Sustainable Materials and Green Buildings
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Lecture 47
Modular Construction

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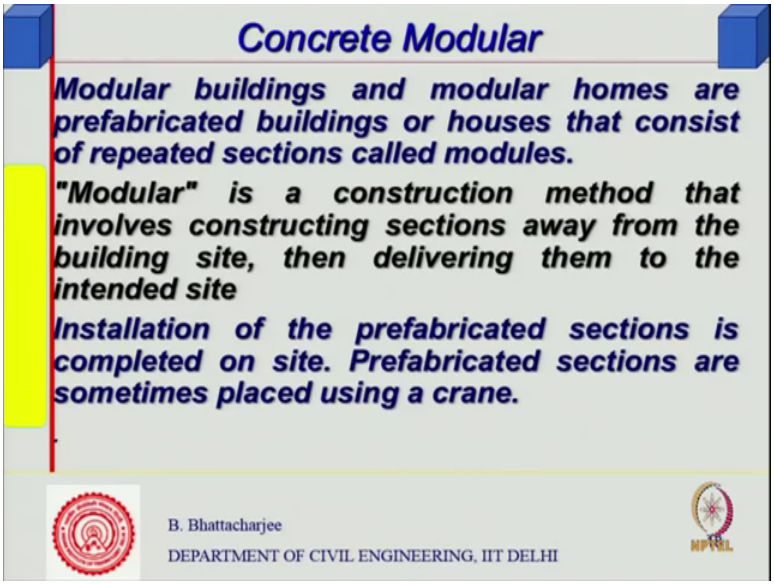

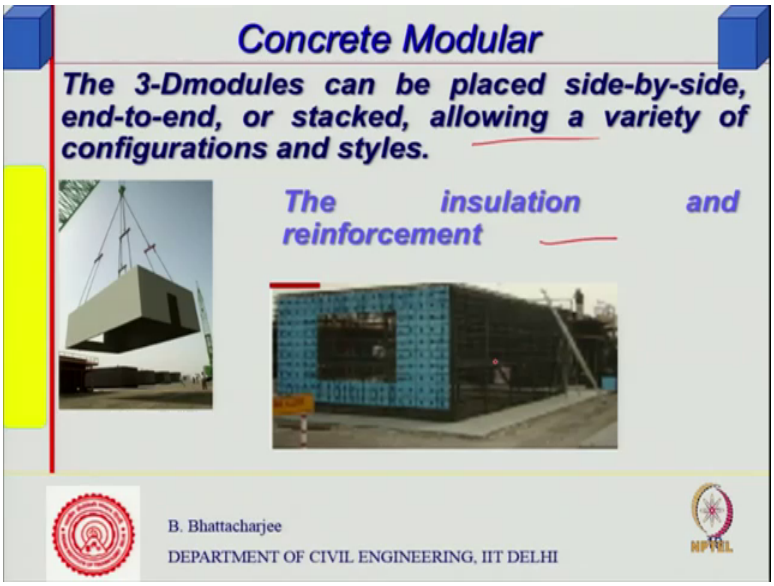

So, we will look at concrete modular as I was telling you, modular buildings and (mod) modular homes are essentially prefabricated buildings or houses that consists of repeated sections called modules. Essentially so it is a actually you know as you shall see it is 3 dimensional module, simply 3 dimensional module. 3 dimensional module. So complete thing that you will be

constructing, you will be constructing actually in this in the you know sections obviously full section away from the building site and then you install the prefabricated section and completed the site.

Obviously, there will be, you will be using cranes, so this is the casting of such a module. Actually you place them side by side so they are very suitable for places like where there are repetitive rooms similar kind of rooms, say hotel construction and hostels. So similar modules are there in the house I mean apartments or repetitive ones hotels or hostels and allowing variety of course configuration style so but it would be it it variety of styles is possible and you can insert insulation and (rein) reinforcement straightway at the site itself.

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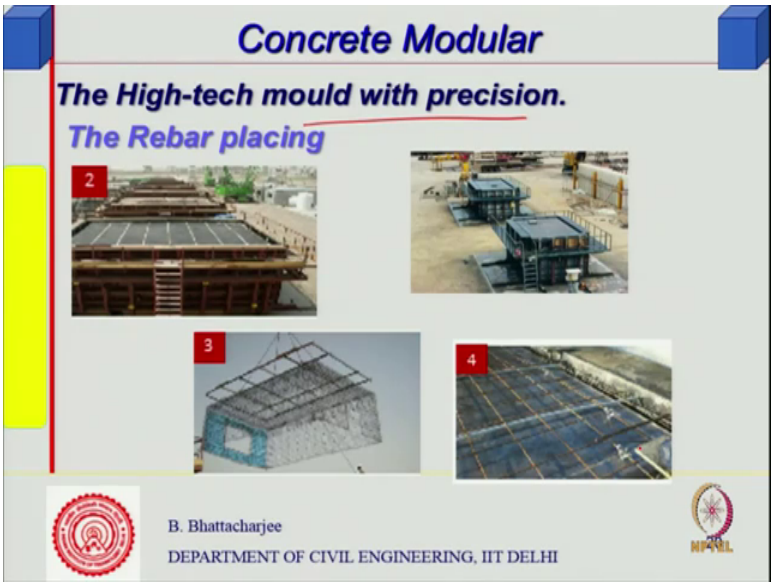

So they would possibly look something like this. There is a casting of a module casting of you know the set of so you have got number of, number of actually casting not a single bed number of casting bed, for each module there will be 1 bed, there is a kind of reinforcement, placing so then once you know the cage comes in, the whole thing comes in there is a formwork and then you do the concreting so precision is definitely required.

And repetitiveness although they are at a given location so you need number of repetitiveness and the cages you know you put it using a crane and once place then do the concreting. The Rebar placing is done something like this and then do the concreting straightway. So it is

basically (pump) pumped concrete, self-compacting concrete can be very easily used in this kind of situation and due to the casting.

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So 3D modules with self-compacting concrete obviously strength has to be high because section will be thin and it must take all handling load. Actually more crucial is the handling load, so minimum 40MPa concrete is what is required.

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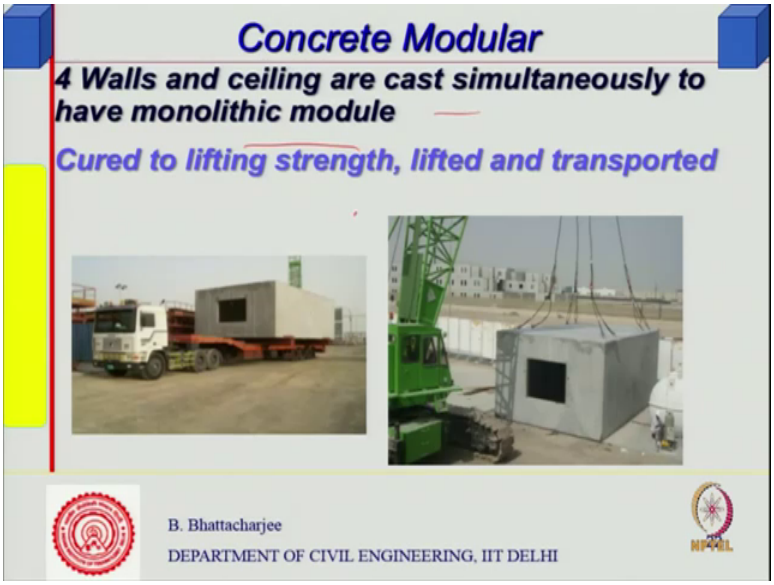

So then this is transported, whole module is being transported, lifted up and you know ceiling cast simultaneously monolithic module so everything is cast in one go, so it is monolithic even structurally it will act altogether. So structural stability from point of view it will act all altogether therefore, the performance better and you can save onto material. So cured to lifting strength minimum strength is required and then transported

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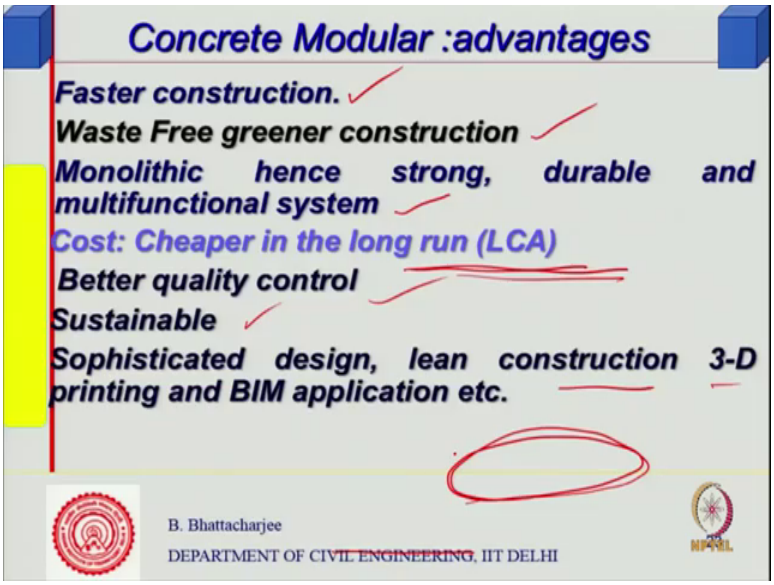

Then obviously this gives you faster construction process. There is much less waste generated in this kind of a system. Monolithic hence strong, durable and you can make multi-functional system. So you can use you know more sustainability this kind of system, material consumption is much less you can add on to any kind of insulation or similar sort of thing. So thermal performance or energy performance you can have better and in the long run it will be cheaper.

After certain number of modules that is 1 thing, break-even point, but since it is you know since it is you can built in design it according to your requirement of climatic requirement. So long run life cycle cost to Birla. Better quality control so therefore sustainable you can design sophisticated design is possible. You can use lean construction method in construction technique there you know there is methodology they use and some cases it might be possible doing 3D printing.

Now, what is 3D printing? 3D printing is nothing, this is a kind of you know technique which has come more from the first from the electronics materials industry using robots and then polymer

molding, now it is being attempted in concrete as well so what you do is you have a, you have a robotic arm with an (extru) extruding nozzle. So the concrete will be placed layer by layer.

You know so you built it up, so a true story concrete, continuous concrete not masonary like but then just concrete may be reinforcement or you know you can put in reinforcement and you put that concrete so what would the robotic arm do? It will just go through like this, put the concrete by layer (extru) through extrusion process although I am not discussing in detail this 3D printing. So you can make this sort of thing through 3D printing as well.

Obviously top slab there will be gap between the top slab casting and the rest of the thing because the whole all the walls will be cast will be cast layer by layer. So you can built in, so you can use 3D printing and building information modeling software you can use to see visualize how the construction. It can in and all those techniques can be easily applied. So that is all it is.

Obviously transportation is a, you have to take care of the transportation and therefore, you know damages during transportation and energy during transportation both. So damages has to be taken care of and then you will spend some energy during transportation. So that has to be taken into account.

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So this is what it is, so that is what. For example, concrete modular a building. This is multi-story modular housing block in London, December 2005. So this is all modular precast modular

concrete block. So you see they look all similar that is the thing. Repetitive units so each unit is repetitive and right so is a housing block, this is of course a housing block so they precast the whole thing, take it out and put it there. One can give this finish formwork in the formwork itself and that is what it is. So that is that is a concrete modular concrete, there is a last thing that concrete line but we have something to in the steel also, something in the steel also.

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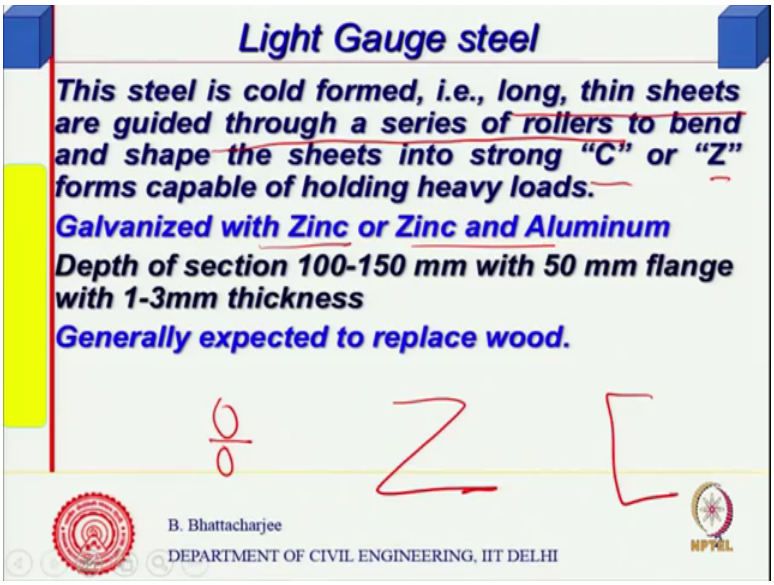

For example, as I was telling you light gauge steels. So this is cold formed that is what I was mentioning in the last class actually. Long thin sheets, long thin sheets are guided through a series of rollers to bend and shape the steel into strong C or Z sections. So you can have sections like these or section like a channel section C form capable of holding heavy load. So this actually work hard steel. You know you have already given some permanent deformation just come between the rollers, number of rollers and you have a several passes.

So thickness will reduce after reach pass pass. Material is same that means you have densified it or you have actually work hardened it altogether. Then you might galvanized with the zinc or zinc and aluminum. Though obviously the steel is steel cannot be exposed on its own because it will have a tendency to corrode. It will oxidize get oxidize very quickly.

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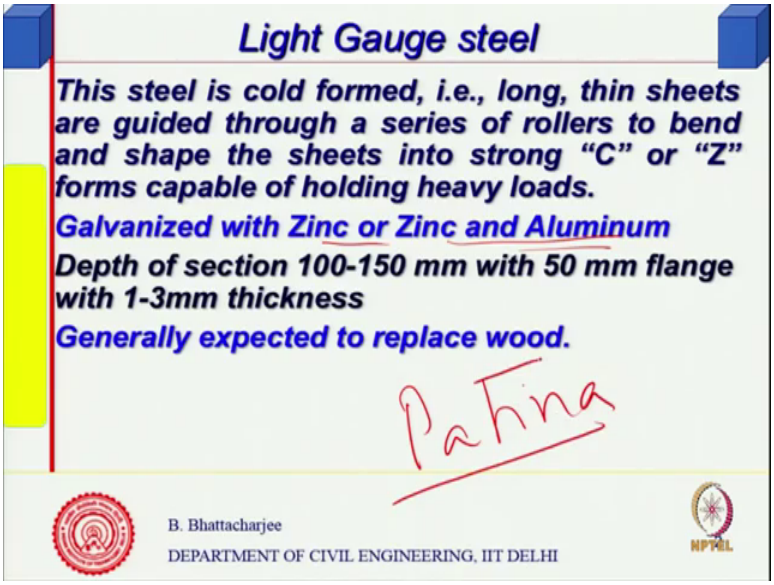

Now zinc is used as a as a sacrificial material there so what will happen is zinc tends to oxidize faster preserving the steel below. That is why this has been used more than few 100 years or zinc and aluminum which are more what we call anodic than the iron. So this will get oxidized and protect the steel.

Now zinc when get oxidized it forms zinc oxides and in presence of water it may become zinc hydroxide and atmospheric carbon di oxide through atmospheric carbon di oxide it might become zinc carbonate. So they call it what is a patina formation you know patina formation which actually is a dense material.

So actually zinc carbonate would be formed at the top, top layer because when when this is you know galvanization means it actually gets into the steel. Defuse as a part of it defuse into a (()) (10:12) so there is an interfacial layer, then pure zinc layer and there is at the bottom you will have pure steel layer. So the top zinc layer which finally forms kind of zinc carbonate which is very you know sustable, relatively stable material and do not get destroyed so easily get. Eventually it will get destroyed or thickness of the most of the zinc would get converted and eventually there can be you know it will take longer time, so that is the use.

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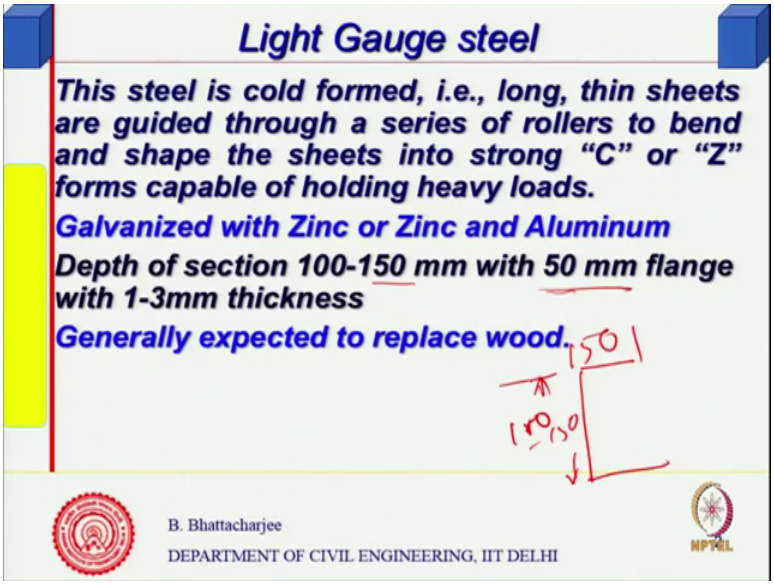

So therefore, steel you cannot use generally in bare form, usually section 100 or 150 millimeter with 50 millimeter flange or 1.3 millimeter you know flange you will get 50 millimeter so something like this 50, 100 to 150. And then thickness obviously is very thin because it has been compressed in a way pass through the roller.

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It was actually originally thought of thought to replace wood right it is originally thought to replace wood but because of its flexibility, fast construction and durability so it has got it is quite high potential.

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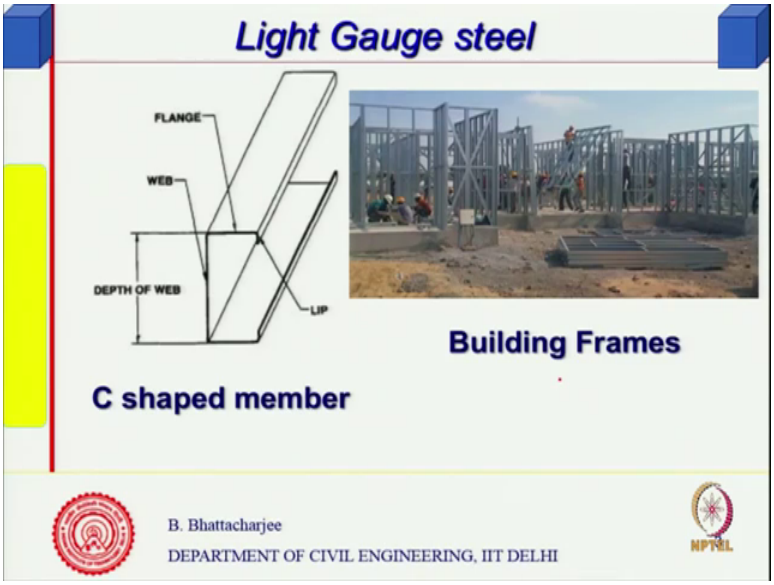

Something like this. So this is the depth of the web C section for example. This is a flange, there is a lip also you can have and there is a thickness. So this is how you know is of course I mean basically all prefabricated thing and then essentially making building frames out of this.

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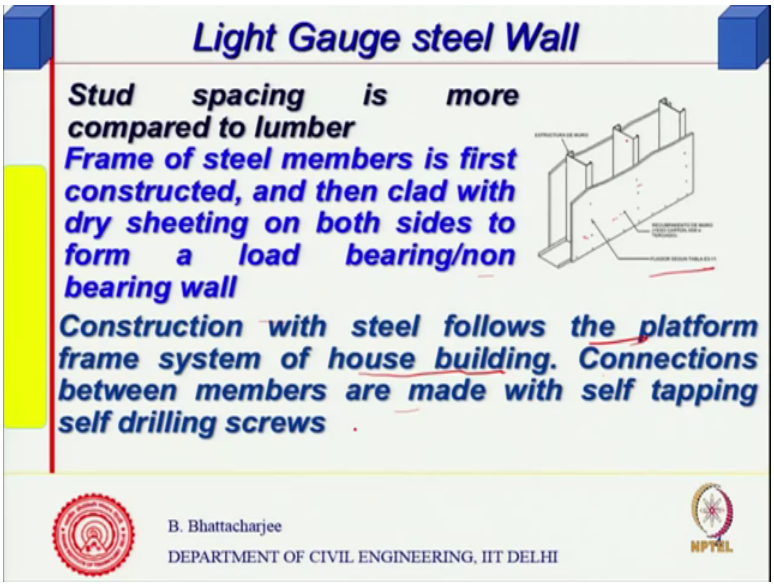

So you can have you know studs basically this is a this is a some kind of finishing right cladding you can have and this is this you know vertical members and frame of steel structures is first you then construct and then clad with dry sheeting so that is what it is. So you get to clad this on both sides to form a load bearing or non-load bearing wall system or roof system similarly so this is

the steel members, this is the final cladding that you see, so that you can choose. You know so basically essentially platform frame system is what is used, connection between the members are made with self-tapping or self-drilling screws. So between members these connections can be in a screw tight.

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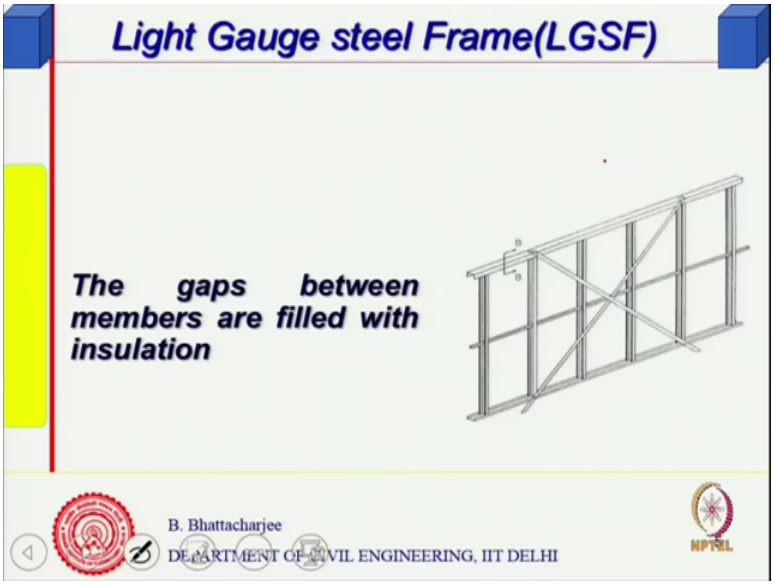

Basically thin members. So you can have you know threaded screw system or bolt system to cover this. You can have pre-punched section with factory made holes on them for ducts, whereas plumbing etcetera can easily pass through this. The gap between are filled with so this in between you put put in the insulation. So steel member in fact there are one or two organizations actually marketing them in India and we have a small building in the IT campus where we use this light light gauge steel small building right. So for measurement measurement purpose temperature and you know everything.

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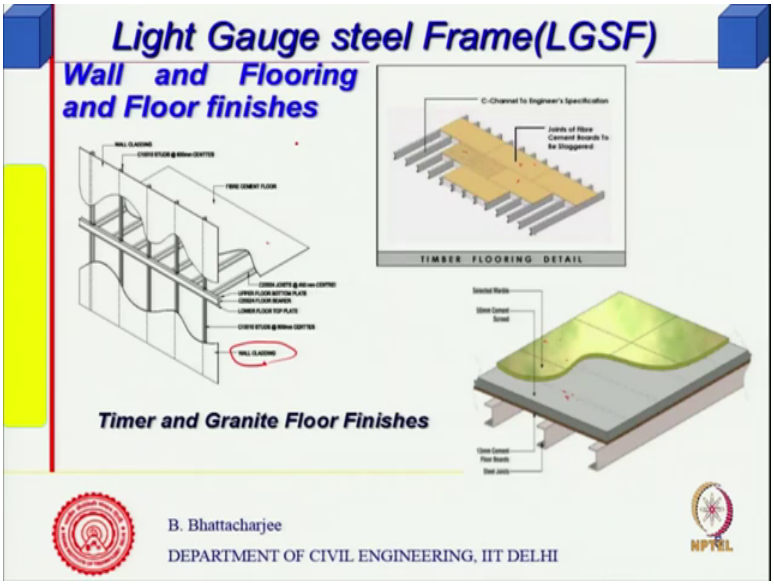

So gap between members are filled with insulations and this is what it would look like right wall cladding, then this is a this is actually your (flo) floor level. There is a C section, there are other C sections here, then you will have fiber cement floor or whatever you want. The type of flooring you want which will be at the top, right. So or you can have you know (tim) tiles, timber tiles something like wooden structures earlier that we used to do place the beams closely space beams and on top of that there is a cladding so it is been replaced by C channels.

So wooden button switch were used ideally the idea was to replace the wooden buttons and these are light gauge so therefore weights are not very large and then you have the cladding. So then you know somewhere you left joints the fiber board or whatever it is there can be other kind of finishers for example some kind of depending upon the type of decking you want you can put insulation on whatever the form of decking that you want you can do that.

So timber and granite, this is a granite floor finish and this is a timber finish and this is how it looks like. So light gauge steel you know so wall and flooring and floor system and finishing so they have high potential in that direction that they can also perform multifunctional you know performances it can exhibit and you can bring in all.

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So this is many places in North America, Australia and Japan they have been using this actually. So this is you can have pre-punched sections, sections with factory-made holes so that wires can pass through them, also since is a frame system you can now adjust doors, windows etcetera etcetera you know locally have (())(15:47) those places wherever you want.

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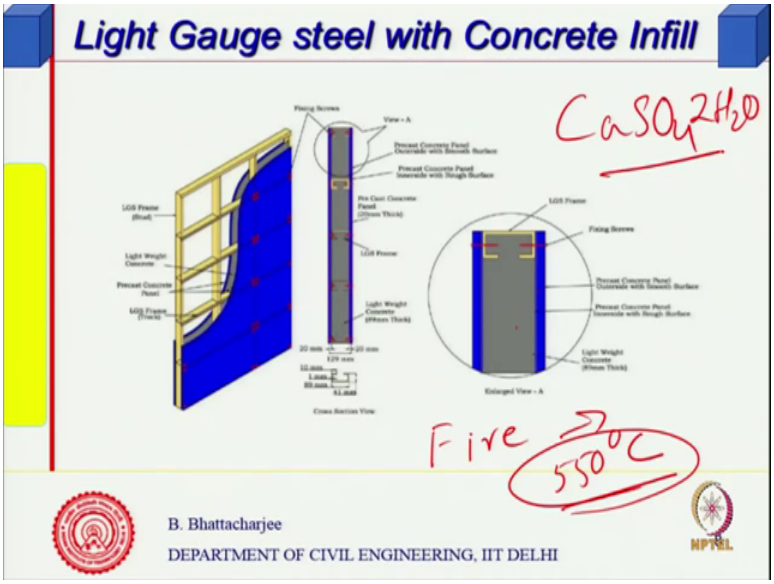

This is what another place is showing, for example, you can have you know pre-crust concrete inside. So you can put you can have pre-crust concrete. So this is your light gauge steel (fra) frame part of the frame and you can have actually or concrete system inside and pre-crust

concrete panel and you know (fillin) infill and so on. So there are varieties of possibilities are there. This is the frame, this is cladding and in between you can put in concrete.

If you want to make it heavier and obviously concrete has you know the one issue would be related to fire so the (clading) cladding must save it, cladding must perform in such a manner that the steel is you know protected from the fire because as you know steel is vulnerable to fire. Unlike two problems with the steel is, one is the corrosion which is of course taken care of by galvanizing, fire is the other issue, fire is the other issue, fire is the other issue because steel beyond 550 degree centigrade normal mild steel, it loses its strength significantly. Right so it will start warping and form inflect hinges.

So this is one point you know the fire is, steel is vulnerable to fire and it is a good conductor. So the fire it is exposed to fire at one point, all other points it will transmit the heat very easily. But, if the cladding normally, for example, gypsum board cladding they gypsum is calcium sulphate 2 H2O. So this ones when subjected to fire it absorbs heat and it gets actually this order of crystallization will go away.

So, and then remaining calcium (sul) anhydrous calcium (hy) it will become anhydrous calcium sulphate. Remaining what remains after losing this (hea) water which absorbs a lot of heat and whatever remain the anhydrous sulphate it is a good insulator also. So this is self is a good (insu). So the insulation property, fire properties of this one is very good and that is why we use gyp board and you will find the gypsum solutes.

So also the concrete which has got a, which has got a large mass thermal mass in the sense that row C. And therefore, it will not allow it will not allow, you know it transmitted from one side to the other or it is a good insulator. So generally concrete you know the (st) steel are encaged in concrete. Here of course you are not, you know you can encage them or keep it in the manner that you like. So essentially here there is a cladding and the concrete you can encage this so fire properties are enhances (())(18:45). So infill or fire properties.

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So building frames low rise it look something like this. Right it look something like this, so you can see that theses sections are C section and then there is an inverted C section. So the flooring system can be constructed in that manner.

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And light allow quick building without heavy tools or equipment. Every component can easily be carried by hand and like you know carpentry. So basically the idea was to replace the timber you know that was the idea. So therefore, we saw all from that side. Generally you need to for

you know you got to join by is screws. So that what it all it needs and since it is steel is strong, light gauge structures are lighter than wood frame structures and equivalent strength.

So it is much stronger than wood. Therefore, much less material you can use compared to wood of course. It is able to shape itself to any form and can be clad and insulated with wide range of materials. It is easy to change or modify this construction at any point in its life span because you can remove when you on the you know independent member and then replace them.

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So that slide you know that is what the main problem is fire it must be protected from fire with fire rated sheeting. That is one thing. Protection should clad the steel and fire rated you know fire rated sheeting or drywall. So that is what it is. So passage of sound more readily that is also a problem because sound travels you know (soul) sound (sou) I mean the insulation quality sound insulation quality of steel is not so good.

Although, because you got this thin section you know it is related to mass per unit area. M which is M is Kg per meter square in terms of kg. So insulation quality is proportional to mass per unit area. Now here thickness is very small therefore its insulation quality will not be good. Besides that, through the steel sound can pass easily. Through air it cannot pass but through steel it can pass easily. So that is that is therefore you have to take care of that.

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So modular construction so this is you know these issues are acoustic issues are important so what you can do is you can depending upon the situation you can actually introduce. Wherever there is a connection might introduce for example if this is, if there is an issue of acoustic transmission, so between these two might put some other material which is a kind of resilient material and things like that so you have to take care of this.

So, for example, something called floating construction, where you, at essentially what we do is in this one you might have a timber placed in between. Now here you have to put in some kind of a resilient material so one has to keep that in mind, fire and this kind of problem obviously is

there. You can have modular construction of this. So far we talked about framed construction individual members, linear members.

So modular construction factory-produced pre-engineered building units straightway. That are delivered to sites assembled at large volumetric components as a substantial elements of building. So off-site modular construction with light steel that is also possible like concrete. So modular units may be complete rooms, parts of the rooms or separate highly serviced units such toilets, lifts etcetera etcetera.

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So you can see that this is you know like as you see the these days there are portable boxes that are used in construction sites but people have constructed buildings with this kind of scenario of course the larger ones. The collection of discrete modular units we usually forms a self-supporting structure on its own. So therefore, you stack them one over another. So it is made of steel right.

For tall buildings may rely on an independent structural framework. So you can have a structural framework and then put them also, but otherwise for low rise building or something of that kind you can have simply modular steel boxes, steel spaces made 3 dimensional space modules made prefabricated lifted up and put it at the side.

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For example, this is what it shows a crane just putting the 1 module module straightway. So very useful again for similar where there are repetitive units like hostels, hotels and even apartments. So simply one can you know put them straightway the module.

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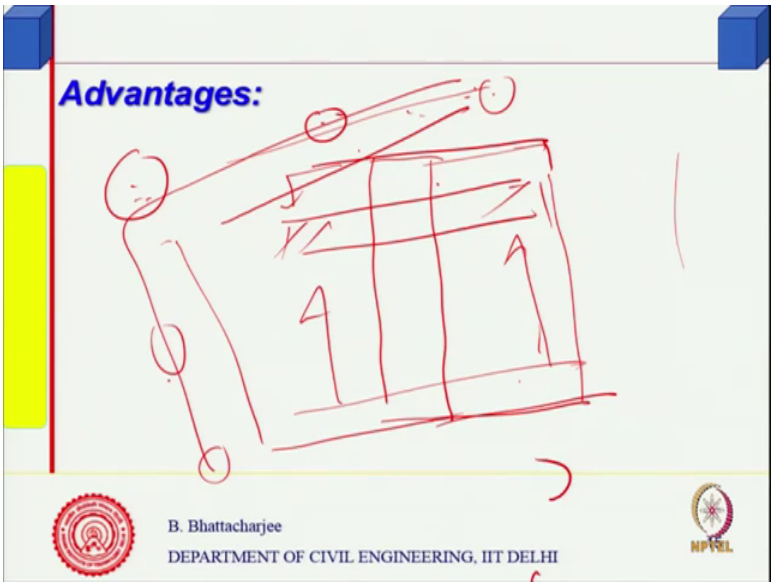

Of course I did not include it here, but there is something called top down construction, I did not it include it here but top down construction. What they do is, they will lift the quite useful for

office. Construct the shaft. Construct shaft which will be of lift shaft or something of that kind and inner core of a multi-story building and this can be done through slip forming rapidly with continuous casting. Then from this support lifting system, cast the whole floor at the ground floor level. Can be of steel concrete composites system, cast the whole floor construct cast you know so steel concrete composite system decking full thing you can cast including furnitures, everything you can put in.

Then this is lifted up straight away and placed here. So all casting is done at the bottom and you can have may be two, three towers and complete building can be cast in this manner it is pretty fast construction. Besides, you can actually bring in a lot of again multi-functional issues here. So next, the next floor will be cast here then it will be lifted up including furnitures they are lifted up. So the whole office is ready.

Like the Intel RND center, new building they were casting about a year back in Bangalore. So it was it was you know 7 stories, so they had actually 3 number of lift wells, number of lift wells you know I think is 6 or 7 so it is a L shaped building. So they did, this is 5 may be 5 or something I do not remember exactly how many of them are there.

So first cast, I mean construct this lift shaft which will take about months. Slip forming and the support the lifting system right on the top. Cast the deck here, cast the you know like whole floor here and lift if up straight away. So in it was expected to complete a 7 story building in 9 months time or something. So that is, that is another kind of form of you know so can be this this one. Since it uses low very low quantity of material all of them and wastage generated is very limited therefore they are they can add to sustainability.

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Anyway advantages of light is economy of scale through repetitive manufacture and rapid installations. So that is, then again you need a break-even number because you have to have you know set up factory basically. So high level quality control in factory production and low self-weight leading to foundation saving. Suitable project with site constraints and where methods of working require more off-site manufacture you know its advantages there.

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Okay, there will be disruptions in the surrounding is very limited and even in renovation projects, supposing you want to in (ex) rooftop extension you know we are considering let us say construct 1 floor above the block. For these 3 storied rest some of them will see the 4 storied, So (())(27:57) use this because there is a light weight. You can actually build an acoustic insulations here due to double layer construction. So basically if you see the section if you see the section see the section somewhere you can make it double layer I hope it is there somewhere, somewhere.

So basically it is you know this this all these are double lift and you can built in insulation there and therefore you know since you can built in insulation so you can actually get thermal as well as good acoustic insulation. Future extension is very easy because these modules are there you were to add you know on both sides right or left side which ever or top whichever side you want.

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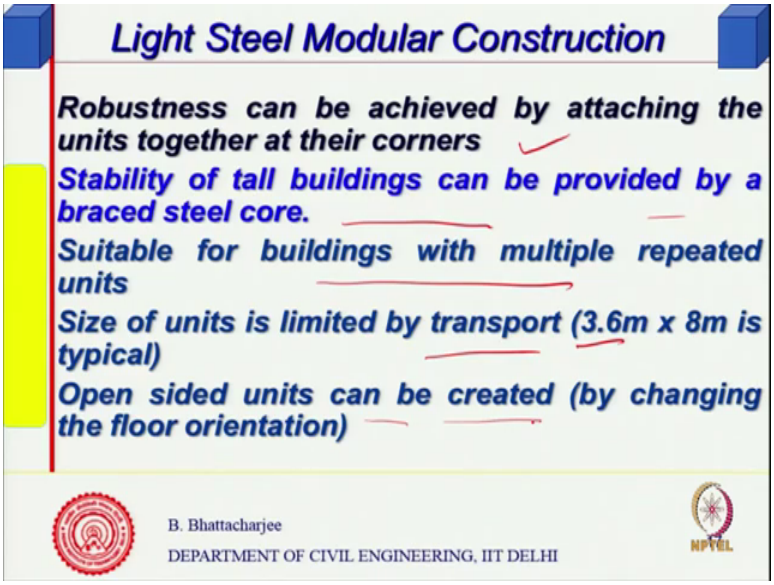

Okay, if you attach the units together right then they will, you know all kind of their structural behavior will be synchronized or together. So therefore, you achieve what is called robustness. So the issue should be otherwise there will the slide during earthquake or wind. So this can be actually taken care of by some kind of attaching the units altogether. Stability of tall buildings can be provided by braced steel core. So you can have a brace steel core.

And suitable for building with multiple or repeated units. Size of units is limited to transport of course, how much you can transport. So 3.6 meter, 8 meter is typical. So this is you know by 3.6 meter, by 8 meter that is the (typ) typical type of thing. So open sided units can be created. Supposing you want to keep one side open, that is possible by changing the floor orientation and so on.

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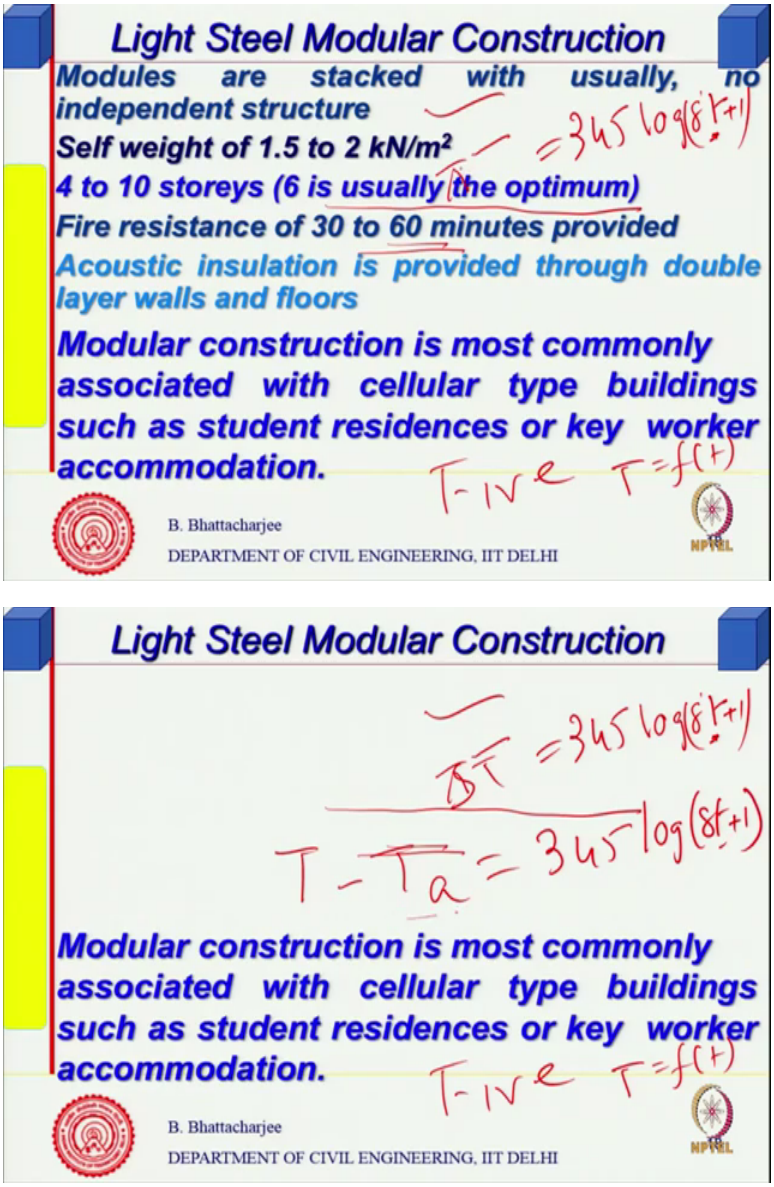

Modules are stacked with usually no independence structure generally you do not need a structure, but you can do that. Self-weight about 1.5 to 2 kilo Newton per meter square and good for 4 to 10 storey building. 6 storeys or something of that kind. Now fire resistance can be provided by providing again good fire resistance coating or some sort of cladding has to be there. Well fire resistance is you generally define in terms of time. It is the time, it is the time for which the element can withstand standard fire. Defined by some time temperature relationship.

Standard fire, fires are defined in terms of time versus (temp) temperature is a function of time. So typically the standard fire used for normal fire is 345 log 8 t plus 1. Log of 8 t, t is a (temp)

time in minutes and (temper) this is t delta t temperature rise. Or you can call it t minus t ambient is equals to 345 log 8t plus 1. So this is the furnished temperature and it is subjected to such temperature. If it withstands for 30 minutes then we call the fire resistance as 30 minutes. If it withstands for 60 minutes then we call fire resistance system as 60 minutes. So that is why you would have seen here it says typically you can have 30 to 60 minutes fire resistance.

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This this issue always remains whenever you are using steel the fire issue is always (the) is there and acoustic insulations is provided through double layer walls and floors. So thermal and acoustic layer so therefore 1 wall another you know steel and you can have insulation in between and if you have that is what it says. Cellular type of buildings such as student residences, workers accommodation, even apartments that has been done, so but, you know should be basically cellular type of building, repetitive units should be there.

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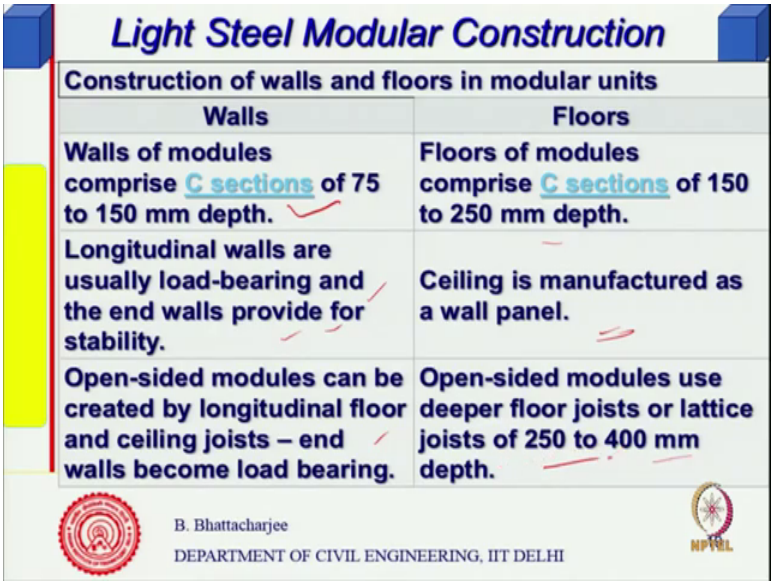

So you know generally walls should be C sections of typically 75 to 150 mm depth. Floors 150 to 250 mm depth C section again. So you may construct the floors with that. The difference is earlier you would have used light gauge elements fabricated as a factory and erected at the side. Now even if the building module you actually completed the factory and transport it. So longitudinal walls are usually load-bearing and end walls provide for stability. So longitudinal load-bearing wall also can be there. Ceiling is manufactured in the similar (pa) way as we said.

Open sided modules can be created by longitudinal floors and ceiling joists. End walls become load-bearing then. So walls are usually long walls are load-bearing the other one is just a supporting system. Open-sided modules use deeper floor joists or lattice so if you have one side open then you have to design this you know you have to have it accordingly.

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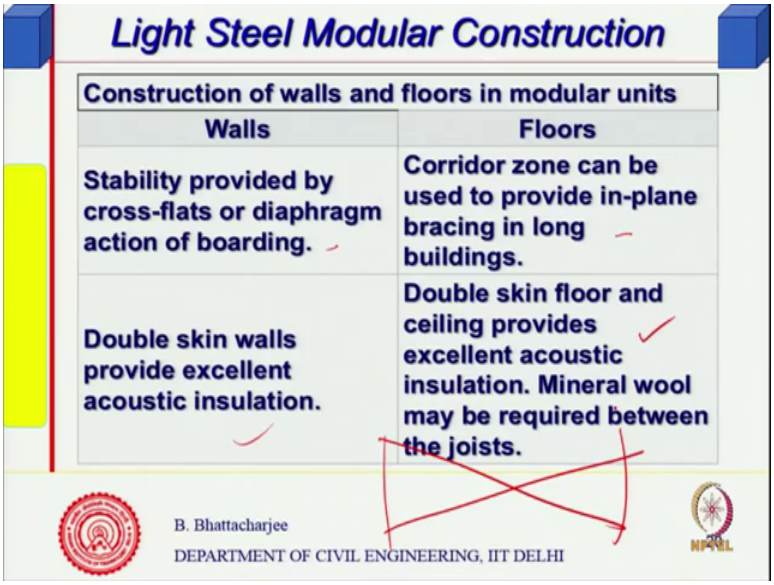

And stability is provided by cross-flats or diaphragm action of the boarding. So corridor zones can be used to provide in-plane bracing in long you know sometime you can have bracings to provide extra stability. Double skin walls provide excellent acoustic insulation as I said and floors also acoustics. You can put in mineral wool or some sort of light weight material which will act as an insulation

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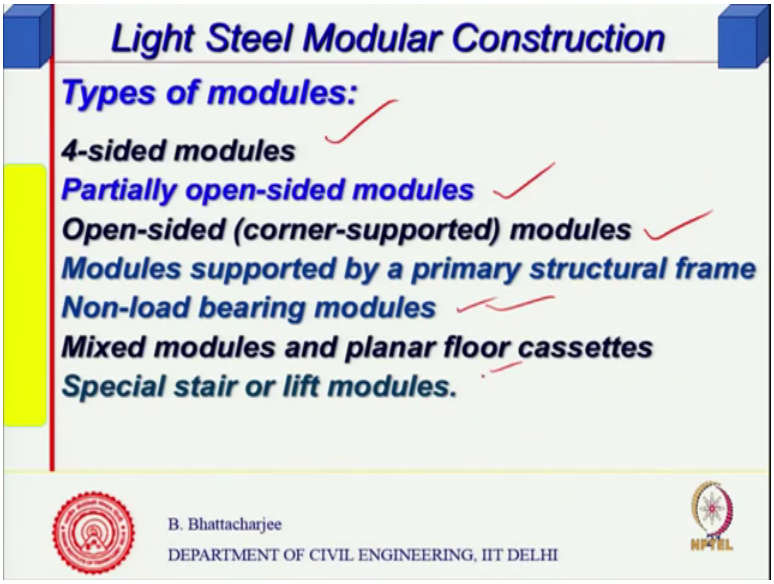

So 4 sided modules is partial, one sided modules. Open sided modules both sides open. Modules supported by a primary structural frame. Now supposing you made a structural frame and then

put in the modules. Then they are obviously not the (struc) part of the structural system they are supposed to take their own loads. Non load-bearing modules, mixed modules and planar floor cassettes. Special stair or lift modules so verities it is a modules are possible.

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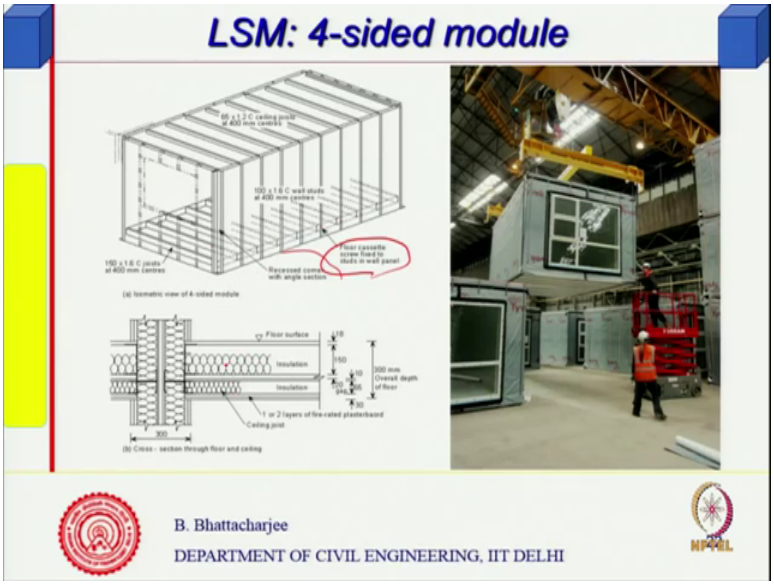

So this what is a factory you know at the factory they are lifting it lifting. So this is process of course corner floor you know the the individual members are here. C sections and insulations in the walls, insulation in the flooring system. Typical construction and then once fabricated they can be lifted up. Transported. So once lifted they can be this is a 4 sided module of course is showing and you can lift them up.

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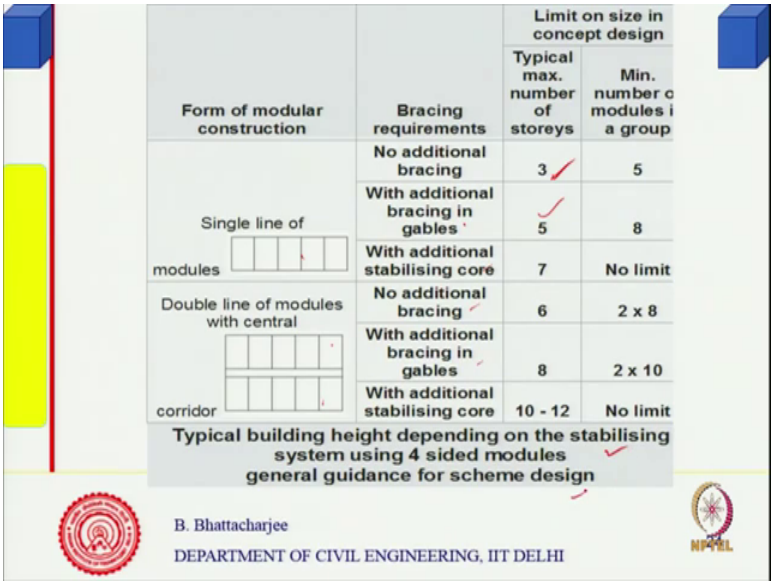

So you know single life of, single line of module is something like that bracing requirements. No additional bracing in this one. Typical maximum storeys, 3 storeys if you are doing you do not need bracing. If you are doing 5 then you need some additional bracing. If you are going for 7 then you have some longitudinal stabilizing core and minimum number of modules in a group.

Double line modules so you can have this kind of modules so construction you know the arrangement of this one, one can see. So you can see we have a corridor and the modules on those sides again bracing requirement etcetera etcetera are given. So typical building height depending upon stabilizing system using 4 sided modules, (gene) general guidance. So such system can be designed.

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And this is 4 sided open system. So you have just vertical members and there is a floor. So open sided module, completely open sided module. So you can have varieties of module forms and mixed combinations could be there. Judicious use of this combinations can provide good constructions.

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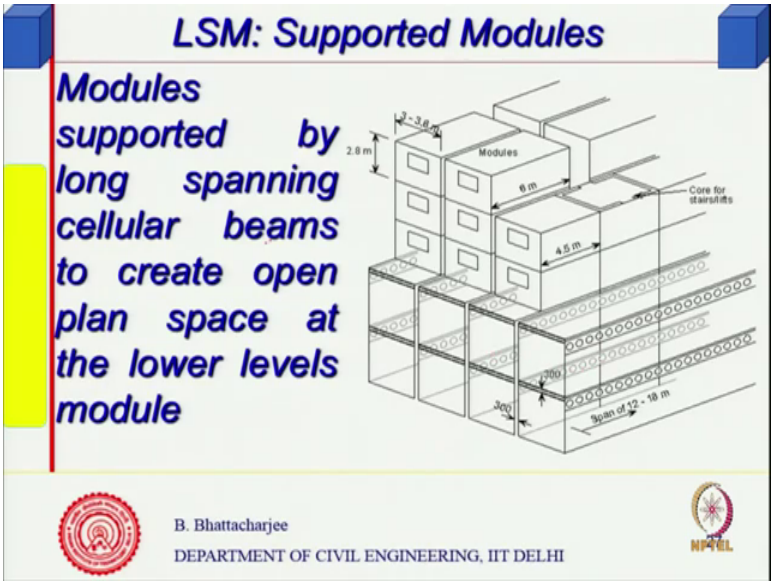

So this is a, this can be combination. Modules supported by long spanning cellular beams so this is a long spanning cellular beams. That means there are holes in this one. To create open space at lower levels of the modules. So that is what it is. So there are these lower levels, there is a, you know like this this is one, one type of module, the other is other type of module at the top and that is what it is, so 1 can one can have varieties of combinations of the whole thing.

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In this one the frame is there already then the modules is supported by the frame and installation of modules behind external firsts steel work has been (produ) frame you create then you put in the module.

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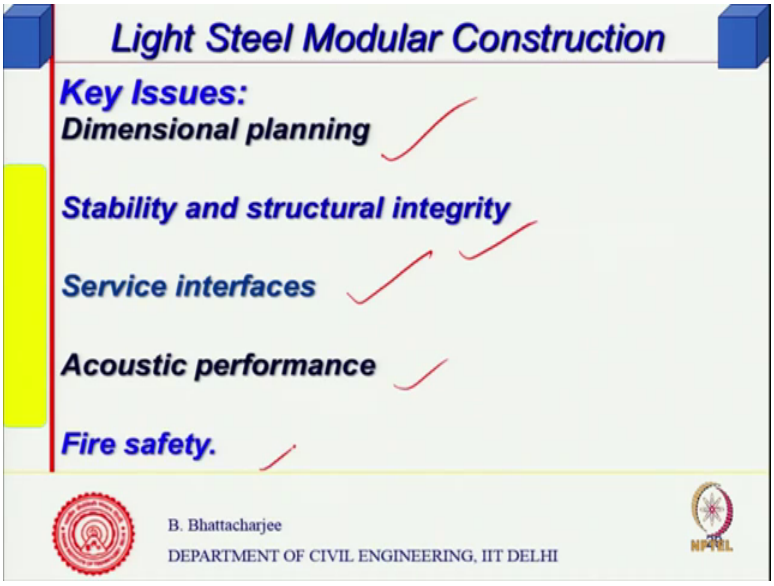

So key issues that are there obviously you have to have dimensional planning, stability and structural integrity, service interfaces, acoustics and fire performances. So these are the major key issues.

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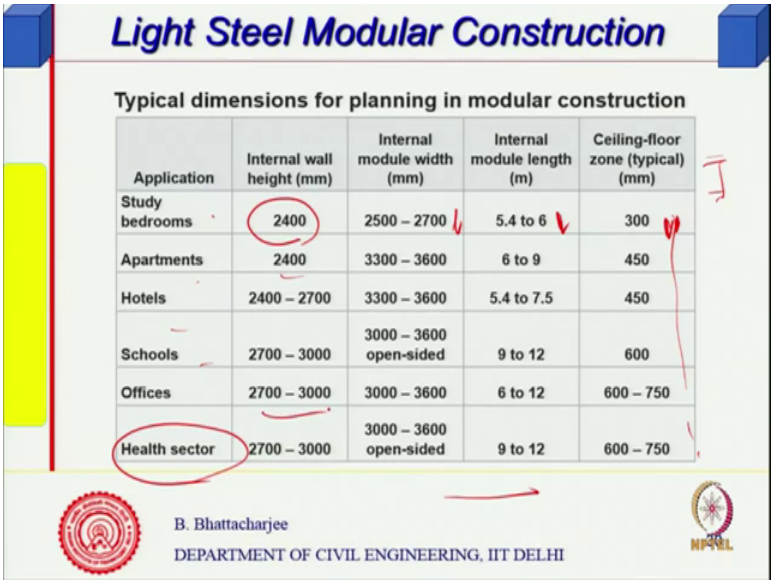

And typical dimensions of planning you know in modular construction okay internal wall height could be 2000 in study bedrooms (apart) apartments, hotels and so on. Width of the module, internal module length and ceiling floor zone etcetera. Typical in millimeter ceiling to floor the height and you know I mean you know in the ceiling floor zone basically ceiling in the floor zone ceiling and floor, floor height could be something of this kind. So this is you know this is what it is. Even hospitals and so on you can offices. So they can be use constructed used.

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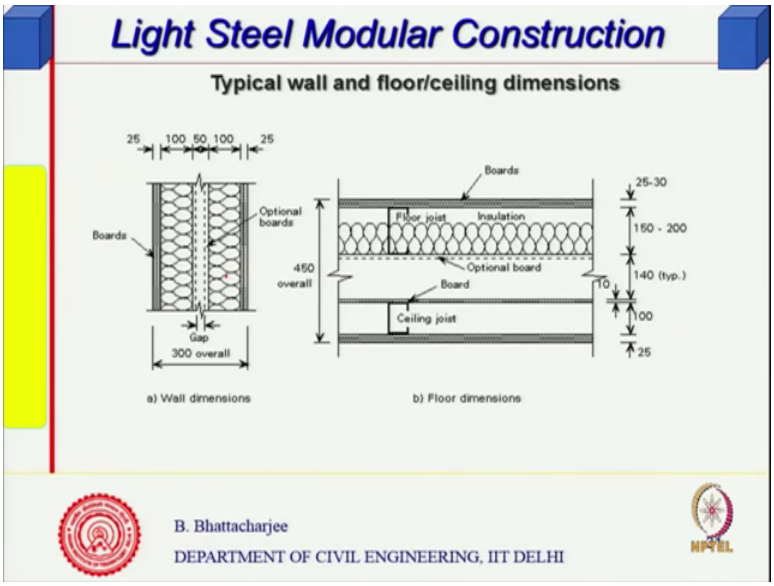

This is a typical wall dimension so you have got the you know this is a gap then there could be optional board and there is a insulation, this insulation there can be board and board and then steels on the other side. You know the (stee) steel is there. So 300 overall including the light gauge steel and it shows that floor dimensions you can have a ceiling joists somwhere here and then joists supporting these boards system. This is a insulation, there is another joists and so on so on, so one can built in all these kind of thing put together in the modular units that is there.

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So key issues of course as I said fire safety, good thermal insulation is there and sustainability take issues can also be taken care of. So that is what this kind of advanced construction technique which can be, which can make it sustainable. One issue is that they are using much less material, but initial cost is relatively high. So if this has to be done taken up. Then you must have sufficient market available for this kind of construction and that is the thing. Then the economics will work out, otherwise economic will not work out. So, if you have some questions, we will look into it.