Design of Masonry Structures
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Module - 01
Lecture - 02
Introductory - Part - II

Good afternoon. So, to continue with what we were looking at in the last lecture; let me just quickly summarize the key takeaways from the last class.

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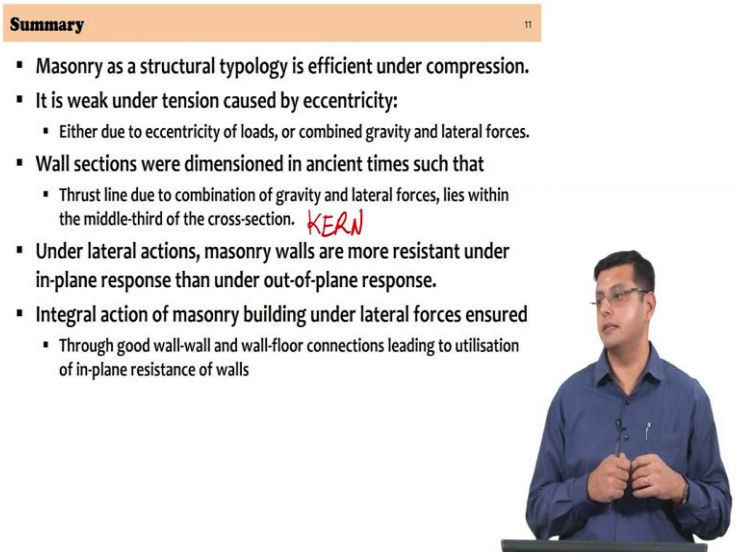

So, we saw that as a structural typology, masonry is one that is efficient under compression and that is utilized quite a bit. We saw the arches and even tall structures are possible because of this good compressive strength of the material itself. So, that is definitely something that you should give due consideration to; however, it is weak under tension and it is not direct tension that we are talking about it, but tension that is caused by eccentricity; eccentricity either of the load itself or eccentricity of the resultant due to a combination of lateral forces and gravity forces.

So, this is a significant weakness and the modern day solution is to go for reinforced masonry, but in the past this was not countered by reinforcing masonry, but rather by dimensioning walls in a way that you have the thrust line due to the combination of the lateral forces and the gravity forces required to stay within the middle third of the cross

section. We saw by simple equilibrium that was shown and this middle third is also referred to as the kern of the cross section. So, as long as resultant is within the kern, it is pure compression in the cross section. So, this is, this is a concept that we did see in the previous class.

We also saw that, when you have lateral actions, when you have earthquake induced lateral forces or you have wind action which is a lateral force, then the masonry is more resistant in terms of its in-plane response. The masonry wall is more resistant in terms of in-plane response rather than out of plane response. So, this is weakness that needs to be kept in mind as far as the wall is concerned.

And when you then move on to the system level, if you want integral action of the masonry building system under lateral forces, this can be ensured if connections are taken care of. The connections become critical and if you take care of connections wall to wall connections and wall to floor connections, then you can harness the in-plane, the good in-plane resistance that masonry walls have. So, that is the gist of what we had seen in yesterday's lecture.

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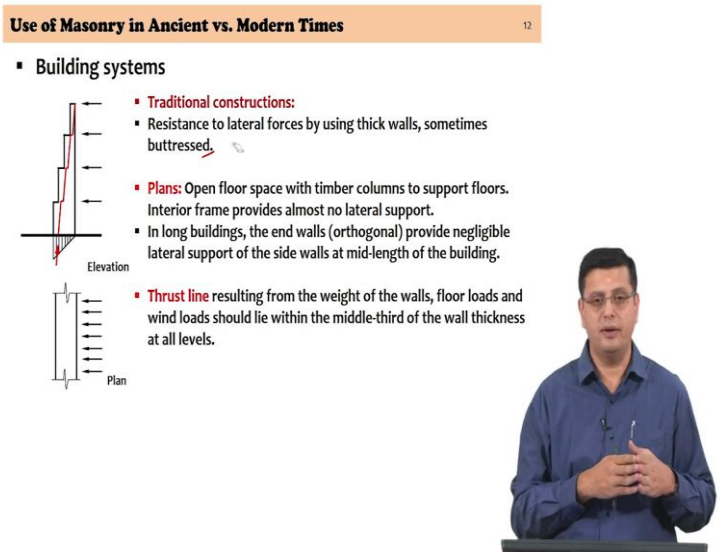

So, what we will look at today, is with this understanding, how do modern masonry constructions differ from ancient masonry constructions. And we will also look at how we can classify masonry, right from masonry units to walls, different elements like walls, columns, pillars, beams, floors and then a classification of masonry systems. So, that is

what we will look at today. As far as ancient building systems are concerned, we examined this concept of the thrust line.

So, in most traditional constructions it is thick walls, thick peripheral walls that actually provided the resistance, even to lateral forces. Under gravity, yes, you have massive cross-sections, but the massiveness of the cross section becomes clearer, once you understand that this is what is actually providing lateral resistance as well, ok.

And in many cases if the lateral thrust is insufficient, walls were also buttressed. So, you will have buttresses at regular intervals. This is a way in which the geometry is altered to take care of lateral forces coming on to a system. Typically, if you look at ancient constructions, you will see that the plans have open floor spaces, massive peripheral walls and in the interior, you might have columns and these maybe timber columns, timber posts, stone columns that are additionally present to support the floor.

Now, these do not really provide any lateral support like we would expect in a moment resisting frame in steel or reinforced concrete. These are primarily to support the roof and are present in the interior and are connected in some way, probably just resting onto the peripheral walls, but they do not provide any lateral restraint. So, the work of providing lateral restraint to such constructions again comes back to these massive peripheral walls.

So, that is how they were conceived and if you have long buildings, if you have long buildings, of course, the end walls which are referred to as the return walls in the orthogonal direction, these need not necessarily provide lateral resistance for the entire length of the long walls. They may be able to provide resistance at the ends, but as you come towards the mid span of the long walls, you do not have any effect of restraint in the lateral direction by these end walls. So, you really have very poor out of plane response of long walls.

So, that is how typically these open floor traditional constructions were conceived and therefore, the wall had to actually, I mean the system actually had to depend on the resistance that the massive peripheral wall will provide and the thrust line is an explanation that you can use to understand how these systems actually performed.

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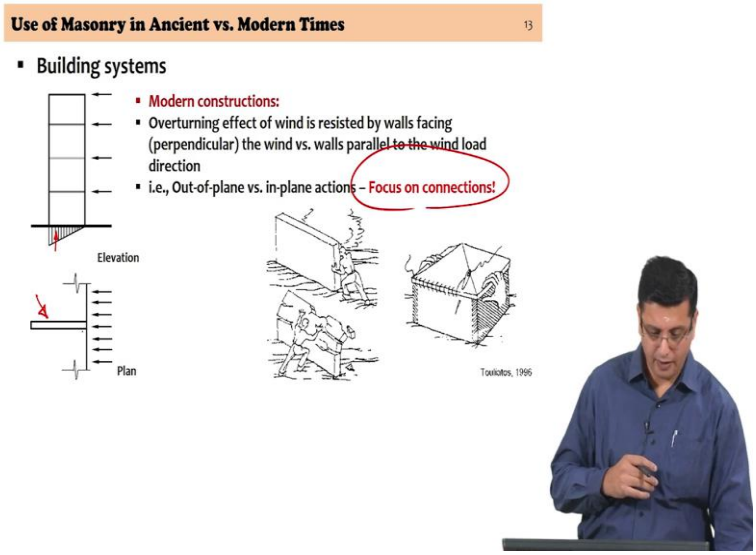

Now, if we were to examine modern constructions in this context of response to lateral forces. The big difference is that we are not looking at massive walls, we are looking at walls that are becoming more and more slender and we have other systems that take care of the lateral resistance, that this lateral resistance that the building is required to provide.

So, this is the overturning effect that lateral forces subject a structure to, is contracted by walls both facing the lateral force, right, the walls that are perpendicular to the force which are what we refer to as out of plane walls and walls which are parallel to the direction of the lateral force wind force or the earthquake force. So, you have, you have both working together ,you have the in-plane walls and the out of plane walls now working together in this sort of a system

Therefore immediately, the focus is on connections, because you need the in-plane walls and out of plane walls to work together, now that is something that we examined earlier and if these connections are poor, the tendency is for these walls to act independently and which is undesirable. If you have good connections in positive connections wall to wall connections and wall to floor or wall to roof connections, then you get integral action. So, the dependence now is on both cross walls and the wall that is face loaded or out of plane. So, it is a combination of these two that is going to be resisting the lateral forces.

That is how the modern constructions are conceived today and the direct impact of this is that, the peripheral walls or the main load bearing walls, do not have to be massive in cross

section, you can start optimizing the cross sections and that is why you get higher slenderness ratios in modern constructions, there is economy in material that is generated as an effect, ok.

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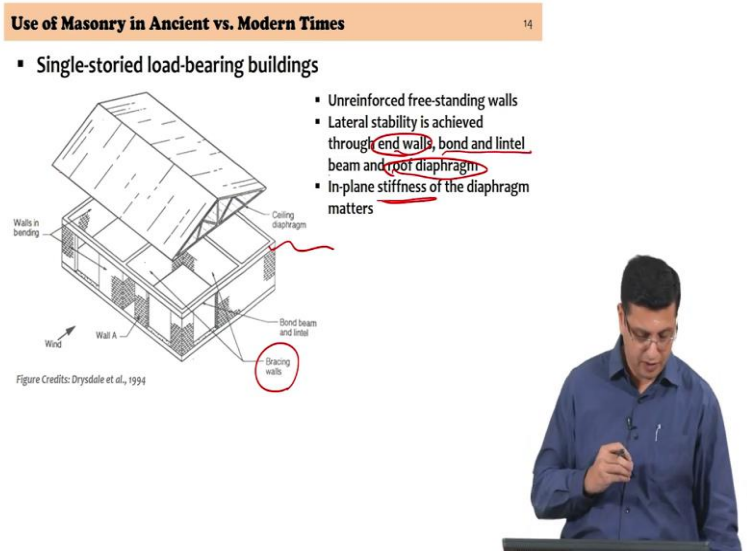

So, if you were to look at single storied, modern single storied load bearing buildings, how do they, how are they conceived and how is the load resistance-both gravity and lateral load in such constructions. So, we really talking of walls which are freestanding walls, free standing simply because you could have a situation where you have a rigid diaphragm which is sitting on the top as the roof, but you could also have a situation where you do not have a heavy rigid diaphragm that is the roof system itself.

The lateral stability is achieved through the end walls. So, you have the end walls which provide lateral resistance to the long walls and you have enough number of cross walls. So, a combination of the cross walls, also referred to as bracing walls because there bracing against the lateral forces and the end walls provide the required lateral resistance. But you also have an entire network of connecting elements which are the bond beams and the lintel beams.

So, at the lintel level you will have connections between all the walls and at the floor level, at the roof or the floor level, you again have these beams which are referred to as bond beams simply because they are trying to bond the orthogonal walls together, different elements of the structure are kept together using this sort of a, this sort of an element.

The roof diaphragm, whatever be the roof diaphragm, it could be a steel truss roof, it could be a reinforced concrete floor system, whatever be the roof diaphragm; the roof diaphragm also has a role to play as long as there is well connected to the walls as well. So, in this scenario, when the roof diaphragm starts playing a significant role in the integral action of the masonry building, the stiffness of the diaphragm, what we are referring to is the in-plane stiffness of the diaphragm matters and matter significantly.

So, you have the lateral stability in such systems coming from one the end walls and the bracing; bracing walls or the cross walls; you also have these continuous beams, these bond beams that will run through the entire construction. So, if you actually look at, that would be the bond beam which is running at the lintel level and as you see, it is running throughout all the load bearing walls, that is the important thing.

So, a single lintel right, it is at the lintel levels. So, a single lintel which we typically provide above an opening, will not qualify as a bond beam, will not qualify as something that is actually connecting all the orthogonal walls together. So, we are really talking of a tensile resisting element that is continuous and holding all the walls together, that is the second element which is the bond and the lintel beam, it could be at the lintel level, it could be at the, it is provided at the plinth level, the lintel level, the roof level and if you have floor above, you also provide at the sill level.

So, you have this which is actually contributing to the lateral stability of the system and finally, the roof diaphragm and this room diaphragm, if it has to significantly contribute to lateral load resistance in the structure, then the in-plane stiffness or what we refer to as diaphragm action becomes important.

How stiff is it in-plane, if it is flexible in its plane, then due to lateral action there will be in-plane deformations in the diaphragm, but if it is rigid in-plane, when there is lateral action there would not be any relative displacements in the diaphragm. So, diaphragm has a very important role to play, particularly the stiffness of the diaphragm and its connections with the rest of the walls. So, your question is about the, in which direction we are talking about in terms of the in-plane stiffness. So, this is the horizontal plane. So, let us say you have a reinforced concrete diaphragm, reinforced concrete slab, right.

This reinforced concrete slab, we are interested in what is its in plane stiffness, what is its in-plane deformability. If you have let us say a timber thrust roof or a steel thrust roof, but

if these are not braced against in-plane deformations, you will have a flexible system, you will have a very flexible system because there are deformations in the plane.

If the deformations in-plane are reduced, curtailed, you get a rigid diaphragm, that is the definition of a rigid diaphragm and the classification of rigid diaphragm versus a flexible diaphragm is primarily on the basis of how much relative displacement do you get within the diaphragm itself in the in-plane direction, in its plane, right, ok. So, this is what is the crux of a lateral load resisting, single storied structure in masonry, in load bearing masonry.

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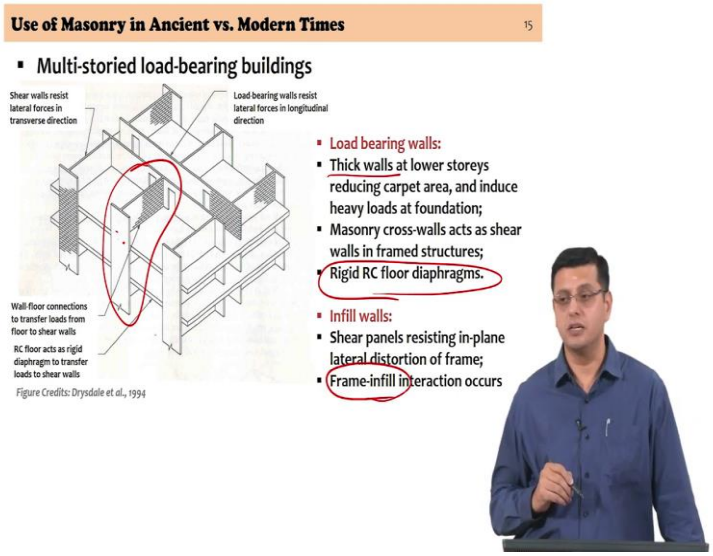

If we were to examine multistoried load bearing masonry constructions and when we say load bearing we are talking of all walls being load bearing walls. Rarely you would have walls which are meant to be partition walls, but the point is, if a wall is actually running from a floor to the roof, it is going to be part of the load resisting system. So, if you have partition walls in load bearing construction, typically this partition walls are not taken to full height, unlike in a, in a frame system, you can still have rather slender partition wall or an infill panel.

So, in a load bearing multistoried masonry building, it is the series of orthogonal walls, end walls, long walls, and cross walls together which form the network that is going to provide the lateral load resistance along with the floor diaphragms and the roof diaphragms.

Of course, because gravity forces are going to be higher at the base at the lower stories versus the upper stories, you are going to have thick walls at the lower stories, it will reduce, it will taper as it goes up, the downside is often if it is a if several stories you would have a lower carpet area on the ground story, higher carpet area on the upper stories and heavy foundations depending on the number of stories such structures go to. So, you basically have if you look at one system if you look at one system constituting of the main wall and the cross wall.

This is the system which works as shear walls in the direction parallel to the lateral forces and in the direction perpendicular to the lateral forces acts as an out of plane wall. Of course, in such constructions it is today inconceivable that we would be providing flexible diaphragms, we use reinforced concrete quite a lot and in such constructions typically you have reinforced concrete a floor slabs and roof slabs and they constitute what is referred to as diaphragm and provide diaphragm action.

So, it is this system of walls perpendicular and walls parallel to the direction of lateral action as shear walls and the floor diaphragm, plus a system of bond beams you also have the plinth beam, the lintel beam and roof beams which are actually working together for integral action of the structure in the event of lateral forces.

You have another category of systems where masonry is used, it is not load bearing, it is meant as partitions and these are typically within moment resisting frames. So, this is really not load bearing masonry, in the stricter sense, these infill panels are typically used within reinforced concrete moment resisting frames or steel moment resisting frames and are conceived as functional partitions, these are not conceived the structural elements in the first place.

However, since brick masonry wall panels are stiff in the in-plane direction, these tend to behave as shear walls themselves once they start interacting with the framing elements. So, when we have the framing elements which are the beams and columns and you have the partition walls, there is very rarely a gap that is designed and left between these, the panel and the frame. When there is lateral action, due to deformation of the frame, you will have interaction between the panel, the infill panel which is conceived as a non structural element and the moment resisting frame which is conceived as the lateral load resisting element.

And this interaction can become problematic and in the section on infill panel, we will look at what is the relevance of this interaction and how do you design against the undesirable effects of this sort of a, this sort of an interaction. So, the frame-infill interaction is an area that definitely receives enough research focus today, ok.

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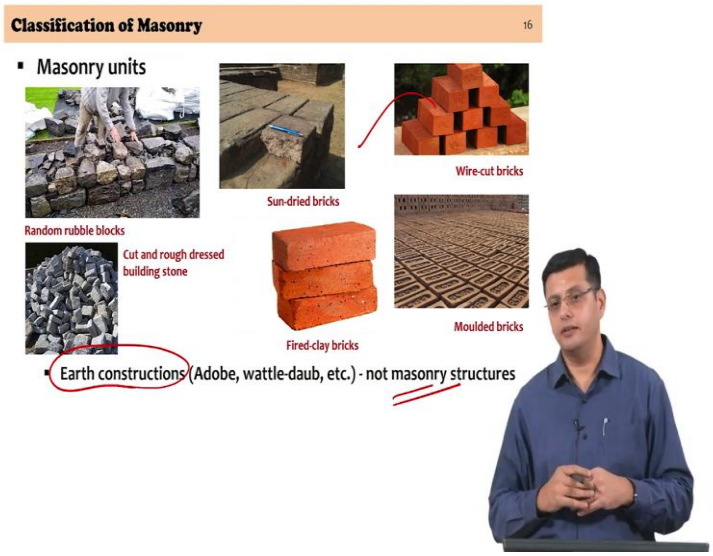

So, with that you now should have an understanding of what constitutes global behavior, desirable global behavior in a load bearing masonry building. At this stage, I think it is the right time to examine classification of masonry, right from its constituents all the way to different types of systems you have in masonry.

So, to start examining units, of course, masonry units, we have seen some historical constructions in the previous lecture, has been around for millennia. So, you I would rather classify these as ancient masonry units, construction units and modern masonry construction units in the first place. So, random rubble blocks is something that is been around for a very long time, is also used today, we still use random rubble constructions typically for foundations, for retaining structures; however, there are issues with the integrity of random rubble construction which can be overcome with specific elements of features like through stones and so on.

So, random rubble construction is a type of construction where the unit that we are referring to, is a random block It is not sized, it is not shaped and it is often only the outer surface is worked on. So, that we have a cut surface on the exterior, but along the interior,

no one is really concerned what is the shape of this sort of a construction. The downside would be that you would have large voids to be filled up with mortar or smaller units and there is an informality to the entire construction using random rubble blocks.

If you are looking at building stone formerly being used for construction, you will have to cut this, they are square cut or rectangular in shape of sizes that can be handled for transportation at the labor at the site of labor and they may be semi dressed or heavily dressed stones, particularly the outer surfaces. So, they could be rough hewn to give the finish that stone would have or even cut and well dressed to give an artificial finish to stone as well.

Sun dried bricks were the first category of units, these where modular, that is the units had a proportion between the length, the width and the thickness of the units. Modularity is clearly seen in several ancient civilizations; however, they were nearly sun-dried. So, it was mud combined with materials, but sun-dried.

The advent of fired-clay bricks was after the prevalence of sun-dried bricks for a, for a rather long time, fired-clay bricks are something that we use to date, of course, there is a problem with fired-clay bricks from an environmental perspective. We use topsoil, which is environmentally, degradation in the environment which is today not acceptable and they are fired at very high temperatures which means that the embodied energy in manufacturing these bricks is rather high.

So, environmentally speaking, fired-clay bricks, though you see them today we are on a tract, where over the years we will see lesser and lesser of fired-clay bricks, we might be using fired-clay bricks only for repair works in existing buildings, but not necessarily construct new buildings with fired-clay bricks.

But fired-clay bricks can be categorized into two, into two types-wire cut bricks, which are basically extruded, the mould is the stiff clay after it is kneaded, is extruded and they are cut. So, you get very stable geometrical configurations; however, you will not have the frog, which is the depression that is typically present on the top surface which helps in creating an interlocking layer along with the mortar construction.

So, wire cut bricks have the downside of not having the interlocking created by the embossed depression at the top of the unit itself. This is in contrast to the moulded bricks,

the moulded bricks are typically poorer in quality, both in terms of strength and durability in comparison to wire cut bricks; however, you can, in the moulding process itself create the frog which is something that provides good interlocking.

There is also difference between the wire cut bricks and the moulded bricks in terms of water absorption, typically the moulded bricks absorb much more water in the order of 10 to 15 to even 20 percent by its weight whereas, the wire cut bricks typically absorb far lesser and this can create problems in terms of the adhesion with the mortar and that something we will examine, when we start looking at masonry strength and parameters that affect the masonry strength.

A point that I want to make at this juncture is, we are also we have also been examining some traditional masonry construction types; however, there are lot of constructions called earth constructions which is completely out of earth- adobe constructions, wattle and daub constructions, where it is earth and structural timber, that is that is used.

These do not qualify as masonry constructions, the word ‘masonry’, I think it is important to appreciate the fact that we are talking of units that are built up to create structural component and the structural system. So, masonry, though masonry uses mud blocks, these are again blocks that are put together to create a wall, but earth constructions would not qualify under the classification of masonry structures.

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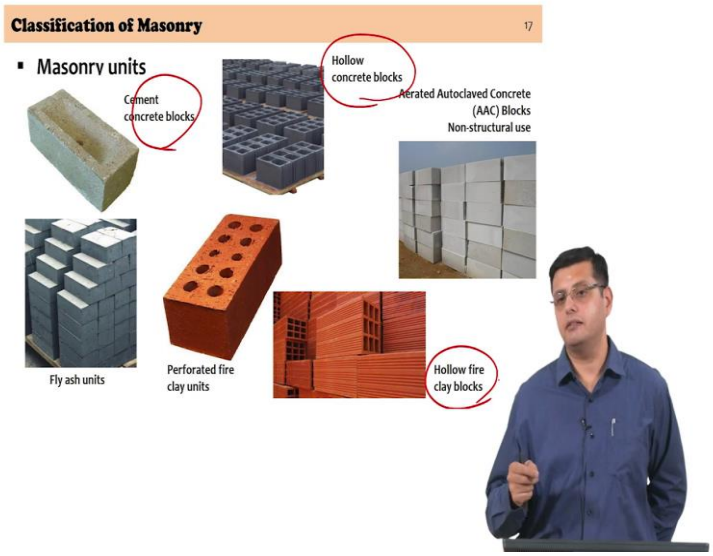

Continuing with masonry units, but modern masonry units, you have cement concrete blocks being extensively used today, you can, you can control, design strengths that you require, that uniformity in strengths you do not get with fired-clay bricks, you should be able to achieve it, but there is a physical challenge in achieving uniformity. The cement concrete blocks can give you that if the design I,s well if the mix is well-designed and quality control in the execution phase is there.

We use hollow concrete blocks as well and hollow concrete blocks are extremely useful when you want to reinforce masonry or when you want to reinforce masonry either in the form of walls or in the form of lintel beams, floors, reinforced floors or beams themselves.

So, hollow concrete blocks are again a category that is extensively used today, both for non-structural applications like the partition walls and for structural applications. So, if someone is procuring hollow blocks, you should be sure what it is been made for, because if it is manufactured for non-structural purposes, the strength of these blocks will be much lower whereas, if it is manufactured for structural purposes you will have a compressive strength of the order of 7 MPa or higher, typically for hollow concrete blocks used for structural purposes.

You have another category called the aerated autoclaved blocks, AAC concrete blocks, now these are large sized blocks, but they are or they are cured by an autoclaving process in the autoclave and this imparts a certain lightness to the entire block because fine pores are generated because of the process of curing and these are normally used for non-structural purposes, these are used for infill walls, partition walls and infill walls. Fly ash bricks are popular, in fact, there is a ministry of environmental and, environment and forest regulation, issued in India that if you are constructing a building within hundred kilometer radius of a thermal plant, you have to use fly ash bricks instead of fired-clay bricks for construction. So, vast majority of the expansions that have happened in IIT Madras have consciously used fly ash bricks in the hostels and in all other construction. So, fly ash units are available, again you have to be careful about whether it is for non-structural use or structural use, because achieving strength using in fly ash units is again challenging, unless fly ash is a replacement for cement concrete itself. So, you could do a replacement in the cement concrete with some amount of fly ash to gain strength, but if it is significantly fly ash, strength is compromised.

As far as fired clay units are concerned, you have what are referred to as perforated clay units and this perforated clay units, you see those perforations. So, if you look at the percentage of openings in this sort of a block versus a hollow block, the percentage of openings of the order of 25 to 30 percent, that is the difference between a hollow block and a perforated block.

These perforations are useful either for providing thermal insulation or for providing reinforcements, but these are perforations and they should not be confused with hollow block constructions. Both hollow clay brick, fired-clay brick and perforated fired-clay brick can be useful structural purposes, again the designation has to be checked whether it is structural or non-structural. The hollow fired-clay blocks are preferred as reinforced masonry construction units.

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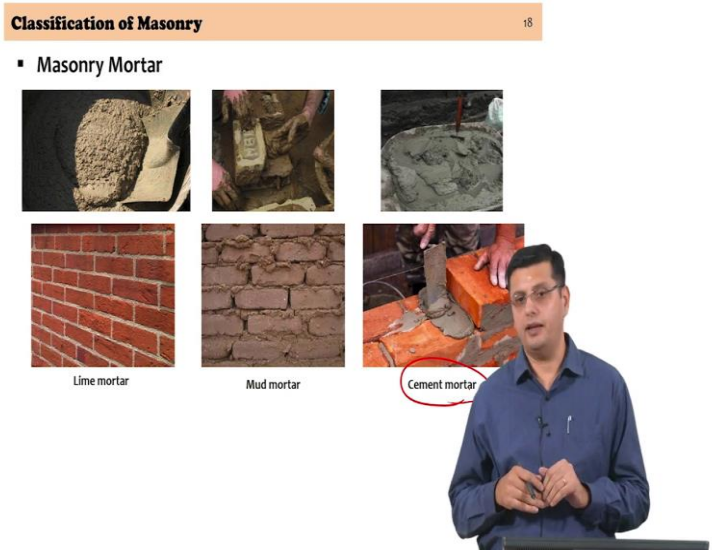

Mortar of course, this is again big spectrum, we have people who works specifically only on mortars in understanding their strength and durability characteristics. Mud mortar was predominant in the construction in the historic constructions, this is of composition that can vary from place to place and constituents that can vary from place to place. So, this is very non-uniform across the world and depends on traditional knowledge that region had in terms of the additives in the mortar itself.

The other variety is lime, mortar that is made with lime and this is of course, very minimal in use today all the lime goes to the cement industry, I am sure you will know clinker forms

very important proportion of the cement manufacturing process and we do not use lime today for construction of new buildings.

Also because of the challenge of longer setting and hardening times that lime mortar requires as against cement which is a fast setting, fast hardening material. So, lime mortar most of your existing buildings, if you are going to be doing in assessment, you should know that might have been made with mud mortar or lime mortar or a combination of the two in many cases, where the mud acts as a pozzolanic additive to the mortar itself.

Cement mortar is what we use in a, in a very standard form today for masonry constructions. We will touch upon an important aspect that is something that we have to face today and that is the non-availability of, non-availability of weak cement. May sound like a paradox, why would you need weak cement?

Few decades ago, we had 33 grade cement, then we moved on to 43 grade, today you might only get 53 grade cement and the problem is the mortar that you make out of it, it could be a one in three mortar, one in four mortar proportion, one in five, one in six, but the big challenge that we have today is keeping the mortar strength lower than the unit strength, because most often in the market you get units which are of strength of the order of 5 MPa to about 15-20 MPa.

Chances are that your mortar may be stronger than the unit itself and this combination of strong mortar-weak unit can be a problem in the behavior under gravity itself and under lateral forces. So, that is something we will examine in our study on strength that the masonry assembly level itself due to this combination of weak mortar, strong mortar-weak unit and vice versa.

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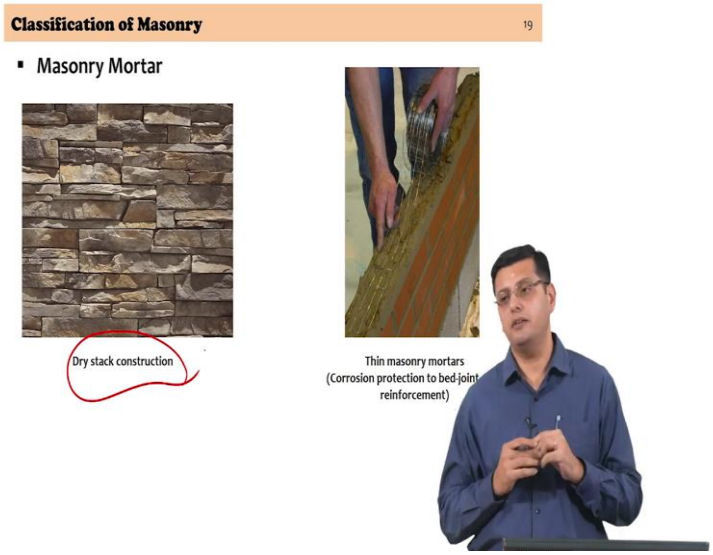

I have classified this under mortars, but we have to accept the fact that some constructions would not use mortar at all, they referred to as dry stack constructions, they do not happen in brick masonry constructions. They happen only in stone masonry constructions and where the informality in terms of the sizes of the units, gives you the possibility of wedging all gaps and either wedging all gaps or having stone blocks cut so well that you can place them one over the other and have a paper thin joint that is formed because in any way you cannot allow moisture to just percolate through such walls. So, if it is a, if it is a structure that is being used. So, dry stack construction is basically mortarless construction.

Today we also have high strength mortars and high strength mortars made primarily because you might have to introduce reinforcement in the bed joints and you need corrosion protection for the reinforcement. So, if you were to go by the standard thinking of the need to provide cover concrete for the reinforcement, you will have mortar thicknesses which are comparable to unit thicknesses. This will compromise the strength of the masonry that something that we will be examining that thicker the mortar joint low will be the strength of the masonry assembly.

So, to achieve good strength of masonry, one of the first things that need to be done is to minimize the thickness of joints and in this case, you have the twin problem of having to put steel reinforcement in the joint and to protect it from moisture. So, entire family of thin, ultra thin strong mortars are being prepared today particularly to take care of this twin

requirement of keeping joints thin but giving adequate protection to the steel reinforcement.

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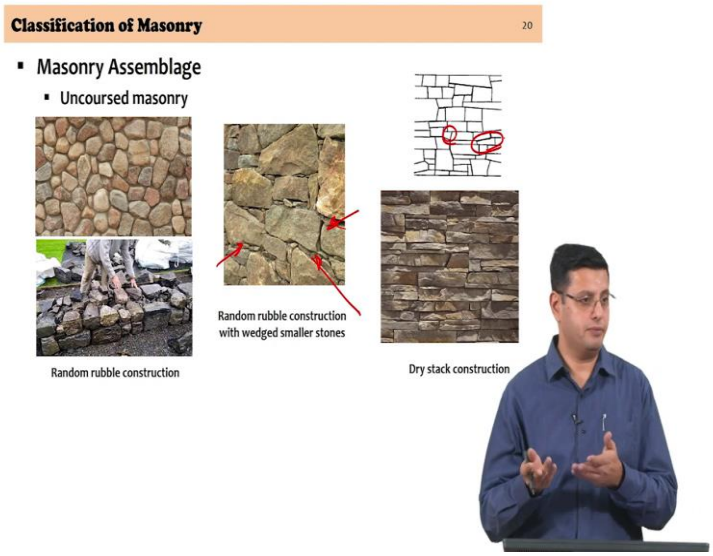

If I now move on from course, from units, masonry units and mortar which is the constituents to assembly, assemblage of masonry. Uncoursed masonry has been used in many of the existing masonry constructions. Random rubble construction is one of the uncoursed masonry constructions wall constructions where both in elevation and in cross section you would not see a pattern, it is totally free of regular courses and as I said, has a certain randomness to the entire construction.

It is a challenging typology, strictly speaking, when you have significant lateral forces. As I said, random rubble masonry construction, where the joints are wedged with smaller units you can see the small units that are sitting here, the small pieces that are sitting here they have been wedged in between, these constructions require, possibly required a lot of patience to make them.

But the wedging actually provides stability to the entire wall and this is another popular historical construction typology itself and then of course, even in dry stack constructions you will see how there is, it is typically free of courses because the dry stacking itself with different sized blocks can create interlocking.

You do not have mortar to hold with all together. So, you can see a unit like that or unit like this is actually providing interlocking in the, in the whole system. So, it is, it is like a jigsaw puzzle and it is held together.

Your question was whether random rubble construction or random rubble with the wedge smaller stones is with or without, with or without mortar. You get all varieties, you get all varieties, strictly speaking, but you could have a random rubble construction mortar less with wedging, you could get it also with mortar.

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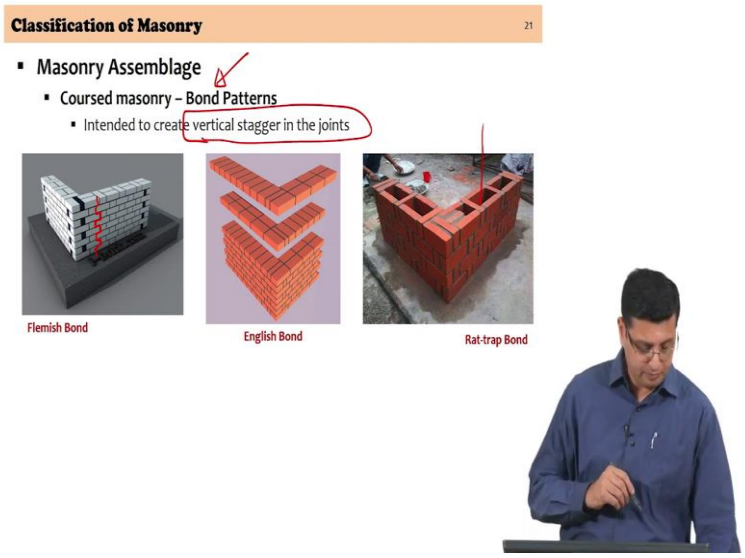

If you come to modern constructions the whole concept of coursed masonry and having a pattern is something that you would have definitely learnt in your earlier classes in materials. But the most important aspect is, to be able to create a vertical stagger in the masonry joints and this vertical stagger is essential for interlocking right.

So, that is really what necessitated different bond patterns. You are aware of several bonds the Flemish bond, the English bond and so on, even the Rat-trap bond which allows for cavity into which you could put reinforcement or leave it as a void, is a category which tries to ensure that the vertical stagger is achieved.

So, if we actually look at any of these, the most important aspect that you will notice is this is zigzag stagger that is achieved, which is providing additional shear interfaces, providing

resistance for lateral action. So, the whole idea of going in for bond patterns is to be able to create vertical stagger across the joints.

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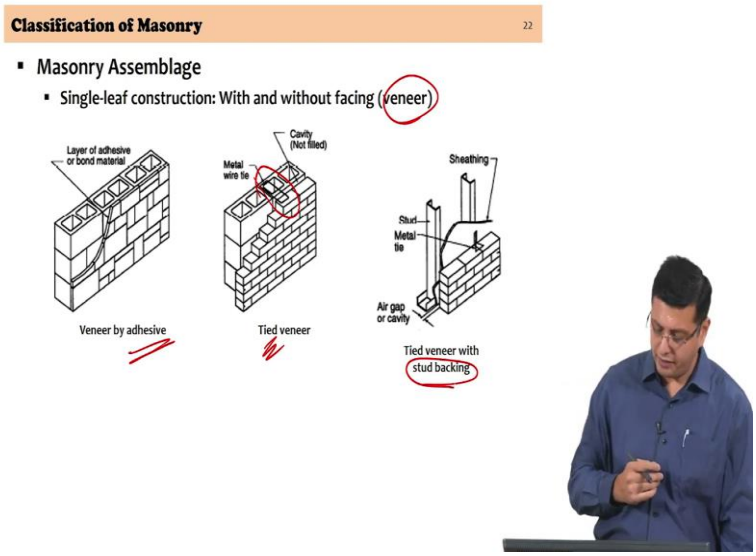

You have single-leaf constructions, what we saw earlier in terms of the Flemish bond and the English bond, are single-leaf constructions. Now, these single-leaf constructions can be with or without facing stones and when you have facing stones also referred to as veneering, it is a veneer, it is a thin, it is thinner than the load bearing construction, the load bearing cross section.

The veneer is really not the is not a load bearing part, it is only a decorative element. You could have different types of veneering, you could have veneer fixed by an adhesive, often you will have, if you want a stone finish you will have stone slabs which are stuck with high strength adhesive on to the brick masonry wall.

But sometimes, if the veneer is heavy if the veneer starts becoming heavy or the veneer is significantly wide in cross section and adhesive might not be sufficient it actually can become a falling hazard if it is a, if a building is tall, it can actually fall and kill people. So, it is a, it is a, it is an important problem. So, you have what is call tied veneering, you will have metal ties that run along the length and along the height at regular intervals, which you design and estimate how many ties are required per unit length of construction itself.

And of course, in cases where you have an interior wood finish, you might have a, what is called an entire frame that is attached, a frame on to which the brick work is attached for a brick finish on the exterior or vice versa if you have a timber work on the interior on a load bearing brick masonry wall, you would have a timber frame inside on to which timber sheathing or timber finish is provided.

So, you would, you can have a similar tied veneering, but you have studs now which are then a part of the member that transfers load between, basically holds the veneer on to the load bearing element.

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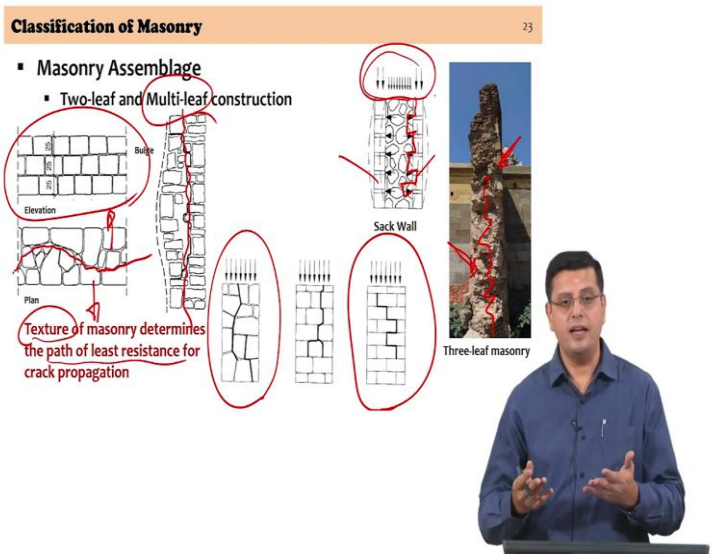

While examining all these typologies, I think it is important to point out two typologies that you will come across in existing buildings. We do not design them like this today there is a there is a serious problem as far as lateral load resistance of these construction are concerned, you see two-leaf constructions and multi-leaf constructions. These two-leaf constructions, you can also conceive them as two leaves with an air cavity in between created for insulation, but two-leaf is also an interpretation from another perspective which will see in a moment.

Now, if you have random rubble construction right, if you have random rubble construction and the elevation looks something like that- you have the front surface of those blocks that are dressed, well dressed, cut and dressed, but if you were to look at the cross section, if you look at the plan at any level, you do not see a regularity in the cross

section and here, this is what is being referred to as the two-leaf masonry, because I can actually see that these two can separate.

When there is heavy gravity forces themselves or under lateral shaking, these not intended as two leaves, but can become two leaves is a problem, that is why today when random rubble masonry construction is being adopted for foundations or any structural use there is a requirement that through stones be given that you have to have a bond stone or a through stone across the cross section, across the entire thickness of the cross section.

So, this is a typology that can throw up a problem, right, but is very prevalent in existing masonry constructions. The problem is when you have this sort of a discontinuity under lateral actions or even under gravity over time, you can have bulging of one leaf of the wall and vulnerability to collapse particularly when there is even slight shaking, ground shaking.

Now, the problem is if you were to look at the cross section of the masonry and the cross section of the masonry, the load bearing wall you will appreciate that in the cross section you must have the stagger of the joints. If the stagger of the joints is not available the resistance to splitting this into a two-leaf system is far easier in this case, in this particular case, as against a case which has coursing which ensures stagger.

So, the texture when we say, when we talk of texture, the word ‘texture’ here, the word texture here is basically the quality of the geometry of joints. How is the, how are the joints laid out, how are the joints formed, are you thinking about how these joints are or are you not thinking about how these joints are. So, that determines what is the texture of the masonry and this actually determines the path of least resistance or the path of crack propagation and loss of integrity in cross sections in masonry.

The other animal to be considering is what is referred to as multi-leaf construction and this is typically three leaf construction where this particular image that you see here referred to as a sack wall is a typology which is used in massive masonry constructions, you can look at fort walls, you can look at temple gopura, the entrance towers most of them all the historical massive historical constructions are constructed like this using the concept of a sack wall, where the outer two leaves, the outer two leaves are thin, they would be about one-tenth of the cross section or more, slightly more.

They are raised to a certain height, poorer material- random rubble, broken bricks everything under the sun, the idea was to have a larger cross section, but it was uneconomical to use the same material throughout the entire cross section, they would have exterior and interior facing with good quality material like marble or any other good material granite or whatever, whereas, the inner core is infilled with poor material.

So, this acts as, when you constructed it of course, acts as one cross sections, but there is a propensity to separation of these layers unless interlocking has been provided or unless some through stones have actually been provided.

But if it is a very massive wall cross section, through stones cannot be provided you might not get so many long blocks. In such situations, the interlocking might help where the courses of the exterior leaf actually have zigzag arrangement, are coursed to have a zigzag arrangement, the picture that you see on the right is a temple precinct wall, an outer temple precinct wall constructed during the Chola period. So, we are talking about at least a thousand years ago, you can actually see that is that is stone masonry, that is stone masonry. So, that is the outer two leaves and in between you see all sorts of lime and broken aggregate and broken bricks, broken pieces of stone and so on.

So, three leaf masonry the problem is, this can be examined as a system that is subjected to even under gravity forces, different deformability across the cross section. So, if you take this cross section, the outer leaves are made out of stronger stiffer material, yes you would agree with me, like stone core stone whereas, the inner core is made out of softer material because you got lot of mortar and you got probably mud and everything that you can think of. So, the stiffness and strength of the core is far lesser than the stiffness and strength of the outer leaves.

When this is subjected to gravity forces this is like an indeterminate problem where the inner core because of lower stiffness is subjected to lower stresses in comparison to the outer leaves which are subjected to higher stresses because of higher stiffness models of elasticity. So, you have non-uniform loading that will come on to such cross sections and the problem is the inner core over time deteriorates and load may finally, be carried only by the exterior leaves.

So, if the exterior leaves are carrying all the load that the entire cross section was originally meant to carry, you have a slender wall system that is carrying very heavy compressive

forces you can have sudden brittle failures in such systems. So, this is a typology to be considered carefully.

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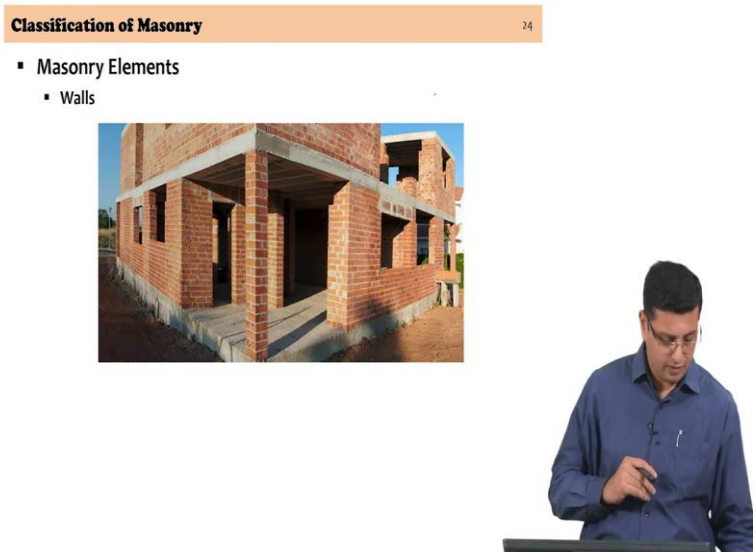

In terms of different structural components of course, masonry load bearing walls is a first element that you should be aware of.

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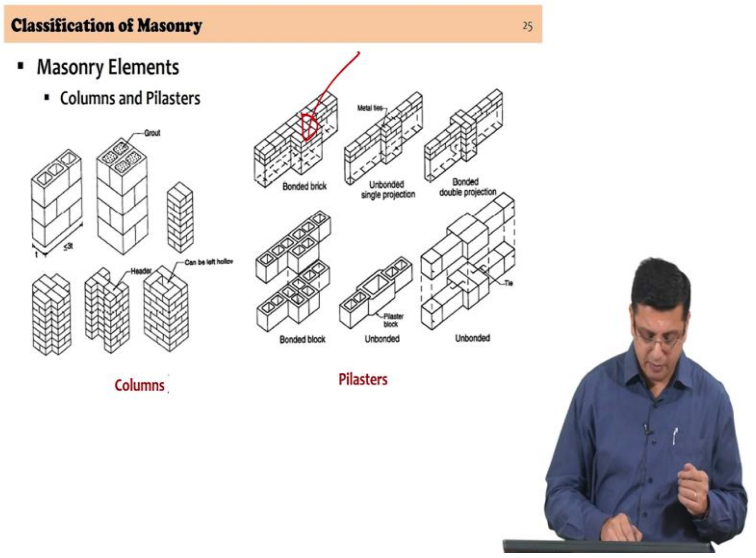

You also have columns and pilasters; the difference between columns and pilasters is the column is a single freestanding element of course, connected to the rest of the structural system. A pilaster is where you have a thickening of the wall like a small buttress and is

basically meant to provide a provide additional lateral resistance to a wall lateral stiffness to a wall.

So, columns and pilasters load bearing columns and pilasters are the other elements that you should be aware of as part of the load bearing system.

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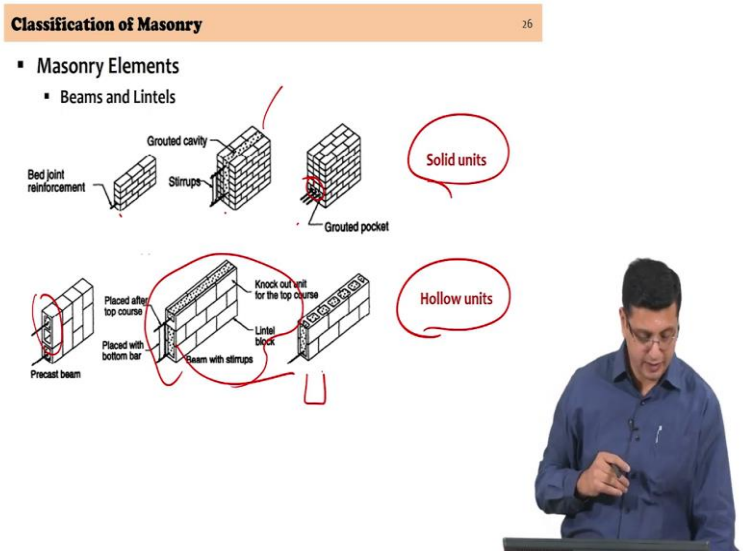

Beams and lintels in masonry can be constructed, but since beams and lintels are going to be dominated by flexure you have tension in them so you cannot construct them if they are flat, you cannot construct them using unreinforced masonry you have to reinforce them.

So, when you reinforce them there either solid with reinforcement in the bed joints or in cavities between the masonry or in a pocket that is created by leading a void or hollow units are used you can see that units which have aligned in such a way that you get a continuity you can grout and place reinforcements is available.

You can also look at situations where U shaped blocks are used, U shaped blocks are used because then you can place reinforcement and grout the reinforcement, I mean grout the location of the reinforcement give protection to the reinforcement that would be the beams and lintels.