Structure, Form, and Architecture: The Synergy

Prof. Shubhajit Sadhukhan
Department of Architecture and Planning
Indian Institute of Technology, Roorkee

Lecture – 36
Evolution of Highrise Structural Systems

Hello everyone, welcome back again to online NPTEL course on Structure, Form and Architecture: The Synergy. So, far we have discussed various a type of structure, their advantages, their application even the materials that we use for that. But, now onwards we will be focusing on something that we always love to see that the high rise or tall building structures.

At the beginning of this course I mentioned that nowadays we are looking for the vertical expansion of the city; that means, making skyscraper and definitely the engineering, the application, the different kinds of structure that we required to make those skyscraper is definitely something of our interest. Many a times we just admire, we just you know appreciate the buildings, but at the same time it is always better to know some fundamentals, different type of functions, different type of services that is required.

But, in this course as because it is focused on the structural form and architecture, we will focus on the structural system only, but along with that for high rise buildings services is one of the major option. So, in upcoming a few lectures we will be focusing on high rise building. This is lecture number 36, in this lecture preliminary we will discuss the fundamentals of tall buildings and the evolution of structures, different restriction of a structural system, their limitation up to certain height.

And, then how we can improve the structure and some live examples as well. After learning this particular lecture we will move forward different components of the high rise structure and we will again do some case studies for mega structure. So let get start this lecture on: Evolution of High Rise Structural System.

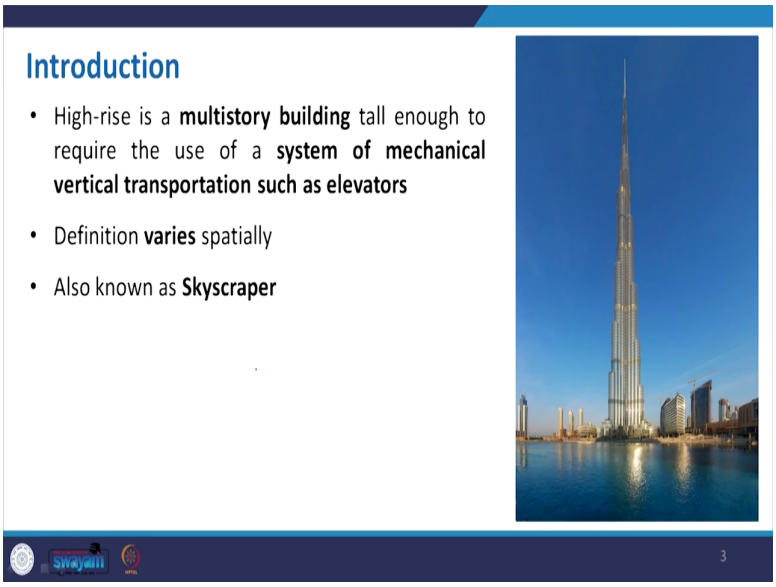
(Refer Slide Time: 02:28)

At the beginning of this presentation, if you a look this particular slide and if I ask you the name of the building; I think all of you can give me the right answer. Yes, it is a Burj Khalifa in Saudi Arabia and you can see that picture in this how beautiful it is, even it is like above the cloud. So, it is always try for the human to you know make something really great, really very tall.

And, that is the reason day by day whenever we say the tallest structure in the world and each year maybe, each day that record is broken by someone or other. So, this is considered to be the tallest, but now also we got the get another Kingdom Tower which is even you know taller than this building. And, there are many in the pipeline, if you go through the website you will get the list that some buildings are under construction especially in the Dubai, Saudi Arabia, in China, in Japan the tall structure.

And, as if you consider in India we are also nowadays going for these high rise building and we have some high rise building in Mumbai and even now the 42 in Kolkata and there are many in pipeline even in your Gurgaon and Noida. So, these are the area like there are project in the pipeline. So, anyway we just go through the presentation and we will try to understand the basis and different structural evolution over the period of high rise building.

(Refer Slide Time: 04:18)



Now, high rise is a multistory building and to be honest there is no particular definition of high rise building or skyscraper in that sense and it varies place to place. Sometimes even a building more than 4 storey is considered to be multistory building and even 10 storey we can say this is high rise, even sometimes 50 storey even do not consider as high rise buildings.

So, depending on the location, depending on the context and the proportion of the surrounding buildings that will vary. Now, as I said that definition varies, but for high rise

structure which is a common phenomena that tall enough to require the use of system of mechanical elevator. So that means, when you can reach a building height by like steer or something is maybe not the high rise category. But, when it is high rise we have to have very efficient elevator or what we call lift, a mechanical lift for the easy recursion.

But, the moment you increase the height of the building remember one thing we have to take care of the evacuation of the inhabits. So, for that we need some mechanical system as well and also this is a broadly known as tall buildings and also skyscraper. Here the example is the same and the previous one, now this is the heights; so, you can see the proportion of this building compared to the surrounding buildings.

So, definitely it is much much taller than the other buildings around it. So, this is one of the skyscraper. Now, all of sudden why we want to build this skyscraper or high rise building? As I mentioned that now we should go for vertical expansion, as because the habitable land there is some scarcity due to you know rapid urbanization, growth in population we need to expand vertically. So, scarcity of land that intensify the need of high rise building.

(Refer Slide Time: 06:32)

Then again when we have the technology and day to day we update it and we have the technology to go vertically so, why not to apply that. So, advancement of technology also contributes to decide upon like to upcoming structure, the high rise structure. Then increasing demand for business and residential space, this is again very important and it is related to the first point that scarcity of land. Now, in planning process we go for mixed land use development where, like both residential its not a no more horizontal expansion is basically the residential tower.

And, the same tower we will have the facility partially of the business or commercial activity as because the demand increases day by day, there is also a need to go vertically. Coming to the next point this is the economic growth and if you see the pattern that the countries they are who are actually having good economy, they are making this building. Because, the making

this building starting from is planning to the execution and you know the system that is required to maintain it really having some relation with the economy of the region.

And so, as true like for the case of Dubai or even in China they are making these kind of high rise building in recent times. Even we all can recall the World Trade Center previously and even now the new one the One World Trade Center in USA. So, this is another example of high rise, I will come to that as well in some of the you know I will show you as an example. Now, innovation in structural system, yes this innovation is must required; the technology were helped us to you know go with the process, construction process.

But, the same time the innovation in structural system how we improve it. As we started with the lecture earlier like we just started with the load bearing structure, only limited to 1 or 2 floor. And, then is a simple your wall and a slab structure. And, then in recent times later in the later stage of this lecture series we have also seen that the folded plate structure, a membrane structure or you can say cells structure which actually removed the boundary of you know having so closely placed column one after another.

So, we can have column less space, if we adequately use it. And now this is nothing, but the advancement of that structural system with new innovation. And, it is upgrading day by day with the input of the engineers, architects and who are working in this field. And, that also has a relation with the improvement of the materials because, in order to go high, in order to resist again the loads definitely we need the material which can capable to resist and make the structure safe and stable.

Now, desire for aesthetics in urban settings, why this is something where we think of urban designer point of view where we will have a skyline of a city. So, if you see the skyline of New York so, all high rise structure is making some you know image of the city. So, this is another important thing that to you know; so, the prosperity of the city or the whatever the advancement in the city that we can depict through that.

Then the concept of city skyline as I already mentioned, cultural significance and prestige; definitely city will have such building which will be iconic, worldly recognized definitely one

should really proud of. So, this is one of the reason we can if the economy support, if the technology support and every other criteria that being fulfilled. Then human aspiration to build higher, this is always a people minds that we should go high and its something you know a sky is the limit.

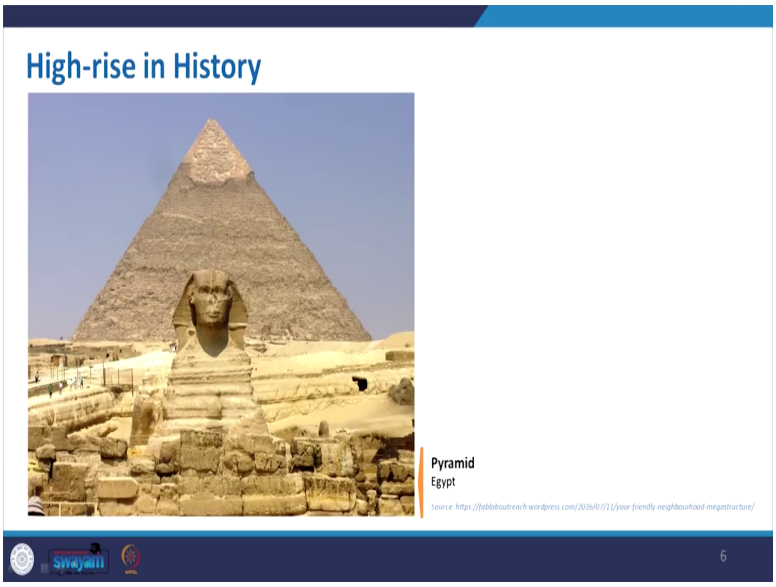
So, this is something where people they always look for building high rise. Now, these are some from the history like it is not the new concept that we think of. Nowadays, we are looking for this option as a need because of vertical expansion, we have spaces like scarcity of land, but earlier what like the supremacy or the prestige of the king they also mean monumental structure.

But, when we call it high rise building; that means, that should be habitable, like it not a very you know high sculpture or any monumental structure in that sense. But, anyway in this regard if we consider the height of the structure; so, definitely we have examples here.

(Refer Slide Time: 11:42)

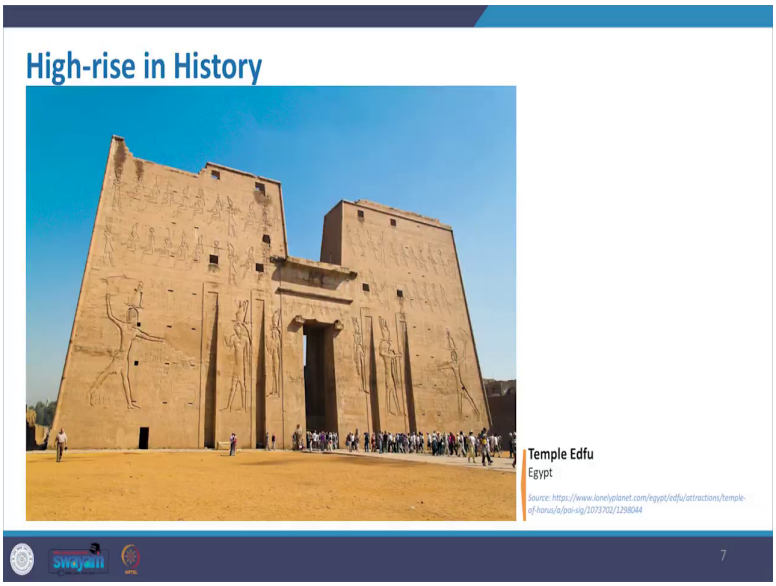
So, this is one summary where you can see different charges, then we have the Pisa, we have Colosseum, even the pyramid the huge structure.

(Refer Slide Time: 11:52)



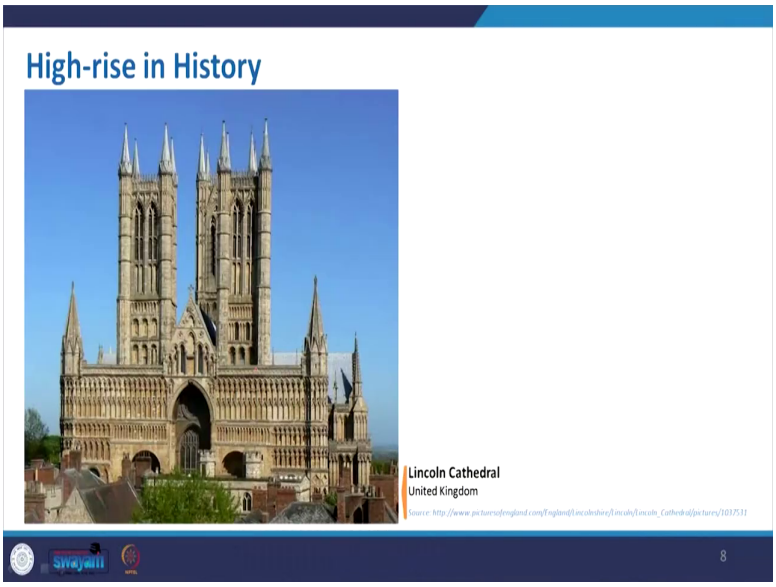
So, coming to that quickly just go through these images, where the high rise in history. So, this is a the pyramid, you can gaze the height of the structure that was made that time with the technology available to them, even this is another example from Egypt. So, normally if you go through the Egyptian architecture and all you find such a monumental structure with the stone and all.

(Refer Slide Time: 12:19)



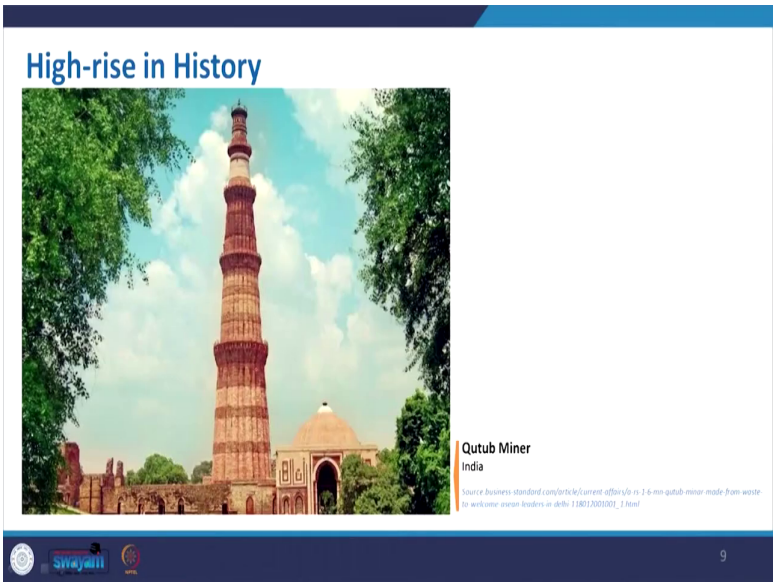
So, in this case this is a temple Edfu. So, here also you can get the scale, this is also considered to be high rise.

(Refer Slide Time: 12:37)



And then also it is the Lincoln Cathedral in United Kingdom so, here also you can see the height of the building. So, we at that time itself like they made it so, that this can be viewed from a long distance. And, this will be iconic building of the city to make the image of the city.

(Refer Slide Time: 12:53)

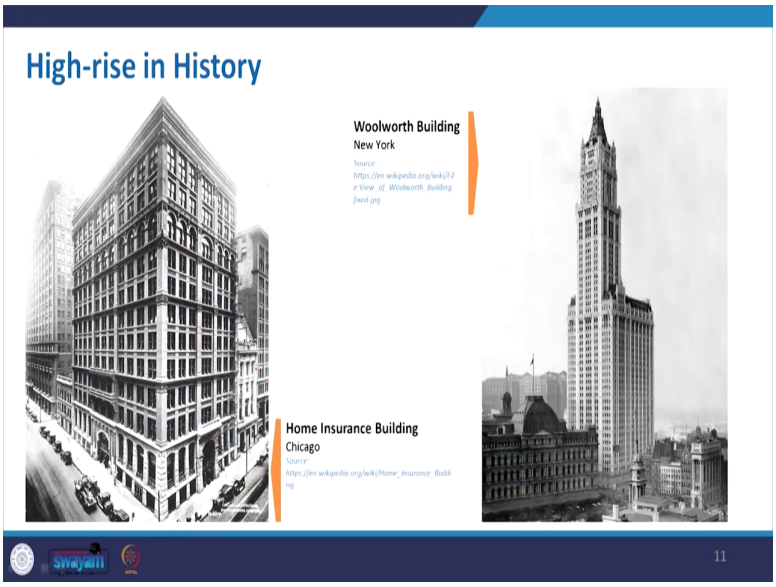


Now, this is very common you know example the Miner or the tower. So, this is Qutub Miner in India. So, here you can get this high rise concept as well.

(Refer Slide Time: 13:12)

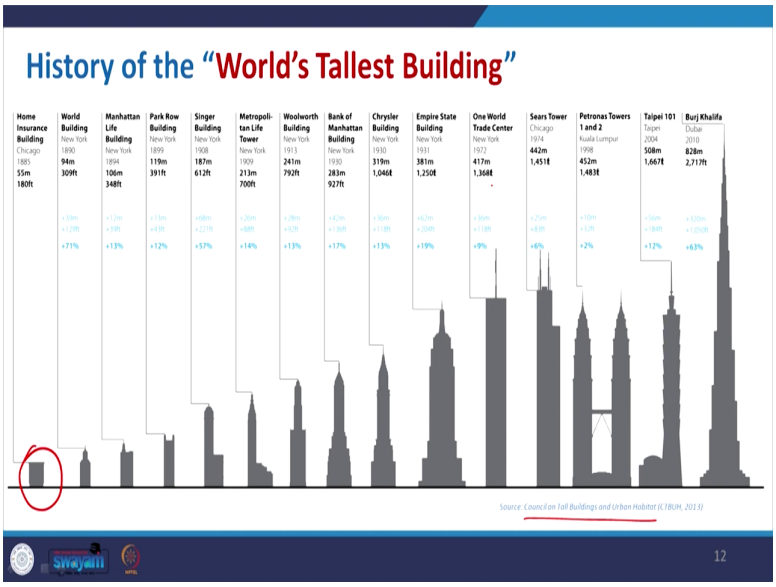
Coming to a temple, this is Sun Temple in India again from Orissa. So, here you can get the height of the building, this is again a high rise structure and that are plenty if you see that all the South Indian temples and all. So, they have a gigantic scale compared to the human scale and this structure was made long back.

(Refer Slide Time: 13:27)



Continuing to that history now if we just go little past to the little past; so, we can get these Home Insurance Building at Chicago where it was considered to be you know one of the first high rise building made for you know habitation. So, all the floors being used. So, as too for Woolworth Building at New York; so, here also you can see the building this is considered to be high rise.

(Refer Slide Time: 14:02)

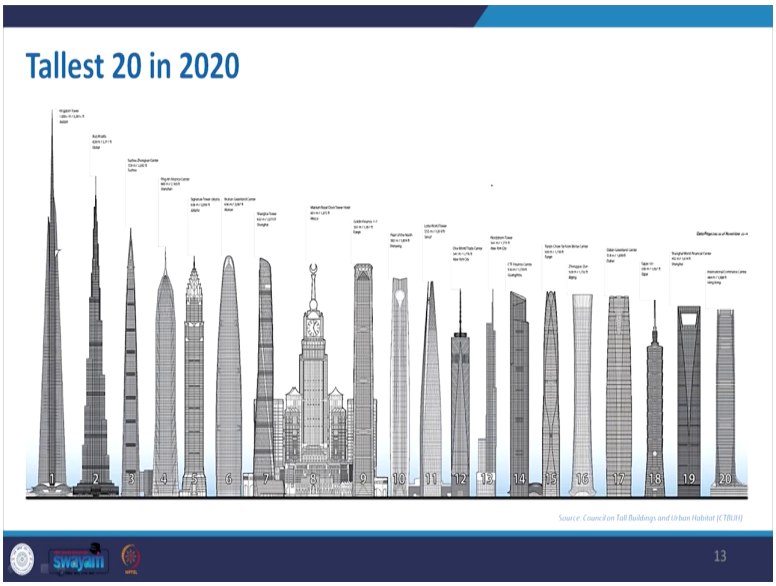


Now, coming to the history of the high rise, here you can see like the Home Insurance Building as I mentioned that is considered to be a your first like your high rise building. And, now we move to the recent time where the completed among the common completed building we have Burj Khalifa as a the tallest and very soon that Kingdom Tower in Jeddah will be you know breaking the record of this in terms of height.

And, just to be mentioned that this kind of you know decision to take whether to you know take that example of take that building or mark that building has tall structure and all; so, there is a council that is Council on Tall Buildings and Urban Habitat. So, they keep on updating the information about all the completing or ongoing project or the proposed project of the building based on their category. So, compared to the height of the other buildings definitely the Home Insurance Building was not that great, but that also included in this.

And, that is in 1885 and now we are in each of already 2 2019, 2020. So, here the many changes you have seen; so, it includes the Petronas Tower, it also includes the Taipei in Taiwan. And, then there are One World Trade Center that is also being there where the Twin Tower was there. But, unfortunately that was now that is rebuilt and then even the new structure is in the picture in the list of you know a world tallest building.

(Refer Slide Time: 15:543)



So, were considering that that the tallest 20 in 2020 that is the overall picture if you see that as I mentioned the Kingdom Tower is ranked first and then the Burj Khalifa. And, accordingly if you go through also it includes the Makkah Royal Clock Tower, also it includes your One World Trade Center in New York City and then you have Taipei.

So, like that you have main issue here you can get a the example of your Shanghai Tower, also you can go for your Signature Tower. So, if you a browse through this particular link rather

building listed in Council of on Tall Buildings and Urban Habitats, you will get more such information about the tallest building.

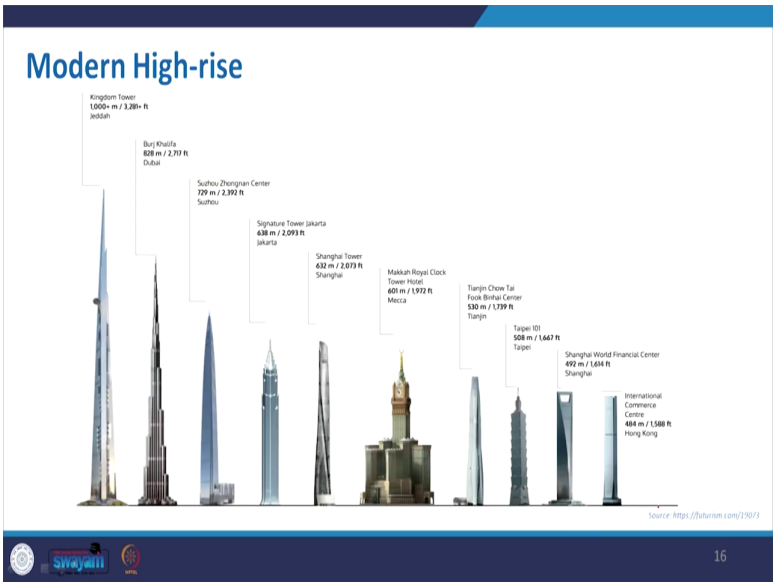
(Refer Slide Time: 16:46)

Now, with that the modern few buildings here you can get the Shanghai Tower in China, then One World Trade Center in US.

(Refer Slide Time: 16:56)

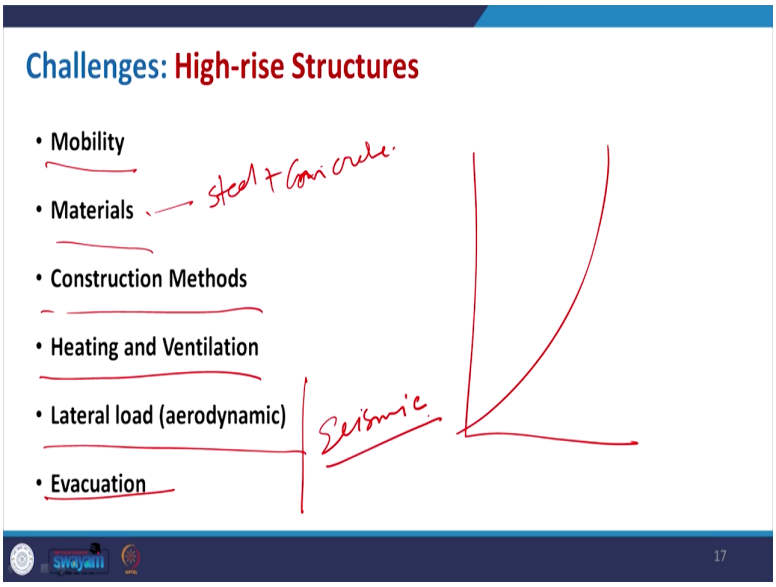
Then you can get these Burj Khalifa and also the Kingdom Tower. So, these are very you know recent development and high rise structure, the skyscraper in the picture.

(Refer Slide Time: 17:10)



Now, this is a similar thing where another pictorial example, where the Kingdom Tower and how like we can compare the other structure as well. So, like day by day it is breaking the record like each say within a 5 years interval, we get a new list each time or someone is breaking someone's record or not. So, this is very ongoing and keep on upgrading about the height.

(Refer Slide Time: 17:40)



Now, coming to the challenges for the high rise which is very important for us; the first challenge is about the mobility. Mobility in terms of vertical movement and for that when the Otis invented the mechanical lift, till that particular point like it was a really a challenge to go really vertical. And, that required some energy to bring all the lift of the material as well, it is not only the movement of the people, but when you built it so, it also requires some kind of system.

So, for high rise this is very important and also we should think of the evacuation like for that you have to think of high level services in terms of lift, high speed lift. So, that within a given time of evacuation whatever the standard time within that the people have for from inside they can come outside. Then the materials is very important like definitely steel, concrete; so, they

are being used for the high rise structure. And, now it is also composite material and new research on different building materials is going on.

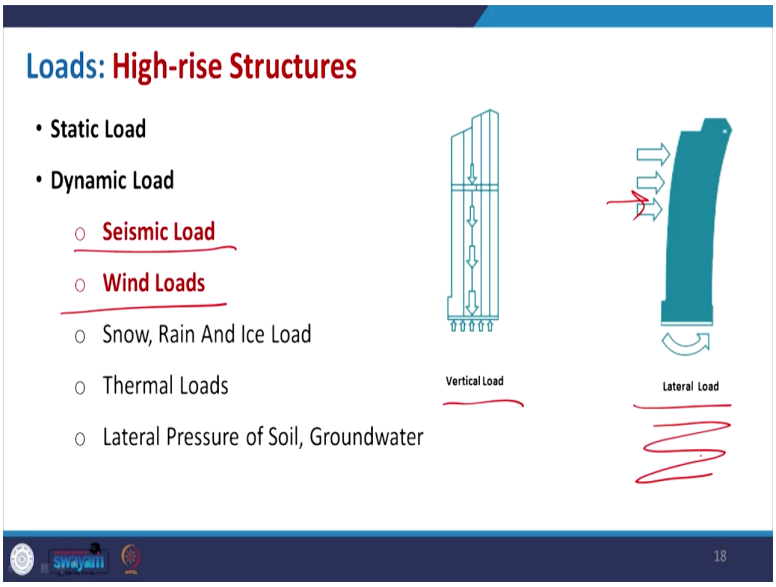
So, maybe in future we will get some even better material for the high rise structure. Then the construction method is again challenging the speed of the construction, the tools and techniques to be used for the construction for the high rise, that the need to be very much you know up to date. Because, the time of construction at the upper level the problem that you can face due to wind in a area and as we discussed earlier that with the increase in height; so, wind speed also you know affecting more.

So, with that how you make your construction, how you create all this structure in a proper manner is definitely a challenge, how that to be dealt with. So, this is another challenge for high rise, then the heating and ventilation at that height we cannot think of a natural ventilation or maybe the cross flow. So, we have to think of the heating and ventilation with the coated glass or maybe double glass as an, then how we can protect from the protect the building from the lateral wind load; so, that need to be thought of.

Then the lateral load, the aerodynamics and as well as the load of your earthquake that is your seismic load. So, that are two major concepts for the high rise building because, when the building height is low then come like your effect on wind are reduced. And, we only consider the axial load, the dead load, live load acting on a building and that can be tackled with your typical frame structure or maybe RCC structure.

But, when the we increase the height, the shape and size, orientation that will matter a lot and definitely when the building is too high that lateral sway will be even more. So, this is very important to know and these are the challenges and the engineers they always take care of these challenges, they simulate virtually, they simulate the building. And, they perform under different tunnel test, different seismic plate test and then finally, they conform the structural design. So, that your start will be in you know intact in real scenario as well.

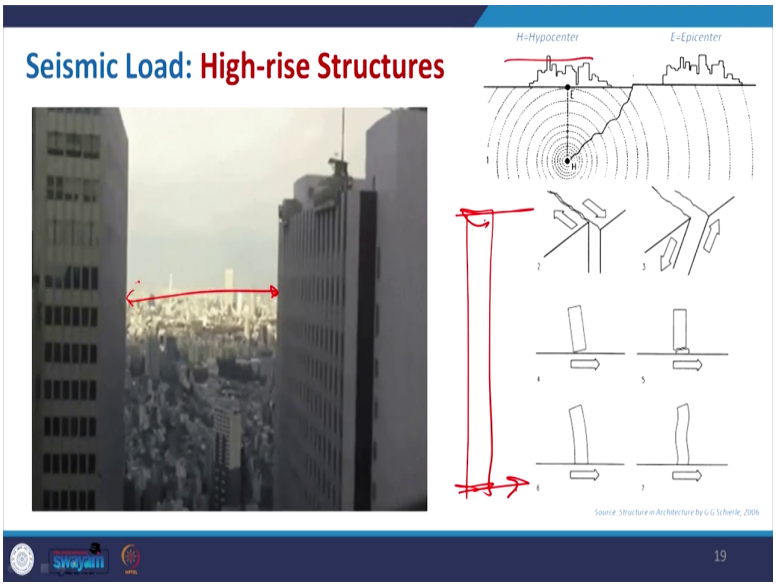
(Refer Slide Time: 21:30)



Coming to the loads acting on this these are similar load that we have discussed earlier, but here also with the context two important parameters which will be very much critical for high rise building. One is your seismic load and other is your wind load. So, normally if we again classify the load distribution so, one load will be your vertical load which is axial load, can be taken care of the column and other things and connecting beam.

And, other is your lateral load either with the wind or maybe the ground motion for like earthquake. So, the different wave being created during the earthquake, certain earthquake and then that will create a challenge.

(Refer Slide Time: 22:16)



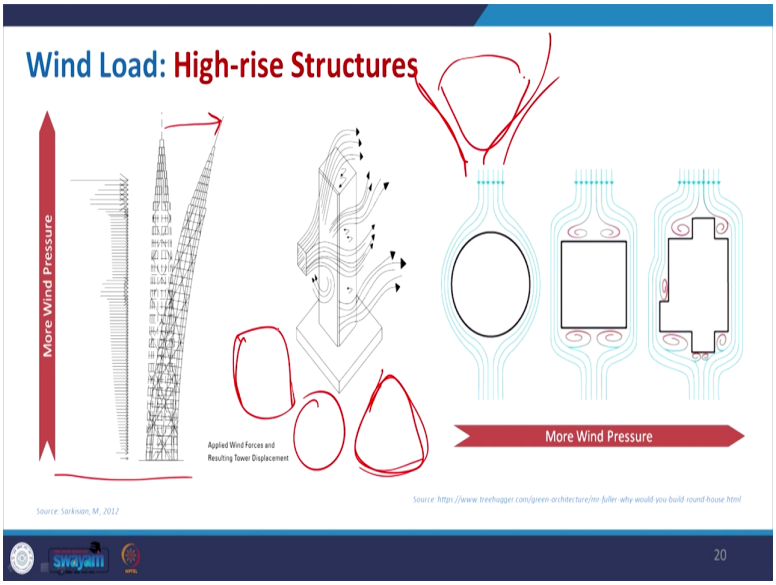
Now, with that in this picture if you can see that how this building, two buildings are actually sway it to each other, you can see that I have fixed that line and then how it is moving and from each other. So, whenever there is a earthquake occurs at the hypo center and then gradually to come up at the epi center and then how would wave are being spread out depending on the intensity.

Then there will be motion, different plate motion and for that the building can fall due to the liquidation, liquid friction or maybe it is just uplift or it may have a serious damage and damping. So, we have seen that well while we discussed about the structure like for earthquake prone area in that lecture we have seen that how things happen in that category.

So, for high rise it will be more vulnerable because of the height. So, definitely the movement at the ground and movement at the top, this even a fraction of second these are different and

that will create some kind of you know you know instability to the structure. And, if it is not properly maintained or it is not properly tackled with a different structural system so, it will collapse. So, this is very vital and there are different way of doing it earthquake resistance that we have already discussed.

(Refer Slide Time: 23:48)



Now, coming to the wind as I mentioned that when you increase the height more wind pressure will act on the building and you will have the sway. So, here you can see that building that the deflection for the it is a neutral axis, that how it deflects. And, also it depends on the form, the moment you have a very much you know circular form or maybe some aerodynamic form so, a wind can easily pass through.

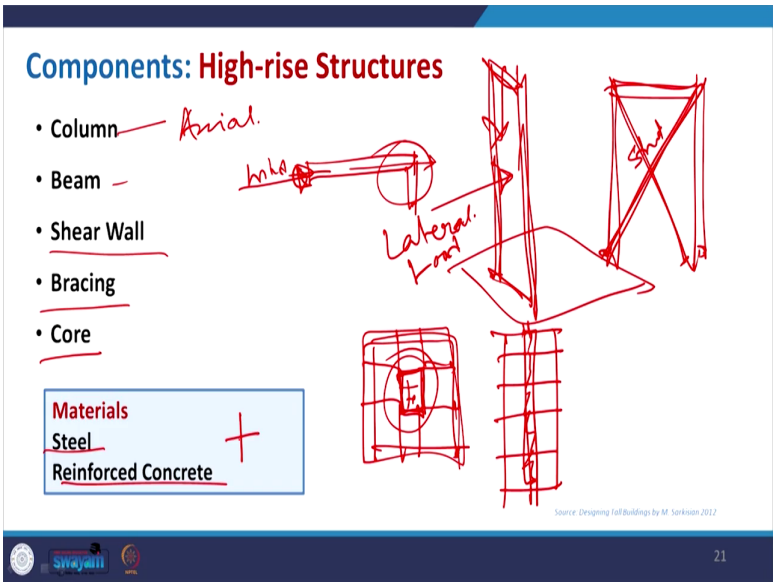
So, the wind pressure that the negative pressure of the drag effect not being created that much in this case. But, in case of a square building it is more than even if your building is having re

irregular shape so, it will be more vulnerable. And, that is why if you see that overall like all the high rise building will take a very basic shape, very you know regular shape either in terms of your you know sample triangular shape or circular or maybe a at that edge they just make a round shape so, that this can be easily taken care of.

(Refer Slide Time: 24:56)

So, like that if I just considered this is my building high rise building. So, in order to depict; so, I just to fix it like this. So, for the wind when this particular end is basically acting like a cantilever to the base; so, it will move much and where your base to the high ratio is too much. So, it will consider to with a tall building and the effect on the top portion of the building is high. So, for that we definitely need to make some structure which will resist again this kind of lateral load.

(Refer Slide Time: 25:36)



Coming to the components is a same thing like you have column then beam, column is a responsible for taking the axial load acting vertically that we have seen. And, the beam is basically taking the load of it is having dual purpose, this beam first which transfer for the load of the floor to the column and also it will take the load off the laterals. So, wind load or something so, that will taken care of.

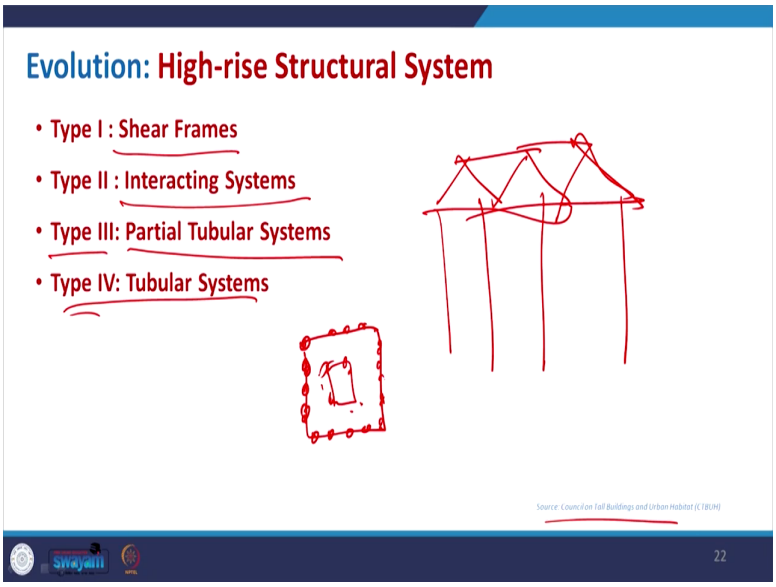
And, this junction is very critical for the seismic activity, it properly not done then there will be disaster. The shear wall is basically the wall simulate to a cantilever to the base. So, if you have a this plane and then you just vertically make this particular wall, shear wall; so, this will act as a extended column or something of similar which will resist the lateral load. So, for high so, for high rise building we use these shear walls to have more shear resistance or lateral for the lateral force.

So, then we will discuss that when we discuss the different components in next lecture. Then bracing we have discussed many a times when you have a frame in order to give more stiffness or rigidity, we just connect it with a diagonal start or member which is called bracing. So, that can be regular that can be symmetrical that can be both way and the core is another important component of that. So, when you are building we will have service, all the service are probably we can make my structure like main structural element, the main structural columns.

Heavy columns are put together very close to each other and we make the service core like this. So, it can be made of your shear wall as well which will essentially anchor this particular floor. This is a typical plan of a high rise building, where the outer portion may have some column. But, the main load being carried out by this particular course so, vertically if you see that your building is having multiple floor and they are connected with the core.

So, again we will discuss this core in next lecture, what different kinds of cores and their material. And, again the steel reinforced concrete, the material we can also combine them to go for a different competition with steel truss and the concrete frame or something like that.

(Refer Slide Time: 28:46)



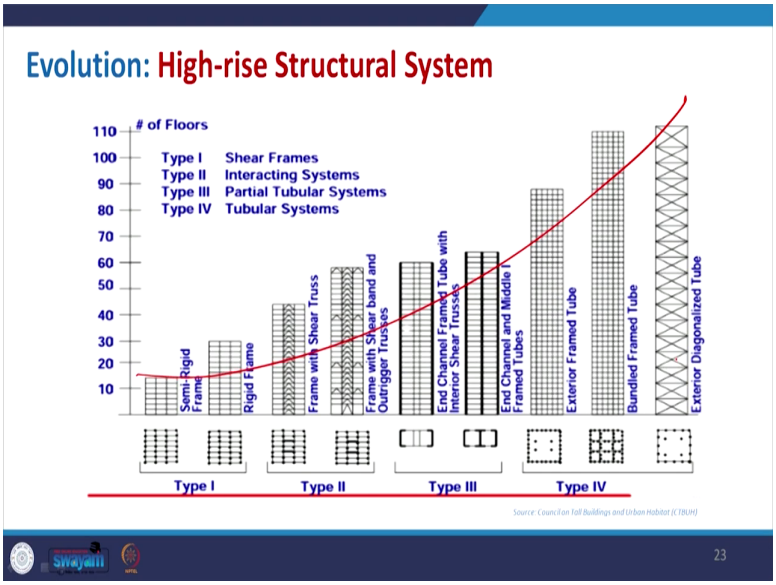
Coming to the evolution of the structure so, broadly its been classified as per the Council on Tall Buildings and Urban Habitat its being divided in 4 types; I is the shear frames, next is your interacting system where your truss steel truss is interacting with the concrete frame. So, both are having different advantages where the we know that truss will have because of this you know triangular you know so these will have better stiffness and can like distribute the load.

And, then the frame will have some rigidity where can take a you know your axial loads that can be combined. Then for more height, if you increase height then we should go for type III that is partial tubular system where basically you use this external portion, external perimeter and place your columns; so, close to each other so, that will form a tube.

So, that will give a basically a thickness to outer periphery and we make it. So, sometimes we may have this tube inside that partial tubular and then we can go for you know fully tubular,

where you can make tube inside tube. So, with this 4 category also we have a different way of classifying it.

(Refer Slide Time: 30:14)

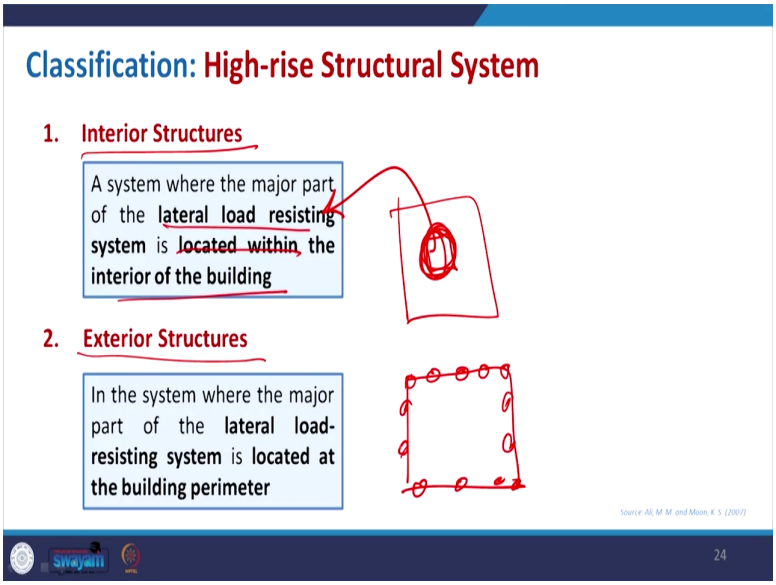


So, here you can see that how things will look like pictorially, in this pictorial representation you can see that rigid frame is basically column beam layout. And, then when it will be having shear stress; so, in with the frames you just you know partially make those frame with the you know truss and we include the truss; so, that will become your interacting system in type II.

So, with your frame you just include the shear truss into that. So, here also framing with the shear band and outriggers; so, this we will discuss in detail. Then we can go with your partial tube, where you can see that this with a shear wall that this portion is being made as a tubular section. And, then we can go for the perfect tubular system and also we can go with the bracing and then we can actually make some combination.

And, if you see that with the structure complexity also you can able to increase the height of the building, for high rise building we should can go and here it is a typical floor that had been taken. So, with a yours normal frame structure you can go up to 8 to 10 storey whereas, we if we apply this your tube structure we can go up to 110 and even more. So, all the storey that now you see the Burj Khalifa and all that is made up bundled tube, we will discuss in detail as well.

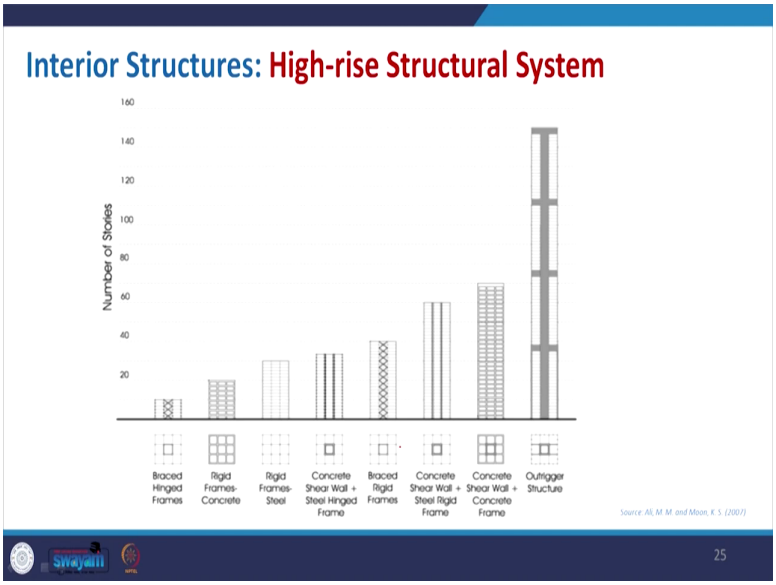
(Refer Slide Time: 31:49)



Now, again the classification is there the interior structure and exterior structure. So, based on that if you cluster then so, that system where the major part of the lateral load resisting is actually located within the interior of the building; means if we have the building and it is located at the interior so, this is called interior structure. Where, like this is basically the

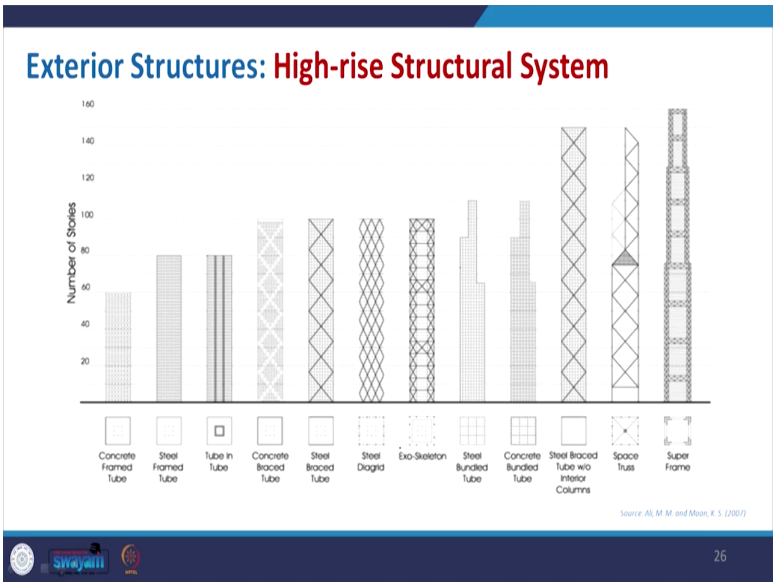
interior structure, where exterior structure that your (Refer Time: 32:20) with like lateral load resisting component are placed at the periphery; so, that will become your exterior structure.

(Refer Slide Time: 32:30)



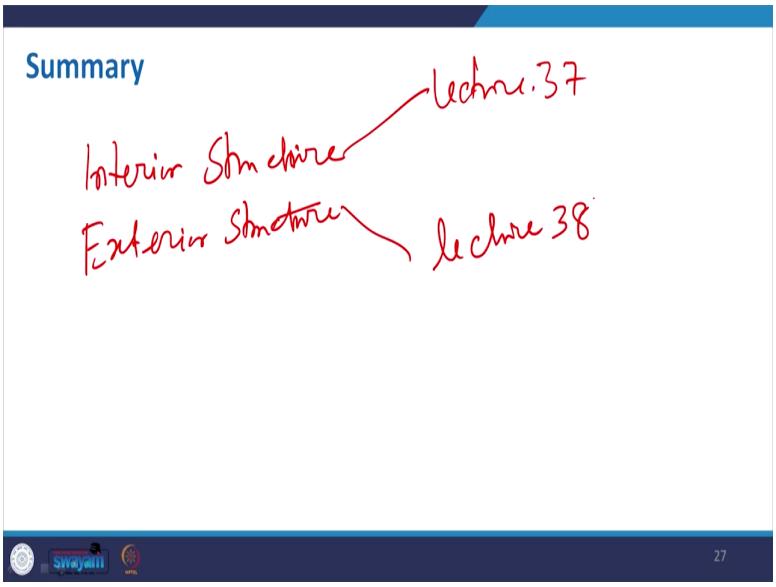
So, here briefly like if you see that these are different type of interior structure.

(Refer Slide Time: 32:38)



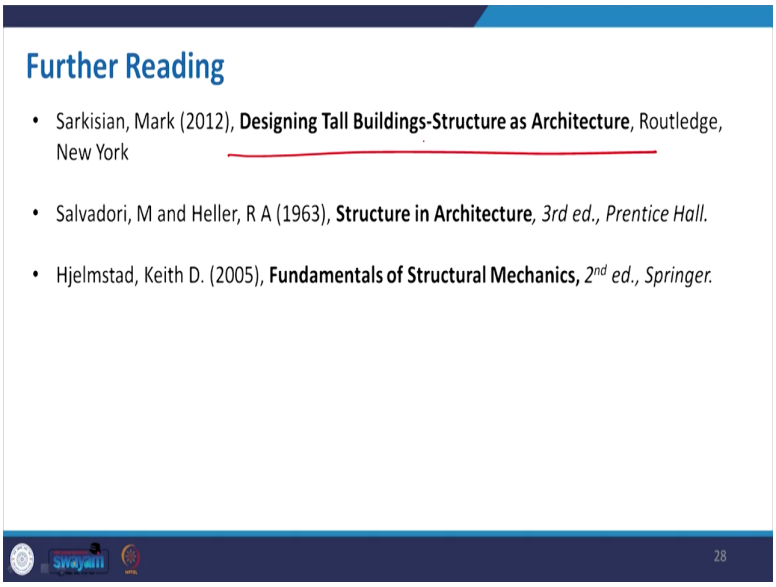
And, then these are your exterior structure; we will not go into detail in this part because we will have a like discussion separately for interior structure and exterior structure; then we will discuss one of this category. So, again if we go for exterior structure we will able to increase the height of the building. Whenever we think of a very tall building 150 storey or 250, we should go for exterior structure and then whenever it is within the limit we can go with the interior structure.

(Refer Slide Time: 33:17)



So, the summary is basically already I have discussed in details that from past to present that how the you know peoples aspiration to build high is being successful and it is continuing. And, then there are different example, broadly here we summarize with two type of structure. One is your interior structure and then we have your exterior structures and we will be focusing on that. So, next lecture the next lecture will be on this. So, this is lecture number your 36, so this will lecture number 37 and it will be discussed on lecture number 38.

(Refer Slide Time: 34:10)



So, we that I conclude here and this is the source that you can get many examples, this is especially a book on Designing Tall Building and it has a relation with the architecture. So, please go through this book, if it is available to your library or I will try to give some kind of more notes as attachment in the forum.

And, thank you all for you know taking part in this course, we will be meeting in the next lecture that is your Highrise Structural Component Part I. And, we will be discussing on the interior structure of high rise structural system.

Thank you.