Design of Masonry Structures
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Module - 04
Lecture - 25
Design of Masonry Components and Systems
Part - IV

So, good afternoon; we move on to looking at reinforced masonry design and today I will give you an overview of the reinforced masonry code before we go into specific aspects particularly the P-M axial force bending moment design, we are looking at the interaction and shear design of walls. So, we begin by getting an overview of what the national building code's recommendations are with respect to reinforced masonry. So, that is what you are going to be looking at today and the guidelines for reinforced masonry itself.

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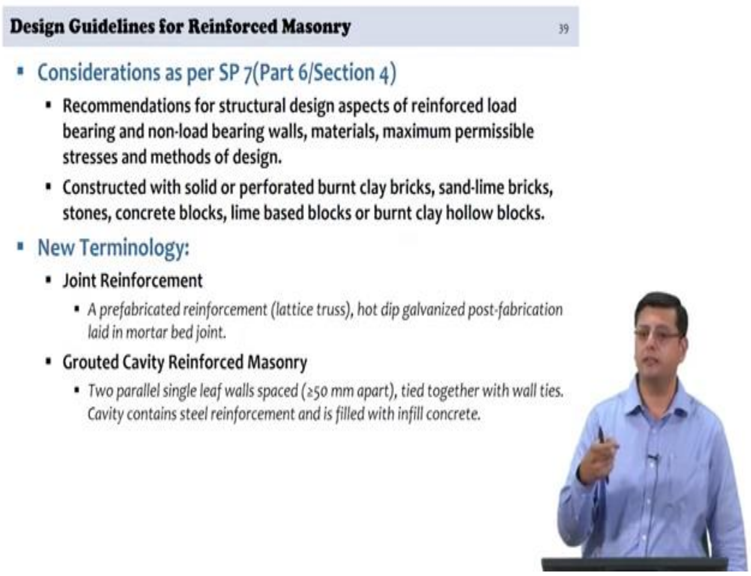

So, we are specifically referring to Part 6 Section 4 of the code which is available in volume one of NBC. So, this deals with reinforced walls both load bearing and non load bearing walls, but we are as I said working with the permissible stress design. And, this code is applicable to all types of materials, all types of units particularly the solid units with cavity walls, so that reinforcement can be placed or perforated walls or hollow brick walls. So, across the spectrum of materials this code regulates the use of different materials and different types of units for reinforced masonry design itself. There are a few words which are specific to reinforced masonry which the code has introduced and therefore, I am just touching upon some of these; it is better we use it specific to how the code examines these words.

When we talk of joint reinforcement, we are talking of the horizontal bed joint and these are typically prefabricated joint reinforcement, you have seen the example that I gave you a lattice type with a truss type or a ladder type. So, this is typically the joint reinforcement with reference to the bed joint of the wall masonry wall itself. When we are talking of grouted cavity reinforcement, we are really talking of cavity walls, you have 2 solid single leaves which are then connected by ties appropriately designed to keep them together. And, in the cavity you have the horizontal and vertical reinforcement which is placed.

So, when we talk of grouted cavity reinforced masonry, it is really a cavity wall construction where reinforcement is placed in the cavity whereas, the wall itself is constructed using solid units.

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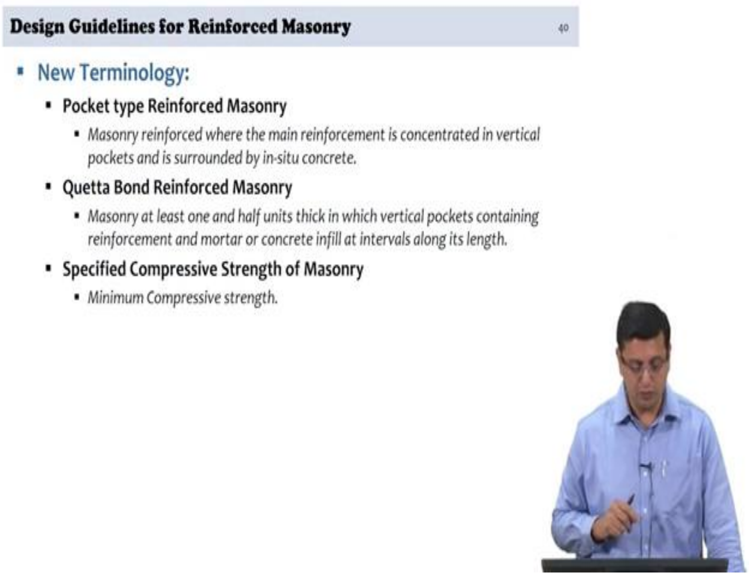

The category that we have been looking at earlier in the different typology of masonry where the hollow blocks are reinforced is referred to as pocket type reinforced masonry; that is the reinforcement is placed within the pockets that are available within each unit. So, it is referred to as pocket type reinforcement, pocket type reinforced masonry where you then have to do in-situ concreting in within the pocket. In the previous category, the cavity wall the entire cavity has to be grouted with concrete in-situ. Quetta bond is the other type that we had seen and this is typically when you have one and half unit construction, the thickness of the wall is one and half units. So, the arrangement you have seen earlier in our second module that you leave vertical pockets and reinforcement runs through these pockets and this also requires in-situ concreting to hold the reinforcement in place.

When the word specified compressive strength of masonry is used it is referring to the minimum compressive strength that the unit or the concrete must have. So, the word specified compressive strength of masonry with reference to minimum compressive strength, ok.

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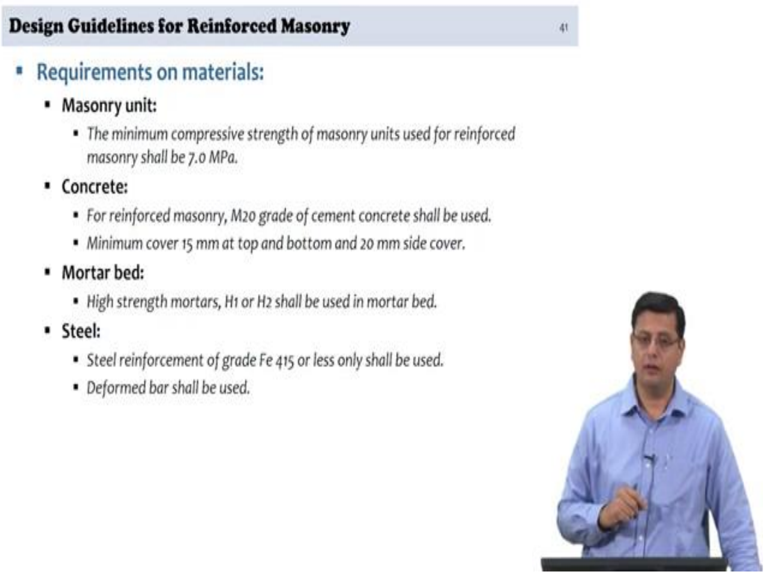

With that it is not exhaustive, but these are words that we have not used earlier. There are specific requirements on the materials that have to be used. There are limits on the materials that you can use as far as design of reinforced masonry is concerned. The constituents again, first one is the masonry unit. You require that the masonry unit, the code requires that the masonry unit has a minimum strength of 7 MPa, right.

So, if you remember the earlier table that we were referring to the strength of masonry units go as prescribed by the code can go all the way from 3.5 MPa, class 3.5 all the way up to 35 and 40. However, when you are going to be reinforcing masonry you need to have a minimum compressive strength of 7 MPa and this comes from the requirement that once you reinforce a masonry wall, the stiffness of the masonry wall is increased. The shear demand particularly, as far as seismic design is concerned- the shear demand that can come to the wall actually increases, but when you have large shear demand in a masonry wall which has low compressive strength of unit, you can have crushing failure of the masonry units which is a brittle failure mechanism.

The steel will not be, the masonry units will not resist until the steel goes into yielding to ensure ductile behavior of the wall, you will have a you will have a compression failure which is a brittle failure mechanism which is to be avoided. And, hence a minimum strength is required for masonry construction with reinforcement and of course, with clay bricks you will have a challenge of getting 7 MPa depending on the region where you are getting bricks from. But, if you are looking at hollow construction, hollow block construction, it is quite easy to get strengths that are of the order of 10, 12 or 15 MPa and higher.

So, this is an important requirement. So, low strength units should not be used for reinforced masonry at all. As far as concrete is concerned, the concrete shall at least be M20 grade concrete and this is particularly where you are placing reinforcement and this comes primarily from the durability requirements that protection to the reinforcement is required from corrosion. So, M20 grade of concrete and as far as the steel is concerned, you have to have a minimum cover of 15 mm at the top and bottom and 20 millimeters cover on the sides.

So, this requirement should dictate number of bars you will actually be able to place within a given pocket itself and choice of bar diameter. So, we are talking of wherever you are placing reinforcement in a groove, ensure that at the top and the bottom if it is horizontally placed your 15 mm at the top and the bottom there are 20 mm on the sides in the cross section as cover provided by concrete to the steel reinforcement. This is far lesser than what is prescribed as minimum cover for reinforced concrete construction primarily because we are already placing it within the unit.

The steel reinforcement is placed in the pocket inside the unit and then you are talking of the cover that the concrete in the pocket is providing to the steel. So, it is already protected, but this is the second layer of protection. However, the units typically are porous and therefore, there is a requirement that the concrete protects the steel reinforcement.

If you are placing joint reinforcement you do not have concrete in the joint, you have just mortar in the joint and you have to use high strength mortars. You are not allowed to use weak mortars and this is primarily from the point of view of durability; higher the strength of mortar lower will be the porosity. And therefore, high strength mortars category H1 and H2 shall be used if you are using bed joint reinforcement, joint reinforcement itself and as far as steel reinforcement is concerned you are required to use steel reinforcement Fe 415 or lesser.

Now, that is challenging you do not want high strength steels because higher the strength more is the demand that is going to go on to the masonry, the masonry part before the steel can yield and that can imply crushing failure before the steel yields. So, you do not want a brittle mechanism. So, you are keeping the steel reinforcement limited to 415 or Fe 415 or lesser.

So, it is important to have compatibility between the strengths that you are examining in the composite material and this requirement comes from a compatibility point of view such that yielding in the bar is allowed for and of course, you cannot use rounded bars you have to use deformed bars for construction.

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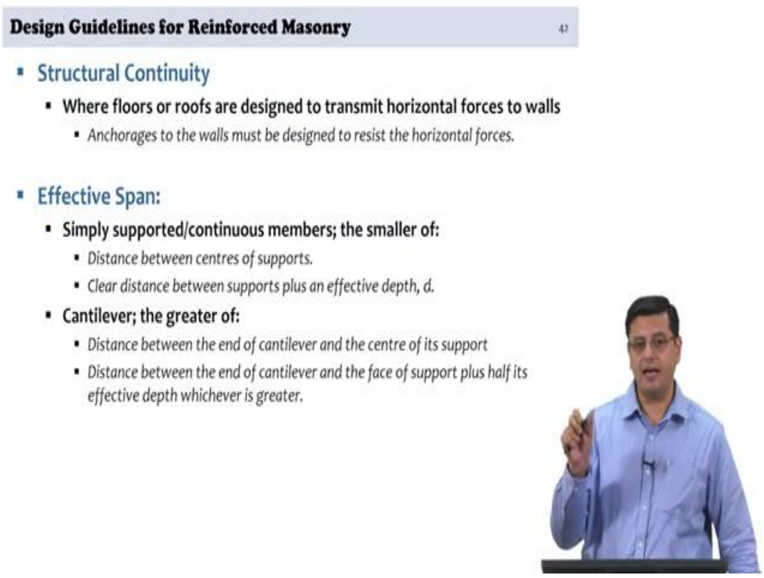

Now, wherever there is a requirement from the design perspective for seismic resistance for earthquake resistance or need to transmit horizontal forces even wind forces, you must ensure that the steel reinforcement coming from the wall is adequately anchored to the floor or the roof diaphragms. The detailing has to be done such that the steel reinforcement from the walls is adequately anchored to the floor diaphragms or the roof diaphragms and should be able to anchor itself, enough development length is essential. So, that transfer of forces between the horizontal elements and the vertical elements is provided for is allowed for by the construction itself.

A little bit of discussion on effective spans because you are going to be looking at reinforced masonry beams, reinforced masonry walls and so what is effective span?, what is the definition of effective span as far as these structural members are concerned and should we will be looking at different effective spans given the type of boundary conditions and given the type of member you are looking at. So, if you are looking at a simply supported member or a continuous member- beam or a wall you use the smaller of the distance between the supports or the clear distance, a clear span between the supports plus an effective depth d of the section itself.

However, if you looking at a cantilever you can look at the distance between the end of the cantilever and the center of the support or the distance between the end of the cantilever and the face of the support plus half the effective depth whichever is greater.

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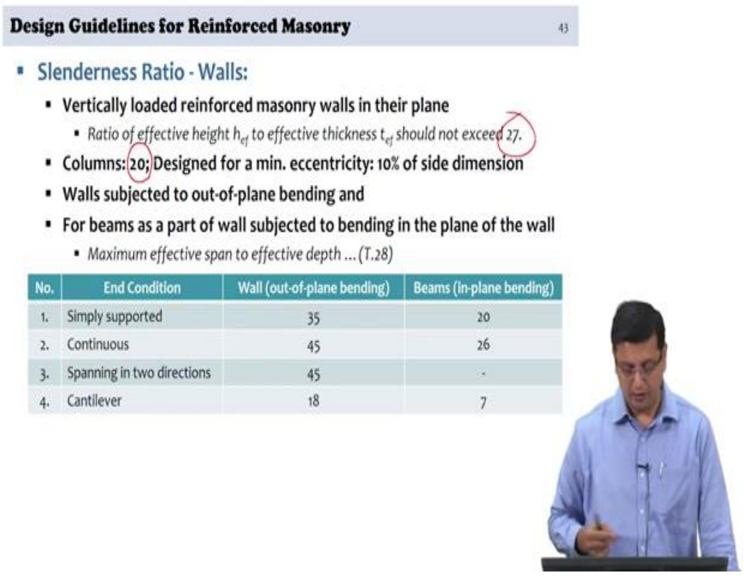

So, these are typical requirements which you see even in reinforced concrete, but when you are making effective span calculations, you have to be sure about what type of member you are looking at and what the boundary conditions are. Again when you are estimating the slenderness ratios with respect to walls when you looking at the ratio of effective height to the effective thickness of the wall for walls, reinforced masonry walls, when they are vertically loaded in their plane we are talking of a maximum slenderness ratio of 27.

So, that is a number you want to keep in mind. The slenderness ratio of the wall for vertical load carrying capacity is limited to 27; however, if you are looking at designing columns this number is limited to 20. So, 27 for walls and 20 for columns; however, all designs of columns must consider a minimum eccentricity of 10 percent of the side dimensions. So, that is minimum eccentricity in the reinforced masonry; reinforced concrete code is 5 percent of the side dimensions, here we are looking at 10 percent of the site dimension. And, that has got to do with workmanship because of the building up of the wall with blocks which can lead to additional eccentricities as against concrete construction which can have lesser problems due to the workmanship itself.

If you are looking at a wall, that is subjected to out of plane bending. So, if you are looking at, first one that we looked at with a limiting value of 27 for the slenderness ratio was for a vertically loaded wall. But, if you are looking at a wall which is design for bending to resist lateral forces or if you are looking at a beam which is sitting in a wall and a subjected to bending in the plane of the wall then you have to use the limits on the effective span, the maximum effective span to effective depth ratio as prescribed by this by this table.

And, you can see that depending on the boundary conditions that you are looking at, you can see that when a wall is being considered for out of plane bending depending on the boundary conditions simply supported to continuous to bending in 2 directions. We are accounting for higher slenderness ratios or higher maximum effective span to effective depth that you can consider for this sort of a wall. Whereas, for beams for in plane bending the values are comparable to what we have been using for the wall under vertical loads itself. And, again different boundary conditions simply supported continuous diagonal bending 2 directions spanning and cantilever walls or cantilever beams in a wall.

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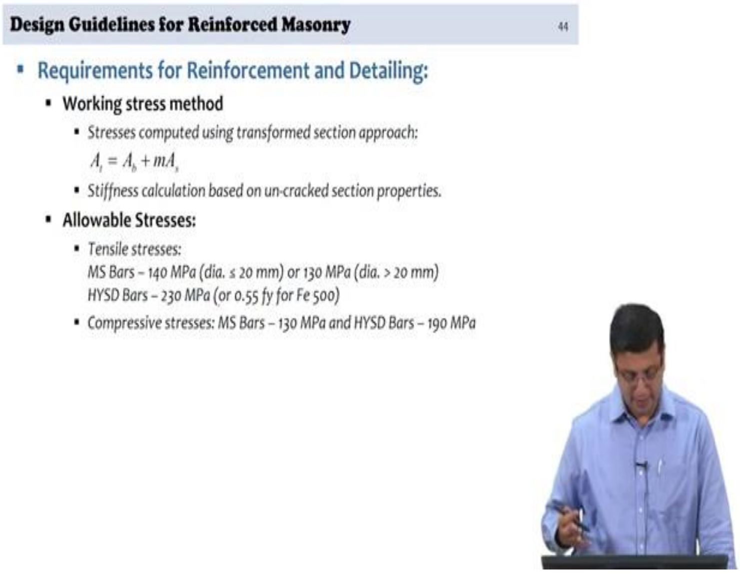

The there are a set of requirements that you have as far as reinforcement detailing is concerned because one of the fundamental reasons because of which reinforced masonry is not very popular particularly in tropical regions where there is moisture, there is heavy rainfall humidity levels are high, is the problem of corrosion. So, it is very important that the workmanship and the materials used do not compromise the durability of these systems and so there are specific requirements as far as reinforcement and detailing of reinforcement is concerned and we look at few of them here.

We have been using the working stress approach to design these walls and so, when you are going to be working on the cross sections we will basically use a transformed section approach. And, I hope I believe all of you will be familiar with the transformed section approach although both the codes IS 456 and IS 800 for concrete and steel do not use any longer a working stress approach. But, you will have to calculate the transformed areas using modular ratio where the actual area of the cross section which is resisting compression, which is the masonry area of the brick portion or the area of the unit plus the transformed area where A_s is the area of cross section of the steel and m is the modular ratio between steel and concrete or steel and masonry modulii of elasticity.

So, transformed section approach has to be used for your design calculations and since we are working within the permissible stresses approach, your stiffness calculations have to be to be consistent with the limits that we assumed for the working stress, stiffness calculations have to be based on uncracked stiffness you should not be using cracked stiffness for estimating the flexural stiffness or the stiffness of the walls. In terms of allowable stresses, as far as the steel is concerned we are talking of depending on the bar diameter, depending on the type of bar that you are using, specifications of what should be the allowable stress, mild steel bars of diameters up to 20 millimeters and mild steel bars beyond 20 millimeter diameter with 140 and 130 MPa allowable stress.

And, if you are using high strength high yield strength deformed bars 230 MPa or you use 0.55 f_y if you are using Fe 500 steel for your construction of reinforced masonry. If you are looking at compressive stresses because the reinforcement bars can be accounted for their additional contribution to resisting compression. And, if you are using mild steel bars you use a compressive stress of 130 MPa as the allowable stress and for HYSD bars as 190 MPa.

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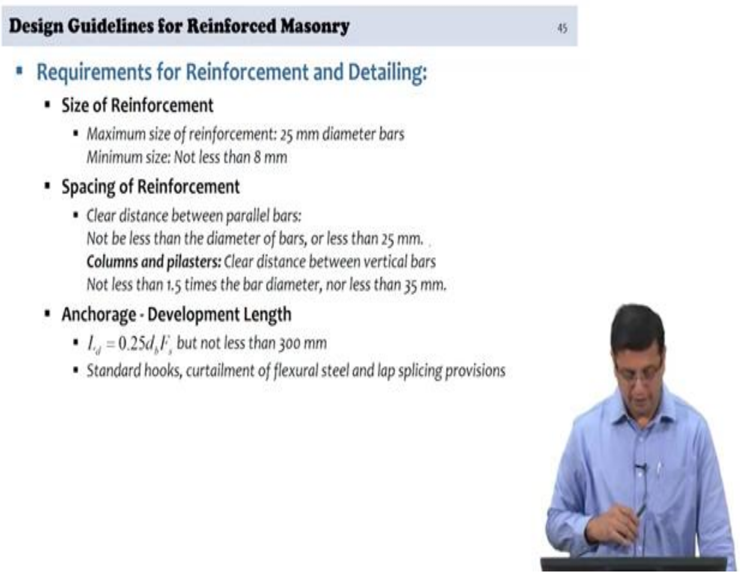

So, these are prescriptions from standard literature and foreign codes on working stress approach to masonry design. Minimum requirements as far as the size of reinforcement is concerned and spacing of reinforcement is concerned, the maximum size of reinforcement bars that is permitted is 25 mm diameter bars because, you are typically are working with embedding this inside wall cross sections and the wall cross sections are limited by unit sizes.

So, 25 mm bars what are prescribed as maximum size of reinforcement minimum size of reinforcement should not be less than 8 millimeters. Spacing of reinforcement bars, you will need to look at the clear distance between parallel bars and the clear distance between parallel bars should not be less than the diameter of the bars or 25 millimeters and this is really coming from the requirement that coarse aggregates which should be able to fill in and not result in honeycombing as you are grouting the pockets with the steel reinforcement.

And, if you are looking at the bar the spacing between reinforcement while designing columns and pilasters the clear distance between vertical bars is not to be less than 1.5 times the bar diameter not less than 35 mm. So, you can make that calculation, but these requirements have to be have to be followed. Again, the development length, we have been talking about the requirement of continuity of steel reinforcement between the horizontal diaphragms and the walls. So, development length (L_d) can be estimated as 0.25 into the diameter of the bar into the permissible stress of the steel f_s.

$$L_d = 0.25df_s$$

f_s is the permissible tensile stress of the steel, but this cannot be less than 300 mm.

So, minimum 300 mm development length has to be provided or L_d as estimated and you can provide standard hooks which can take care of the anchorage if you are not able to provide sufficient development length. And, as we do curtailment of flexural reinforcement as in reinforced concrete design in beams, you can also do curtailment of flexural reinforcement in zones where the moment demand is lesser than the maximum demand. Lap splicing is again something that you will have to take care of because reinforcement is going to go in the vertical direction all the way through the load bearing walls. So, lap splicing provisions also have to be accounted for.

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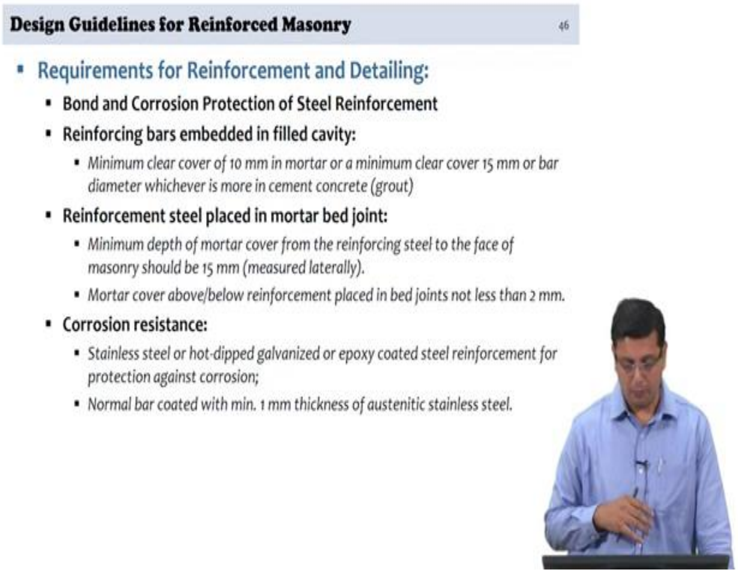

As far as issues of bond and corrosion protection of the steel are concerned, it is these reinforcing bars are embedded in these cavities and a minimum clear cover of 10 millimeters in the mortar or a minimum clear cover of 15 millimeters or the bar diameter whichever is more in the grout has to be provided. And, if you are placing reinforcement in the mortar bed joint you have to ensure that the minimum distance that you have, if you are looking at the cross section the minimum distance that you have between the edge of the reinforcement and the face of the masonry is not less than 15 millimeters. So, when you are measuring laterally along a cross section between the face of the masonry and the reinforcement there must be at least 15 millimeters of mortar.

Above and below the mortar joint you should at least have 2 millimeters of material and today we have high strength mortars which are thin high strength motors. So, you can actually minimize the bed joint thickness if you are going with flat trust type of flat lattice type bed joint reinforcement such that you do not increase the bed joint thickness because you know that higher the bed joint thickness lower is the strength of masonry; such that you do not compromise with the strength of masonry, you can use high strength motors in the in the joint and you bring down this cover to almost 2 millimeters for bed joint reinforcement.

For corrosion resistance, it is prescribed that you can go for stainless steel, but of course, stainless steel would imply shooting up of prices, the cost of construction. At least galvanized, hot dip galvanized, or epoxy coated steel reinforcement has to be used to ensure there is protection against corrosion. But you could also have bars which have regular bars the steel bars, but they are coated with a layer of austenitic stainless steel to provide corrosion protection.

So, the fact that the code is dedicating section specifically on what provisions you must take care of for corrosion protection is simply because of this problem being able to defeat the whole purpose of the typology reinforced masonry particularly in tropical or high humidity climates.

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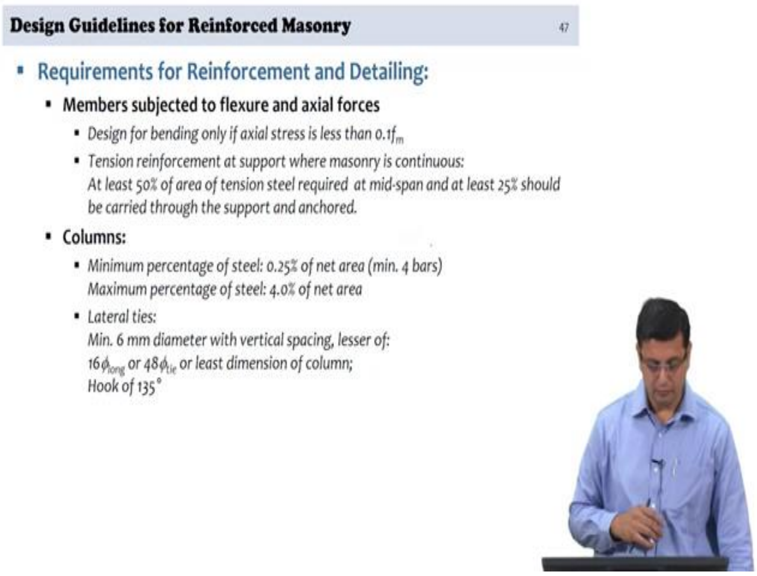

Some specific guidelines as far as the structural design is concerned; we will we will be going in examining each design in detail, but what you are going to see in the next few slides are overall requirements as far as the structural design is concerned. So, if you are looking at members that are subjected to flexure and axial forces, we would be looking at treating P-M interactions for reinforced masonry walls in detail, but the code requires that if the axial stress levels in a wall that has both flexure- bending effects and axial forces due to gravity.

If the axial stress is less than 10 percent of the compressive strength of the material, you can treat the wall as a pure bending design; meaning that we are really not depending on the beneficial effect of compression in the in the wall. So, you are looking at a design for bending only if the axial stress level is less than 10 percent of the axial stress of this compressive strength of the material masonry and whenever there is continuity of the wall at the continuous ends where you have tension reinforcement at the supports, there is a requirement for continuing the tension reinforcement across the support. So, at least 50 percent of the tension steel that is required at the mid span and at least 25 percent of that should be carried through the support and anchored effectively into either the return walls or the slabs whatever be the boundary.

When you are looking at columns the minimum percentage of steel that you must consider for reinforced masonry columns is 0.25 percent or 0.25 percent of the net area, but not less than 4 bars. So, the minimum number of bars that you should provide in a reinforced masonry column is 4 bars minimum percentage being 0.25 percent. However, the maximum percentage of steel that you can provide is 4 percent and that is really on the higher side you would not be providing anywhere close to that for structures which are 2 or 3 storied reinforced masonry structures. Lateral ties have to be provided within columns.

So, your cavities must be sufficient enough to be able to provide lateral ties. These ties should have a diameter of at least 6 millimeters and with the vertical spacing being the lesser of either 16 times the diameter of the longitudinal bars or 48 times the diameter of the ties itself. So, these are very specific requirements that you can check as far as the spacing of the lateral ties or the least lateral dimension of the column and you are required to provide 135 degree hooks which are required to ensure that confinement is not lost to the core concrete before the yield capacity of the steel reinforcement is reached. And, this is a particular requirement for seismic resistance of masonry and reinforced concrete constructions.

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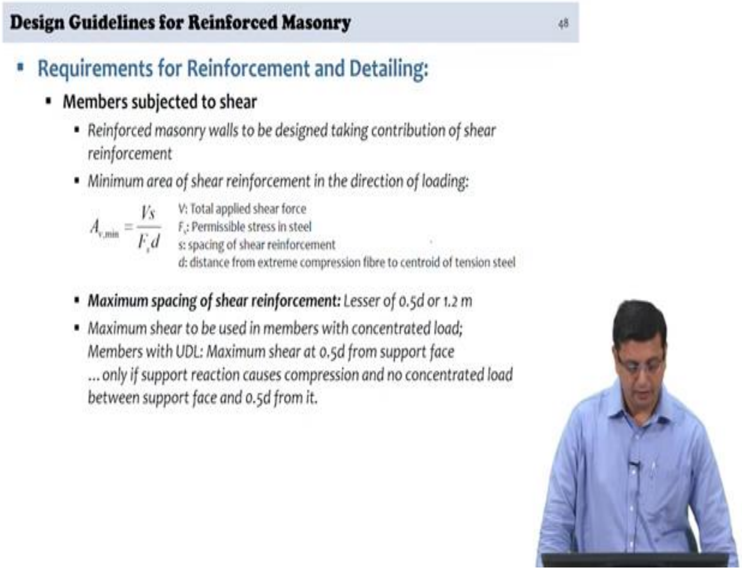

When you are looking at walls or beams which are subjected to shear, it is required that the reinforcement be considered when you are designing for shear and the minimum area of shear reinforcement, depending on the direction of loading A_v minimum is the shear force into the spacing divided by fs which is the permissible stress in steel divided by the distance between the extreme compression fiber to the centroid of the steel that you are placing.

$$(A_v)_{required} = \frac{Vs}{f_s d}$$

So, $Vs/f_s d$ is the minimum area of shear reinforcement that you should be providing and there is a spacing requirement as well the maximum spacing of shear reinforcement is the lesser of 0.5d or 1.2 meters and then depending on whether the wall is subjected to concentrated loads or uniformly distributed loads the either the maximum shear demand at the point of concentrated loading or you can look at in the case of a wall with UDL or a beam with UDL the maximum shear at 0.5 d from the support face as long as the support reaction causes compression in that zone.

And if there is no localized compression providing the beneficial effect of compression to shear, you cannot use this distance of 0.5 d for estimating the shear demand you will have to look at the support face itself. So, this distinction between locations we have concentrated loads versus those with UDL, but not taking the shear force at the support face, but at 0.5d from the support face as long as compression is available at the at the location where the shear force is being estimated.

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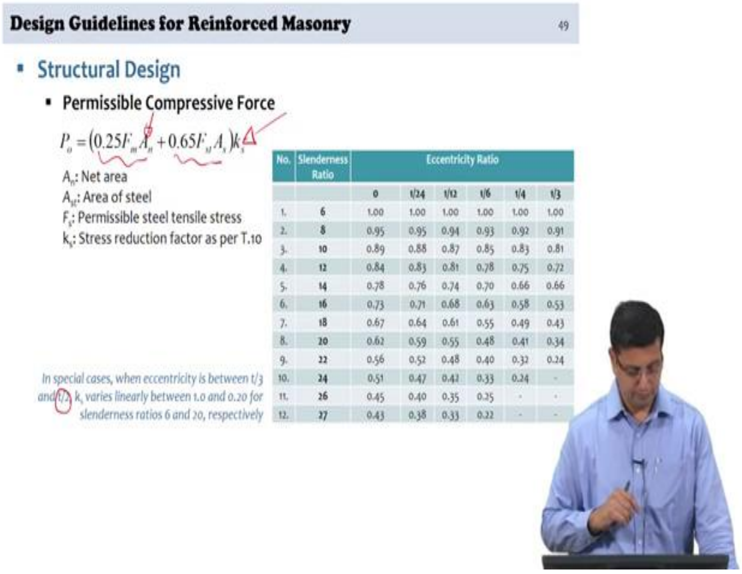

Again, broadly we need to define the permissible compressive forces the permissible shear stresses and the permissible tensile stresses because that is again what you are going to be checking against. So, if you look at the permissible compressive force, you have 2 parts of this expression. If you remember the expression for unreinforced masonry, we used 3 modification factors the shape modification factor, the stress reduction factor and the area factor.

We are not bringing in the area factor and the shape modification factor anymore because those are not going to be governing and negligible in terms of their effect if any and therefore, we are only going to be looking at the second order effects eccentricity ratio and the slenderness ratio. So, k_s as earlier the stress reduction factor continues to be there in the expression that is your shape that is your slenderness stress reduction factor, but you have these 2 parts- a part that looks at the resistance to compression or compressive forces coming from the masonry.

So, you have 0.25 which is a number that is coming back to us if you remember the basic compressive stress was taken as one quarter of the compressive strength of the masonry. So, we are limiting the stresses carried by the masonry to one quarter or lesser than the strength of masonry itself compressive strength of masonry and A_n is the net area that you can consider; the second part of the expression brings in the permissible compressive force that the steel can take which is 0.65 f_{st} is the permissible stress in the steel A s is the area of cross section of the steel itself.

So, you will have to look at the same set of stress reduction factors that we used earlier for the unreinforced masonry design it is a same table where you look at the eccentricity ratio as estimated varying between no eccentricity to an eccentricity of one third or even one quarter, one half and then different slenderness ratio is going all the way from 6 to 27. So, this is something we have seen earlier and will help us estimate what is the permissible compressive force for a given dimension and for a given combination of materials of the composite.

So, you can look at depending on whether you have a ungrouted wall or a grouted wall or partially grouted wall you are actually using the portion which is of masonry cross section, unit plus the grout as being part which resists the compression that is the left hand side that is one half of this expression and the other half is just the steel. So, you account for the presence of the grout when you are making this estimate.

Student: Sir, the grout will have a different compressive.

The grout will have a different compressive stress. So, you depending on the material depending on whether you are looking at concrete grout in a concrete unit or a concrete grout sitting in a clay brick unit perforated clay brick unit that distinction would have to be made in terms of the limiting compressive strengths, but Fm here is actually referring to the strength of the masonry strength of the masonry unit itself. So, it is strength of the masonry unit will be either the lower of the 2 or the grout is at least equal to the masonry compressive strength.

So, if you remember one of the earlier requirements was that the grout material must have a strength at least equal to the unit strength. So, from that perspective if you can make an estimate of net area depending on whether you have an ungrouted wall or a partially grouted wall of fully grouted wall you are accounting for the part that is taking care of compression and the second part which is resisting tension, but is also contributing to the compression resistance.

Student: So, it is a slightly conservative value.

It is conservative considering the fact that the grout and the unit are required to have at least the same strength.

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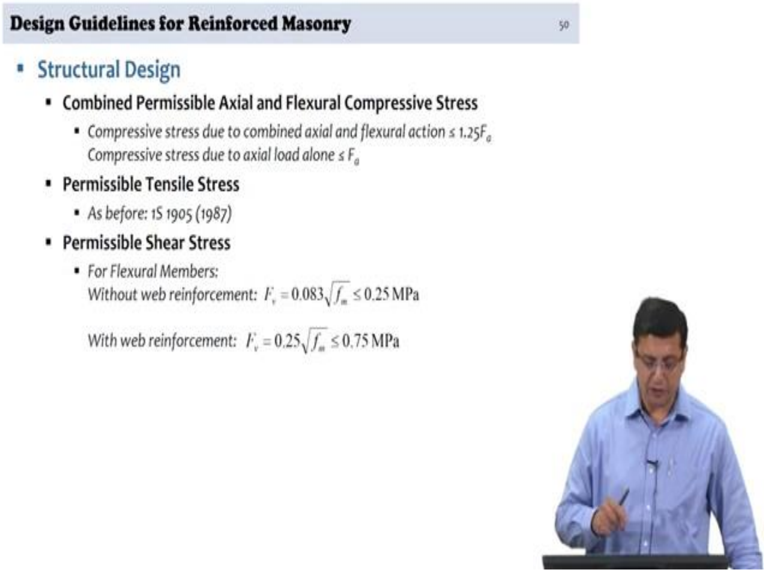

In case you are looking at a combination of axial force and bending then you have you had the earlier possibility of an increase in the permissible compressive stress accounting for the strain gradient. You could increase the permissible compressive stress for unreinforced masonry design by 25 percent and that is again permitted in this design way if you have compressive stress due to a combination of axial force and bending action then you can increase the permissible stress in compression f_a has 1.25 times f_a, but if there is no strain gradient it is f_a.

As far as permissible tensile stresses are concerned it continues to be what we used for the unreinforced masonry code, which is again if you remember varies between point 0.07 to 0.1 MPa in the cross section. As far as permissible shear stress are concerned the code distinguishes between beams that you might be designing, reinforced beams that you might be designing and walls and again distinguishes the walls based on whether you are looking at slender walls or squat walls and allows an estimate of the permissible shear stresses.

For flexural members; so, if you are looking at out of plane bending of walls or if you are looking at beams- reinforced beams, if you are placing web reinforcement or if you are not placing web reinforcement to take care of shear then the limiting value of shear stresses are prescribed, the one with web shear reinforcement being higher. But, varies as the value varies as the square root of the compressive strength of masonry which is which is how the shear strength varies with the compressive strength of masonry itself. So, you have limiting values on this up to 0.25 MPa without web shear reinforcement and up to 0.75 MPa of shear stress for flexural members with web shear reinforcement.

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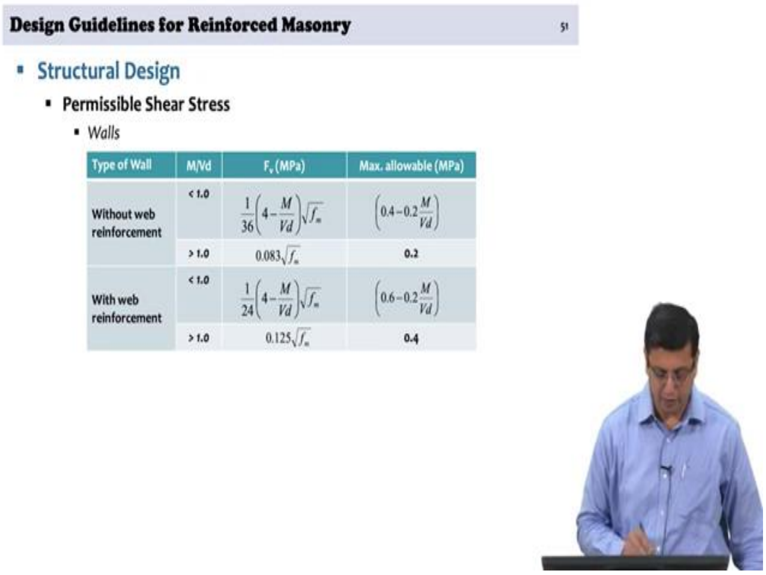

We will examine the basis behind the expressions for the walls in a more detailed manner when we come to the design of the walls for shear, but basically you estimate the permissible stresses, limited by a maximum value F_v for your design, where you are providing web shear reinforcement and require the web shear reinforcement to be resisting the shear forces coming onto the wall or without the web shear reinforcement. But, then this is the classification based on M/Vd ratio which is nothing, but the aspect ratio of the wall h/l.

So, the aspect ratio of the wall less than one would mean we are looking at squat walls and aspect ratio greater than 1 would mean we are looking at you looking at slender walls and so depending on whether we are looking at squat walls or slender walls the shear behavior starts dominating in a squat wall. And, so the limits on the shear stress is based on consideration of the aspect ratio you see that M/Vd ratio comes into the comes into the expression and varies as the square root of the compressive strength of masonry.

When you have walls where you are designing web shear web shear reinforcement and the aspect ratio is greater than one, the maximum value of the maximum value of the permissible stress is 0.125 square root of f_m that is missed out at and limited by 0.4 MPa. So, you have greater than one situation as well.

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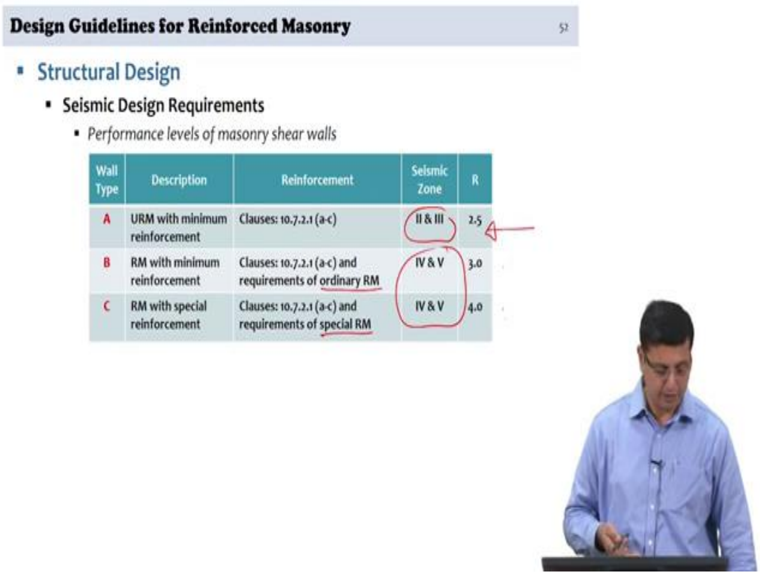

Ok. With that so you have the definitions of the permissible compressive stresses, tensile stresses and shear stresses, but if you are looking at seismic design requirements, we have seen this in the beginning of the lecture with respect to this module. So, I am just capping and recapping and then giving you an idea of what these detailing requirements would be. So, based on the performance level of the shear walls in the masonry structure; you can designate walls as meant to resist in plane shear and detail the reinforcement design and detail the reinforcement to different performance levels.

So, the different performance levels of the masonry shear walls that the seismic design provisions of the reinforced masonry code considers are 3 different categories - type A type B and type C and type A is what is referred to as unreinforced masonry, but detailed with minimum steel ok. So, it is detailed unreinforced masonry, they are no longer purely unreinforced masonry, but the steel is not designed it is merely prescribed based on some minimum requirements and this is limited to zones 2, and zone 3 and if you are using this, if you are in this category of shear wall then you can use an R factor of 2.5 whereas, the next 2 categories B and C are the ones that are referred to as reinforced masonry which means you are actually designing the wall as a flexural wall or a shear wall and estimating how much of steel reinforcement has to be put in.

While the first one type A wall will still have to be designed as per the requirements why IS 1905, you will check the shear stress requirement the permissible shear stress permissible compressive stress and permissible tensile stress and then provide the minimum reinforcement for it to qualify as a type A wall. Whereas, type B and type C would have to be designed as per the requirements that you saw in the last few slides on effect of span and permissible shear stress permissible compressive stress and then minimum reinforcement has to be taken care of.

So, it is designed and conforms to minimum requirements of reinforcement, type B is referred to as an ordinary reinforced masonry; type C with more minimum requirements of steel becomes a special reinforced masonry category with both these categories being applicable to zones 4 and 5 with R factors 3 and R factor 4. So, what are we talking of in terms of this minimum requirement. So, when we say reinforced masonry it is the reinforced masonry design prescriptions as in the national building code for type B and type C whereas, for type A go back to IS 1905 and the minimum requirement minimum steel requirement is as prescribed.

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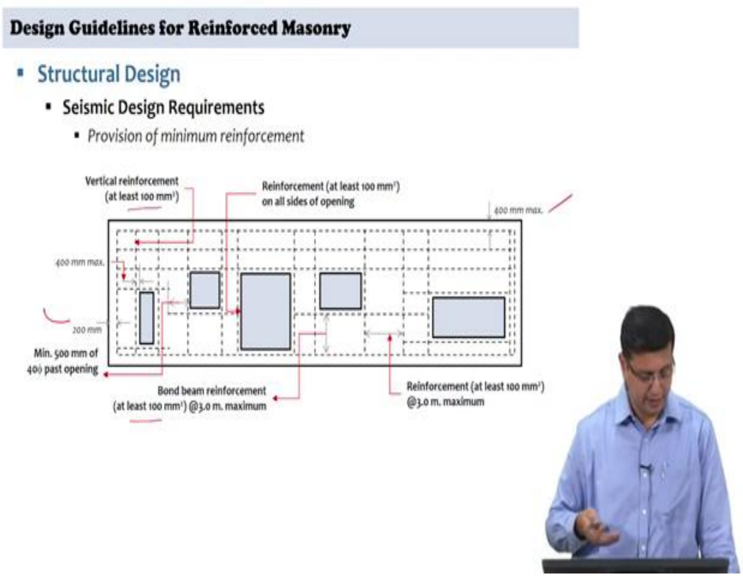

So, there are critical zones in which reinforcement has to be provided in the critical zones in which steel has to be provided with respect to the vertical steel is on either sides of the opening. When you have openings this the sides of the opening is a critical zone similarly the edges the ends of a wall where you have boundary conditions that is a location which is again referred to as a critical location. So, vertical steel reinforcement has to be provided in those critical locations and there is a minimum requirement of how much steel must be provided in those critical locations and it is prescribed to be at least 100 mm^2 in those areas.

Similarly, horizontal steel has to be provided in again critical locations typically where the wall interacts with the floor slabs. So, at the top and the bottom of the wall a minimum requirement that you have a bond beam reinforcement. So, you have the lintel band and the roof band or the plinth band where the steel reinforcement is at 100 millimeter square and the spacing between these is at least 3 meters apart. So, if you give 100 mm bond beam reinforcement, then the spacing is about 3 meters which means you must at least have a if your interest or height is about 3 meters you means at least have a roof band of and a plinth band.

You are you are allowed to give more depending on the seismic design itself and then these are the other critical locations the edges of the edges of the walls and the edges of the opening itself where specific requirements have to be adhered to as far as how much steel at what distance are you giving from these important locations. So, what the code gives you an entire set of verbal requirements which is again reproduced here in this drawing for the different types of walls.

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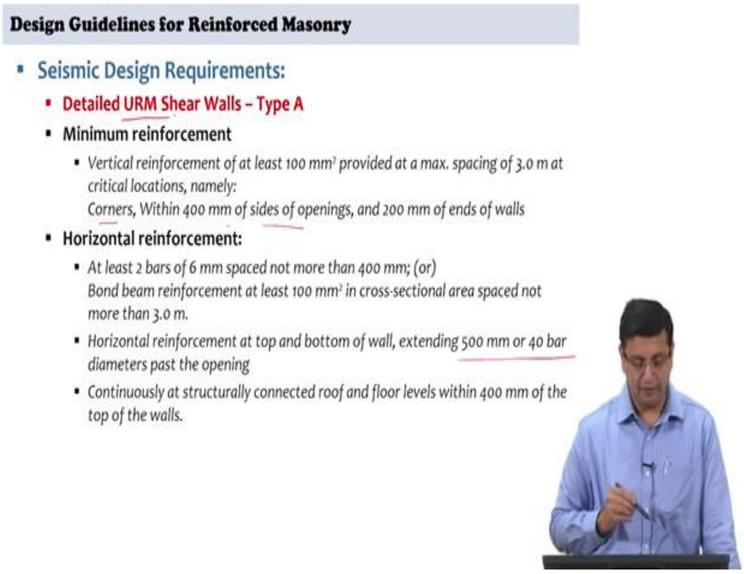

So, the first type A is referred to as a detailed URM shear wall. So, the URM shear wall is coming from IS 1905 design, but it is detailed as per the requirements of the national building code that is your type A wall then a minimum requirement of vertical steel as we saw in the previous slide and maximum spacing between them in the critical locations which are corners of walls and 400 millimeters around the sides of the openings and at the ends of the walls- 200 millimeters from the ends of the wall.

Horizontal reinforcement again, minimum what needs to be provided and at what spacing and also with respect to openings the steel reinforcement has to should not be terminated where the critical location is or the opening itself is ending, but should be further extended into the masonry construction at least 500 millimeters or 40 times the bar diameter around the opening and close to the roof or the floor again that is a critical location where continuous horizontal steel has to be provided either in the form of a bond beam or in the form of steel reinforcement that runs in that location.

So, these set of specifications have to be adhered to and would classify as the minimum reinforcement requirement over and above the designed URM shear wall as per 1905.

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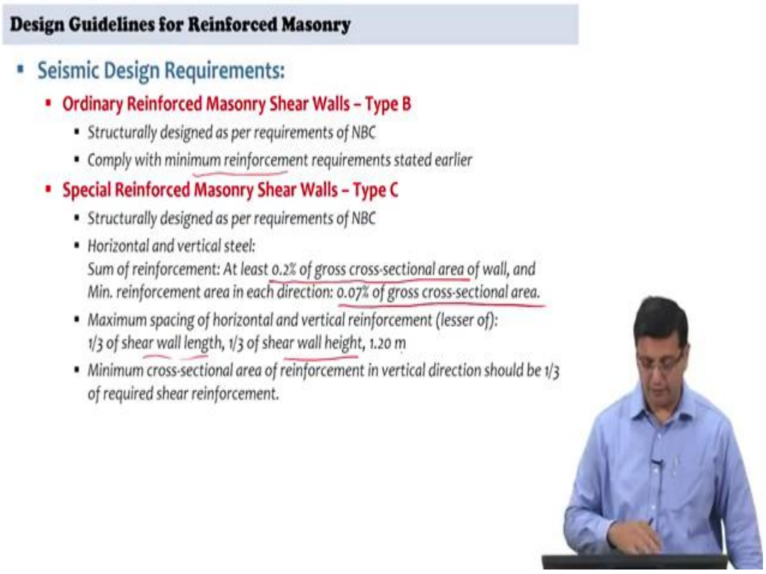

The other two categories type B wall and type C wall. In type B wall you are designing as per the requirements of the National Building Code and ensuring that over and above the steel that you are already designing as per the requirements of the code, you have complied with the minimum requirements that are stated earlier. Whereas, in the specially reinforced masonry walls type C walls you again you are designing them as per the requirements of the National Building Code, but there are minimum percentages of steel that are required. So, the horizontal and vertical steel together the sum of the reinforcement should at least be 0.2 percent of the gross cross-sectional area of the wall and the minimum reinforcement in each direction; the minimum horizontal steel and the minimum vertical steel should be individually 0.07 percent of the gross cross sectional area. So, when you come to the special reinforced masonry wall shear wall construction you have you will not use the minimum requirements that we have been using for type A and type B wall, but it is more in terms of specific percentages that you have to adhere to. Also, the maximum spacing of horizontal and vertical reinforcement should be the lesser of either one third of the shear wall length or one third of the shear wall height or 1.2 meters lesser of 3 values and in terms of how much horizontal steel you are providing and how much vertical steel you are providing typically your vertical steel will be more than the horizontal steel the minimum cross sectional area of reinforcement in the vertical direction should be at least one third of the requirement of the shear reinforcement. So, this link between the 2 is essential if you remember one of our earlier slides in the introductory lecture it is established that the vertical steel improves the effectiveness of the horizontal steel.

So, you can have bed joint reinforcement acting as shear reinforcement, but they cannot be as effective as a construction where vertical steel is provided to account for good anchorage of the horizontal steel itself. So, this broadly gives us the overview of the entire set of recommendations as far as reinforced masonry design is concerned. Of course, there are some most specifications which you can read. But what I have discussed with you today are key aspects that we have to remember within this course as well. And, we will start looking at in-plane flexural design P-M interactions and then the shear design of the wall in the next two lectures and so on.