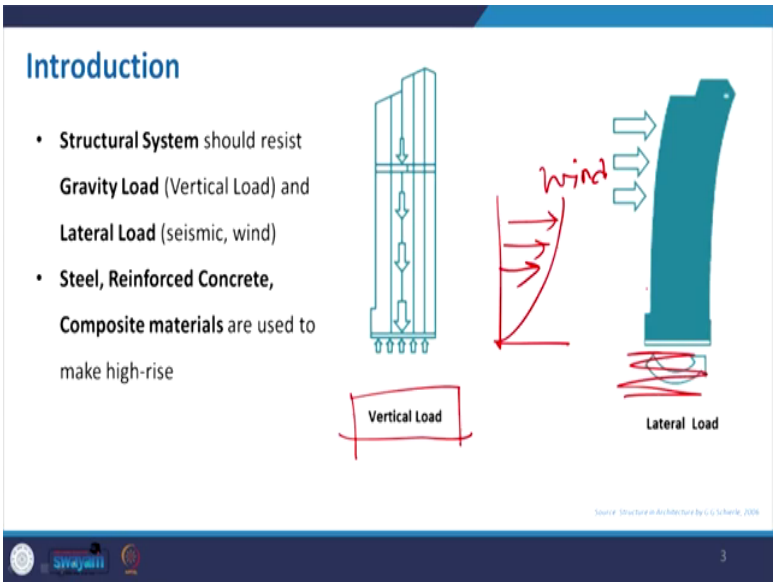

So, were mostly the high rise structure, two different component, load component majorly to be taken into consideration; first one is basically the axial load or the vertical load which is also referred to the gravity load. And then it is acting like vertically towards the center of the earth and this is called vertical load. Now compared to that as, because the heights increases, there will be you know high speed and due to that wind speed, there will be much more lateral load. So, we should also take that into consideration.

So, this is something where wind will play a crucial role for the high rise. And even we have discussed many a times with the increase of the height, the pressure the wind pressure is also increasing exponentially, so that we need to take care of. Not only the wind, but at the same time, if your building is somewhere in the earthquake area; then definitely there will be a threat from the earthquake or seismic activity.

Then there will be some oscillation and that will have a direct implication impact on the high rise. So, this lateral load and as well as the gravity load to be taken into consideration for the high rise structure.

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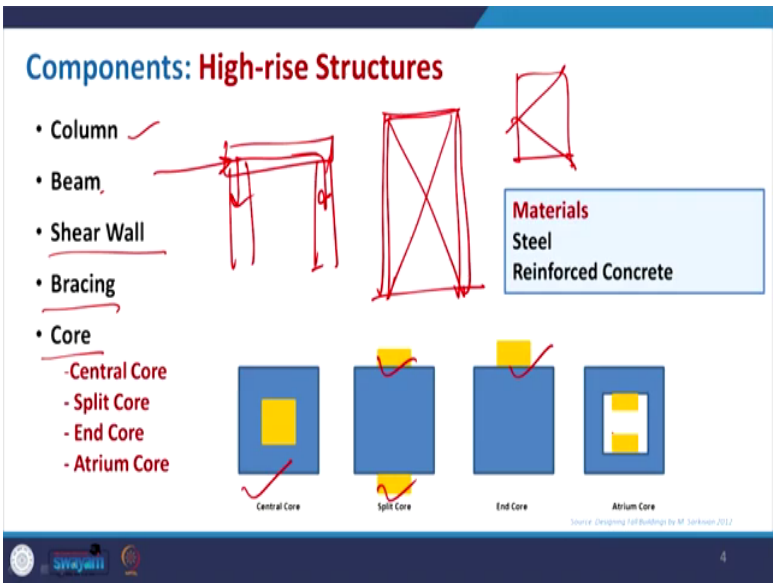

Now, coming to the components in general terms, we have columns which will be basically responsible in most of the cases to take care of the gravity load. Beam is basically taking care of the lateral load and also it will basically you know, transfer the load of the floor to the column and also it will protect against the lateral load. Then the shear wall is basically again extended column we may say that, which will act as a cantilever to the base; which will helpful to you know take care of the lateral load as well as the gravity load.

The bracing is basic you know, give better stability and also resist against the lateral load for the structure. And in this case the bracing can be done in many way, it may be one side

diagonal bracing, it may be of cross diagonal bracing, it may be sometimes of k diagonal bracing.

So, we have seen in our previous discussions; how the bracing can you know help it. Basically this will act as a triangulation or triangulated member associationship. So, in that relationship, it will act as a thrust and then it will make it easy to transfer the load. Now also we discussed about the core, and core depending on the position we have already discussed the central core; it may be split core in different parts, it may be one ended core, or maybe we can have a atrium and the core.

So, core will give internals stability; the core can be made of shear wall, it can be a frame structure that we have discussed in the part one of this discussion, like where we discussed about the interior structure.

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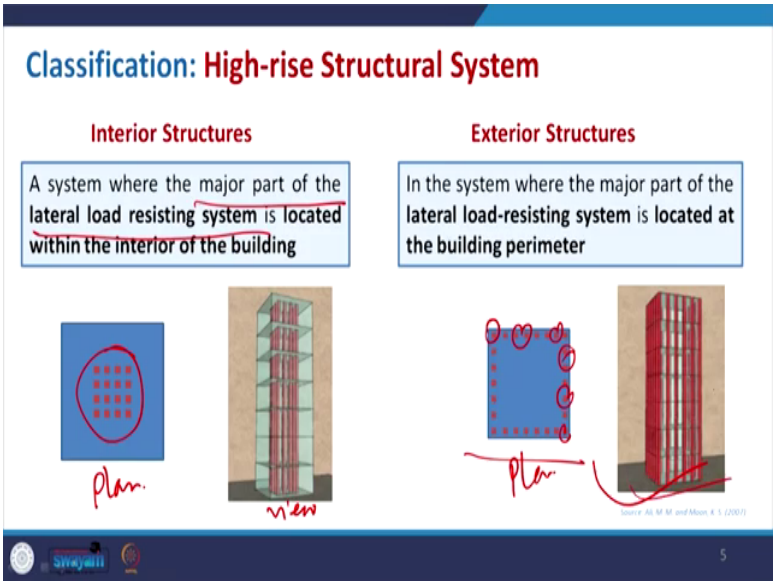

Now, for the interior structure and exterior structure; interior structures were major part or major portion of the structural member responsible for the you know axial and lateral load is placed you know interior of the building is interior structure and whereas, when it is to be placed at the perimeter, then it will become your exterior structure.

So, in this slide if you look it carefully, the placing of the main columns; if we see this as a plan and this is a view, so in this case all the structural members major and remember major part of the load is carrying by this. So, that is why I core refer it to the majority of the structural members; because the structure which will take the lateral load resisting resistant, so they will be placed at the center or maybe interior, not centered all the time, we have seen in the code that different kind of thing, but interior.

So, here it is placed in this; on contrast we can see in this plan that those columns are placed at the perimeter. And if you see the view, it will look something like that this is a schematic view, but this is basically the exterior. So, in upcoming slide we will not discuss with the interior, we will only discuss the part of the exterior structure. And how like we can reach to a different height and how we can make things you know make systems more stable, more you know strong to that it can go even the higher we know reach and then can make tall story.

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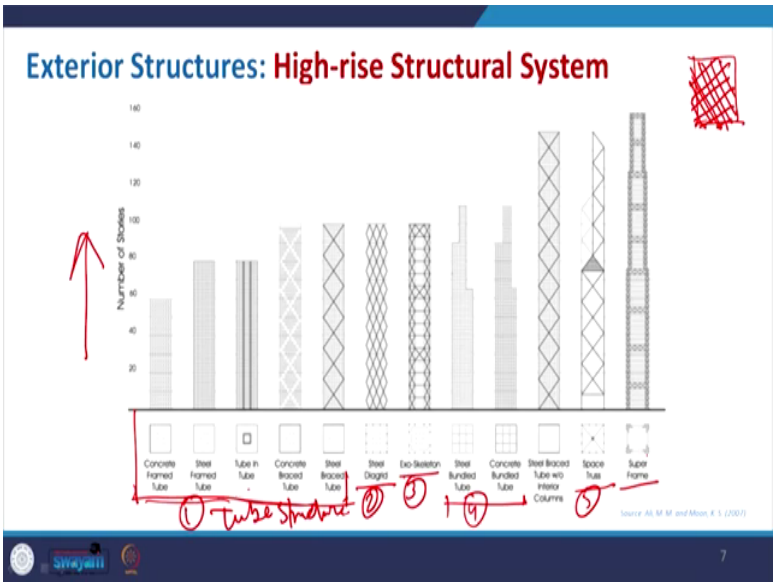

Now, here it is again a schematic pictorial where it shown the story, number of story that bridge story we can achieved with this kind of structure, if we use for high rise and then these are different system. So, basically in this case, there are frame structure and this frame structure can be made of concrete, it can be of your steel; then we can move to the tube structure. So, frame structure normal frame structure that we have seen in the interior structure; but here are the first category that we can see here, is basically tube structure.

So, what is tube structure we will come to that. Then we have diagrid and in some of the lectures we have seen that diagrid means where the grid itself is not perpendicular to the edge, it is making a diagonal. So, if a structural system is designed according to this, we will have a diagrid structure; then we have this is number 1, diagrid number 2, 3rd is a exoskeleton

structure. So, skeleton structure means, if I say that I am here; so my skeleton if I just remove everything and if I just make a make an X ray, so whatever the skeleton will look.

So, this is basically hidden. So, this is inside my body, but sometimes it I just try to make something where you know the whole structure is outside of the building and giving the support to the building and also resist the lateral load and that can be exoskeleton. So, which is actually an outside of the building or maybe it is we can call at the exterior. So, we will see that how that system is working and also some relevant examples on that particular note.

Now on that when we have this tube structure diagrid and the exoskeleton sometimes even to go high, we can have bundle tube. So, if you have one tube and then we make one after another, they are connected, so that will make bundle tube structure. Now sometimes we can also have tube in tube structure, so we will discuss in that. Now beyond that there is another system where we use the diagonal bracing to create some space truss.

So, this is another category to that. And then moving forward, we can have super frame, ok. This is another concept, where we can even go beyond that. Even now also in the recent times you know we also improve this super frame concept and we can have super frame conjoint models. So, then we can even go higher with this structure and again we can use a steel for this kind of a material or maybe the main portion of the structure will be in steel and then the concrete or the composite material.

So, now we slowly move forward and we will try to see what are the types and then each types of them at least we can get one example and then I suggest you; use such similar more examples, so that you can understand that this building basically the fundamental structure is being adopted with this concept.

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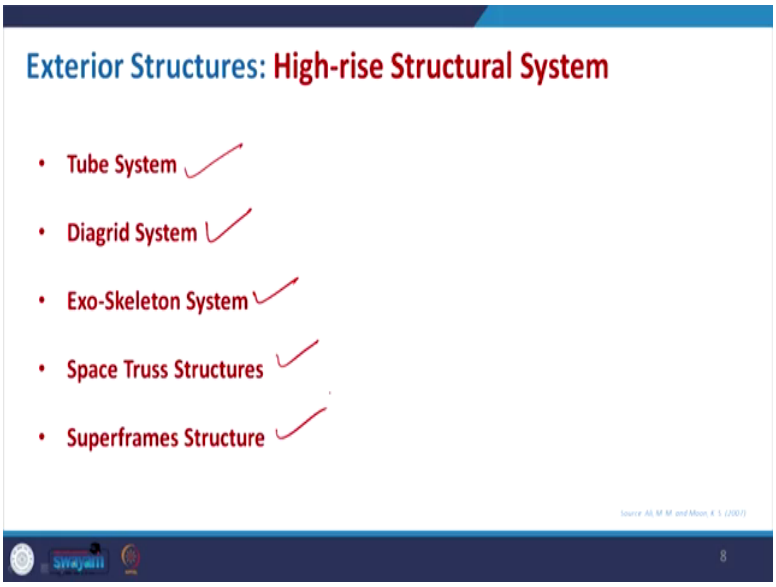

Now, coming to the slide, exterior structure yeah mainly we can see five types into this category. So, one is tube system, then diagrid system, exoskeleton system, space truss structure system and super frames structural system. And now we move to the tube system.

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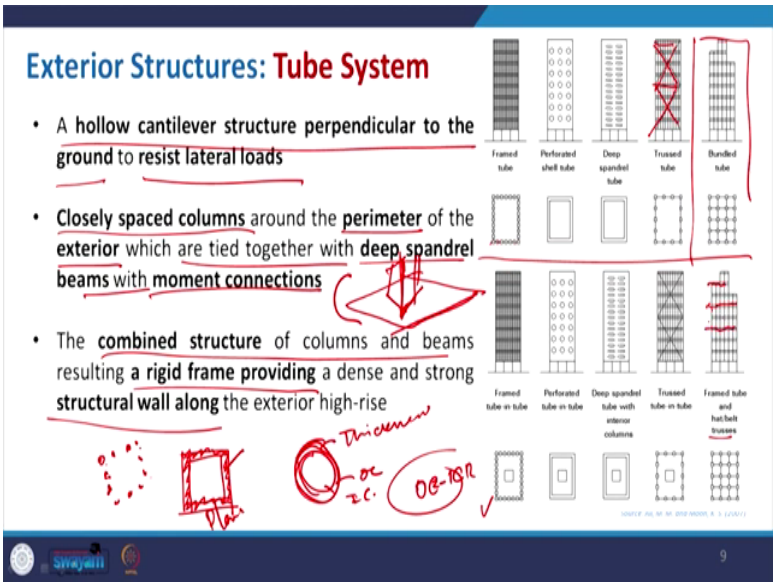

Now, what is tube ok? I like I am saying or I am uttering this tube so many times till now, but what exactly the tube. So, I will just make it very simple. So, instead of tube in structure, if I ask you the tube that we use for the water supply or maybe the tube you used to you know spray water to the garden.

So, it is basically something like this, will have a thickness. So, you have outer circle and we have inner circle and the thickness is basically your outer circle radius and the inner circle radius. So, that will give you the tube form. Now how it is different, from the structural point of view that is not much different, ok. So, this is something which we are much familiar with the tube; but at the same time if I make something like this having a thickness, we have a inner square and the outer square and this particular portion either it is solid like this, so this is tube.

Sometimes we do not even fill the entire cross section, but instead of that we just placed the structural element so close to each other. So, close to each other that it will look like, it will act like a tube and that is the main fundamental of this tube structure. So, whenever you place your columns very close to each other, so that will help to make your structure stable and also it will make your structure resistant enough from the lateral sway, due to the wind pressure at you know higher level, at higher height.

Now, what exactly it is let us understand this; a hollow cantilever structure perpendicular to the ground to resist the lateral load, so what is perpendicular then. Then if you have this ground and then you just make this box. So, this is a plan and now you just erect this building. So, it will act as a cantilever. So, you just make a rotation to this surface. Now if I just consider this as a ground and this is your column and then you just rotate it like this. So, this is basically act as a cantilever.

Then closely space columns around the perimeter and this is very obvious to have the under perimeter; because we are now talking about the exterior structure. But we will see that sometimes even we can place these columns even interior in tube in tube structure; means, one tube outside one tube inside at the core and then we connect it with the floor or sometimes with the you know we also call it diaphragm and then maybe with the beam, will come to that. Now, in this case the perimeter as I mentioned and they are tied together with deep spandrel beam, ok.

So, it is getting connected, all the columns to be connected at different levels with a moment connection. The combined structure of columns and beams resulting a rigid frame provided a dense and strong structural wall along the exterior high rise. Now what exactly it is? If we take this example where it is very solid, you can still make your building; but where from we will get the light, you will not have any view, it will act as a chimney ok, chimney like or tower like structure.

But we have to create the opening as well, we also have to get the view; for that reason we just create some punctures ok, and when you place column close to each other; that means,

the opening percentage will be less. So, still it will act like a solid wall structure and that will protect your building, that will make your structure stable.

So, here these are different schematic where you can see the frame tube, where these are all small small column ok; not small exactly like here in the picture representative, but they are placed very cores closely each other, it may vary from 1.5 meter, 2 meter to even 3 meter and then it is getting connected with the spandrel beam.

Whereas, it is a solid core like this, but there are some punctures to get the view. Here it is the spandrel beam, here you can get that your tube, the column spacing is little bit you know away not usual like this, but additional in the elevation you can see that we can use some structural bracing. So, this is advantage of getting this diagonal brace tube, where you can create a good opening ok, to view outside.

Now bundle tube where you can see that, even interior, different individual structure being make together. Now, this is where it is single tube structure and this is the bundle tube structure. So, you can either go with a solid one with little perforation or maybe you can think of this structural bracing here. Now coming to the tube in tube structure as I mentioned that, where there will be an interior tube and exterior tube.

So, this is one form where your frame tube in tube. So, you can get this, where perforated will have another core like this and then in the bundle tube is basically the same thing. But here the build process means, at the height you can get something; like already we have seen in the previous that, we had different floor levels ok, maybe each 15 floor or 20 floor will have a truss to just make the truss belt.

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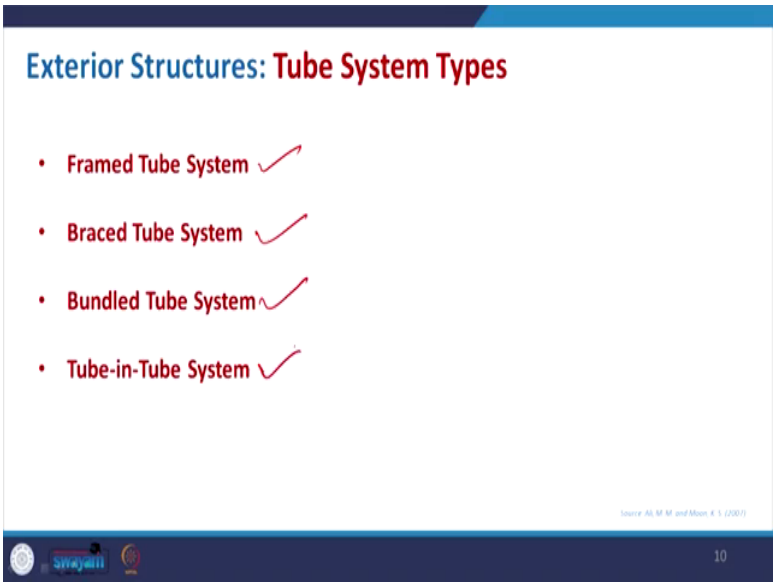

Now, coming to the tube system, again it is subdivided into four categories; frame tube, braced tube, bundled tube, and tube in tube.

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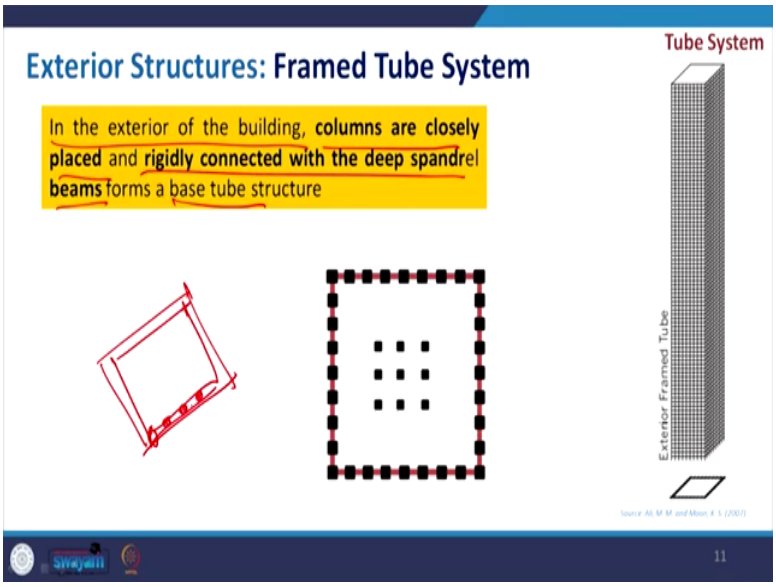

So, the first one is basically the frame tube. So, in this case the material can be steel, material can be concrete. So, again you can see that all this black square, small square are nothing, but the columns and you can see that how close they are placed, ok. And they are connected with a red line, which is basically a spandrel beam and that will give you a structures something like this.

And you can still use it up to certain level and after that it will not really act, because of this is when you use concrete; but with the still you can even go up. In this frame structure exterior building, columns are closely placed and rigidly connected with a deep spandrel beams and it is basically a brace tube structure, a very basic tube structure that is similar. So, only differentiate instead of state of a solid tube, we have now the columns closely placed and they are connected.

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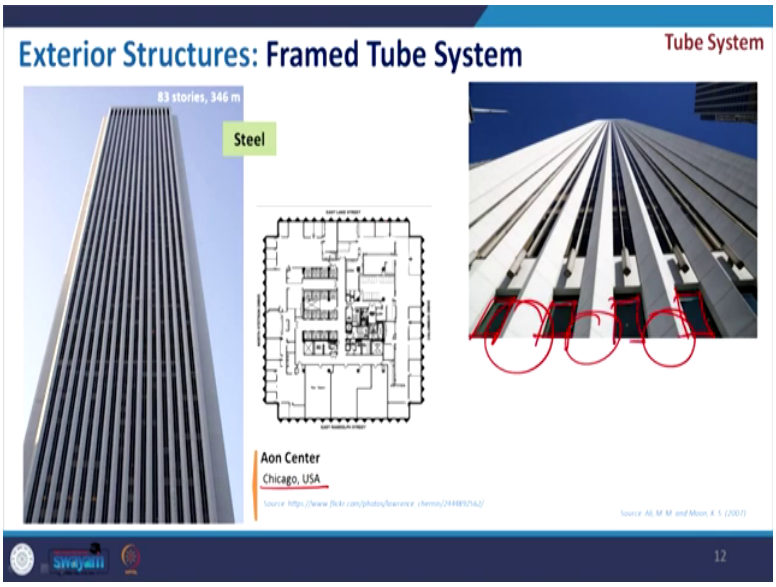

Coming to the example; in this case this is Aon center in Chicago. So, in this case these are, this black portion these triangles are nothing, but the columns; these are visible here you can see and the profile ok, how closely they are placed. And this structure is looking very simple, but then also it is giving a beautiful you know facet with your this triangle position of the column.

And here you can see that, they are connected and then the limitation that I have told you that, you cannot have large opening; because you have to place the columns very close to each other.

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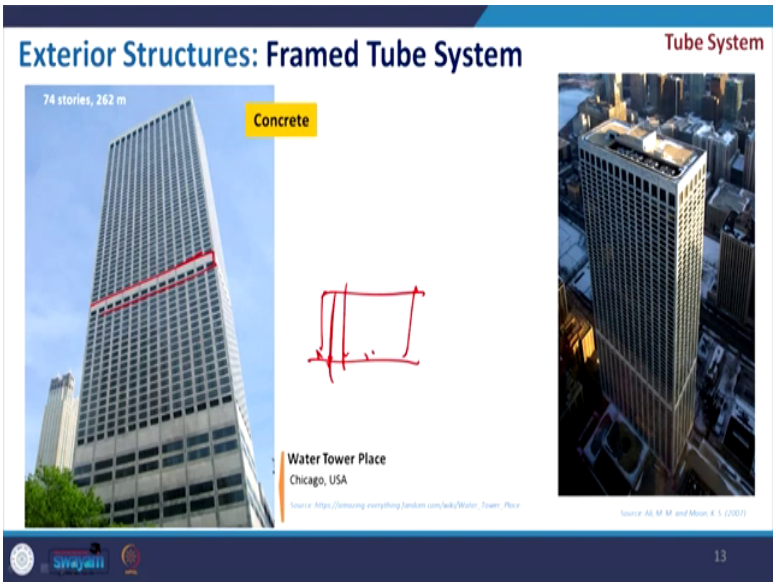

Coming to the concrete again it will be similar to that and you can see that in some portion you can have a deep beam and all to just give better rigidity. So, again it is something very simple of a rectangular plan, where the columns are very closely placed and then it is just connected with this beam.

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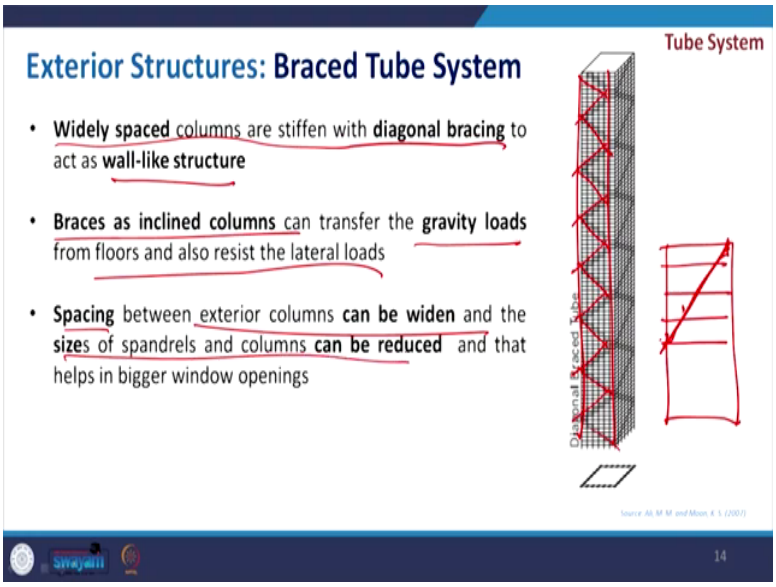

Coming to the braced tube, in order to remove those restriction related to the close spacing of between two columns; if we want to increase it, then in that case this bracing structural bracing system will help us. Widely spaced columns are stiffened with diagonal bracing and this will perform as a tube like this. So, here you can see that, compared to this diagram is very closely placed, now it is placed little bit away and if you see that ok, it is being you know braced with the diagonal members. So, that will help. So, braces are nothing, but the inclined column, yes.

If you see the detail, so basically floor to floor or maybe sometimes it make combined of say few floors and then they connect this all the floors and it is inclined common. So, it will solve the dual purpose; first it will help to place those columns little bit away, at the same time it will also help to transfer the load from the floor to the column. So, this way it will help, ok.

The spacing between exterior columns can be widen and the size of the spandrel and as well as the columns can be reduced; as because of this structural bracing, at the same time you can go the higher.

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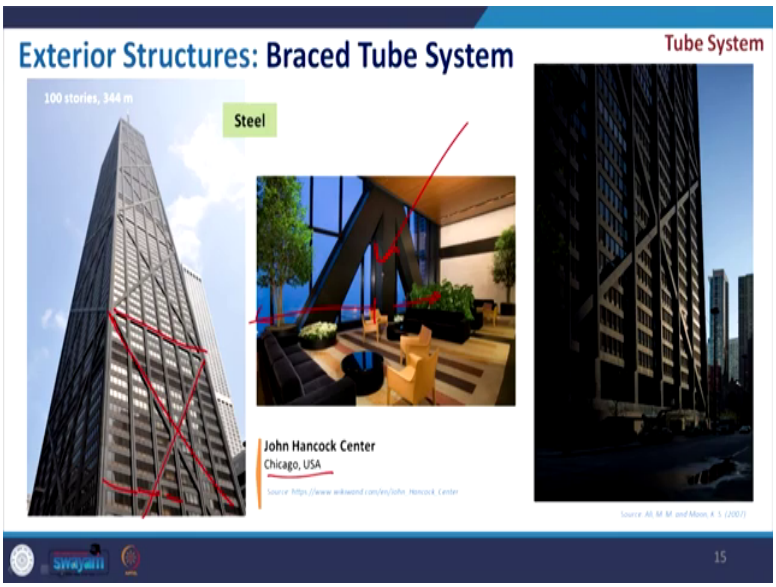

So, coming to the example, this is one of the beautiful example in this category that John Hancock center again in Chicago; Chicago, USA like in this place you will get very beautiful high-rise structures and they are really good example of the mega structure and high-rise structure system. So, in this case here, again you can easily see that how this bracing is done ok, you have earlier; if you remove it, it is nothing but your column, closely placed column.

Now you can get some width, you can get some opening; so in that case this bracing will help us to have a wider opening. So, here you can see the structure and this is from the interior. So, in this case, you can still get this inclined bracing into interior; but considerably you can get a

better view. And if you place this in a symmetry or also it will give a different experience. So, this is made of steel.

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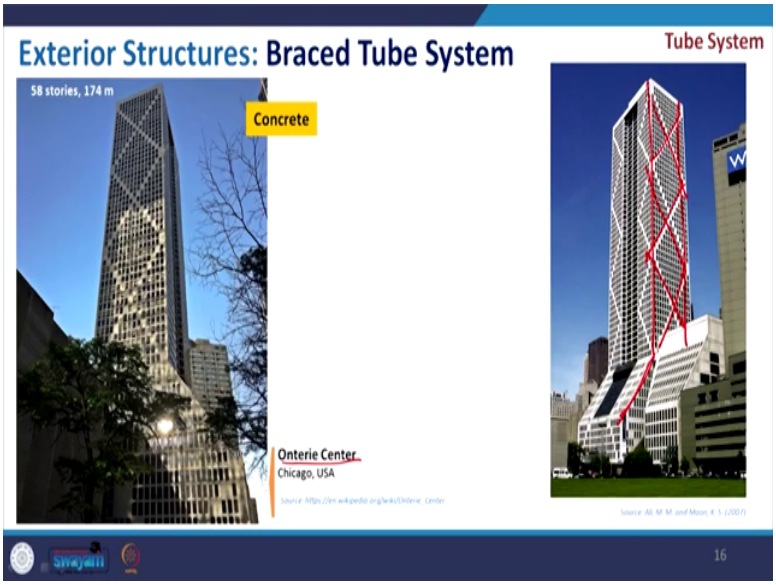

But with concrete also you can go with this. So, this is example of Onterie center, again in Chicago. So, here you can see how this being done. So, again with this normal you know, column frame tube structure; so diagonal being used and there is no horizontal beam. So, this will actually help it to you know, resist again the lateral load.

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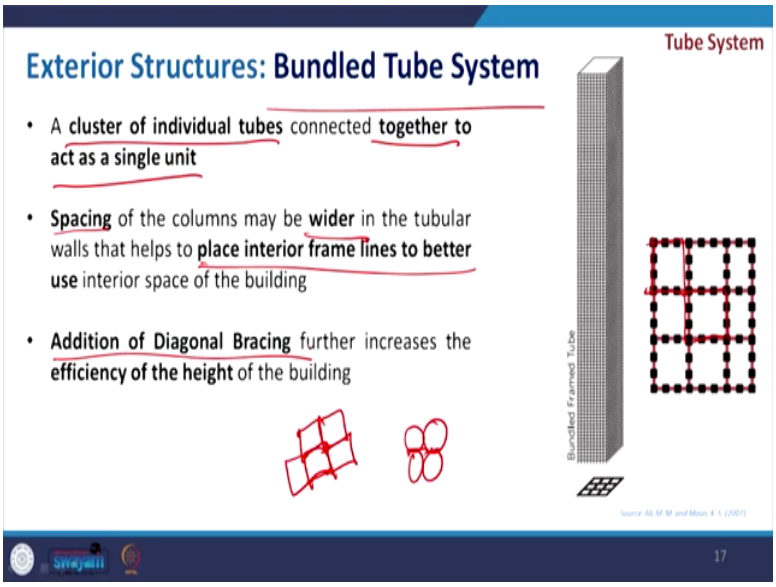

Moving forward, now we are having the bundled tube system. So, where you have multiple tube having a close proximity, we can tie up. So, this is true for your square tube or something like that, ok. So, in this a cluster of individual tubes connected together and act as a single unit that is the beauty in this. And here you can see that this is considered to be a single tube, this is another tube, and they are connected to have a form of this.

Spacing of the columns may be wider and we can use bracing as well in this; and that will help to place interior frames lines in a better use. Addition of diagonal bracing further increases the height; with this we can still go better than a single tube, but again if you add bracing, it will help to go further.

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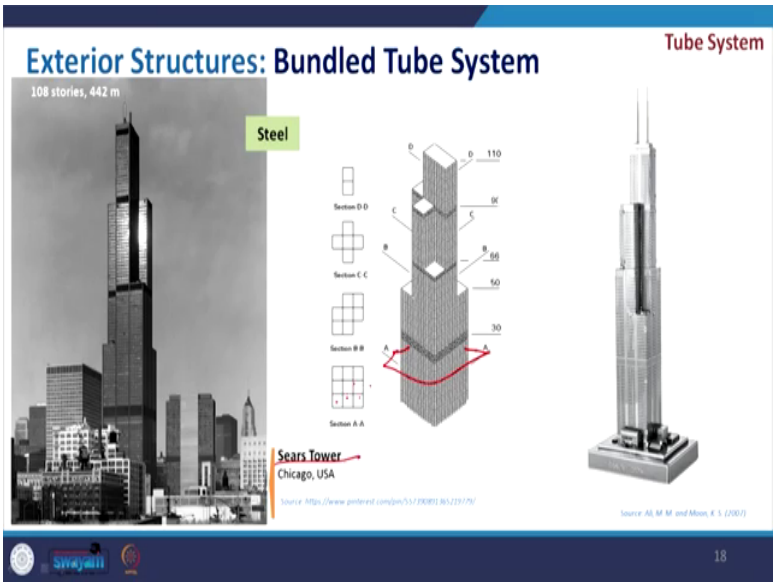

So, this is again a very good example of the same category, Sears Towers, again from the same place. And here you can see if you see the plan, so section is given. So, this is a section cut. So, you can get 1, 2, 3, 4; 3 by 3 grid and then how these being changed over certain you know height and this is example of this particular bundle tube. Now in the recent time there is another example, you just go and search about this; this is basically the Burj Khalifa.

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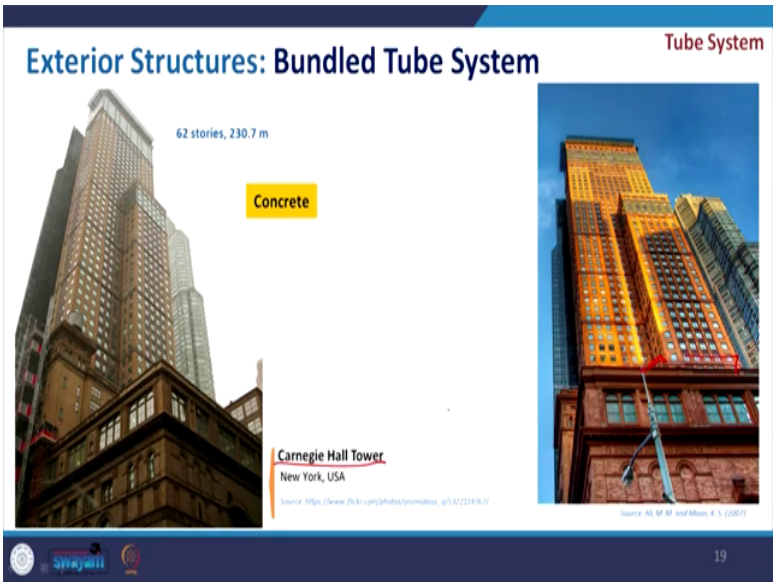

Now, coming to the concrete, earlier it was made of steel; now in this bundle tube this is made of concrete and then in this example which is your Carnegie Hall Tower. So, in this case you can also see similar kind of arrangement, where this small block, the large block they have been clubbed together to create this.

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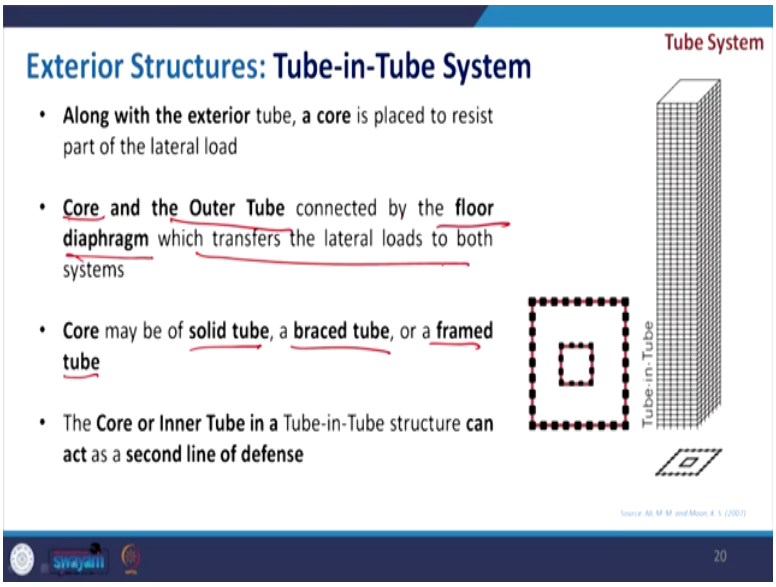

Coming to the last category of your tube system, that is tube in tube, where you have interior tube, the exterior tube; interior tube maybe up solid, maybe braced tube or the frame tube. As we can see in the slide, the core and outer tube connected by the floor diaphragm, which transfer the lateral load to both the system. So, in this case along with the exterior members; the interior core will also take some ocean on the lateral load. So, that is the reason we can even go higher with this.

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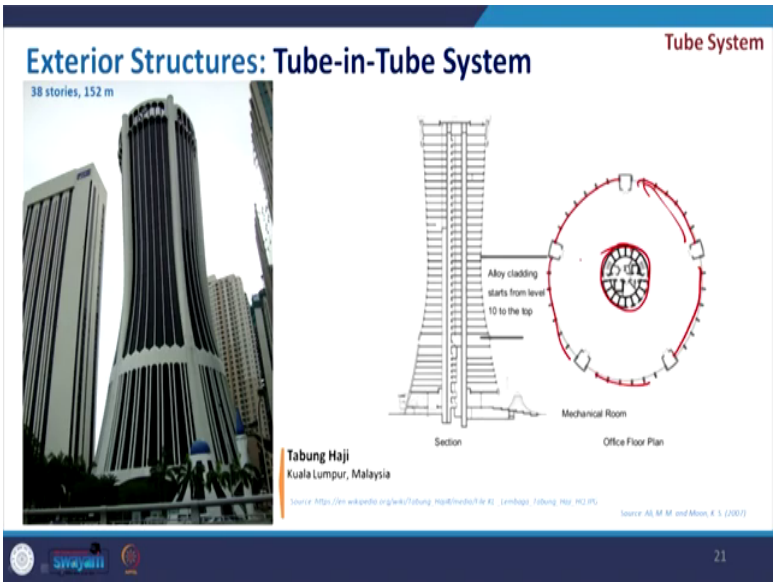

This is the example of Tabung Haji. So, where you can see this is a circular form. So, we have column placed outside, ok. So, this is basically your one tube and then you have a code system at the centre and they are connected. So, this is one example of tube in tube system.

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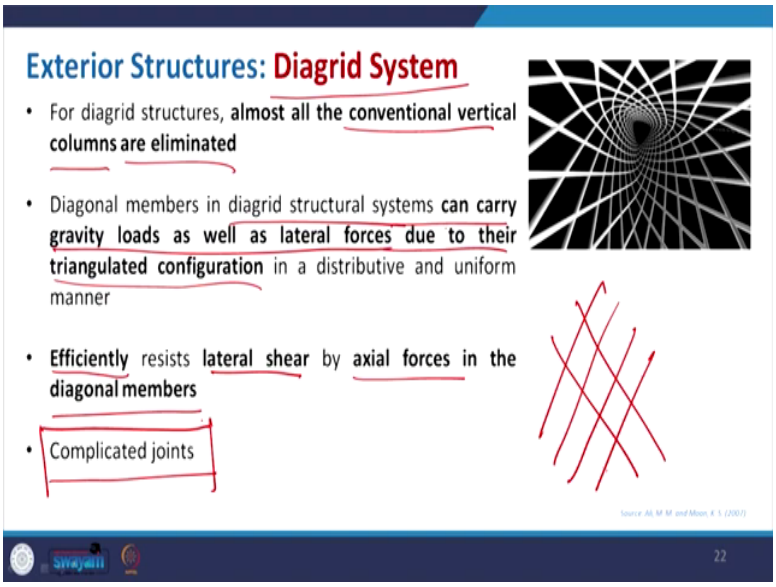

Coming moving from the tube structure to the next that is the diagrid system. In this diagrid system is basically the vertical columns will be eliminated, and conventional vertical columns are eliminated and it is forming a grid which is diagonal like this. Diagonal members diagrid; like it is something like bracing, but here it is all the columns are making this particular grid as a diagonal.

So, this system can carry gravity load as well as the lateral force. So, this is the beauty of this structure, and this is only possible because of their triangulated configuration; like the way that truss is distributing the load is the same manner. Efficiently resist the lateral shear by axial force in the diagonal member.

So, this is actually helping to resist against your lateral shear; but the main issue is the design and the complicated joints. So, in we make this structure during the construction, proper care

to be taken; because it is not very simple, even the shuttering will be something different. Coming to this example, so here you can see the building 30 St Mary Axe in London.

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So, again you can see here the you know, it will be better understood from this where it is under construction building; where the members are basically making this grid and in a diagonal manner and these are the joints. So, this joint to be taken up special care of. And here you can see the opening, so this is one example and diagrid system here it is very simple; where the steel being used to make the entire frame and the glass used as a glazing.

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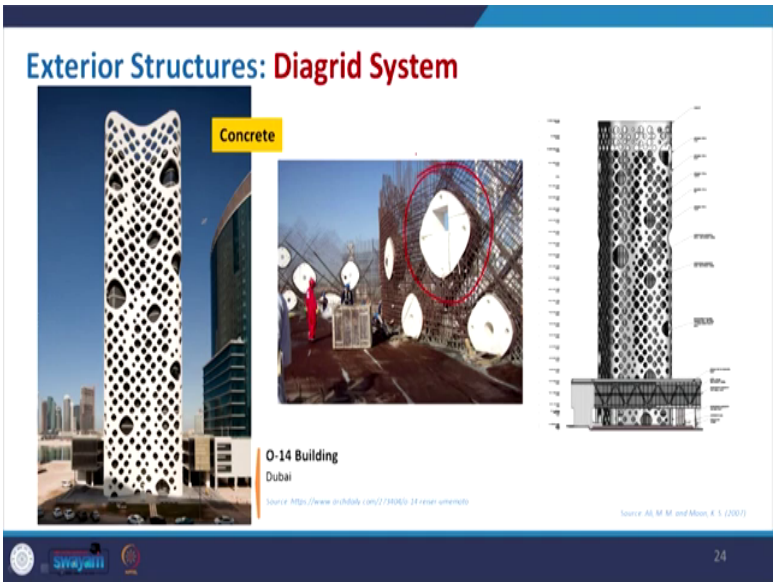

Now, coming to concrete little bit solid perforated one, this is O 14 Building in Dubai. Now, you see the way I told you that how to make the reinforcement and the overall grid. So, this is basically a solid wall and where main beams are running and making a grid and this perforation. So, this is a beautiful example of your diagrid, but in a different form; it is not exactly the column is visible, making diagonal with some angle, but here it is some perforation.

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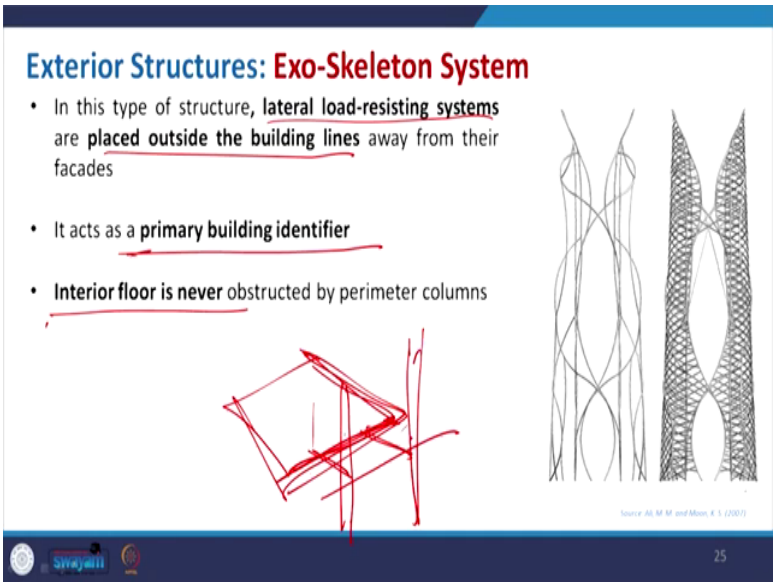

Coming to the exoskeleton system, in this type the lateral load resisting system are placed outside the building lines. Sometimes like if this is your floor; basically in order to take the load, there is a connection from the building and you have the system outside and which will carry the load. It acts as a prime you know primary building identify, because we will first see those structure that your skeleton and then whatever inside. Interior floor is never obstructed by perimeter column. So, this is basically having no such columns or something. So, you can get a different view altogether.

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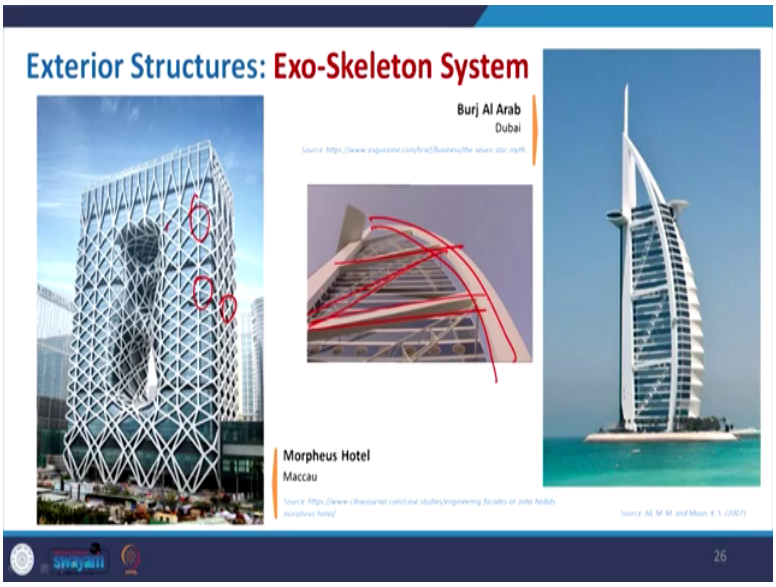

Coming to the example, we have two examples; one is Morpheus Hotel in Maccau design by Zaha Hadid Group. So, here you can see that how this is being done. So, these members they are actually taking care of the lateral load, which is actually protecting this. And the other example is from the Burj Al Arab in Dubai, where again and the main structure whatever the hotels you can get, this insight is being supported by the external exoskeleton.

So, here you can see that this whole structure being made, and then all these beams and then the truss space truss or space frame being you know attached to this building and it is holding the whole load of this particular structure. So, this is another example of exoskeleton system. You can definitely find more and I think it will be better if you can search more and then share with me in the forum.

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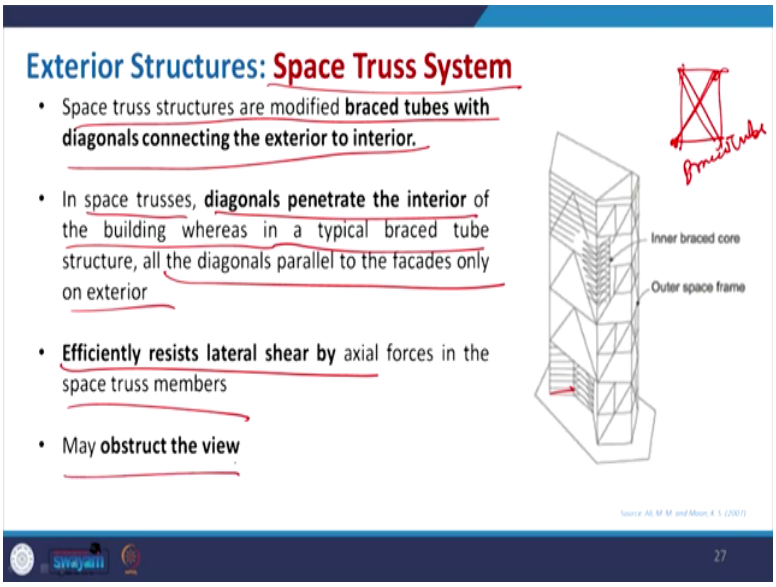

Coming to the next category of that, we have space truss system. So, in this space truss system is, the space truss structure are modified brace tube with diagonal connecting exterior and interior. So, in the earlier case, in the bracing we just connect those exterior beam, this beam to beam at the junction of the column. So, this is the bracing.

So, here also with the frame we connect interior. In space trusses diagonal, penetrate the interior of the building; whereas, in a typical brace tube structure, diagonal only placed a parallel to the exterior plane. So, what I explained, this is in case of brace tube structure; but in this case they are actually connecting the interior. These also efficiently resist the lateral shear by the axial force present in the truss member.

And again it is acting with the triangulated manner; but with this truss and all in the building wherever it being placed, will have some obstruction to the exterior view.

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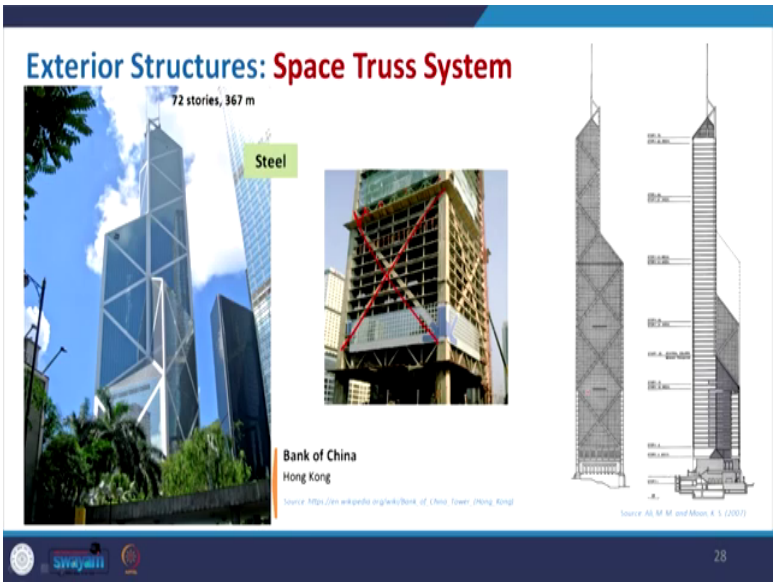

So, here the example of Bank of China. So, here you can see that the truss being used at different level and also we have this diagonal bracing as normal. And overall the structure you get is something like this. So, this is the example of spaced truss system. And you can get more on that.

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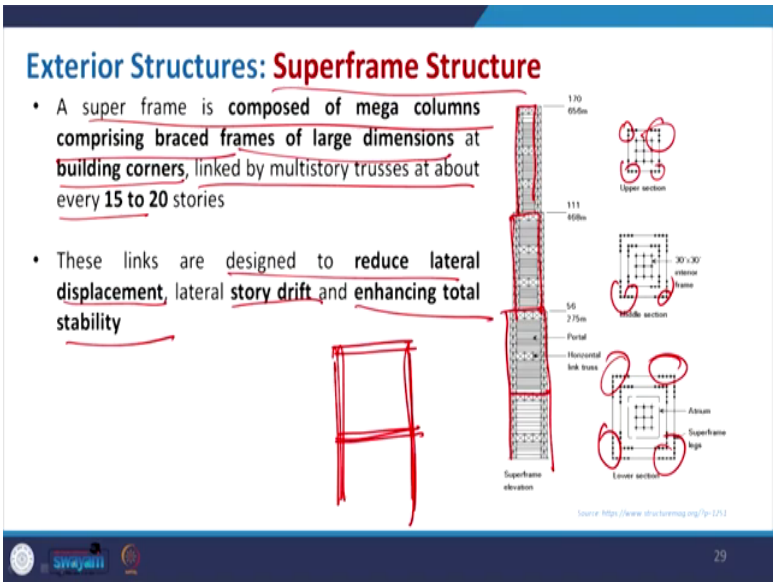

Now last, but not the least into this category, and as I said that now there are more advanced improvement; whether advancement and improvement to this super frame we can go for the conjoint super frame structure and all, these are the proposal can go even better, but this concept is something developed. And then in this case, the super frame is composed of mega columns, ok; comprising braced frame of large dimension ok, at the building corner. So, these are very important things.

So, first of all we have mega columns, the size will be huge, and they are placed at the corner of the building. So, if you see the plan, so these portions if you see that main columns are placed at the corner. So, this particular portion if you see, we can use that kind of mega columns and linked by multi story trusses in each if each like for 15 to 20 floor.

So, here also you can get that ok, you just make those columns ok, mega columns and then you give a connection; at not in each floor, but in different floor. These links are designed to reduce the lateral displacement and the story dripped due to the wind ok; enhancing the total stability as well, because of this super column and the super beam combination.

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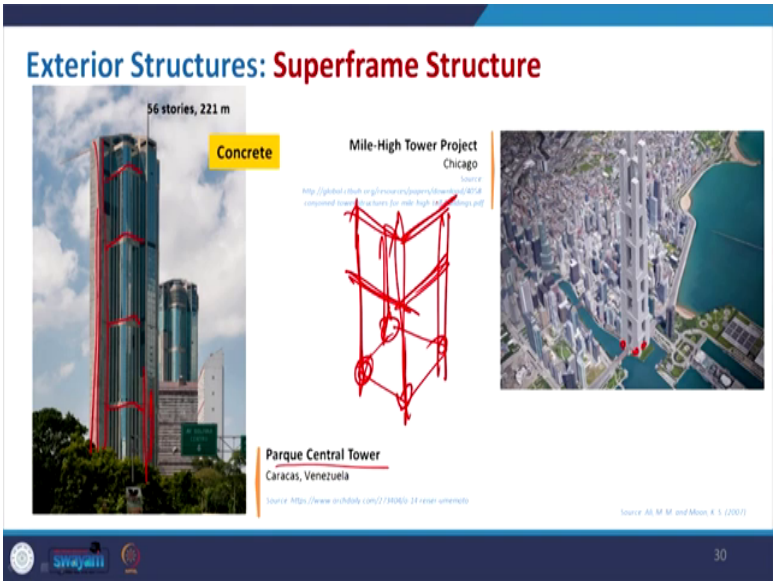

Coming to the category example; so this Parque Central Tower this is made of concrete here also it being applied, partially where you know the core being designed with this solid heavy mass. And then the rest of the things is getting connection and alternatively it is being tied up with those core in this building. So, this is the example of the super frame.

But as I mentioned that the mile high tower project in Chicago, so here is being designed. So, you can see that multiple story being made, and this is really going to a larger height. And in this case it is basically the conjoints. So, four different structure, they are conjoint to each

other. So, if I want one structure to be built, so those corners to be made very strong with the super column of mega scale and then is getting connection at different you know 15 floor or 20 floor each to give better stability helping in resisting the load, especially the lateral load.

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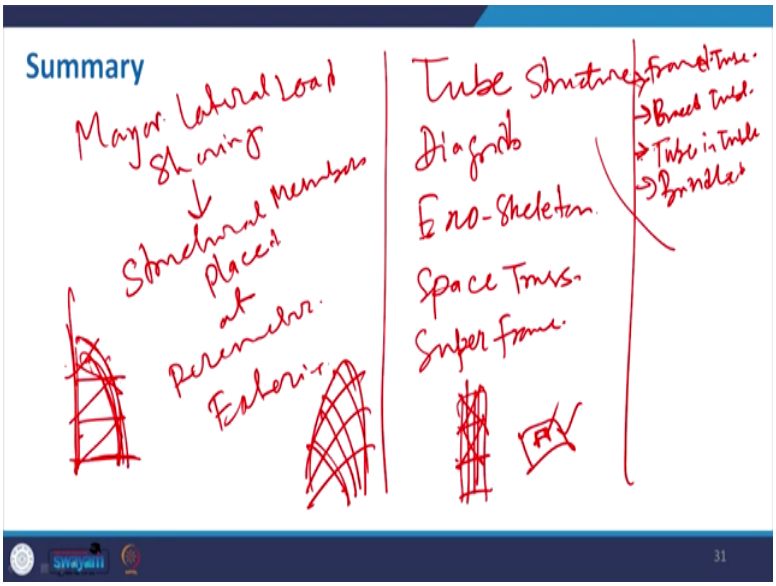

So, with this like now if we want to summarize. So, this is all exterior structure and when we call exterior structure, when major part or what we call major lateral load shearing ok, to be done by the structural member placed at perimeter or maybe this is basically the exterior structure that is the fundamentals. And based on that what we have seen, we have category of tube, we have also discussed tube structure. We have discussed about the diagrid, we discussed about the exoskeleton, we also discussed about your space truss system, and also we discussed about the super frame.

Now in tube what we have seen that, there are frame tubes, and definitely when you go with frame tube, you have certain limitation. And when you frame tube and then when you add bracing, so it will become the braced tube that will give a better stabilities. So, brace tube structure will look like that; when you have this and you have connection at different floor level.

This will actually relax the restriction of the close spacing between the columns in case of the framed tube. And then also we have seen in this category your you know tube in tube, where you both like the interior as well as exterior both will take the load and also the bundle tube that we have seen in case of your Burj Khalifa, ok. So, what I ask you to just search and then get the detail of the same bundle tube.

Now coming to the diagrid, we have seen the example, where basically all the columns are inclined and they are making the grid that will carry both lateral load as well as the axial as well. The exoskeleton that we have discussed about your example of your Burj Al Arab, where basically the main structure being placed outside of the building, so that the floor will not have restriction of the column; and this is something where this structure itself is giving the first look of the building. So, this is your Burj Al Arab about the exoskeleton structure.

Then the space truss, we have seen that were not only the outside of the building, but also in there is the truss the bracing is connected to the interior. And we have seen some examples of the category. And super frame is the concept where you have to use some like super column of high dimension at the corner and then you erect the building and then at different interval you have to connect it with your super beam, and by this you can go up.

So, this is all about this a shear structure; but this is something based on some category, where interior and exterior structure are separated. Also I have shown some of the examples using concrete and still; but there are n number of lists, we can always add on and I just leave that task upon you, so you just add more example into this category.

Even in a recent development, so people are also thinking of going beyond the super frame, so they go for the super beam conjoint; where different super frame structure being attached together with different structural component, may be a different level of your space truss or something, and we can go even mile high tower. And one of such projects which is there in Chicago I have shown that.

So, just go into detail and I have given the few of the links as a source of those pictures where from I have taken. So, if you browse to that, you can get more information and that will definitely help you to understand this, maybe you can get more you know insightful idea that we can use as a student, you can use it for your design; if you are designing something of no high rise hotel or something. And even you do not design, then it is always better to know the system; only we appreciate the beauty and overall form of the skyline, but also know how it works.

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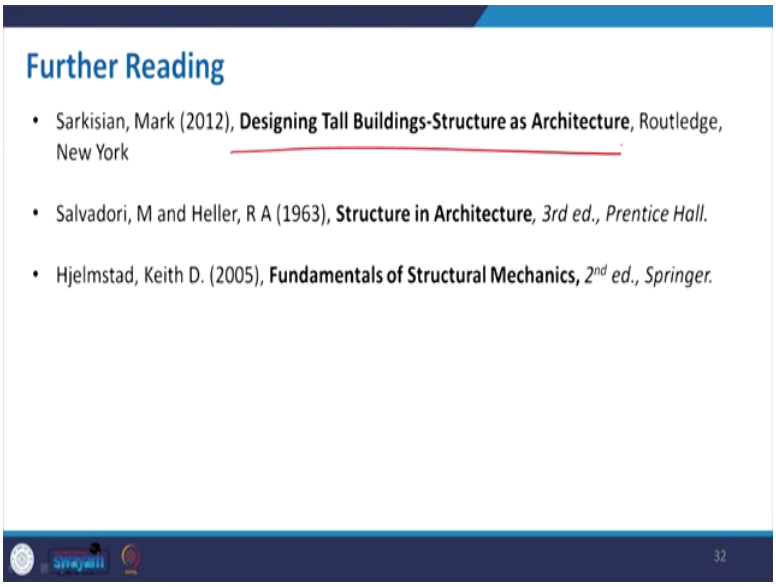

So, with that I conclude this and these are the study material I have mentioned earlier. So, this book is very useful; if you get access to this, please go through this book, you will get more information, more case studies as well. And as I mentioned case study, so the next lecture will be on that.

So, we have learned about the evolution of structural system and then we also came to know about the interior structure and the exterior structure; but now it is better to have not all few very important buildings, which are really you know put the footprint for in the list of the tallest structure in the recent times, we will touch up on a few of them and try to know the detail of that. Like the material we use, the spacing and some more insight; not with only one diagram or something, we will try to understand that, ok.

And also after that what I suggest that, you will I will give you some example, you just go through that case study, and then just discuss it in the forum. And I will be happy to discuss that thing; if something to be clarified, I will be more than happy to do that. So, with that I conclude this lecture and will be meeting in the next lecture, which is your mega structure and architecture case study. And before you know conclude it; finally, I would like to thank you to take part in this course. So, we will be meeting in the next lecture.

Thank you.