Design of Masonry Structures

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Module - 01
Lecture - 01
Introductory - Part - I

Welcome to our first lecture in the course on Design of Masonry Structures. This week will be an introduction to masonry as a structural material; we will examine the use of masonry as a structural solution from ancient times to the present. It would be useful at this stage to look at the present-day use of masonry and the kind of standards or the codal framework or the normative framework within which structural masonry is used in different countries. And, the kind of normative framework that we have in our country as far the use of masonry is concerned. And in a few days, you will start appreciating the fact that the term “masonry” is quite loosely used.

The word “masonry” can refer to a very vast majority, a very vast spectrum of structural construction materials and systems. So, they can vary right from sun-dried unburnt bricks all the way to stone masonry, and in today’s context, cement blocks or modern materials such as aerated autoclaved blocks, fly ash bricks and so on. So, you have an entire spectrum. It could be used along with mortar, of different types, which leads to different types of masonry. It could be used even without mortar and we refer to that as dry-stack masonry.

And today, we have an entire class of masonry called hollow-brick construction, very often reinforced, sometimes not reinforced. So, you already see that with the combination of the structural units and the choice of the mortar, you can get different types of systems which classify as masonry, ok.

Reinforce them, you get reinforce masonry, otherwise we refer to them as unreinforced masonry. So, this entire spectrum exists and you will see that in our course we are going to be dealing with the more formal, the more recent, modern masonry constructions, where either cement blocks are used for construction, hollow concrete blocks are used for construction or solid fired clay bricks are used for construction, ok.

So, we will also be largely focusing on reinforced masonry, where, as I would emphasize, in the codal framework in the country today, unreinforced masonry is not seen as a structural typology that should be used and therefore, we are moving towards having reinforcement in masonry.

So, predominantly our course will focus on how do you design masonry structures, particularly reinforced masonry structures, for a combination of forces acting on it, ok. So, I begin today's lecture by giving you a perspective on how masonry is used and how has it been used in the past, but that clearly comes from an understanding of what is the strength and what is the weakness of masonry.

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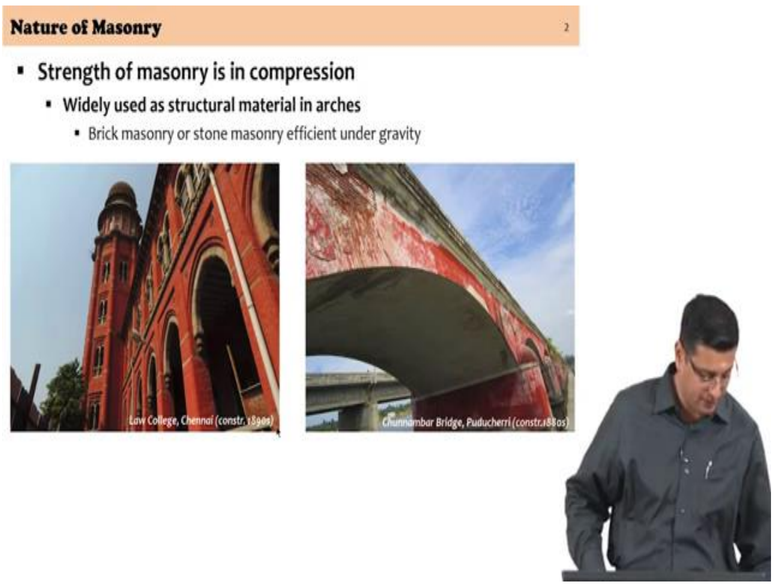

And when I talk of masonry, I am talking of the assembly now, unit plus some mortar acting as a composite, right. So, if one were to examine historically how masonry has been used, this is clearly understood as a material which is good in compression, ok. You use stone blocks. Stone can have compressive strengths as high as 200 MPa. Granite has a range that goes all the way from about 70 MPa to over 200 MPa.

So, if you use building stone to construct an entire structure, you can be guaranteed that the compressive strength is good. If you make it monolithic, you are going to get the granite compressive strength.

If you use small blocks and have mortar, you are going to be limiting the compressive strength and this is something you will understand in a few days from now, how the mortar is going to be limiting the compressive strength of masonry. However, given the fact that you are using a material which is strong in compression, you are going to have to deal with the fact that this is a material which is strong in compression, right.

Now, evidence from history tells us that this is widely used in arches, right and most massive constructions in the past, have been constructed on the structural typology of arches. The use of arches is predominant/prevalent in historic masonry constructions and that is simply because an arch is known to be good in compression. Masonry is extensively used in the form of arches and this could be brick masonry, it could be fired clay, it could be sun-burnt bricks, simply because of the fact that you have good compressive strength, the structural typology of the arch ensures that the entire cross section is in compression and you use a material which is good in compression.

So, masonry arches is something that you would see everywhere. Historical structures in and around your city. This is formal construction in masonry (from 1890s). That is a massive tower that you see there and a structure which is heavily relying on arches for equilibrating gravity forces. So, arches are something that give clue to the fact that this material really works well in compression and can be relied upon.

Bridges; extensive number of bridges in and around our country, all over the world, are built in, are built using brick or stone masonry. These are structures, this particular example that you see here, is a structure that is about 140-150 years old and they continue to be in service conditions. One has to assess them structurally, but this is putting the material to its best use, which is the strength of masonry itself. You would be surprised to know that the Indian railways, for example, has 1,30,000 masonry arch bridges.

And 1,00,000 of them, i.e., 1 lakh out of this number, was built in the colonial period. So, we are talking of bridges which have been in service condition for over 100 years easily. Of course, you need a quantitative structural assessment of such structures and that is needless to say. But it is the predominance of the typology, is due to the strength of masonry itself.

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We also see a large number of towers, a large number of towers, not recent constructions, these are constructions that are at least 800 to 1200 years old towers and if you were to use a material to build towers that are 100 meters or taller, the material is working well in compression. Of course, we are not yet discussing the behavior of such structures under lateral action. That is something we will examine and we will examine them particularly to see the stability when you have a combination of gravity forces and lateral forces.

However, if you were to assume only gravity forces acting, which is not always the case, you will have lateral forces. Under gravity, you have massive masonry structures constructed in the past. You have two examples here, they are very famous examples, the one on the left is the Brihadishwara tower; the Brihadishwara temple in Thanjavur which is not very far from here, you can go and visit it. It is about thousand years old, it was constructed between 1003 and 1010 AD in about 6 to 7 years.

And of course, there is the geometry of this structure, which is also responsible for its stability, which we will examine in a few minutes. But it is a massive masonry tower, it is a stone masonry construction. And the one on the right is a brick masonry tower. It’s one of the tallest towers in the world. You can actually go up this tower. This is in Italy, in a town called Cremona and as you can see it is a fairly slender structure. It is completely in brick masonry and rises to about 120 metres in height.

An instructive exercise is something that you can do and I will ask you to work through this. If I were to take just a stack of bricks, right. I am just stacking one brick above another, right. What would be the size of one brick? Standard brick, we are not talking about historical brick, I am just taking a standard brick size, what we use in India today.

Student: 19 x 9

19 x 9 x 9, units?

Student: (Refer Time: 10:24).

Centimeters, ok. So, if I were to take a standard nominal size of the brick and keep stacking bricks one over the other, ok. Could you make an estimate of what height the stack of bricks can go before it crushes? I need to make some assumptions, you can plug in some numbers and try to look at it. If I were to assume that the density, it is only under gravity forces, I am not assuming the presence of other actions now.

Let us assume the density of brick, density of brick to be about 1800 kg/m^3. That is a fairly good estimate, 1800 to 1900 kg/m^3 as the density of brick unit itself. We are not talking of density of masonry yet, brick unit. Only under the action of gravity forces. You know the area of cross section now. It is 19 cm x 9 cm.

What is your estimate of the height to which you can construct this? You need to know the compressive strength of the masonry because you can assume that it is going to fail by crushing. What would be an estimate of the compressive strength of the masonry? You are familiar with concrete. You talk of M20 concrete, M30 concrete or M40 concrete or so on.

Masonry units, you will you will see in the next week that we have a different classification for their strengths, but 5 MPa or 5 N/mm^2; or 10 N/mm^2 is a fairly good estimate of the strength of bricks that are predominantly available. You will see that if you assume a nominal strength for the brick and look at a brick that is about 19 cm x 9 cm, the stack can easily go for a few kilometers. Of course, there is going to be an issue of stability and that is the reason why these towers have stopped at 100-120 meters in height.

Of course, you can improve the compressive behavior of a material by choosing the right cross-section, integrating stronger materials in the cross section, and choosing a form that gives you better stability. And that is the reason why the figure on the left, the Brihadeeswarar temple with the more stable form, would have a better performance than something that is most slender and uniform in cross section all along the height.

Of course, the tower on the on the right, in Cremona, also would have a wider cross section of masonry at the base than at the top, although the tower in itself in geometry, is uniform from bottom to top overall geometry. So, masonry is good in compression, but it is always important to do a SWOT analysis on all structural systems. What we do understand is, this is not a material that is meant for tension.

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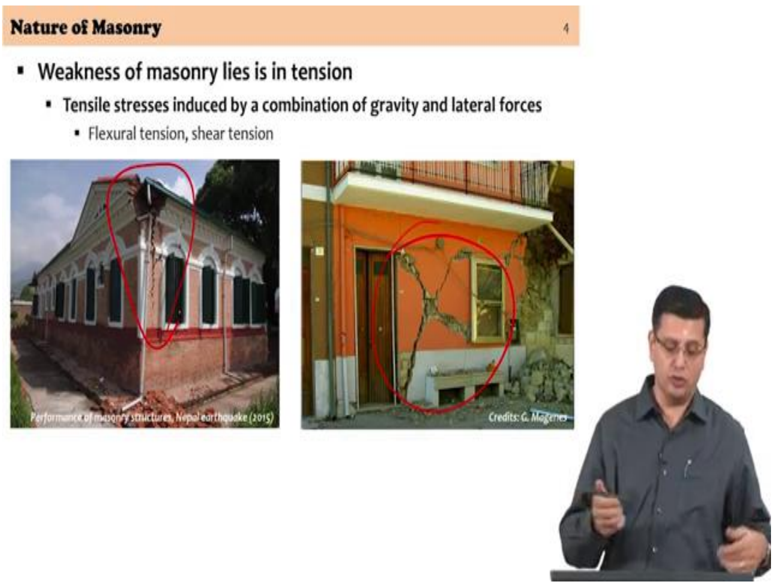

Masonry has never been put to use in situations of direct tension. It is rarely, you would never find masonry be put to use in direct tension unless you have reinforcement built in and that applies to reinforced concrete as well. Because concrete as a material is weak in tension and you reinforced, you reinforce concrete so, that you have tensile resistance in this system itself.

The same applies to brick masonry. In fact, it is notorious as a zero tensile strength material. If you are working with existing masonry, particularly with the use of lime mortar or mud mortar. So, historical masonry is notorious as a zero tensile strength material. It might have some residual, it might have some finite non-zero tensile strength, but it is so, non-uniform/variable that you cannot depend on it as a tensile strength of the material.

So, it is very often we assume that masonry is a zero tensile strength material. Modern masonry will have, particularly the masonry with cement mortar, will have some tensile resistance and this tensile resistance can be measured and can be used in your design; however, it is very small in comparison to the compressive strength, typically of the order of 10 percent of the compressive strength or lesser, but again so, variable that you cannot depend on the tensile strength of masonry.

So, in this particular slide there are two things that we can look at. Tensile stresses when we exclude the possibility of direct tension, what leads to the formation of tensile stresses? In structural systems under the combination of gravity and lateral forces, you will have situations where tensile stresses can be generated. Particularly in the form of flexural tension or in the form of shear tension. That is where you get principal tension situation in masonry.

So, when you have that, the x crack that you see in the figure on your right, is the effect of an earthquake on a 2 or 3 storied unreinforced masonry structure. It could, it is in stone masonry. You can see the formation of these cracks which are called as classical legs cracks and those cracks are actually forming along the lines of principal tension. This demonstrates that masonry behaves as a very brittle structural system, as a very brittle structural material and under the combination of gravity and lateral forces, you do not have the necessary ductility, particularly under actions like earthquakes.

The figure on the left, has another story to tell you. And this is not so much about masonry having low tensile strength, but an important aspect of existing masonry structures, which is poor connections between the structural load bearing walls. Unless specifically designed, these walls are not tied together or held together. In regions where earthquakes are prevalent, the structure over several hundred years evolves in a manner that tensile resisting elements or ties are introduced such that the structure works together.

We will examine this more closely when we start looking at detailing for earthquake resistance, but historically, structures were given timber bands and sometimes steel ties to ensure that all peripheral walls and all load bearing walls act together. However, in the absence of any such tying material, in steel or in timber, you would have a very low resistance to separation between orthogonal walls and that is exactly what you see here.

The only resistance that is available against the separation of orthogonal walls is really what is referred to as the toothing between the toothing between the two walls.

Have you seen how a mason constructs a masonry building where does he begin?

Student: (Refer Time: 19:20).

Yes.

Student: (Refer Time: 19:21).

Yes, a mason would start constructing a masonry wall or an or an assembly of walls from the corner, and you would see that the brick courses are laid such that the alternate to form a toothing pattern what you see here.

However, when lateral forces are significant that toothing pattern is not sufficient to hold the two words together. The interlocking provided by the mere toothing is not necessarily sufficient, in some cases that may be completely absent. So, the only resistance that is there between separation, between the two orthogonal walls from separating is the shear interlocking available between the two orthogonal walls.

Again, we are talking of a material which is not strong in tension. So, this separation action causes tension and you can get cracks very easily formed at the junction of orthogonal walls, orthogonally juxtaposed walls. So, be it within a wall.

So, the difference between the two slides, the two pictures that you see here, the one on the right tells you that crack formation within a wall happens rather easily; the picture on the left on the other hand, tells you that separation between orthogonal walls, simply because you do not have a tensile resisting material there can happen rather easily, when you have significant seismic forces. In fact, even moderate seismic forces.

So, this is definitely the limitation of masonry and this limitation understood at the component level, a single wall, is the basis with which many of our historical structures have been constructed and we will examine that in a few minutes. Similarly, in regions of significant earthquake activity or heavy wind forces, in regions where heavy wind forces are present, you have ties that basically hold all the masonry walls together.

So, you need something else, you need something else to keep the structure together, ok.

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In that context it becomes interesting to examine how historical masonry constructions were conceived and how do they survive if they have to survive several centuries. They are definitely countering different types of actions constantly.

So, I take up this example of the Ctesiphon palace in present day Iraq. In the past, it was the part of the Mesopotamian civilization. And we will examine the equilibrium in this mud brick wall. So, it is a sun-dried brick wall that we are examining. As you can see with respect to the scale there, the human scale with respect to the wall, you will appreciate that it is a multistoried construction and we are talking of a construction that is at least 3000 years old. And this sits in the middle of the desert. We are not examining the vault here, that is another interesting example and we will keep it for another day, we will examine the wall.

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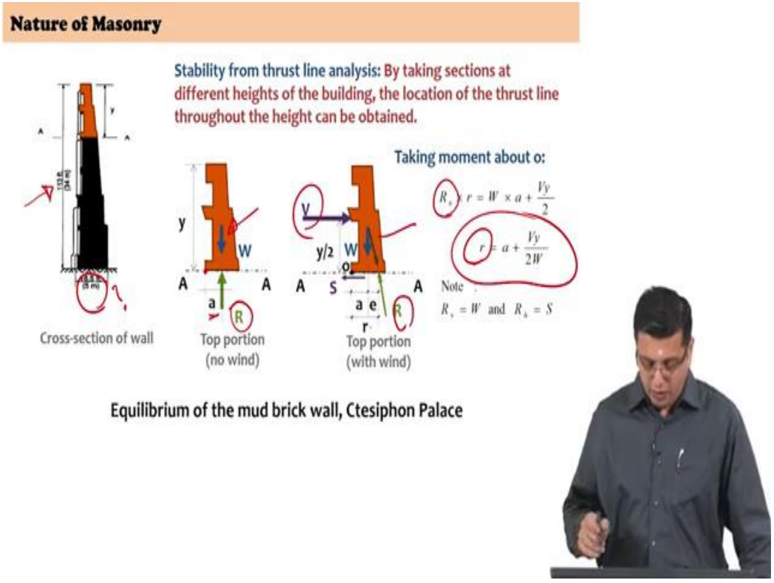

Now this wall, if you were to take the cross section of the wall, you will understand that we are talking of a 34 meter high wall. A 34 metre high wall would be how many storeys?

Student: (Refer Time: 23:25).

It is 10 plus, right. Assume 3 meters per storey and you have a 10 storey construction. Now this is the palace wall, it is the remaining part of the palace wall and you see that the cross section is definitely thicker at the base and tapers to the top, that some optimization that has happened there. But it is interesting to examine why 5 meters, why 5 m? Could it have been 3m? could it have been 4m? could it have been 2m?

So, that is an important question. If it has survived several thousand years in the desert, where apart from the role of carrying gravity forces, it also has to counteract.

Student: Wind.

Wind, Right? Desert storms are common. So, you are talking of significant wind forces. So, you have a situation where gravity forces are acting along with lateral forces. So, this is a situation where the masonry wall is not going to be only in compression, this will definitely be subject to some amount of tension. Question is, how did it survive? What is the story behind the stability of this construction?

It's going to be examined now under two conditions; one, let us assume that the wall is not subjected to any wind and the second case we look at equilibrium under combination of both wind and gravity forces. I will examine a section A-A from the top, at a height of 'y' and we will do our equilibrium calculations on that. What is true for that, is then true for the rest of the structure and let us see if we can deduce something out of this exercise, ok.

So, I am looking at the first case which is the no wind case, it is purely under gravity forces. Now for that section that is being considered, the gravity force W acting about its centre of gravity at section A-A, we have the cross section of the masonry wall, the resultant of the gravity forces acts at the centroid of the cross section there.

And since the resultant R acts at the centroid of the cross section defined at a distance 'a' from the edge, You have uniform compressive stresses in this cross section, yes? At the inner edge and at the outer edge the cross section is going to experience uniform compression simply because the resultant is acting at the centre of the cross section.

Now, if I were to examine the equilibrium under a combination of gravity and lateral forces, we will make little assumptions which will not jeopardize our estimations here. I assume that the wind forces are acting uniformly from the top to the bottom of the structure. That is, the wind pressure is uniform from the top to the bottom of the structure.

So, if I look at this height 'y' that is under examination, the resultant of the wind force 'V' is acting at the at mid height y/2 and you have the gravity force W acting at the centre of gravity of this block. And now if you examine section A-A and R, cross section at that point because of the combination of the lateral force and the gravity force there is a tendency of the resultant now, moving towards what we refer to as the leeward side.

So, the wall is standing against wind, you have the windward side and leeward side. Point O is on the windward side. Due to a combination of the wind force V and the gravity force W the resultant now, is shifting towards the leeward side. Of course, now there is an eccentricity of the resultant with respect to the cross section, where eccentricity is e with respect to the centroid of the cross section and therefore, the point through which the resultant is acting geometrically is defined as a+e which is r with respect to this point O on the windward end of the wall itself, which is the gravity force into a and the wind force, Vy/2.

From which, it is possible to get an expression for this geometrical quantity r which is nothing but the point on the cross section through which the resultant is acting, right. So, I rewrite this expression in terms of r and we have a simple expression to estimate the point through which the resultant is acting at section A-A in terms of the centroid of the cross section from the edge O which is a plus the wind force into y/2 divided by the gravity force W.

So, this little expression here is going to help us write down what is r at different cross sections. If were to take ten different cross sections A-A, B-B, C-C, D-D …. I would get r_1, r_2, r_3 and all r can be written down, right? Of course, you need an estimate of the wind force and you need an estimate of the gravity forces acting here. Once I do that, I have different points estimated r_1, r_2, r_3 and so on are and if I were to connect all these points you are basically doing what is called the thrust line analysis.

A combination, under the combination of gravity forces and lateral forces, you are estimating the thrust line of the system, which is the line of action of the resultant of the structure under a combination of lateral and gravity forces. So, what we are basically doing is a simple hand calculation referred to as thrust line analysis for stability check, ok.

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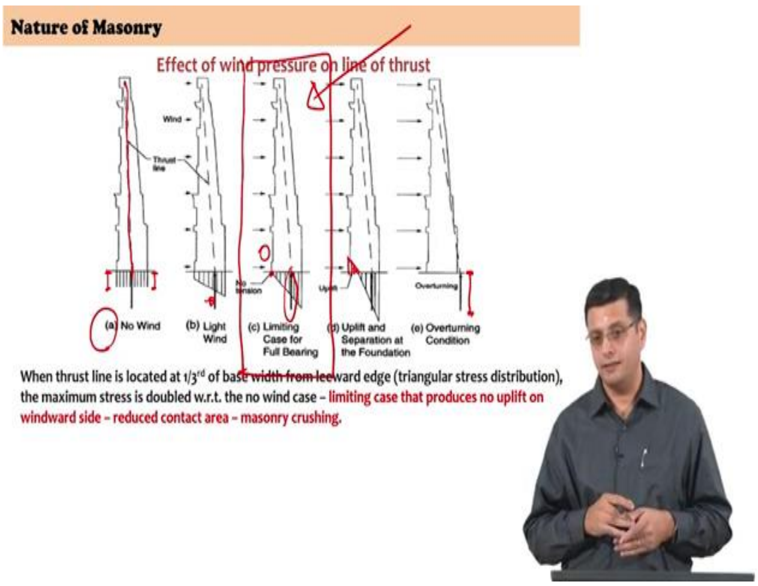

So, with this background if we now examine, what might be happening to the wall under the effect of wind and gravity. In the first situation, so, what you see here is the thrust line that is running from the top to the bottom and the thrust line in different situation. So, the first situation: no wind case, the stresses at the base of the structure are fully in compression and uniformly in compression that is the compression on the windward side and the compression on the leeward side are equal and you have uniform compression on the cross section.

But as you start having some amount of wind force acting on the wall cross section, under the combination of lateral and gravity forces, the resultant starts shifting slowly towards the leeward edge and in situation of light wind under a combination of these forces, the cross section is still fully in compression, but you have one edge which is in lower compressive stresses the other edge which is now in higher compressive stresses.

As you move forward there is a limiting case that you will reach and that limiting case is a very important situation where the cross section is still fully in compression, yes, but this edge which we have designated earlier as O is now reaching a state of zero stress which is, it is no more in compression and it has been decompressed at this point in time. Beyond that it will going into tension. Hence that point where it has been decompressed, that the edge fibre has been decompressed, is a limiting case for us why? Because we are looking at a material which is weak in tension, we really do not want tension to come into this cross section.

So, that is a limiting case for us. Under the assumption that the material is behaving in a linear elastic manner, we can assume that the cross section is under a triangular distribution of compressive stresses, which simply implies that the resultants now is acting at the centroid of the triangular distribution, which is at the edge of the middle one third of the cross section, because the centroid is at two thirds. Hence the middle, the edge of the middle one third is where the resultant of the lateral gravity plus lateral forces is acting.

If were to assume that the wind force is acting from the other side, that the windward and the leeward sides were flipped, it means that the resultant in this limiting case basically moves from this the right edge of middle third to the left edge of the middle third, but always needs to remain within the middle one third, right. If it is within the middle one third of the cross-section then there is no tension in the cross section.

If it goes beyond the middle third of the cross section, then if the material has some tensile strength, then I can assume that it will take some tension. But if this material does not have tensile resistance, which is typically the case with masonry, then any tension would imply formation of a crack, right? And that is what is written there as uplift. And that is what you would expect that a crack is formed and slowly there is uplift or the length of contact and length across which compressive stresses are still being transferred, starts reducing. So, the section starts becoming partial.

If you now continue increasing the wind forces, the area under compression keeps reducing, it will reach a stage where the compressive stresses are so high, that you have reached the crushing strength of the material and the material crushes. When it crushes, the overturning of the system and that is how the loss of stability is going to actually progress.

Now, I come back to the central limiting case and I said that under a combination of lateral forces and gravity forces, the resultant has to lie within the middle one third for us to be in the limiting case of no tension in the cross section. If it so happens that there is going to be tension in the cross section, as a builder what could you do? as the structural designer of that wall what would you do? But now my calculation show that resultant is outside the middle one third what can you do?

If I were to increase the dimension the width of the cross section, width of the base itself, the middle one third increases right. We were only talking of t/3. If t is the thickness or the width of the cross section, t/3 is the middle one third. The game is bringing this resultant within the middle third for the combination of gravity and lateral forces. So, if one we are able to do that, the easiest way to do that would be to increase the width of the wall cross section and that is possibly the rationale behind most historical masonry constructions, to keep tension out, because they knew that this material does not work in tension it is good in compression.

So, ensure your cross section is fully in compression. This is today understood as a mason’s middle third rule. So, mason would make an empirical calculation of what could be the lateral forces coming on to the structural wall, what is the gravity force and then dimension the cross section such that you do not have tension in the cross section.

Now, just think back about the Ctesiphon palace wall, if it has to survive several millennia, under a combination of gravity forces and lateral forces, there is no tension occurring in the cross section and that is why it is 5 meters at the base. So, this gives you an idea of how historically masonry was constructed. It is conceived as a lateral force resisting element, but predominantly under gravity forces dimensioned to keep tension out.

Today you and I are able to put reinforcement into masonry or have other elements that can give tensile resistance. So, we start reducing the cross sections. Here if you reduce the cross section it will simply overturn because of zero tensile strength available in the masonry, ok.

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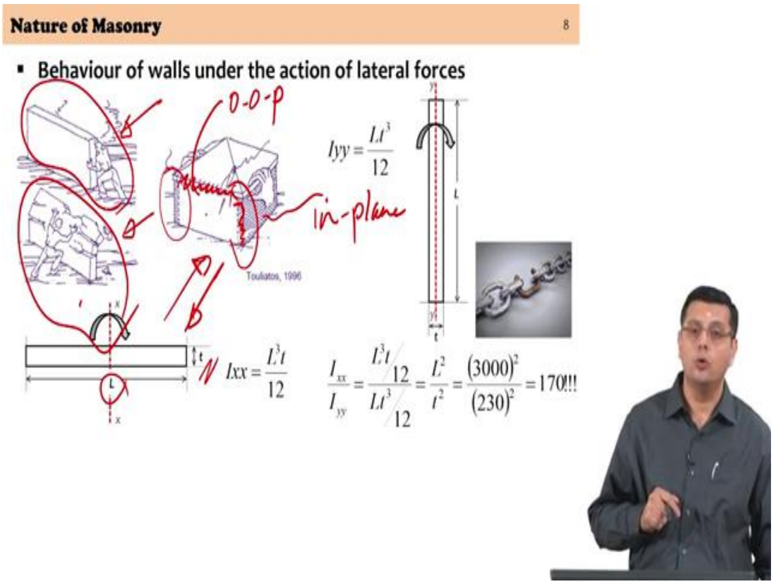

Having said that here we looked at the stability under gravity and lateral forces. Within the resistance of a wall to lateral forces, there is a certain difference that we have to examine and this is another aspect of weakness which becomes essential to keep in mind because it keeps coming back to us in earthquake resistant design.

So, if you were to examine a masonry structure as composed of four load bearing walls with a roof and we have seen a picture where separation between the orthogonal walls happens under the effect of lateral forces like earthquakes, right. So, we are talking of this sort of a connection between the orthogonal walls. If you were to assume that the connections are very poor, like we saw in the previous photograph, that under the earthquake it just ripped apart like a piece of paper.

If the connections between walls is poor and if the connection between the roof slab and the wall; so, we are talking of vertical to horizontal system connection and connections in the horizontal system between elements. So, if we were to examine these two types of connections and say both these connections are poor, then if you take a masonry structure and subject it to lateral forces it will easily separate and then the walls are all left by themselves to defend the lateral forces. It is no longer the whole box, it is no longer the totality of the structure, but its individual walls which will have to fend of the earthquake forces.

So, if you consider that sort of a situation where the walls are not connected to each other and the roof slab is not connected well to the walls, right; two poor connections, two types of poor connections exist in the structure and examine what happens to the wall when subjected to lateral forces, in two different situations. When the lateral force is acting in-plane of the wall, right; in the same plane of wall and when the lateral forces are acting out of plane, are perpendicular to the wall that is the second case.

So, this is referred to as in-plane action and that is referred to as the out of plane action and we are basically examining a wall component with respect to in-plane action and out of plane action. You will agree with the me that both are looking at bending action in-plane, bending action out of plane, right. It is subjected to shear, but there is bending in that direction, predominant direction in plane and out of plane.

The second moment of area or moment of inertia is a good geometrical parameter, that captures the bending strength, the bending resistance right. So, if I were to look at. So, what would you expect between the masonry wall subjected to in-plane lateral forces and out of plane which do you think is more resistant, intuitively?

Student: In plane.

In plane, right. The cartoon there says you can even push it with your own hand in the out of plane direction, which of course, depends on the stability in the out of plane direction, but it is very instructive to simply plug in some numbers to the strong axis and weak axis bending strength, bending resistances and look at in-plane versus out of plane, is their significance difference between the resistance available in masonry?

So, if I were to take the wall, put some numbers there, we will some numbers there, let the length of the wall is L, the thickness of the wall is t and we are looking at the major axis bending of this wall about X-X, I_{xx} the second moment of area would work out to be $L^3t/12$, rectangular cross section simple. If I were to look at out of plane bending and estimate the second moment of area I_{yy} same L length and t thickness would be $Lt^3/12$.

It is useful to plug in some numbers, let us say the wall is about 3 meters long and about 230 mm thick, which is a standard masonry wall thickness for a one brick thick wall. So, if I were to then plug in some numbers and take the ratio of these bending resistances, I take I_{xx}/I_{yy}, knowing that I_{xx} is going to be higher, you will see that the ratio works out to something like 170 which means if you have two walls- you have a wall which is in the direction of the earthquake, the in-plane wall and the other wall you have the in plane wall and you have the out of plane wall, under shaking. Let us say this is the direction of shaking, what do you think will happen if the structure is not behaving as one entity. It is now simply a pack of walls, some in the in-plane direction, some in the out of plane direction and the roof that is sitting without connections on it.

And if there is shaking in this direction what would you expect given the bending resistances that you see. You would simply expect walls that are in the out of plane direction to fall way before the in-plane walls really start resisting and holding the structure together because the connections are completely not there. So, even under low to moderate earthquakes, this sort of a failure mechanism, which is referred to as an out of plane failure mechanism is extremely predominant in masonry constructions.

Now, if tensile resisting elements were put in place, if ties were put in place to hold all these walls together and in the cartoon its very nicely shown as some stitching that is happening between the roof and the walls and some stitching is happening between the walls. So, if you have good interlocking along the walls, between the walls orthogonally and if you have good connections it could be in the form of a concrete band, it could be the form of j bolts or whatever, if the connections positive connections are good, then under a similar action of lateral forces acting on this wall what would you think will happen?

The out of plane wall is still the out of plane wall the in-plane wall is still the in-plane wall, only the connections have been improved. The out of plane walls still has lower bending resistance, but it would try to fail, but when it tries to fail, it is held at its ends to the in-plane wall. So, it starts transferring those lateral forces to the in-plane wall; the in-plane wall has 100 times more bending resistance and starts protecting the structure.

So, that is an important lesson in the way masonry structures will respond to lateral forces and that is the reason why the emphasis is always on connections. So, if you improve connections, you get what is referred loosely as ‘box action’, which is good for earthquake resistance and this is really nothing, but the out of plane behavior is the weakest link in the chain and the strength of a system is regulated by the strength of the weakest link and if you fix the weakest link which is the out of plane behavior, you get better behavior of the overall structure.

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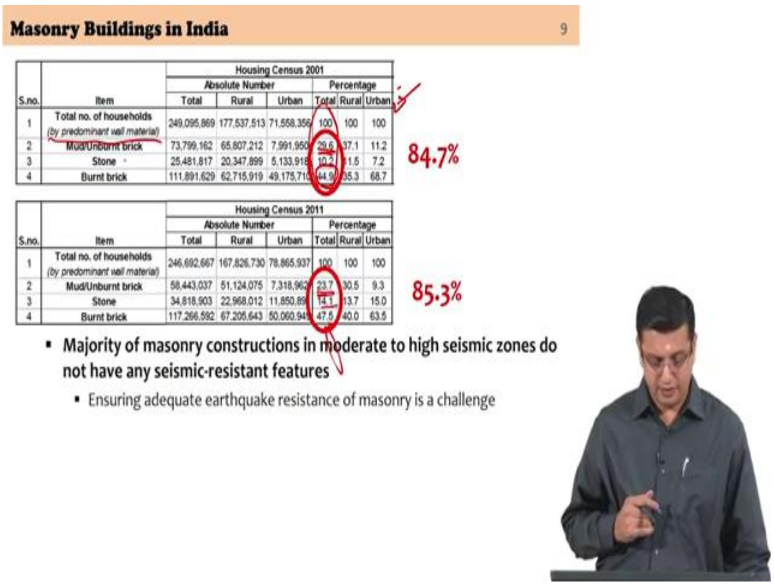

With that I would like to conclude today’s lecture looking at masonry statistics in our country, ok. We have this interesting numbers that we can examine. I am looking at the housing census from 2001 and the housing census from 2011, ok. And this is information that is been pulled out of the building census, from the census of India in which the building census is a component. If you were to look at total number of households, you can examine the percentages, you do not have to get awed by the numbers we are running to into millions of built residential units.

So, total number of households by predominant wall material and the predominant wall materials examined here are mud or unburnt bricks, which is not fired, sun burnt bricks, stone and finally, burnt clay bricks, the three categories that I am examining. You have total, you have rural and you have urban. The rural plus urban will give you the total, let us examine the percentages.

Now, if you were to examine the percentages out of a 100 percent of these, if you add up the percentages of unburnt brick stone and burnt brick for the 2001 census, we get a total of 84.7 percent; meaning 84.7 percent of the bill stock of this country running to millions, we are talking of the total of 249 million houses, these are, these are houses housing families of 4 to 5 people, that is how the calculation is.

Now, if you were to look at the 2011 census, 10 years later, look at those numbers they add to 85.3. Essentially we have not changed, we have we continued to build almost in the same pattern; however, if you examine the individual numbers from 29.6 mud brick it has come down to 23, which is good news, we are building less kuccha constructions.

But it has simply moved into the burnt clay brick or stone. So, from 10 percent it goes up to 12 to 14 percent and 44.9 percent of burnt brick increases toward 47.5 percent. So, essentially if you look at the build stock in this country, we are still talking of predominantly masonry constructions. No engineer has built all these structures, mostly they are mason constructed constructions. Majority of these constructions, if you look at a country like India, 60 to 70 percent of our land mass is sitting in seismic zones III, IV and V- moderate to high seismic zones.

If you look at these structures, most of them will not have any seismic resistant feature in terms of what we are talking of these ties, these connections which have to be good and so on. So, in a country like ours, earthquake protection or risk reduction in earthquakes, of predominant majority of the population living in such constructions is a big challenge.

So, we stop here and we continue our lecture on the introductory aspects to masonry construction in our next lecture.