Design of Masonry Structures
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Module – 04
Lecture – 29
Design of Masonry Components and Systems Part VIII

Good afternoon, continuing from the P + M design that we have been looking at the previous lecture, today we will examine how you go about designing for shear. We already looked at the overall framework that has to be adopted for shear design. We go to the specifics today and then initiate the overall design framework in terms of how you estimate the demand in terms of shear force and then the axial force and bending moments required for each component design within an entire system.

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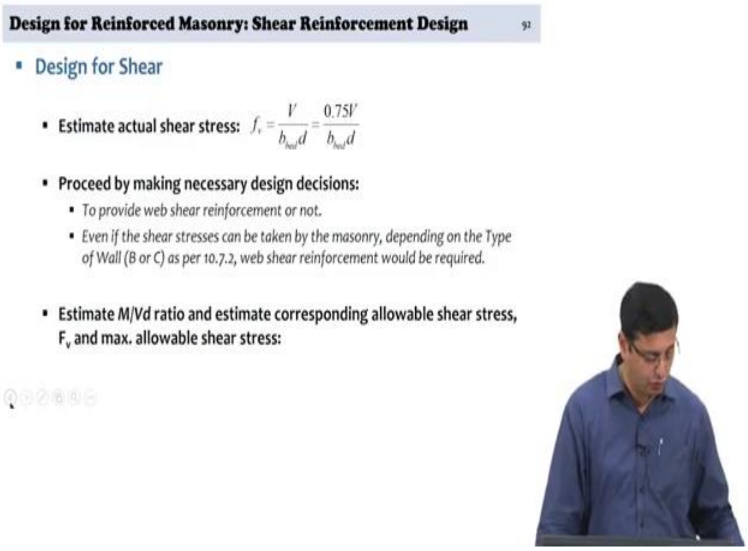

So as far as design for shear is concerned; we are really beginning with an estimate of what is the actual shear stress that is expected on the masonry wall. Now, I am assuming that we have already estimated the shear force that has to be attributed to a given pier in a masonry wall.

So, from the shear demand we then arrive at what is the value of shear stress that we are looking at in terms of the demand shear stress on the masonry wall. And this value of shear stress can give us an indication whether the masonry alone, that is the unreinforced masonry wall alone, would be in a position to resist the shear demand. And this is the stage where you actually make up your mind on whether you are going to use designed web shear reinforcement or just have the masonry take care of the shear itself.

So, if the shear demand is not significant you might be in a situation; where you do not have to design shear reinforcement. You still would have to provide minimum horizontal and vertical steel as per the wall category A/B/C that we have seen earlier. So, not to be confused with the need to provide the minimum reinforcement; you need to take this decision of whether or not the wall will have designed shear reinforcement ok.

So, for that you make an estimate of the actual shear stress that is expected in the wall, the shear stress f_v as the shear demand that you are looking at; V divided by the width of the wall itself into the effective depth d is considered. We take about 75 percent of the shear force itself is the shear stress that we are looking at; here 0.75V/bd is your estimate of the shear stress f_v.

And here you make the decision of whether you are going to go with the web shear reinforcement or no web shear reinforcement. Of course, that depends on the level of shear stress that the wall is experiencing given the distribution of shear force in the wall itself. And this is where I recall the requirement that particularly with wall type B or wall type C, now that you are designing the masonry wall, you are in wall type B or wall type C; the web shear reinforcement as required by 10.7.2; we will examine for wall type C in a moment, but needs to be provided even if the masonry can actually take all the shear stress coming on to the wall. Typically for zones 4, 5 for 1, 2 storied structures; we are looking at shear stress levels for which you typically would have to provide designed web shear reinforcement. For lower seismic zones you might see situations where you do not have to provide additional web shear reinforcement in the masonry wall.

So, to begin with we have discussed this fact that it is really the aspect ratio of the masonry wall and its boundary conditions which will determine the kind of behavior that the shear wall would have. So, the estimate of this ratio M/Vd is the first, once you have done the estimate of the actual shear stress; we need to then look at what this M/Vd ratio is.

And the M/Vd ratio; if you remember will then lead us to what are the allowable shear stresses that the code permits F_v; you need the allowable shear stress F_v and that comes from looking at boundary conditions and the aspect ratio of the wall. So, if you have a squat wall which is wide, longer than it is taller versus a slender wall which is taller than it is longer; you will be able to establish what the allowable shear stress is.

So, the M/Vd ratio has to be estimated. So, you are looking at the bending moment demand on the wall; the in-plane bending moment demand on the wall M; divided by the shear force that you have estimated multiplied by the effective depth which is the distance from centroid of tension reinforcement to the edge compression fiber; that estimate is then used to determine what are the allowable and the maximum allowable shear stresses themselves.

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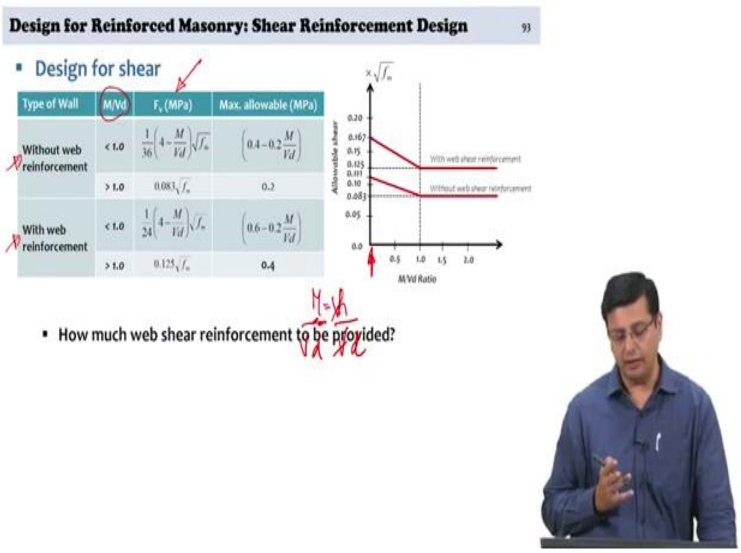

So, if you recall we had this table where there are two parts to the table; when you design considering the masonry to take care of shear or you design such that the reinforcement takes care of the shear coming on to the wall.

So, the upper part of the table looks at without web shear reinforcement, where as the lower part of the table is considering web shear reinforcement. And in this case when you say considering web shear reinforcement the assumption is that only the shear reinforcement is taking care of shear, you are not considering the contribution from the masonry itself. There is always a contribution from the masonry, in addition there is a contribution that you want to assign to the steel reinforcement. When you design for shear reinforcement you assume that the masonry is not contributing anymore all the shear is going to be carried by the shear reinforcement.

So, we have seen this table earlier, the M/Vd ratio here is categorized into less than 1 and greater than 1, looking at walls that are squat versus wall that are slender. So, that is one categorization, after the first the initial categorization which we do as with and without the web shear reinforcement design. The M/Vd ratio is estimated and then you know which category the wall would fall into for which the allowable shear stress F_v is prescribed.

If you see that the allowable shear stress is prescribed as a function of M/Vd; therefore, the aspect ratio of the wall is a governing parameter as far as the shear resistance that the masonry wall can offer and the masonry compressive strength, here represented as $\sqrt{f_m}$ .So, the two important parameters that govern the shear resistance of the masonry walls are really the aspect ratio.

The aspect ratio is also affected; the wall is also affected by the kind of boundary condition it has and then the masonry strength here represented as under root of the compressive strength; which is how the shear strength varies with compressive strength. So, you can then estimate F_v and look at the maximum value of F_v that the code permits within the allowable stress design.

So, to examine the overall contours of these values; if you represent what this table tells you in terms of the relationship between allowable shear F_v and the M/Vd ratio. We will look at with and without web shear enforcement what these numbers look like. Basically our M/Vd ratio is what is representing the aspect ratio; M if you were to represent; M as Vh; M/Vd is nothing, but your h/d.

So, it is really giving you the h/d ratio; it is really representing the aspect ratio. And there are factors that will take care of the boundary condition in the way the boundaries are affecting the shear deformation of the wall itself.

So, if you look at with and without web shear reinforcement, depending on the M/Vd ratio, the value goes from (for without web shear reinforcement) $\frac{1}{36}\left(4-\frac{M}{Vd}\right)\sqrt{f_m}$. So, that is the lower red line that you can see from M/Vd ratio 0 and at M/Vd ratio of 1, you come to the maximum value that we are considering $0.083\sqrt{f_m}$, but this is limited irrespective of a compressive strength; it is 0.2 MPa for any value of compressive strength.

So, there is a limit in value put there and if you have web shear reinforcement; you are going from an M/Vd ratio, h/d, small h/d to larger h/d ratios from 0.167 and then it saturates at $0.125\sqrt{f_m}$ and the maximum value there irrespective of the compressive strength is 0.4 MPa.

So, this calculation that you will make on the aspect ratio of the wall will determine what is the allowable shear stress for the design itself and you have to ensure that the shear stress itself is within these parameters; otherwise it would mean you will have to design the web shear reinforcement or change the dimensions of the walls such that the masonry itself can resist the shear demand coming on it.

So, this is to arrive at your allowable stresses; once that is done it is about coming back and estimating how much of web shear reinforcement should you be providing and how do you do that. So, is there a minimum; is there a basis with which you estimate how much of web shear reinforcement you should be providing. Yes, and it is a rather simplified assumption that is done here. You know that in reinforced systems; as you have studied in reinforced concrete, the shear resistance comes from several parameters.

In reinforced concrete you have the portion of concrete in compression that resist shear; you have the aggregate interlocking across a shear crack that can resist shear. You have the dowel action that can actually resist shear and then the shear reinforcement that you would provide; the tension resistance of the shear reinforcement also would contribute to the shear resistance.

So, it is a rather complex mechanism as far as shear design is concerned; however, the approach that is adopted in provision of shear reinforcement in masonry is rather simple. We estimate with some basic assumptions how much of minimum web shear reinforcement should you be providing; knowing the shear demand coming on to the wall and with knowledge of the type of steel that you going to use.

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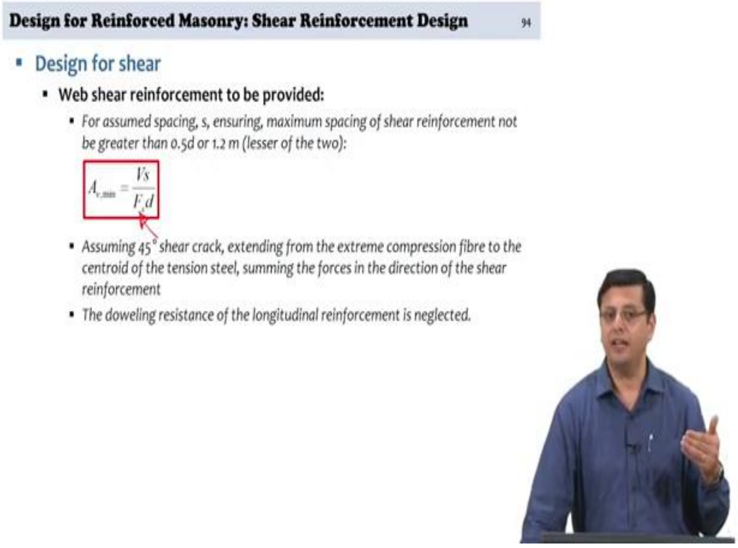

So, as far as the design for the shear reinforcement is concerned, it is prescribed that you make an assumption of what the spacing is going to be and that is anyway required as a design step. So, you begin by assuming a spacing s, but you now have to ensure that this spacing respect the requirements of minimum spacing the code prescribes for shear reinforcement. And therefore, ensure that the maximum spacing of the shear reinforcement is not greater than 0.5 times d, where d is the effective depth of the wall cross section that we are looking at or 1.2 meters; take the lesser of the two and that is your spacing that you are assuming to make this calculation.

And the minimum area of shear steel that you would be providing would be,

$$A_{v,min} = \frac{Vs}{F_s d}$$

F_s is the permissible tensile stress of the steel that you are using for the construction and d is the effective depth.

So, this is basically arrived that from a very simple assumption; we have the masonry wall panel h in height and effective depth d, we assume that a 45 degree shear crack is extending from the extreme compression fibre to the centroid of the tension steel. And then if you sum the forces you will be able to arrive at how much of steel is required to equilibrate the shear demand that the wall is experiencing.

So, in this particular assumption, you really do not consider the contribution of other effects such as the dowel action that the longitudinal reinforcement would actually be providing. There is a contribution which is there, but we not making an estimate of how much that component of the shear resistance itself is. We make an estimate of what the minimum web shear reinforcement that you have to provide is and then check against the minimum prescriptions for type B or type C wall, ok.

So, the process is quite straight forward; first you make an estimate of the shear stress itself f_v; then use the M/Vd ratio for the wall that you are designing and establish the maximum value of allowable shear stress and the maximum value of allowable shear stress. And then you take a decision whether you want to go with web shear reinforcement or the masonry itself will be able to counteract the shear demand. If web shear reinforcement has to be provided, then this is the minimum web shear reinforcement that you provide.

Estimate how much $A_{v,min}$ is and then compare it against the minimum requirements of a type B or a type C wall.

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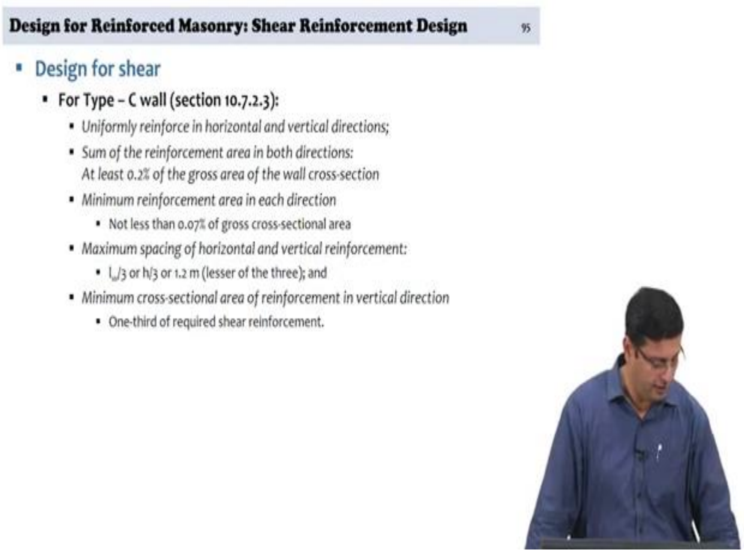

So, at this stage we will basically go and check what the minimum prescriptions; I am and looking at the type C wall prescriptions here. It requires that you provide the steel reinforcement both in the horizontal direction and in the vertical direction. And we have talked about this earlier, the horizontal reinforcement as shear reinforcement becomes more effective in the presence of vertical reinforcement. And therefore, it is about providing both horizontal and vertical reinforcement uniformly in the masonry wall.

But there are specific requirements in terms of how much of reinforcement, minimum reinforcement should be provided. There are two requirements, basically the sum of the reinforcement in both directions that is how much of area of steel you are providing in the vertical direction and how much of steel you are providing in the horizontal direction should be at least 0.2 percent of the gross area of the wall cross section.

So, this is one requirement that has to be adhered to and the second requirement that in each direction the minimum steel that you provide is 0.07 percent. So, in many cases depending on the zone that you are designing and the size of the structure that you looking at and the criticality of the wall in terms of attracting shear forces; you might be providing the minimum steel, the minimum steel that it requires.

So, these two requirements have to be taken care of the sum of the reinforcement in vertical and horizontal directions and the minimum reinforcement in each direction. So, should be 0.07 at least in each direction and the sum should be atleast 0.2 percent.

Spacing of the reinforcement; you already have a requirement in terms of the spacing of the reinforcement, this is what type C wall or type B wall would be prescribing. Here in this particular case is the maximum spacing the horizontal and vertical reinforcement is the lesser of these three values that you would estimate; l_w length of the wall divided by 3 or the height of the wall divided by 3 or 1.2 m.

So, that 1.2 m spacing is something that you will see is a recurring number that comes from established experimental work which shows that at least 1.2 m spacing of reinforcement is required for minimum desirable behavior of a masonry wall panel.

There is also another requirement that this code puts in that the minimum cross section area of reinforcement in the vertical direction has to be one-third of the required shear reinforcement. So, this is an additional check that you would make, that you have the area of shear reinforcement that you are estimating and then ensure that in the vertical direction the minimum cross sectional area of reinforcement that you have provided is at least one-third of the value that you providing for the shear reinforcement itself.

So, this is basically your shear design that as far as this code is in concerned is required to be done. Pier by pier you would be caring out the shear design; mind you there is no specific prescription for; there is no specific design prescribed for the spandrels, ok. The design of reinforcement both flexural reinforcement, the P+M design and the shear design is for the piers; for the vertical load resisting elements.

You do not have a design process prescribed for the spandrels; the spandrels are the portions between the vertically aligned piers and minimum steel is prescribed for the spandrel regions. So, if you look at areas of masonry above the window opening and below the window opening; you will have to ensure that the minimum reinforcement that we have been talking of a type A, type B, type C wall is adhered to as far as these regions are concerned.

So, design is only going to be for the piers.

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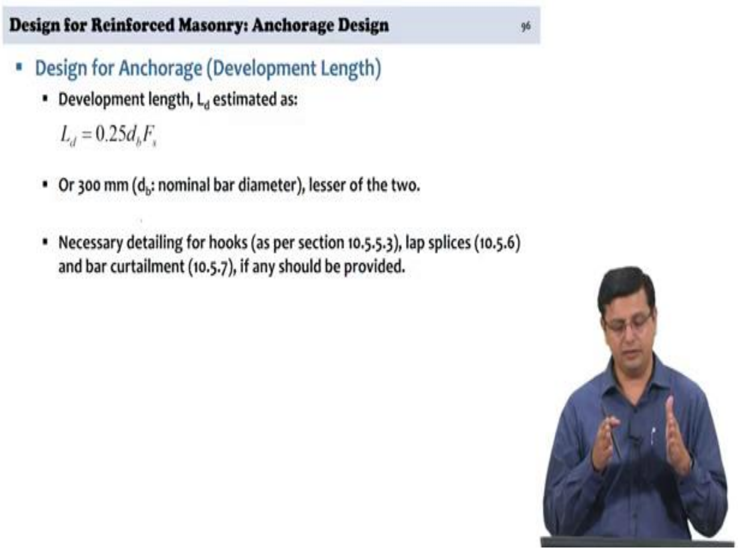

Once assume you have designed your wall to carry axial forces; we will looked at the prescription, axial forces both the steel reinforcement has a contribution as well as the masonry itself.

We had a simple expression that takes care of the maximum allowable axial force for a wall under compression. Then if you have P+M in-plane or out of plane; you can do the P + M design approach that we have examined earlier and then the shear design depending on the shear demand coming on to the wall. Once those three are done; of course, the shear reinforcement or the flexural reinforcement are going to be effective; only if you provide adequate anchorage for the reinforcement bars. And therefore, one has to look at design for development length, design for anchorage by achieving the required development length. And here again prescription is rather straight forward and most of the principles, most of the prescriptions that you would adopt for reinforced concrete are applicable in this context.

So, the development length L_d has to be estimated for each of the locations, each of the bars, where it is 0.25 into diameter of the bar into the permissible tensile stress of steel or 300 mm. So, you would make that estimate and provide the development length that is required, the lesser of the two estimates is what you use.

You are also allowed to provide hooks as you would in reinforced concrete where development length is becoming difficult because of congestion of reinforcement or practical difficulty in placing an extension of the steel bar; you are allowed to go with hooks. And we have seen that there is a section that tells you the detailing of the hook as in reinforced concrete has to be taken care of.

You would need to do lap splices because you are looking at the vertical reinforcement that would have to run continuously across the entire height of the masonry walls. Therefore, lap splicing and where should you do lap splicing and what is the overlap that you required for lap splicing is again something that you can take care of.

Bar curtailment is again allowed for as in reinforced concrete where if the expected demands are lesser than M max; the maximum moment, then you are allowed to go with bar curtailment. So, these prescriptions in the detailing stage have to be adhered to and with that the component level design is complete. So, what we will do in the next couple of sessions is to take up the design process from system level and arrive at the design forces that are required at the component level.

So, that is where it would be instructive to examine design of a single storied structure which has a certain distribution of the shear walls and a multi-storied structure with the distribution of the shear walls. And then arrive at what are the design forces required for the masonry walls that you would be designing. So, with this the component level design aspects are complete.