Design of Masonry Structures
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Module - 01
Lecture - 03
Introductory - Part - III

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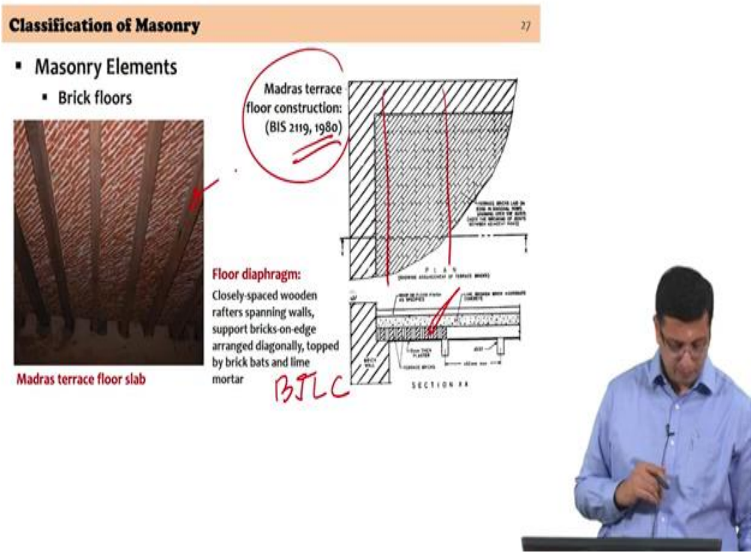

Floor diaphragms, brick floors, various configurations of brick floors are available. As existing masonry structures, you would be able to see brick floors which are composite, primarily made of brick masonry, but has a behavior that, to an extent is analogous to the systems that we are aware of or the system that we are familiar within the current context of modern constructions. Particularly, reinforced masonry, reinforced brick or reinforced concrete floors themselves.

So, this first category of brick floors that I am looking at, is referred to as, quite popularly as the Madras terrace floor. This is something that was predominant, prevalent in the Madras presidency and that is why it gets the name the Madras terrace floor slab. So, if you look at the configuration of the madras terrace floor slab, it is constituted by closely spaced rafters. There are timber rafters and these timber rafters are the main supporting system of the brick floor.

These rafters may be rolled steel joists in some situations and if you have larger spans that have to be spanned with the brick floor, you would actually have rolled steel joists in one direction and in the orthogonal direction, timber rafters or smaller steel sections. So, the main supporting system is a tension resisting system, tension resisting material. The timber being good in tension, if it is going to be steel, that also is a material that is good in resisting tension.

The compression strength providing element to the cross section is the brick layer that is supported by these joists. So, these are closely spaced rafters that you would normally see. The brick laying is typically brick on edge. The edge of the brick is what is sitting on the plane on which the floor is being constructed and this layer of bricks, the brick masonry layer is topped by concrete, it could be lime concrete, it would be even cement concrete.

Basically, we refer to this as brick jelly lime concrete, where broken pieces of bricks are used as brickbats and in lime mortar you get a composition called Brick Jelly Lime Concrete referred to as BJLC, typically in specifications brick jelly lime concrete is the topping layer. And, then if it is the last floor, you would have the weathering coat and probably tiles or if it is an interior floor you would have some tiles which are meant for tiling, finishing the floor itself.

Interestingly, this is a system that is of course, not very prevalent today, but a few decades ago it still had constructions been made using this sort of a system. If you examine the system, the composite system you will appreciate that the cross section is made up of the tensile resisting element at the bottom and the compression resisting element of the top.

So, if you look at regular bending, sagging moments on the cross section, it is very similar to what a reinforce concrete cross section would be. So, you have actually an IS code that details the construction of these floors called Madras terrace type floor construction and you must pay attention to the way the brick is laid on edge. And the way it is constructed, it is a unique process in which this floor is constructed.

Once the timber rafters are placed, the brick on edge is laid diagonally, in a diagonal fashion starting from one corner of the room that is been spanned across to the other end and this is typically carried out without the use of any props or scaffolding to hold up the floor system. The way it is executed is layer; the first layer of brick is placed, there is mortar that is applied to the larger surface, because a brick is placed on edge and the next brick is placed within a few minutes. And, in the matter of a minute, it will develop the bond with the mortar, and that bond is sufficient to hold it in place, it does not require a prop, it does not require any additional support system.

So, this construction proceeds without any support system and the diagonal alignment is also to make use of the link that you would get between, the maximum link that you would get between two rafters or the edge of the wall itself. So, this is a unique system where it is a pleasure to see the person who actually making this sort of a roof. It depends a lot on the skill of the workmen who is executing this sort of a floor. It is useful to understand the existence of such a system, because in many existing structures, masonry existing structures, if you are intervening you might encounter this sort of a floor system.

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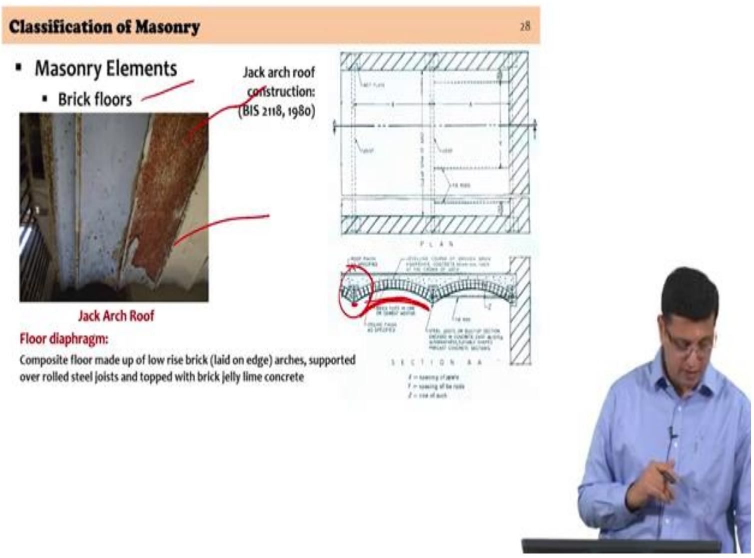

Another brick floor system that is again not a system that is prevalent today but can be found very well distributed in many colonial buildings across the country is referred to as a jack arch roof system. And in a jack arch roof system, in a way analogous to the previous typology that you have seen, you have a tension resisting part of the composition and you have a compression resisting part of the composition. In this particular case what is done is, you have a brick arch which is what you see exposed here, the plaster layer has fallen off and so you are able to see the brick construction and this is in the form of an arch, that spans between the two support that you see.

The supports are typically in steel, rolled steel joists are used. The arch is of low rise, it is not a typical semicircular or segmental arch, it is a very low rise arch or a segmental arch with a very large span to rise ratio and then over this entire composition you have concrete layer as a topping and then finished of depending on whether it is an internal floor or the roof itself. Again, there is an IS code that regulates the way this is constructed, a code of practice for the jack arch construction. And you can actually see how the arch itself is sitting between the rolled steel joist.

So, you have the I section here, what you see here is an I section. The I section spans across the room and then the I section itself is used for seating the arch and construction of the arch. What is of a challenge in the sort of a construction is protection of the steel elements from corrosion, and hence you can see that the rolled steel joist here in cross section is itself encased in concrete, but often the base flange is not encased.

You would find some situations where that is encased, but very often it is not encased and you can actually see the bottom flange exposed and often corroding, in various stages of corrosion, primarily because brick being rather porous can hold moisture and here you have steel rolled steel joist which needs to be protected against corrosion.

So, this is a rather challenging, it is a good flooring system; however, from a rehabilitation point of view it is a very challenging floor system. So, this is something that is prevalent in Madras, in Chennai, you can go around and see this sort of a construction in several colonial buildings across the length and breadth of the country itself. So, that is the second variety of brick flooring that you can see commonly.

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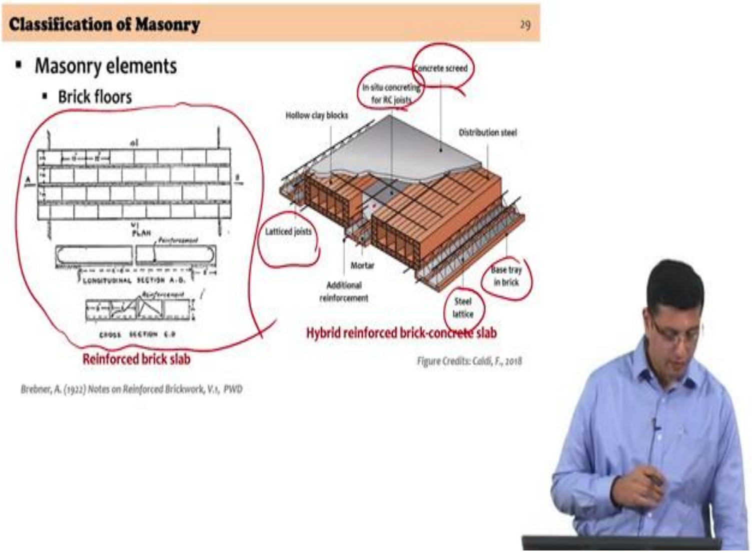

Of course, in the modern context we are more used to reinforced concrete floors. And this reinforced concrete floors in brick masonry buildings is a very common structural typology. The reinforced concrete floors act as rigid diaphragms and is a very common and useful typology in terms of even the lateral load resistance of a masonry building.

The diaphragm being rigid in plane has a positive role to play in the lateral load resistance of a masonry building. It acts as an element that ties the entire structure together if provided with bond beams along with the reinforced concrete slab; however, reinforced brick slabs are also not uncommon. In fact, reinforced brick slabs what you see in the slide here, this is reproduced from an early manual by the PWD and this is a detailed report which is on reinforced brickwork, reinforced brickwork and in this case, we are talking of solid units. We are not talking of hollow brick work, hollow block construction, but solid brick work.

Reinforced brick work for beams and reinforced brick work for slabs was something that was in use in the early 1900s, in this country in the Indian subcontinent and gained prominence primarily after poor performance of masonry buildings in some devastating earthquakes across the subcontinent. This gained prevalence as method for reinforcing walls in places like Quetta in Balochistan, where even the Quetta bond, which is a wall construction system with a void created to hold the masonry, is a development from the zone after earthquake effects on masonry structures.

So, if you look at the detail here, you actually have brick laid with reinforcement that is running between the brick work and this reinforced brick slab construction is something that is found in buildings that are early 1900 buildings in the country. But today this is again a typology that has a significant problem from corrosion perspective. Once the steel that is present in the brick slab starts corroding, the brick work starts spalling. Unlike concrete that spalls and you can repair concrete in a reinforced concrete slab that is effected by corrosion, with spalling and other effects on the concrete, repair of a brick slab is very challenging, because replacement of parts as a patch repair is not something that is simple. So, in situations of excessive corrosion damage, replacement of the slab is the only option that you would have. However, considering these difficulties and considering the fact that you have hollow blocks which are a good solution for reducing the weight of floor slabs or weight of any construction, Hollow blocks used as a part of a hybrid reinforced floor system is common.

This is again a typology that is not so prevalent in India yet, but in countries in Europe and New Zealand and Australia you would have these constructions, and if you actually examine this picture here, it give, it will give you a very good idea of what a reinforced brickwork cum concrete slab would entail. If you look at the cross section, you have got the main resisting elements which are really these joists, these latticed joists, they are basically reinforced concrete ribs.

They have steel reinforcement, they would run, span across the dimension required and we supported on walls or be connected to beams in the in the masonry wall or a masonry wall. These are referred to as lattice joists, because we are actually looking at different configurations of a steel lattice that is embedded in the concrete.

You have a base tray in which this is seated and that is what holds the lattice and that is the space that is finally concreted as you can see here. There is in situ concreting to create these reinforced concrete joists and the spacing of these joists would depend on; of course, the span and the kind of loads coming onto the floor slab itself.

Between these joists, you actually have hollow clay blocks which are good in compression. They are hollow**.** So, the weight is reduced in the slab construction, acting to give, could shear transfer to the entire system and the compressive strength that is required for the cross section of the slab in bending itself.

Finally, this entire construction is stopped with a concrete screed and forms the composite cross section that we are talking of. So, this sort of a reinforced brick concrete slab is something that is becoming prevalent in several modern constructions across the world.

It also has another advantage that you can actually have precast elements assembled and the screed concrete alone done in situ that will have all the other elements that are brought in assembled, they are precast, prefabricated, brought to the site and assembled and the screed concrete alone is the one that is executed at the site.

So, this is definitely becoming a popular system for construction. The other advantage is that when you have these hollow slabs, functionally, they may be used for some ducting as well. So, you have an interesting structural coum functional solution in the form of modern brick concrete floors.

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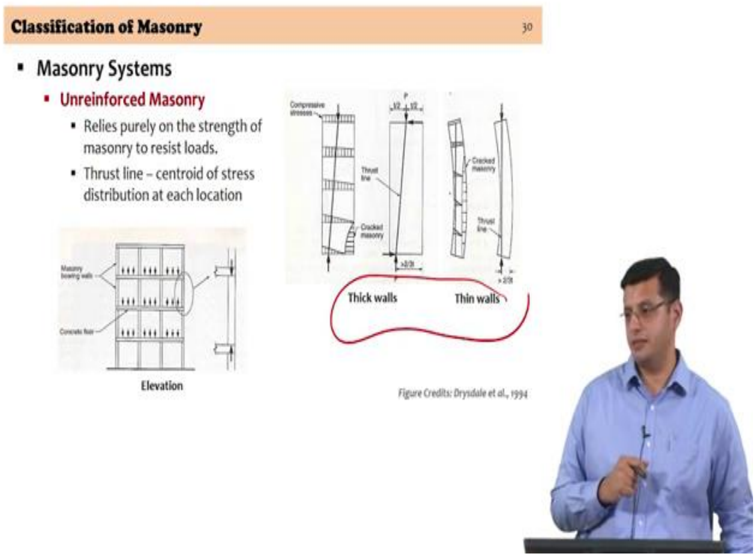

So far, we have been looking at the different types of masonry elements. We examined walls; different types of walls possible. We then examined beams and lentils, and these are, these have to be reinforced and then different types of brick floors between traditional and modern reinforced brick floors.

Finally, to look at systems, masonry structural systems and the classification of masonry based on their structural configuration, we will examine different categories. The first one is unreinforced masonry, where the word unreinforced is something that we are introducing, because we have started looking at reinforced masonry. Earlier this would just be referred to as ordinary masonry, because it is without reinforcement. The unreinforced masonry as we have seen earlier when we were examining the nature of masonry, it relies purely on the strength of masonry in compression, even in tension, in flexural tension.

So, if bed joint mortar has a finite, but small flexural tensile strength, it depends on the flexural tensile strength that the masonry will have to resist a combination of lateral and gravity forces. Similarly, it will depend on the unreinforced masonry wall to resists the shear forces. So, it is the wall, the strength of the masonry that is actually taking care of lateral, of lateral cum gravity or gravity loads alone. We have examined the thrust line as an understanding of how the resistance of a cross section and the component develops. From that perspective, if you actually look at unreinforced masonry walls, the thickness of the wall is an important aspect that cannot be overlooked and if examined why walls have to be of a certain thickness, this is to ensure that there is no tension, net tension in the cross section; however, we tend to optimize, we tend to optimize these cross sections if you are building unreinforced masonry constructions.

Today we might want to look at thinner walls, but the fact remains that if the resultant of the combination of loads crosses the middle third, then you will get cracking in the cross section. You will get tension in the cross section and if the material is of poor tensile strength then you will get cracking. If there is finite flexural tensile strength, the wall need not necessarily crack the moment you have tension.

But definitely, the thickness of the wall matters and slenderness ratios are stipulated by codes to ensure that you do not get into a situation where masonry cracks under combination lateral loads and gravity forces. So, this is definitely the first category. This category, because of its notoriously poor performance under earthquakes, has been almost outlawed in a few countries.

Countries such as New Zealand for example, introduced legislation that required that no new constructions be executed with unreinforced masonry, because when your land is highly seismic, you cannot have a construction that has extremely poor performance.

If it does not have positive features like good connections between walls that we have discussed earlier. So, unreinforced masonry is predominant today, in today's context mostly in regions where seismicity is low.

However, even if seismicity is low, we cannot classify any zone as being completely aseismic, meaning, if we do that then in case of an accidental loading even due to a low magnitude earthquake or low level of ground shaking, these structures can get into the inelastic range, which is not desirable and hence the direction in which most countries are moving, is to have codal stipulation that requires minimum earthquake resistance built in into these constructions.

Even if you are looking at constructing, the structures in the lowest seismic zone in a country, which is the direction even a country like India has adopted recently. So, unreinforced masonry as a typology in the future you would find only in existing buildings and those existing buildings if they are public buildings, it is mandatory that they are actually retrofitted against earthquakes. So, you should, you should see a shrinking stock of unreinforced masonry buildings. This as a typology is something that overtime will reduce.

So, if you cannot construct an unreinforced masonry what options do you have; and among the options the three options that we will examine, of course, two of them- reinforced masonry and confined masonry are possibly the most feasible, practical, and efficient as lateral load resisting load bearing masonry constructions. There is also a third category which we will examine, which is called Prestressed Masonry. However, that is not a very successful typology due to issues that we will examine in a moment; however, is a concept that works rather well for existing masonry structures.

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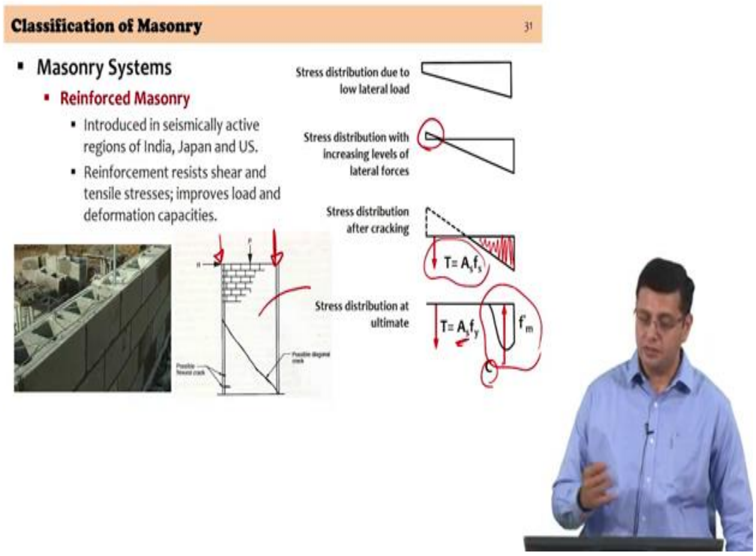

So, the second category is reinforced masonry and when you look at reinforced masonry it is, it is actually paradoxical that structural system like reinforced masonry was developed partly in India as well. And it is only in 2016 when the national building code introduced a section on reinforced masonry, that we formally adopted this as a structural system, almost a 100 years later. So, in the previous slides when I showed you the PWD technical note on reinforced brick masonry that was 19 late 1910s 1920s, but it is only in 2016 that we have formally introduce reinforced masonry into our codes as a structural design solution.

However, this has been a prevalent typology in a several countries which are seismically very active. United States, California, California district, Japan as you know, reinforced masonry and New Zealand, reinforced masonry is a highly a prevalent typology for construction of low to mid rise constructions. So, residential buildings, small office complexes and commercial complexes, all small scale in comparison to moment resisting frames like steel and concrete moment resistant flames.

So, you need to reinforce the masonry and so there is a certain difficulty if you are going to be working with solid blocks. So, the use of hollow block construction is conducive to the need to reinforce masonry, you basically have to be placing reinforcement in pockets and you need vertical continuity. So, going back to the discussion on stagger to avoid vertical joints and the need to have vertical continuity for you to put steel reinforcement, is something that needs to be examined carefully, because you still should not have vertical joints, stack bonding with vertical joints is not desirable.

But you must have continuous vertical cavities and hence bonds that allow for the formation of vertical channels into which we can have reinforcement is definitely a challenge which has to be tackled. So, if you have a reinforced masonry wall subjected to lateral forces, you have the masonry part of the wall and then you have the reinforcement sitting within the wall.

This reinforcement starts acting when the brick masonry starts cracking or the masonry starts cracking right. Now there are different possible mechanisms for cracking under a combination of gravity and lateral forces and hence depending on the geometrical configuration, are we looking at walls of an aspect ratio less than 1 or an aspect ratio larger than 1, masonry walls to resist in-plane shear, would have to be designed with reinforcement that matches the kind of mechanisms that you want to avoid at ultimate, at failure. So, shear and tension, flexural tension and shear caused due to a combination of gravity and lateral forces is what you would need the reinforcement for. This reinforcement of course, provides additional strength resistance to the wall.

So, strength improves, but more importantly we are concerned about the deformation capacity. So, the deformation capacity improves, because of the reinforcement you have distribution of cracks and additional lateral displacement capacity or deformation capacity that the reinforcement should be able to provide.

So, considering concepts that come from reinforced concrete, distributing the steel is a good practice. So, you should be able to look at configurations where steel is being distributed across the masonry walls. So, that distribution of cracking is achievable and if you distribute cracks you get better deformation capacity, because your steel can then possibly start yielding as the crack propagation progresses.

So, conceptually the way reinforced masonry systems work, is very similar to how reinforced concrete systems will work from a design and analysis perspective. So, if you take a reinforced or if you take a masonry wall that subjected to both gravity forces and lateral forces, the distribution of resultant compression is non-uniform, you would have lesser compression on one end of the wall, higher compression on the other, under the action of lateral forces which actually will be cyclic.

So, initially when the level of lateral loads are low, you will probably have a situation where the entire wall is still in compression, but this may not be the case. The design loads might themselves take the wall into cracking because of tension. The masonry wall might have some finite tensile strength and if the case is so, the masonry need not crack. You have the entire cross section still active for gravity and for lateral forces. This again, need not be the case with increasing lateral loads you would have cracking in the cross section and partial sections which will be available to you for equilibrium under gravity forces.

When you have cracking in a cross section, if the cross section is reinforced, you have the possibility of using the tensile resistance available from the reinforcement that is sitting there. So, tension is equilibrated in the cracked portion of the cross section by the rods that you are provided, the steel reinforcement that you have provided. And compression by the part of the masonry wall that is in compression.

So, that is how we would approach analysis in design of a cross section. Very similar to how we would approach the same in reinforced concrete and at ultimate, the stress distribution would be such that your masonry, the remaining part of the masonry in the cross section is now reaching its ultimate capacity in compression plastifies and your steel has yielded.

So, the tensile force that this cross section will equilibrate is equal to the sum of the area of cross section of all the bars, all the bars should have yielded into the yield strength of the bars, equilibrated by the compressive strength. Principles that we adopt in analysis of cross sections, in reinforced concrete are adopted in masonry with a conscious effort to understand how the masonry block and the grout which is within the masonry block, may work differently if they are of dissimilar materials.

If you take for example, a hollow clay brick block with concrete grout in the cavity, then the compression properties of the grout will be different from that of the hollow brick itself. So, the zone in compression may not necessarily be one single material, could be two different materials and you might you will also have steel reinforcement there.

Typically, we would provide symmetrical reinforcement. So, this zone in compression that you see, would actually, in the in the case of a hollow brick, hollow clay brick construction have the hollow clay brick in compression, the grout in compression and the steel reinforcement in compression. On the other cracked side, we will actually have only the steel reinforcement which is resisting. So, the cross section properties will change and you will have to consider the behavior of possibly three materials, in concrete we consider two materials and we are happy to go ahead with the analysis of the cross sections. That is the fundamental difference that might arise, other than that all concepts as far as ultimate strength limit state design is concerned can be adopted for reinforced masonry.

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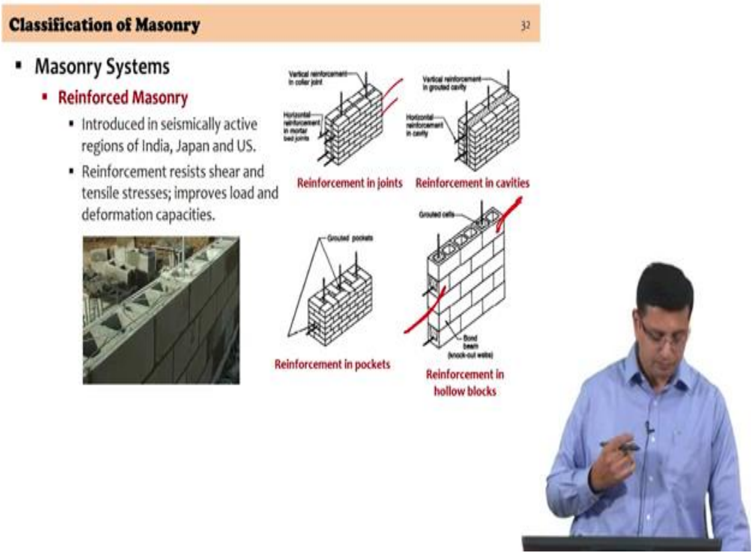

How do you place this reinforcement, the hollow block construction is not necessarily the only possibility that you have. There are different configurations different options available, like you saw the reinforced brick slab, it is also possible to place the reinforcement in joints.

Of course, if we place reinforcement in joints, the joints will become thicker and particularly when they are in the bed joints as you see here, if you place reinforcement in the bed joints, the reinforcement plus the mortar that is required for the joint, is going to be significant enough in comparison to the height of the brick work layer itself and this is a problem in terms of achieving good compressive strength of the masonry itself.

So, that is the challenge when you want to place the reinforcement in the joints. You cannot even reduce the mortar thickness in the joint, simply because you need corrosion protection for the steel that you are providing and mind you, if it is brick work then you are looking at a material which is rather porous and has high water absorption as its characteristic. So, something that absorbs water significantly placed close to steel is definitely not something that you, a situation that you want to create and hence you need a mortar joint that protects the steel from reinforcement. So, while this is possible, there are practical difficulties that one has to face are in terms of long term durability of such constructions. You can construct cavity walls and have the cavity the space in which the matrix of reinforcement is placed.

The vertical and horizontal reinforcement bars can be placed in the cavity and the cavity is grouted. So, this is a convenient way of construction. However, in this case the two leaves which are on either sides of the reinforced cavity have to be held together with use of metal ties again and these metal ties would actually go into the joints of the brick masonry or concrete blocks if you are using and these metal ties are again susceptible to corrosion.

The other possibility is to create pockets, create voids, we saw the example of rat trap bond, the Quetta bond is another possibility that by bond configuration you create a vertical cavity, vertically aligned cavity and horizontally aligned cavity; so that you run horizontal and vertical reinforcement.

Challenge of introducing vertical stagger and being able to get a continuous vertical void is the basic geometrical challenge that one would have in these typologies of reinforced masonry and finally, the hollow block construction where, with the combination of hollow block are as you see here and U shaped blocks you can get the network of horizontal and vertical reinforcement placed in the walls.

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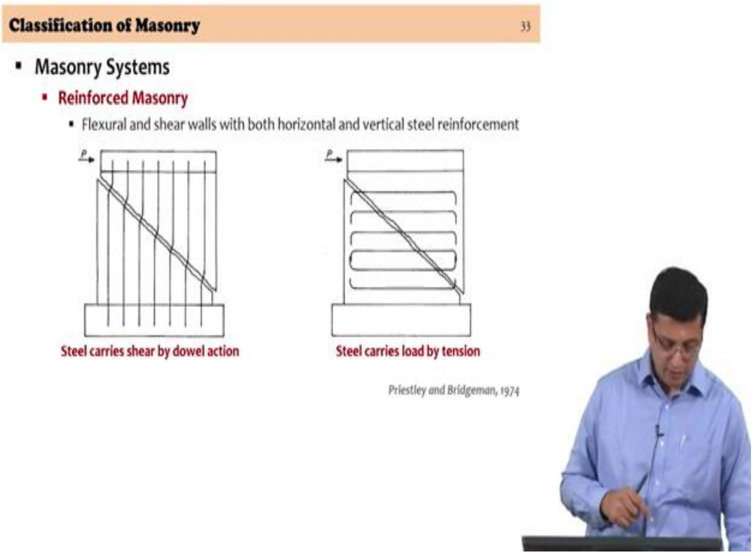

Again, when we talk of reinforced masonry it is a combination of both horizontal and vertical steel reinforcement because you need reinforcement to provide flexural resistance and provide shear resistance to the reinforced masonry wall. When you look at a wall subjected to in-plane lateral forces, the vertical steel, what is referred to as a longitudinal steel for a wall, a shear wall or a flexural wall, actually carries shear by dowel action.

So, with the formation of a diagonal crack, the steel reinforcement is spanning across these cracks and the resistance in shear is by the formation of dowel action in the steel reinforcement. Where as, if you look at the same wall the cracked wall with the presence of horizontal steel, the horizontal steel is in direct tension, is at different layers actually resisting the lateral forces by tension. It is established both experimentally and from an understanding of the behavior of reinforced masonry, that the horizontal steel is the one that makes the vertical steel work more effectively under the reaction of lateral forces.

Which means if you have a wall that is constructed reinforced only with vertical steel and a wall which has both vertical steel and horizontal steel, the wall with the horizontal steel can resist lateral forces almost three times as well as a wall without horizontal steel. So, the horizontal steel has a very critical role to play in providing the lateral resisting capacity to the masonry a wall.

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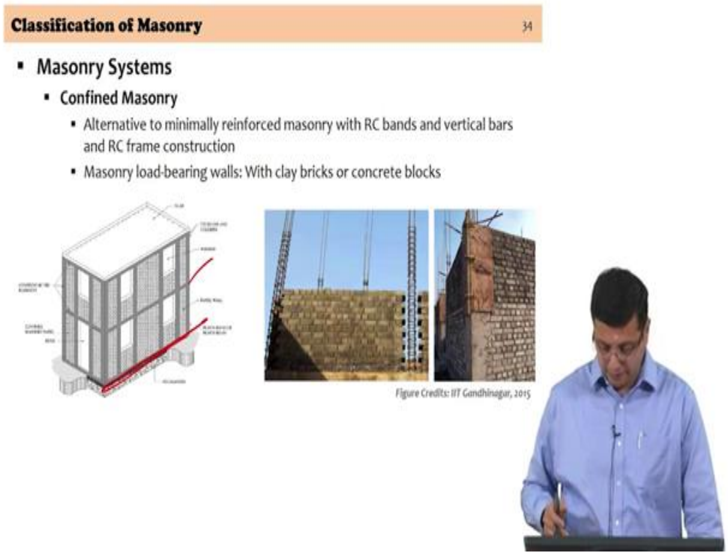

Confined masonry is the other typology. This is an alternative which has been developing over the last few decades, 5 to 6 decades, and quite predominant in many highly seismic developing countries. In fact, large areas of Latin-America have confined masonry constructions.

Confined masonry today is again a typology that the code has recognized and the 2016 version of the code actually has confined masonry as a structural possibility and is also a increasing in terms of numbers in our country as a construction typology. So, the interesting aspect of confined masonry is that, it is really a combination of a load bearing masonry system and a moment resisting frame. However, the reinforced concrete elements in this sort of a construction, are really not meant to behave as it would in a moment resisting frame. These are meant to behave as tension resisting elements as ties i in the vertical direction and the horizontal direction.

So, the reinforced concrete elements are acting as ties and they are not acting as flexure resisting elements as in a moment resisting frame. So, that is the fundamental difference between reinforced concrete moment resisting frame and confined masonry construction with RC horizontal and vertical ties. Another important aspect is the fact that the reinforced concrete elements, the vertical reinforced concrete elements do not have a foundation of their own. The load bearing construction is the masonry construction, that is all, which means the vertical bars, the reinforced concrete vertical elements come and are embedded in the plinth beam which is the reinforced concrete plinth beam.

So, you do not have, like you would have in moment resisting frame a separate footing for the columns. You would not have that in a confined masonry construction, that the masonry load bearing construction has running foundation over which a reinforced country plinth beam is provided and the vertical RC elements are actually embedded in the plinth beam itself. So, the vertical load carrying function is by the brick masonry. The lateral load resistance is also by the brick masonry. However, the RC tie elements improve the deformation capacity and allow for lateral resistance and good earthquake performance of these constructions.

In fact, the IIT Gandhinagar campus has almost all the residential buildings, 3 is to 2 and 3 storied residential buildings, hostels and faculty blocks and staff housing, constructed using confined masonry and we will be examining confined masonry as a typology for structural design and detailing.

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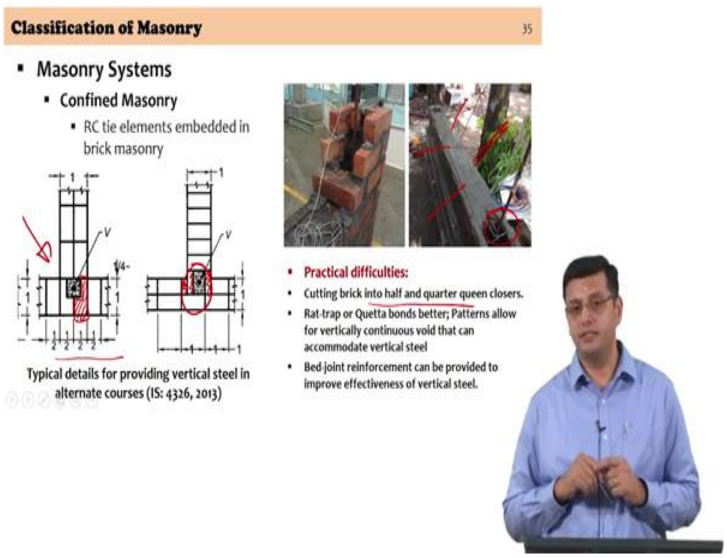

Another way in which you can achieve confinement, here it is referred to as confined masonry because you intend to provide confinement to the masonry wall. If you do not provide confinement to the masonry wall it is brittle under the action of lateral forces. It would not have the deformation capacity for good lateral load resistance. It will crack and fail with very low ductility.

The confining elements confine the masonry wall and provide the deformation capacity, the confining elements themselves go into tension and that is why we are talking of RC ties as beams and RC tie columns. Now you can construct confined masonry systems by having a space designated for the RC tie elements, the beams and the columns. You could also construct confined masonry systems by creating pockets and embedding reinforcement in those pockets in the masonry and this. I am touching upon this typology, because IS 4326, which is the code for earthquake resistant design and detailing of buildings in India, revised in 2013, actually provides detailing for solid brick masonry construction with these RC horizontal and vertical tie elements, where what you really need to do is create pockets by cutting brick, layer by layer, and then constructing the wall so that the vertical pocket is available, steel is placed and is grouted.

However, this construction is quite challenging because if you look at the drawing; if you look at the drawing, the shape of the brick that you require is rather difficult to achieve unless you are going to be manufacturing the brick in that shape. But it is actually uneconomical to manufacture brick in that shape, numbers will be low and time taken and the cost for some bricks would be more than the rest of the bricks.

So, it is, it does not make sense to create bricks like that. You can again see that you have different sizes of bricks that will be required and this creates a lot of difficulty in the field to actually cut the brick to that size; there are lot of wastage and the workmanship is also affected due to this sort of a sort of an exercise.

So, you need to cut bricks into half and quarter queen closers for a given coarse to ensure that the vertical stagger is not there. We use half quarter bricks and that is called the closer and here if you use his closers, you are actually going to a have to break these bricks and you also have to break them in the shape that is shown in one of the courses and the alternate course here.

If you can actually use something like the Rat-trap bond or the Quetta bond, you can actually can you can create a cavity without having to break these bricks into funny patterns like the one that you see here. So, that is definitely going to be a challenge. To make the confinement effective and to ensure that the vertical steel that you are providing also works well to provide deformation capacity, it is useful to provide bed joint reinforcement as you see in see in this picture. Here you see that there is bed joint reinforcement in the form of a truss, that is placed and that goes around the vertical steel itself.

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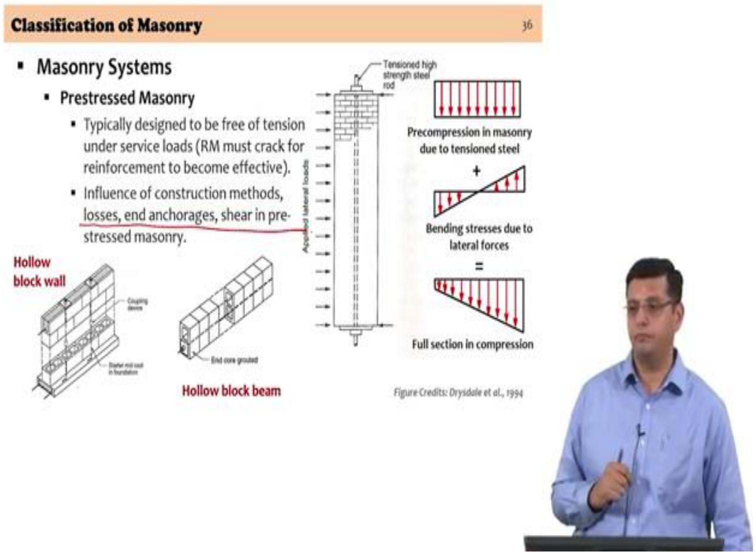

The final typology is Prestressed Masonry and basically in reinforced masonry you require that the masonry cracks and that is when the reinforcement starts working, but in prestressed masonry you do not wait for the masonry to crack, you are tensioning the bars such that you introduce the precompression and the pre compressed masonry works to counteract lateral forces and gravity forces together. So, the main difference between reinforced masonry and prestressed masonry is that here you do not have to wait for the wall to crack for the system to be effective.

So, this is again with the use of hollow blocks, you put in your reinforcement, you put in the cables and the cables are tensioned to create the prestressed system itself. Beams also can be created using such a system; however, this particular typology has not taken off because of several challenges. The fundamental notion here is you have pre-compression due to the tensioning in the steel.

When you get bending forces due to lateral action you get tension in the cross sections. But, because you already have a precompressed wall the net tension is no longer present in the cross section, you have the full section which is in compression.

However, there are different challenges, particularly the losses of prestressed because of the end anchorage, because of creep in masonry, this has become a typology that is not so efficient owing to the losses that can come into the construction and the effectiveness of the prestress can be lost.

So, it is a very cumbersome process of construction and then finally, because of these issues you lose the prestress faster than you would do in reinforced concrete you do not have a very efficient system. So, as a new construction this is really not taken off, but for improving the performance of existing systems, the prestressed masonry is a useful system, ok. I will stop here.