Structure, Form, and Architecture: The Synergy

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Lecture – 39
Mega Structures and Architecture – Case Studies

Hi everyone, welcome back again to the online NPTEL course on Structure, Form and Architecture, The Synergy. Today we are at lecture number 39, and we will be discussing on some of the mega structure high rise buildings, and we will try to see their architectural form and structural arrangement. In last two lectures, we have discussed on different structural system, specially classified under the category of exterior structure and interior structure for high rise building. And we have seen their application how you know different height can be achieved, how different resistant structure can be formed with those that we have discussed in detail.

Now, in this lecture, we will basically focus on some examples, we will take very few examples and then we will try to understand that structural system used in this structure these examples. And with that, what will be your task after this to find more such information such more case studies which can have different structural system that we discussed in our previous discussions like exterior structure or interior structures. So, let us start today's discussion on mega structure case study.

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So, in this slide I have you know picked up four examples and we will be discussing on this four examples about their structural arrangement architectural form and different systems. And I guess that these all four examples are known to you and take few moments and just check whether you know these buildings or not; if you know its great, but if not then also after this discussion I think these four examples will be what do you mean by all of you, because we will discuss in detail.

So, let start one by one. So, the first building I think all of you got this on the left hand side this particular thing that it is your Shanghai tower, the second one is Burj Khalifa, third one is One World Trade Center in New York and the last one is your Marina Bay Sands in Singapore, so we will be discussing one after another.

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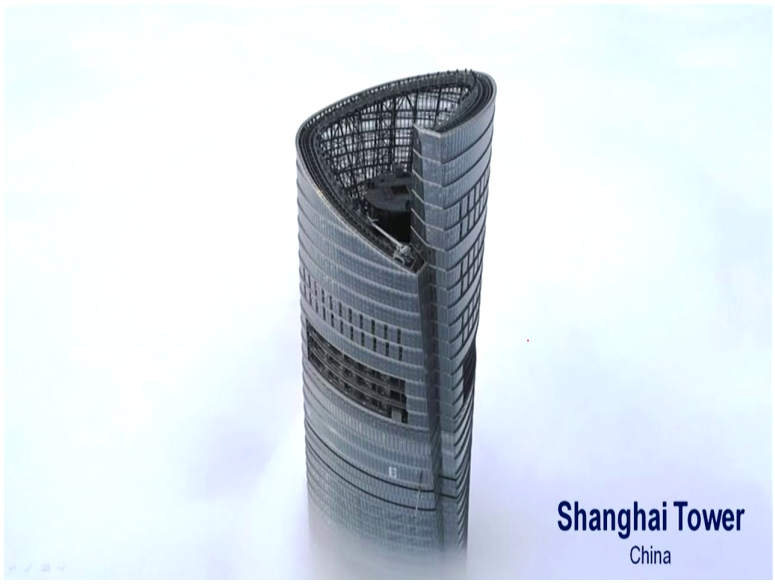

Let us start with a Shanghai tower in China.

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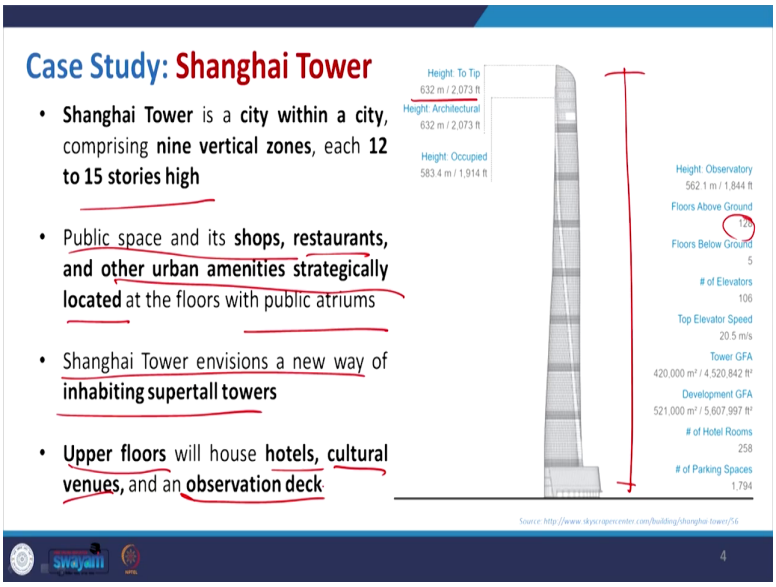

This is basically a different concept by which this building was made; its tower if you look into this slide and that here it says, it is a city within city concept. So, when we started discussing the need of high rise structures, one particular point I told that we rapid urbanization with the high demand of you know accommodation and housing. It is very difficult to go for horizontal expansion with a constraints situation that is why like high rise will accommodate and can meet the demand to extent, but at the same time not only residing in a building, but we all also need to do some activity.

We need to move from one place to another place for shopping activity or maybe some official activities. So, for that it would be something great if we can get those facilities and you know, what is a daily a day a day-to-day basis activities within close proximity. So, with this concept this has been done here like this is basically a city within a city comprising of 9 vertical zones.

So, if you see the building, this building is having a height of 632, meter and then if you can consider the floors above ground it is 124, this is a really tall structure. And if you see that this the whole height is being divided in several zones, and each will have say 12 to 15 storey and different function being assigned. Some of them are maybe the hotels, maybe restaurant, shops and some of them are the hotel rooms for the residential purpose.

So, public space and so its restaurant and other urban amenities strategically located at the floors with public atriums, and normally that to be open for all. Again this is a new way of you know, inhabiting super tall towers. The concept the upper floors will have you know you know hotels, then you have cultural venues, and observation deck from which you can actually see the entire city.

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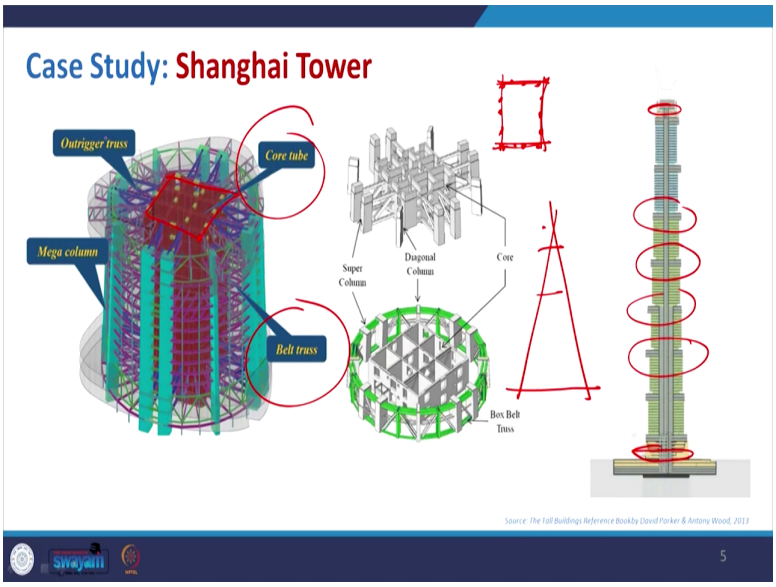

Coming to the structural system, in this as we have discussed earlier in the example of exterior structure and interior structures; in this case it is the structural form that being used is the code tube structure. So, tube structure if you recall recently what we have discussed that where you can phase up columns with very close interval, and then they are being connected with the spandrel beam so that will form as a tube.

Along with that what they have used in different height is the belt truss. And then also as external column they have given some mega columns. And then at different height if you can see those portions, they have used the outriggers trusses which will actually help to resist again the wind loads, wherever the have you know changing the sections of that.

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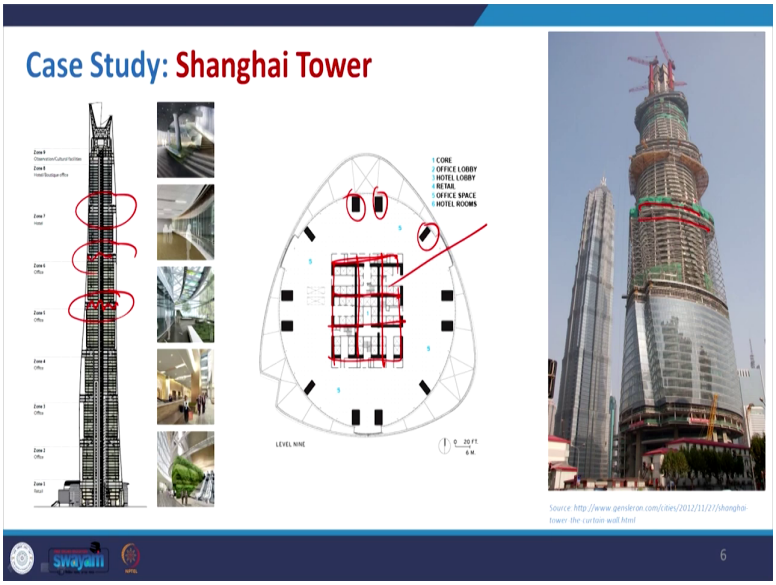

Now, coming to the plan it is very simplistic plan as we have discussed here in this core tube. So, this is basically the core I was talking about and how it is been connected. So, this tube is

there at the core and then you have some mega columns which is running through. And then at different height, maybe at a with say 15, 20 floors height; so they have use the belt truss at the system which is making it strong. So, here you can see the under construction building where you can easily identify those areas, where no those belt truss being used.

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Now, coming to the next example before coming to this example let also discuss the profile that building it started with a larger cross section and then at a certain height, the cross section also get reduced and this is basically to tackle the lateral load. So, basically when we discussed the shape like a pyramid shape or conical shape which will have a better performance against the wind load, heavy wind load at the top. And then reduction in mass at the upper storey, definitely help to make the structure more stable.

So, in this the combination of the tube, core tube, the shear wall tube and then the outrigger truss, some mega columns at different portion is really making the structure you know stable. Now, if I ask you a question that considering the plan the structural arrangement where we can feed this building; whether it is your interior structure or exterior structure. So, in judgment you have this majority of the lateral load sharing portion is inside that core tube core.

So, we may classify into interior structure, but at the same time like we have some mega columns at the exterior at the periphery, so what would be the answer? So, what I want you to just give the logic or what do you think that how we can classify or it is something new kind of (Refer Time: 09:17) both can be given equal weightage. So, I am expecting that kind of feedback comment from your side. Coming to this example and definitely with the state like all other buildings in this, so this is really giving a dominance and it is giving a feeling of standing alone or very strong appearance with this shear load.

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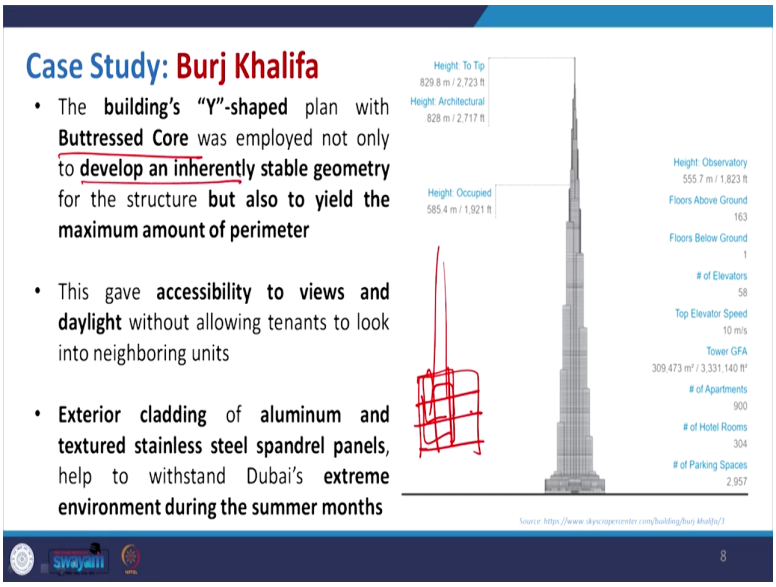

So, Burj Khalifa it is in Dubai. Now, in this case earlier also I have mentioned the concept has been taken a little bit from the bundle tube structure, where we have discussed some other examples where like a you have multiple tube when they together and then you just change the cross section at the top but, it is not exactly the bundle tube ah. Here it is some modified structure being used and Y-shape a building plan is being formed with a hexagonal core at the middle, so this is also referred as the buttressed core.

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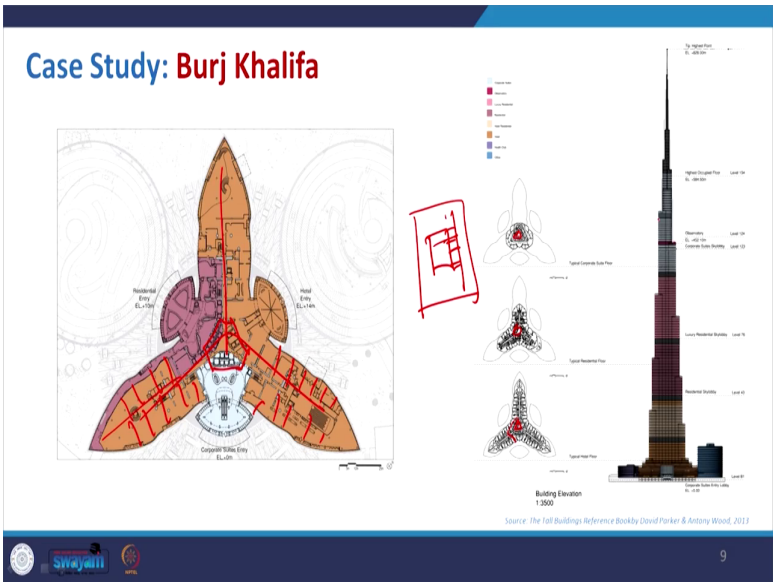

And this is having a one major implication that is this Y form of the plan that we will discuss, we can see this plan. So, this Y form having a core hexagonal core, it is not only giving a good stability with 3 legs kind of arrangement, but also it is maximizing the amount of perimeter. So, this is one of the good aerodynamic profile that we can have. These also allow when you set your rooms at upper storey in both the you know in this wings we can refer this wings, so we can place the rooms on the corner. So, all can get some external view without really disturbing or without having any disturbance to the privacy to the neighbor.

So, this is one form that where we can maximize the view, whereas in a close form structure if we take something like this, so if it is a double loaded corridor, so then definitely we cannot get a proper view for hotels. Now, in this case again the exterior cladding and aluminum textured stainless glass being used to make this building, the outer surface which are found

very efficient and considering the extreme weather condition, especially in summer in Dubai context.

And here, if you see that the floors above ground it is 163 floors have been made and the total height is 8 to 9. So, almost 830 meters wherever the architectural height is a little bit low if you just have considered the habitable space, but in this the height occupied is only up to 585 meter. Now this is the plan, I was talking about and if you see that the plan how it going to change where it is a similar core is being continued. So, if you find that this core hexagonal core is there, so this is very predominant this core it is continuing, but the wings they become very shorter and it is happening with very systematically; so we get the form of again a conical shape in this category.

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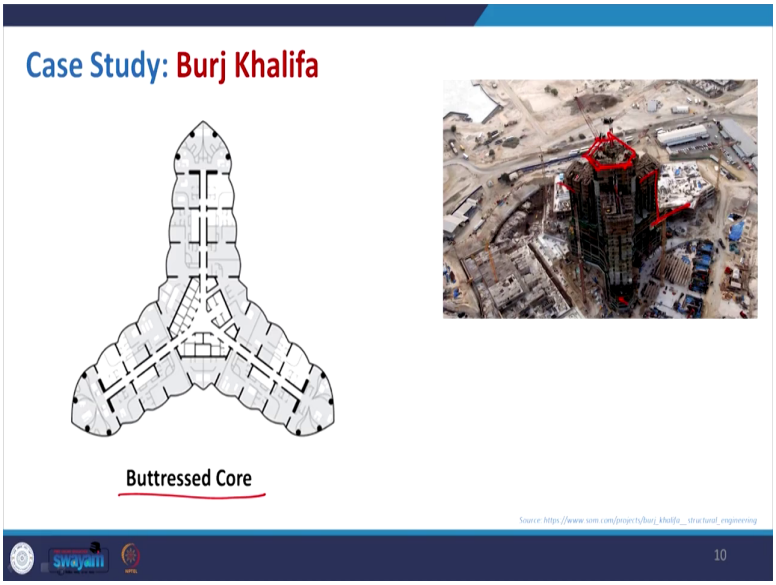

Now, this is a detail view. So, what I was talking about this shear walls and this core is facilitating to get a better view for all the hotels that being all you know, residential areas very much you know attractive to get this view. So, this is Y-shaped structure is called buttressed core with this, this is under construction building where you can see that the core is been made here and the wing they are actually under construction.

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Now, coming to the next example this is from your World Trade Center in New York. So, in this case again these structure is having a height like storey of 94 and a height of 546 up to the top, but the occupied height is only up to 386.

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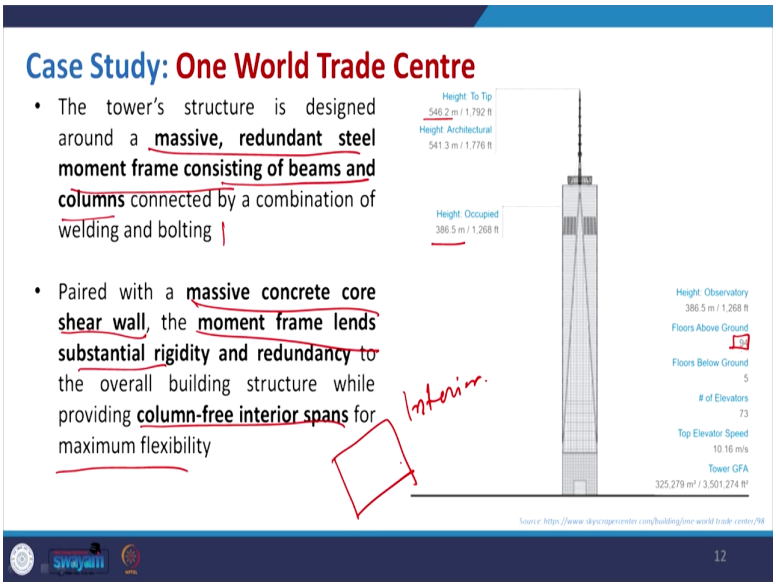

In this case, it is a massive structure where the main structure being made with a concrete core and where the moment frame consisting of beam and columns is used they are welded and bolted and that being used in this structure. Now, massive concrete core shear wall, and the moment frame they altogether is giving the better you know resistance against the lateral load also the axial gravity load.

So, they combine in a combined manner giving the rigidity and adding the steepness to the building. But applying the core is basically what is related to your interior structure, so the major structural element which will take the major portion of the lateral load an actual load placed inside as a concrete core in this building is definitely to be categorized as the interior structure.

Now, if this is so, then my question is the you know example we have taken for the Burj Khalifa; what would be the exterior or interior? Again I leave it to you and you give your comment and justification why you think that that is there, and we will get back to those answer and we will discuss on you know whenever we may have some forum discussion, then we will share it with you.

Now, in this case this flexibility is always a problem for the structure where we use the exterior one, whenever you use a heavy column or very closely spaced column like tube structure, so that will hinder the external view that is one problem. And also if you have a very you know regular frame structure column with regular interval, so the interior space will have some constraint we cannot get a column less space. But whereas in this case a huge massive core being used, so that like the other requirement of columns can be reduced and the interior space can be used in a better way that is the you know point of this kind of frame and core structure.

Coming to the form again that we have discussed earlier, during like the building shapes and their requirement in earthquake prone or seismic prone areas and there I have a made a comment like you know simpler the plan is better the performance and this is so true in this case also. In this building, it has take it has taken a very basic shape and then just is playing with the basic shape not really very curved shape or something.

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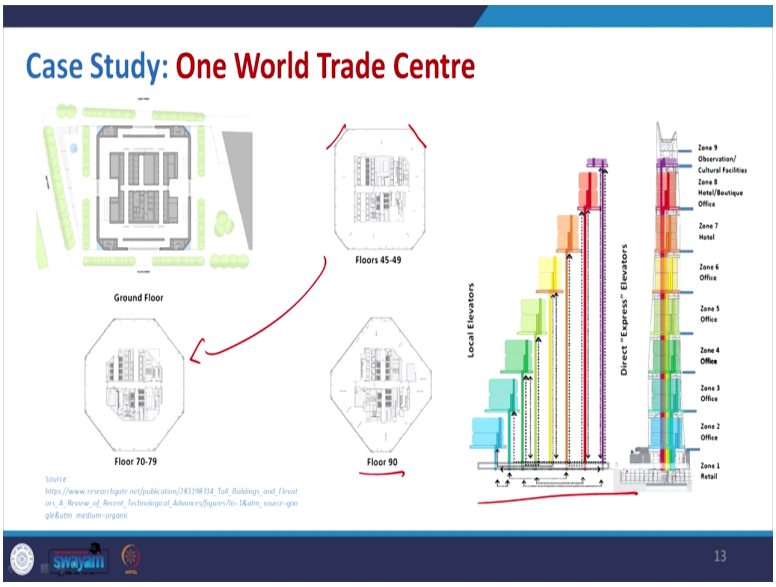

Where core and the core is being a constant element, and then there is some rotation at some upper floors. So, the ground floor if you see the core is something like there and then, this will continue with a very state form not exactly the square form, but with a sample with the 45 degree angle and then this shape again evolved to some kind of and what we can get here is the octagonal form. So, this is transforming to the octagonal form after a certain time and then at the top again it changes, so that will give the profile of the building.

Now, one thing is also important for high rise structure. Along with the structural stability and all the services are very important issue, like how people can evacuate in case of emergency; in case of fire, in case of your earthquake, this is one or even to day-to-day activity. If this I am staying in a 100 floor, so and I just want to get down, so using stair I cannot think of this kind of you know situation, like definitely we need some kind of vertical movement vertical

mobility, so that can be subbed with either escalator or maybe sometimes most of the cases it is with the lift or the elevator.

But for a high rise building definitely if you have a single lift that is from ground to the top level, it is not really solving our issues. Then the unnecessary waiting time will be there people will not really liking that, so we have to separate the zones. Like this if you see in this slide that zone has been divided, and then different elevator like some express elevator, they will have some you know restriction this may be something which will stop at different alternate level or else depending on the initial few levels you have one, then from there you get another one. So, like that this joining is very much important for this.

So, as to for the services of the pipes system, the service floor is also required for this kinds of high rise structures; like how you can supply the water, how we can take the waste out of the toilet or kitchen, because with that height if you just normally allow the water to come to the first floor. So, you cannot take that pressure and how to really control the pressure. So, there are some system the mechanical system these are very important.

So, if you are interested to know the services of the high rise structure, definitely look in to those you know resources which is available in a book form. And even I have mentioned about a book here, The Tall Building Reference Book; so, if you can get access to this book through library or maybe if it is available in some forum. So, you can go through this book and you can definitely get much more idea on this kind of services and the system.

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Now, coming to the construction again, the structure is very simple state forward, but along with that the frame and also you can see that in this section that in different segment we have these outriggers trusses or belt trusses a different level. Now, here you can see that how the thickness in the concrete core is running through and through and different services being club together. Definitely, when you go up then the number of lifts and you know quantity people to be served like that also varies and accordingly that plan has to be made.

This is the under construction photograph that I have picked up, in this case this external stair case that egress staircase is also very you know having strong impact on that that is attached to this. So, in case of emergency it can is easily you know helping this. So, basic form is giving this kind of you know advantage to club some kind of stair through fire staircase or egress staircase and helping the structure to perform in a better manner.

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With that moving to the last example in this discussion that is your Marina Bay Sands hotels in Singapore. So, this is very nice a photo graph that like I have picked up, at least I liked it much. So, where you can see that three structures multistoried building, it is holding another horizontal slap at some higher altitudes. So, this is something where it is not like others where only one building has made with you know high rise and then a core is designed. So, here it is something where at this height means the challenges are very much more than compared to the single building, where the system to be designed for the only single tower.

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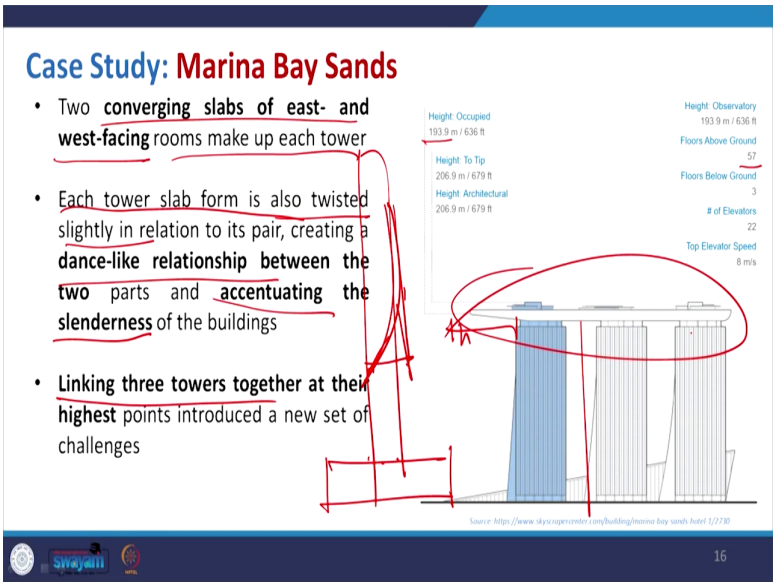

Now, looking into the height, so this height is not that much compared to the other buildings that we have discussed today. So, the height is around you know 200 meter that you can see and the floors again it is considered to be low. And three towers, there are looking identical and they are holding a particular slab at the top. Now, in this case a two converging slab of east and west facing rooms make up each tower what exactly this is.

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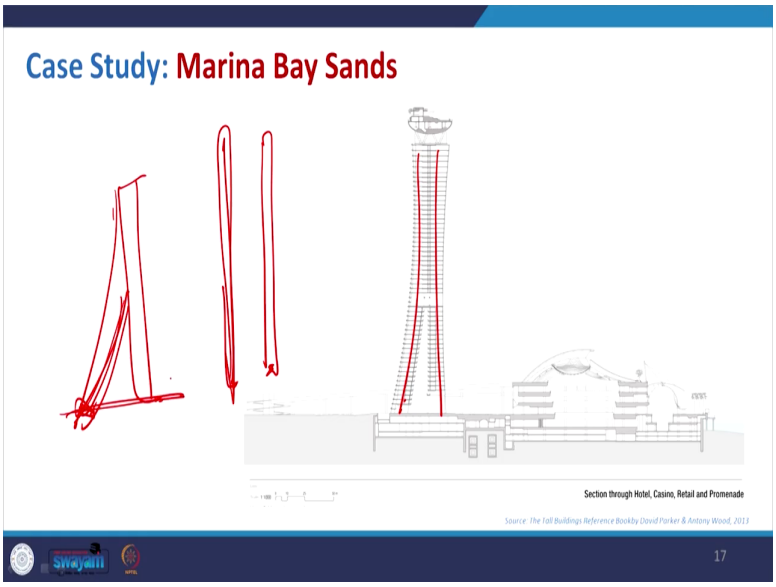

So, for that we need to require this particular section. So, this is one this is another one and this can be you know fixed or this can stand separately, but in this case these two slab they are making some arrangement like this to giving the stability. So, this is like when we have discussed the racking shore. So, this kind of arrangement is giving the stability to the tower.

Now, two converging slabs of east west facing room make up the each tower. Each towers slab form is also twisted slightly in relation to its pair, so that it will give a dance-like relationship that is the view aesthetic being done with this kind of arrangement. Though in order to stability we just make the arrangement like this, where the building is getting this shape.

And then also it will help to accentuating the slenderness of the building, so that in both the cases like it will give the stability as well as the beauty. Linking three towers as I already

mentioned that was the challenge, because this is not at the ground floor normally you know many buildings we get the heavy base at the bottom and then you have the tower, but in this case it is at the top. So, this particular portion to rise trees and there is a portion of the cantilever, so that is definitely a good engineering that being made to create it.

So, coming to the section already what we have discussed that, again it is having the frame structure and then, this is the cross section that something like this if you want to see from this side. So, this is the profile, where the structural arrangement is something like that it is not very straight, so this is giving some stability to the structure.

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Coming to the plan, again the plan is a simple yes, but it is not exactly in a linear form rather it is giving some kind of radial access. And here, you can see this is actually the top floor where different you know water, swimming pool type, water body being created and then there are

some a roof gardening has been done. But, if you see just the you know this towers, so you will get a very symmetrical tower that being placed one after another is a very basic form that has been taken here and then this the upper slab is being placed on top of it.

So, like that, in this case the building height is not that much comparable to the other examples I have taken, and these are very few. Again I am saying, so if you search of the tallest like tallest at 20 that I have also shown in the previous presentation, when you discuss the evolution of structural system. Then you can find n number of list there which are having like more than 100 storey and like say for example, the Taipei 101, you can search or else you can go for the Petronas Tower even some cases you can get even higher and some of the buildings are under construction. But the last example, I have included a purposefully to show the complexities not about the tower also to hold this and that can be formed.

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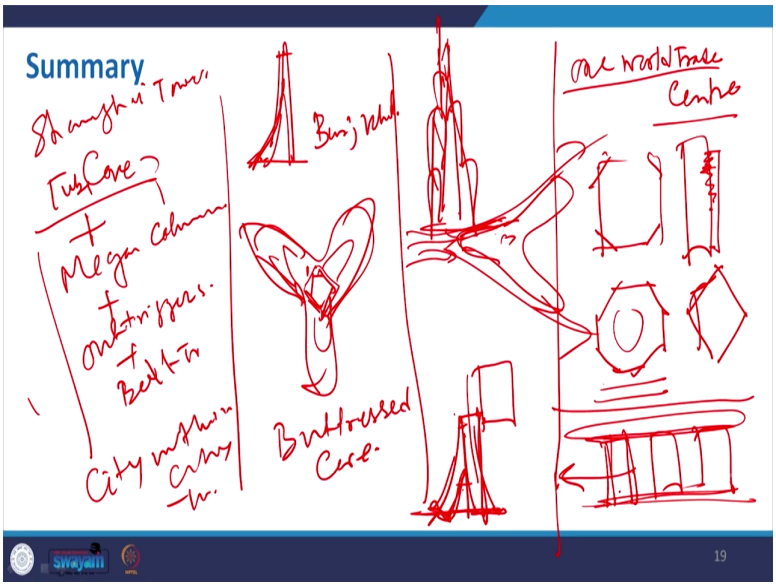

So, here the basic idea to create this tower where this lake kind of from being created, so this angle is giving some kind of extra stability to the structure. Now, coming to the summary, in this case this is something where we have seen different structural system and for a particular building, so again if we just quickly look into this. So, when we discussed about the first example of the Shanghai Tower, then where we have found that again the basic form has been taken and then the structural system has been designed with a core and that core is tube core.

So, we are talking about the Shanghai Tower and along with that there is some you know mega columns at the periphery, and then along with that we have some outriggers belt truss at different height. And the whole tower is being like divided in different zone, where different purposes different you know activity like shopping, then you have some restaurant, then you have hotels, so this has been classified and that is with the concept of city within city towers.

Coming to the next example of a the Burj Khalifa; this is also similar to the bundle tube, but here are the structural system that is been used as a Y-form. And then a hexagonal core at this and it is referred to the buttressed, buttressed core structure. And now the form is being taken with some advantage; in this case, like if you have this kind of Y-shape form and then the wind prevailing wind direction is from this, so it will direct the wind in a systematic manner. So, this aerodynamic form is giving a better result compared to a square 1 or maybe something of the other kinds. So, this Y is giving a better resistance you know against the better resistant towards your lateral loads, especially the wind.

And then again like at the top with the this basic form this flows being reduced, so that the mass is being reduced at the top, so that we can get a structure like this like you know a conical shape. Now, then what we have discussed on the One World Trade Center. There we have found again a basic form being taken where almost square is form with the sample at the corner had been taken, and then gradually it evolved with the octagonal shape and again it will come to a very basic shape at the top and then the form being created.

So, in that case what been used? So, again a core system the concrete core being used at the middle along with the frame and then at different height the outriggers been also placed. And

along with that in the building what we have seen that egress stair case, which is very strong and protective staircase being placed, which is also adding some kind of steepness to the building.

The last one that we have discussed with this hotel the Marina Bay Sands in Singapore, there is basically this tower three towers they are holding a heavy mass at the top and giving a different viewer with the angle. In order to get the better stability and improve the slenderness of this particular tower, so what has been done here?

So, the two slabs like, they are one is very straight and the other one having some kind of bending. So, this is giving a support increasing the base, so that this will have the better stability and the again the basic form being repeated with little bit twist is to get aesthetic beauty of our dance like form in this building. So, these are four mega structure example that have picked up for demonstration.

And again if I want to classify So, the first one again that is open to you also like here it maybe interior structure, as because we have that tube core or also we have some heavy column at the periphery, so that may also lead to the exterior structure where in this case predominantly it will be of the interior structure because this core is being made at the center.

And for again if we go for the World Trade Center, One World Trade Center again it is predominantly the concrete core and that is also helping to you know reduce the number of columns unnecessary to have flexibility in the interior planning of the building. Whereas, in this case, again this having the core system for the each tower it is not the core system in this case.

So, in this example what you get that the core is not at the middle. So, the core at the side so when we discussed about different core, positions so the it can be splitted, it can be a one end like this. So, this is a very simple and as because the storey is not that much compared to the other building. So, the system is again the core and along with the frame structure, but the main challenge was to take the load that been calculated and that is resting on top of it. So,

this kind of form and this kind of base, this particular tiltation is creating the stability, adding the stability to the building.

So, with that I conclude here and we are almost at the verge of completing this particular course. And we will be discussing the next lecture on the architecture and the structure the past, the present and the future futuristic architecture, so we will be discussing on that. Before that like these are the study material, and this is very a useful document and this is a one you know edited book that you can always refer to get more idea about the tall building.

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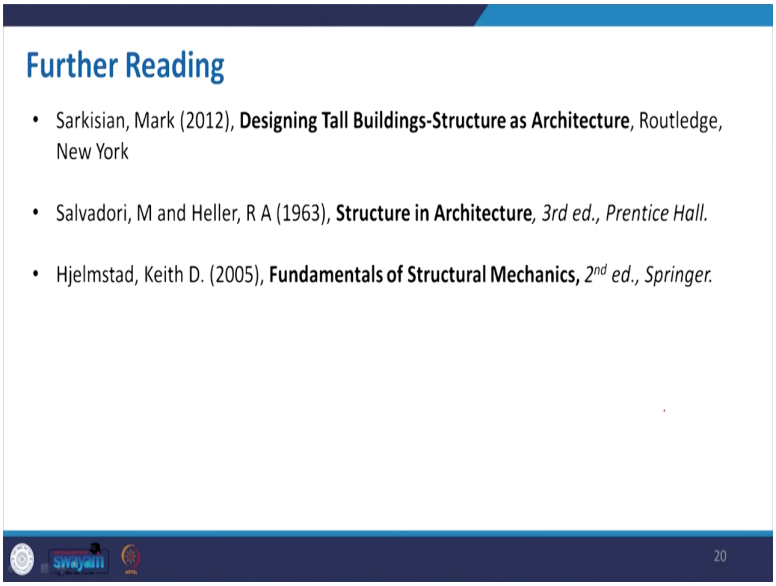

And just search about that book in your library and already if it is there or if it is subscribed by your institutions, then you can easily get some more information from that. And we will be discussing, we will be merging whatever the discussion that we had over the last you know few weeks we will be summarizing this and we will try to compare that what we actually you

know have progressed from the primitive edge with a stone hinge to the modern architecture and again the futuristic architecture of you know, very high in applying very high end engineering.

So, we will be discussing that in the next lecture. And again before you know concluding this, I would like to thank you all to take part in this course very actively, and we will be meeting in the next lecture.

Thank you.