**Design of Masonry Structures**
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**Module - 02**
**Lecture – 09**
**Masonry Materials and Properties Part - V**

Good morning, we continue looking at behavior of the masonry assembly, we were examining the behavior of masonry under compression, the standard tests that are conducted to get the compressive strength of masonry and the various factors that affect the compressive strength of masonry.

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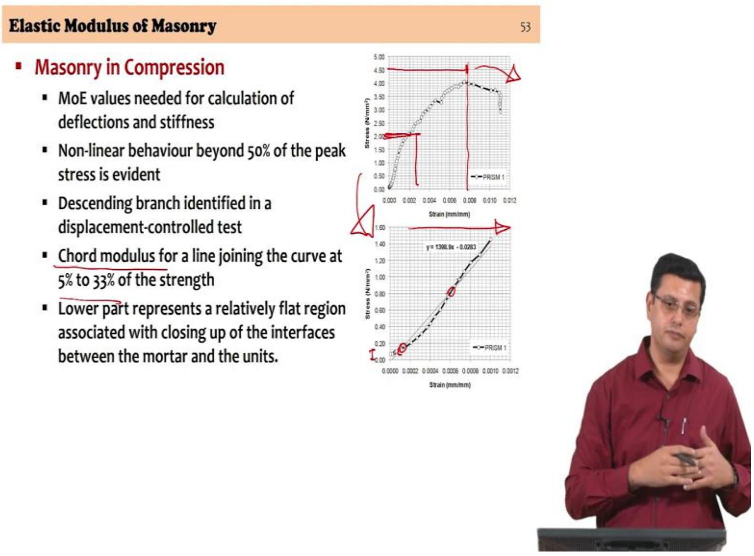


In today’s lecture we continue examining other mechanical parameters, we continue examining masonry under compression, but the modulus of elasticity is a parameter of structural interest and we will examine how you go about getting the modulus of elasticity (1) and (2), what is the kind of protocol that you should adopt, both from a test perspective and from arriving at the value of the modulus of elasticity of masonry. And then in case you do not have the possibility of actually carrying out a test to be able to use the modulus of elasticity of the material that you are going to be using in your design, are there any ways that you can still use reasonably accurate value of the modulus of elasticity for your design, right.

So, mind you we are still examining masonry under compression. So, the elastic modulus that we are referring to is the elastic modulus under compression, many materials have elastic moduli that are same in compression and tension. Masonry is not a material where the modulus of velocity is same in tension and compression. The modulus of elasticity in tension considering that masonry has very little tensile strength is really not important from the design perspective, but when we when we are carrying out analysis of existing structures, particularly historical masonry an estimate of the modulus of elasticity of masonry in tension may become important; however, our focus is going to be on the behavior in compression.

So, with the modulus of elasticity values you have the possibility of estimating deformations. So, deflections and the stiffness calculations would require a value of the modulus of elasticity of the material. We were looking at a standard prism test for compression, it is the same test that is going to be able to give you a full stress strain curve of the material and from the stress strain curve of the material you can establish what the modulus of elasticity is. So, it is standard practice today to carry out tests that are strain controlled or displacement controlled so, that you get post peak behavior of the material itself.

So, if you are carrying out a force control test, the force control test would be able to give you the stress-strain curve of the material up to the peak, beyond the peak you have to look at the descending branch; that is the resistance of the material starts decreasing and you cannot have a force control test anymore because you cannot reduce the applied force the system is not going to respond. Displacement controlled or strain-controlled tests are where you continue to increase the displacements or the strains and you get reducing resistances beyond the peak.

So, a displacement control test or a strain control test is what is going to give you the entire stress strain curve of the material from initial loading, elastic behavior, pre peak softening, peak strength and post peak softening until failure. So, let us assume you have the stress strain curve derived from a standard compression test, standard prism test on the masonry, you can then use this to arrive at aspects like the modulus of elasticity and the Poisson’s ratio if need be. What you can clearly see in the stress strain curve is that, at about 35-40 definitely within the first half of the stress strain curve, you start getting non-linearity, you start getting non-linearity in the material.

And this is this is strongly representative of a material that is composite and porous in it is constituents, the unit being porous the material being composite because of the units behavior, the mortar behavior and the interface which we have seen has a significant role to play in the co-action between the unit and the mortar. So, this sort of a complex composite is actually going to have non-linear behavior beyond 50 percent of the peak.

So, to be able to use this and arrive at the chord modulus, arrive at the modulus of elasticity we basically make use of the chord modulus. If you remember when we were talking about the modulus of elasticity of the brick we were talking of the secant modulus. The difference between the secant modulus and the chord modulus as you know is the secant modulus you go from the origin, but in the chord modulus we are not going to be going from the origin as far as the stress strain curve of the masonry is concerned, but the prescription is that you go from about 5 percent of the peak stress to 33 percent of the peak stress, we are stopping at 33 percent because you start seeing deviation from linear behavior, but can you think of why we neglect the first 5 percent.

So, if I were to if I were to zoom in on this initial one third of the stress strain curve. So, initial one third of the stress strain curve is what is enlarged for you in the finger down there and you see that the chord modulus that we are looking at is examining a 5 percent to 33 percent range, why 5 percent is the question ok. The reason why we look at about 5 percent of the peak stress is simply because this is a composite, you have the brick unit and you have the mortar joint, you can have some voids that form between the mortar joint and the unit itself.

And as you start loading there is a certain rearrangement of the entire system because of the initial load you get some compactness in the entire stack, but this can actually create a bias in the estimate of the modulus of elasticity because this is not material behavior, this is actually closing of voids. So, it is prescribed that the initial 5 percent be neglected and hence you take a chord modulus that goes from 5 percent to 33 percent of the peak strength and get the modulus of of elasticity.

The point that you definitely would like to keep in mind is you cannot do one test and determine the modulus of elasticity, we are already talking of a material which has significant variability in comparison to other structural engineering materials such as concrete or steel. Therefore, it is always going to be an average and depending on the code which you are depending on these numbers can vary. Some codes require that you test a minimum of 3 prisms, other codes require that you test 5 or 6 and take an average of the compressive strength and then you can also look at the stress strain curves and arrive at modulus of elasticity values from the average estimates across the set of specimens that you are testing.

So, please keep in mind that it is not one single specimen that you are depending on for arriving at these average compressive strength values or the average modulus velocity values. Yes; so 5 percent is to ensure that the closing up of voids is neglected that is not material behavior you do not account for the initial 5 percent of the loading. 33 percent is we do see that there is non-linear behavior around 50 percent of the peak stress and beyond. So, to be sure you are examining only the linear elastic range you looking at the first third of the stress strain curve and the therefore, you stop at 33 percent, 34 percent, but the point is we looking at first third of the stress strain curve right ok.

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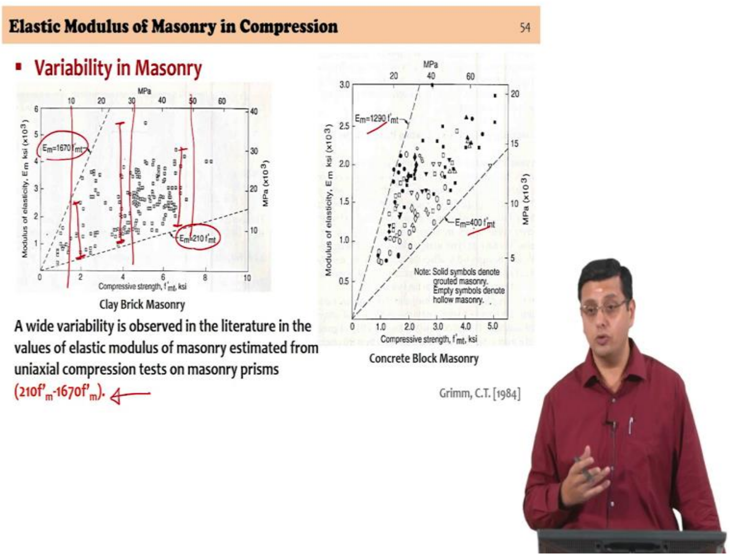


Masonry is a material that is highly affected by variability and the graphs that you will see in a few minutes will convince you that the kind of variability that you will expect in clay brick masonry is far significant and you should be careful about having statistically relevant numbers whenever you are working with actual materials and actual values coming from the tests. Of course, the variability is lower in the concrete block masonry; however, you still do see significant variability.

So, this is an interesting graph that looks at the compressive strength on the x axis and the modulus of elasticity estimated from a stress strain curve of the same test on the y axis and you have got several tests sitting here of course, this is not from one single type of clay brick masonry, it could be from different locations and different countries manufacturing processes and workmanship. However, you can see the kind of scatter that exists even for one level of compressive strength.

So, if I take a compressive strength of about 10 MPa you can see that you have a scatter even they you look at 30 MPa you have a scatter there and so on. So, the point is the if you look at this sort of a data and pull out an upper bound lower bound of the modulus elasticity as a function of the compressive strength and mind you this is simply because the modulus of elasticity happens to be correlated to the compressive strength right.

The correlation is empirical, the value between modulus of elasticity as a function of the compressive strength is an empirical correlation. So, if one were to look at modulus of elasticity $E_m$ here, as a function of compressive strength $f_{mt}$, this outer boundary and here the lower bound itself, you can see varies between 210 to 1670. So, it is almost 8 times from the lower bound to the upper bound, 210 being the factor in the lower bound 1670 in the upper bound. So, this is a fantastic piece of research where lot of these tests have been clubbed together and what is of what is of immense interest is the kind of variability that you will get; the kind of variability that you will get.

So, what can you do in the face of such variability is to be careful in the adoption of fixed values for parameters such as modulus of elasticity and have always a range. So, that you have an upper bound lower bound estimate and that is definitely going to give you a little more little more prepared in terms of the behavior of the system itself. As I mentioned what you saw earlier is clay brick masonry ok.

Now, clay brick masonry as we were discussing yesterday we talking about clay brick which is very different in composition, in nature compared to the mortar itself, but when you look at concrete block masonry grouted, hollow, partially grouted, the grout material and the block itself- the concrete block itself and the mortar joint, the mortar material are materials which are rather close to each other.

So, the variability exists, but still reduces when you go from clay brick clay brick masonry to concrete block masonry. So, here you see that again it is about 3 times where your factor, the multiplying factor to the compressive strength to get your modulus of elasticity is about 400 to 1290- 3 times here, earlier we had seen it is about 8 times. So, appreciate the reduction in variability, but the variability still exists that is a quantity that is going to be affected by your estimate of the modulus of elasticity from the stress strain curve. So, it depends a lot on the way the experiment is being carried out and variability that can come in executing the experiment also.

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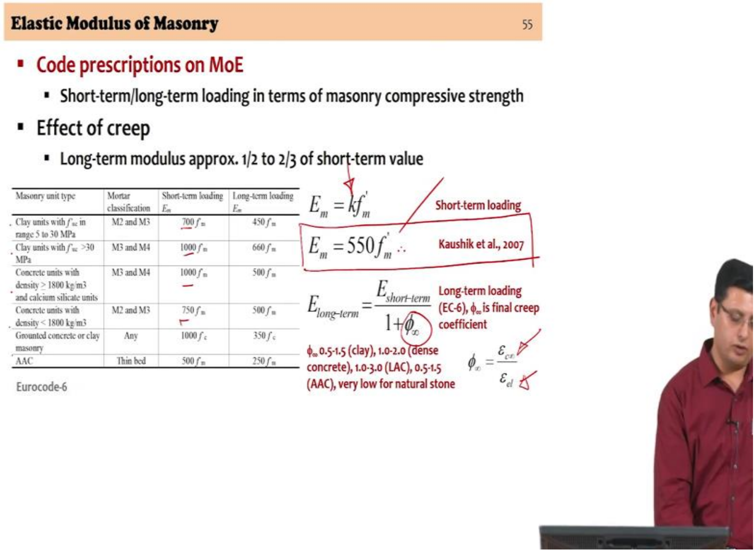


So, well if you do not have the luxury of doing a test, but you still need to make an estimate of the deflections, you need to do a deflection check, what is the modulus of elasticity that you can assume? You do not have direct estimate; a closed form solution that comes from knowing the strains of the constituents. So, what is typically prescribed by the codes is a relationship that is based on the strength of the masonry in compression ok.

So, what the code if it distinguishes between short term loading and long-term loading, which the code should mostly do, is to give the modulus of elasticity as a function of the masonry compressive strength. As you had seen in the previous slide the factor k as an empirical parameter coming out from statistically relevant number of tests, $E_m$ as the modulus of elasticity as a function k into $f_m$ which is the masonry compressing strength. Such a format is normally prescribed for short term loading and is specified in the code that it is for short term loading. Now, if it is for long term loading masonry is a material that is quite significantly affected by creep.

So, here I have just got one example that is typically used for the Indian conditions, if you were to use a factor then 550 is a good estimate for the type of clay brick units that you get in India and the construction practice is adopted in India. So, 550 times the compressive strength of masonry that you are adopting in your design is a good estimate of the modulus of elasticity.

So, the reason why we need to be looking at short term loading versus long term loading is primarily because masonry again is a material that is significantly affected by long term loading effects particularly creep. So, code should actually be prescribing the modulus of elasticity under short term loading and a way of arriving at the modulus of elasticity for long term loading or prescribed values in a similar manner with empirical coefficients such as k for short term loading and long term loading right.

So, if you were to look at typical values, you are looking at the long term modulus, you get softening in the material over long term loading, which means the modulus of elasticity is going to be is going to drop with respect to the short term values. So, you got a stiffer more brittle material initially, but over time it is get it is becoming softer and the modulus of elasticity is going to be about one-half to two thirds of the modulus of elasticity for the short term itself.

So, if you were to use the short-term modulus and arrive at the long-term modulus, one way is to look at the creep coefficient that is material specific. So, if creep coefficients for the type of material that you are using, it may be clay brick masonry, it may be concrete block masonry, it may be your autoclaved aerated concrete. So, depending on the type of material you use, if there is an estimate of the creep coefficient then you can use the creep coefficient to be able to arrive at the long-term modulus.

$$E_{long-term} = \frac{E_{short-term}}{1+\phi_u}$$

$$\phi_u = \text{Final creep coefficient}$$

So, you use the short term modulus divided by 1 plus the creep coefficient, here the parameter was we talking of is the final creep coefficient and the final creep coefficient is going to be from long term loading tests, the final strain to the elastic strain is estimated to give you the creep coefficient; the final creep coefficient itself. So, if the value is available then you can make a more accurate estimate of what the long term modulus of elasticity is going to be, this format is followed in the Euro-code the European norms for masonry constructions which is EC- 6 and that is what is reproduced here for you.

As you can see the values of the final creep coefficients can differ significantly depending on the type of material you can see that the value for clay brick masonry and concrete block masonry can be significantly different. So, if you have these values you could use them to arrive at the long term modulus, but if not codes may specify what values for these coefficients should you use for the type of masonry that you are examining for short term loading versus long term loading and again for different types of mortar that has been used for the masonry construction.

So, word of caution modulus velocity be conscious whether you are looking at short term loading or long term loading, values typically prescribed by codes would be for short term modulus, but if you were to make account for long term effects know that you will have to get the modulus of elasticity for long term long term loading itself.

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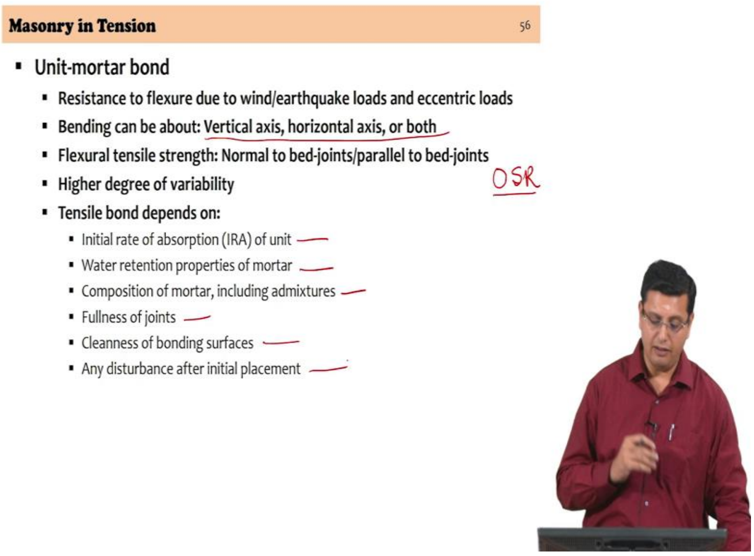


So, we have examined compression, we have examined the stress strain behavior of masonry in compression, modulus of elasticity coming out of the behavior in compression of the assembly, we need to now examine the behavior in tension right. And again, it is not about direct tension, we are not interested in characterizing the strength of masonry in direct tension. There is a finite value of the masonry tension strength in direct tension, but we are really not interested because that is a value that is rather small non-zero, but rather small and not dependable right. The masonry tensile strength is not something that you can depend on and hence from for most practical purposes it is good to assume that you have a zero-tension material.

So, if there is some tensile strength in the material that is a cushion that you have that is that may work in your advantage though you are being conservative in your calculations. But here what were really interested in is flexural tension. It is the strength of the bond between the masonry unit and the mortar and that matters particularly when you have lateral loads right. So, the unit mortar bond is what we are characterizing when we talk of masonry in tension and it is flexural tension that we are examining.

So, combination of lateral loads and gravity is when you would expect masonry to go into flexural tension, it could also be due to gravity loads that are acting eccentric to the wall cross section itself. The bending in a wall you could have bending about the vertical axis, bending about the horizontal axis or a combination of both vertical bending and horizontal bending and we will examine each of these cases to understand what sort of a interface behavior- unit mortar interface behavior would you get and how do you characterize that because you need the strength.

So, when you start examining the bending behavior about a vertical axis, about a horizontal axis or a combination of both vertical and horizontal which is referred to as diagonal bending. Two parameters become important- it is the flexural tensile strength normal to the bed joint and the flexural tensile strength parallel to the bed joint right. So, the flexural tensile strength when the action is normal to the bed joint when tension is normal to the bed joint and when tension is parallel to the bed joint.

So, you need both these estimates and often you may be able to do a test to characterize one and the other one is for the same material that the masonry is composed of, you can get an empirical correlation between the tensile strength parallel to the bed joint and tensile strength normal to the bed joint. And the ratio between the tensile strength parallel to the bed joint and the tensile strength normal to the bed joint is very often referred to as the orthogonal strength ratio and we will come back to this aspect when we deal with design.

So, the strength in tension in two orthogonal planes is referred to as the orthogonal strength ratio and typically you would have the flexural tensile strength of the bed joint parallel to the bed joint twice as much as that of the strength normal to the bed joint. So, OSR; OSR the Orthogonal Strength Ratio of about 2 is typically expected, but again this value will change from material to material. This is a parameter that again has a high degree of variability so, if you are doing tests you need to have significantly large number of specimens. So, that scatter is reduced; however, keep in mind that variability is going to be a going to be an issue in this sort of a situation.

This bond, the tensile bond, depends on a number of parameters that we have looked at earlier, the initial rate of absorption IRA, the water retention properties of the mortar, what sort of composition does the mortar have, have you used admixtures, how well is the joint itself made, workmanship therefore matters, whether the surfaces are clean or the dust particles that inhibit the formation of good bond and after placement, if there are disturbances in the initial period after placement your bond can get affected. So, there are workmanship aspects, material aspects and specific properties of the units and the mortar that will matter in establishing good bond and thereby giving you good flexural tensile strength normal and parallel to the bed joint.

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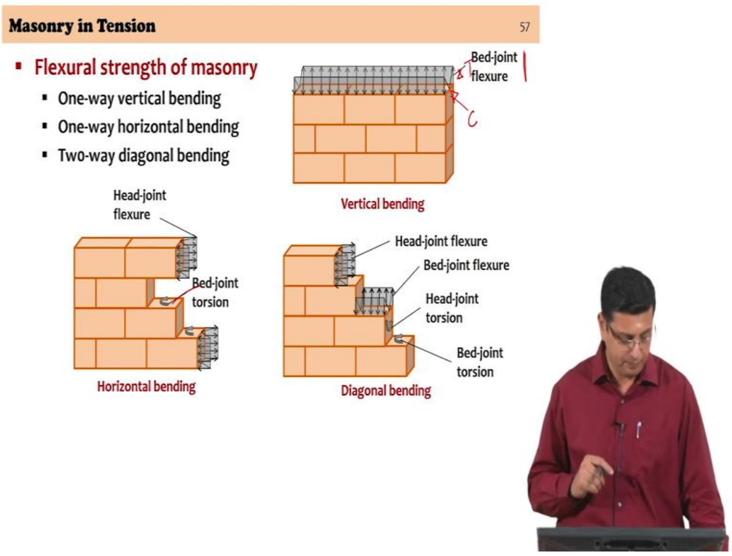

So, let us examine the 3 typical cases when you have a combination of gravity forces and lateral forces, where the flexural tensile strength is required for the masonry to resist the external actions.

One-way vertical bending. So, if a wall is bending between supports right and is assumed to be free on it is edges on the vertical edges, if a wall is free on the vertical edges and it is supported only at the top and the bottom and it is subjected to out of plane loads, if it is subjected to wind loads or inertial loads due to an earthquake and there is gravity force acting along the wall itself under a combination of gravity, loads and the out of plane loads the wall is expected to be in vertical bending right.

When the wall is in vertical bending the bed joint; the bed joint is subjected to flexural normal to the bed joint. So, each bed joint is going to be subjected to tension, compression induced by flexure. So, same joint would have compression on one end and tension on the other. So, this is a joint you got tension on one end and you have got compression on the other, one end of the cross section is experiencing compression, the other end of the cross section is experiencing tension and that is the flexural tension effect on the bed joint.

This is the effect of vertical bending of the wall and this is happening because you have top support and a bottom support or in your wall the sides are free right. The sides are free from any effect coming in, any restraining effect coming in from a neighboring wall or any other edge restrained. So, in this particular case when you have one-way vertical bending, the parameter of importance is the bed joint flexure, you should be able to estimate what is the bed joint flexural strength. In this case tension is actually acting perpendicular to the bed joint right, you will agree with me you have the bed joint and you see that the tension is acting perpendicular to the bed joint (normal to the bed joint).

So, bed joint flexure is a parameter that is essential if you were to estimate the vertical bending capacity of a masonry wall. If now you were to examine one-way horizontal bending that the wall has very little restraint at the top and the bottom. The top support and the bottom support is almost not effective to restrain the wall, but your lateral supports the edges the vertical edges of the wall are restrained. In such a situation the wall is expected to go into horizontal bending and when you have horizontal bending the bed joint is expected to be in a state of torsion.

So, in this situation if you were to examine horizontal bending happening in the masonry wall, then there are two aspects that you will have to consider - one is that the head joints will have a tendency of opening up and will be in a state of flexural compression-flexural tension, whereas, the bed joints will be in a state of torsion- will be subjected to torsion. So, they will be shear stresses due to torsion and when we talk of flexural tensile strength parallel to the bed joint we really talking of this phenomenon that the tension is acting to split the unit bond mortar parallel to the bed joint right. So, under horizontal bending the two aspects of importance as far as the strength of the masonry wall and horizontal bending would be the head joint flexure and the bed joint torsion.

Now, if you were to have a masonry wall which has restraints on more than 2 sides supports which restrain the wall on more than 2 sides, 3 sides or 4 sides are restrained and out of plane loads are acting on this wall when loads or inertial forces. Then you would get a combination of vertical bending and horizontal bending and that is referred to as diagonal bending or two-way bending and when you have two way diagonal bending 4 parameters come into the play now. You have the bed joint and you have the head joint.

The bed joints will be subjected to flexure, the head joint will be subjected to flexure. So, in this situation both the head joint and the bed joint will be subjected to tension normal to the bed joint, normal to the head joint and in the other case you will have torsion on the head joint and torsion on the bed joint and that will require the estimate of the flexural tensile strength parallel to the joint itself.

So, this would is basically affected by head joint flexure, bed joint flexure in which case it is the flexural tensile strength normal to the bed joint and then will also be affected by head joint torsion and bed joint torsion and therefore, you will need an estimate of what the flexural tensile strength parallel to the joint is if you need to know at what level of shear stress will you get failure in the joint itself. Of course, to complicate matters if you were to make an estimate of bed joint flexural tensile strength, head joint flexural tensile strength, perpendicular and parallel to the joint, you will get different values for the same masonry.

So, it is a typology a structural typology which presents to you this complication of different strengths in different directions and so, you will have to be prepared for that from estimates of strength perspective. However, we make simplifications in design but if you are doing an assessment, if you doing a detailed assessment of masonry strengths, it is essential to understand that you going to have different values for each of these actions and each of these failure mechanisms in the same masonry wall itself, ok.

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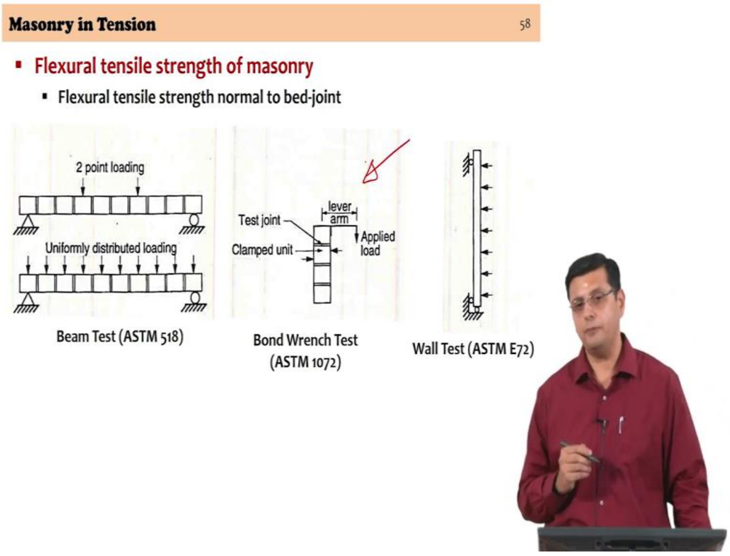


So, how do you estimate the flexural tensile strength of masonry? You have normal to the bed joint and parallel to the bed joint. The flexural tensile strength normal to the bed joint can be estimated there are different codes that regulate the type of experiment that you can carry out to estimate these values to measure make an estimate of these values from experimental tests. If you were to create a beam and subject the beam to bending, then the bed joint is subjected to flexural tension normal to the bed joint.

So, you are making a beam with a single stack of bricks supporting it and then subject again to 2 point loading and you would have the flexural tensile strength normal to the bed joint that you can estimate, you can also do what is called a bond wrench test will examine the bond wrench test in a moment. You can also do a wall test subject the wall to some lateral loads and then the single stack of bricks when subjected to lateral loads we will have failure of the joint with tension occurring normal to the bed joint, you can make an estimate of the flexural tensile strength normal to the bed joint. It is interesting to examine the bond wrench test, it is a rather simple test very effective in estimating the flexural tensile strength normal to the bed joint.

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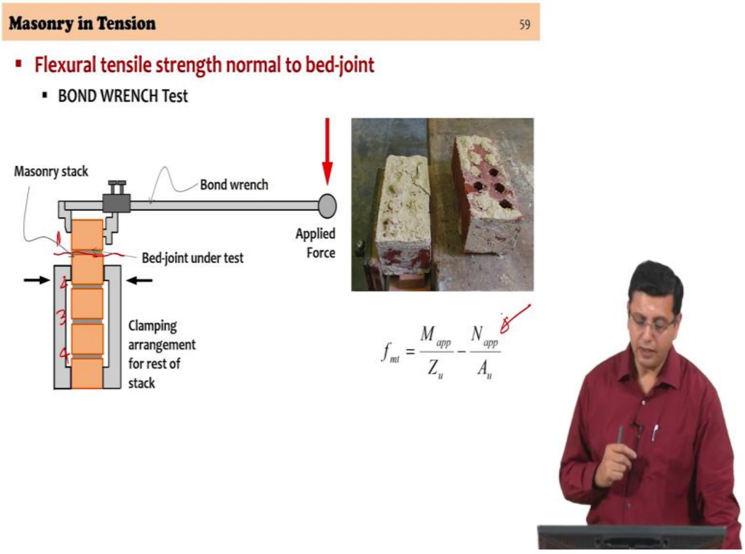


So, in this test called the bond wrench test what you are really doing is, you prepare a stack of bricks, you have the stack of bricks that is seated inside a clamping arrangemen,t you clamp. So, you make a stack of bricks at about 5 stacks high and then you have a camping arrangement to hold the lower 4 brick units, you have a wrench that will hold on to the top unit and the bed joint that you are testing is really this bed joint here. The bed joint that is being tested is the one that is between the clamped portion and the part that is going to be that is going to be pulled out; I mean that is going to be wrenched out.

So, you have this bond wrench and at the end of this bond wrench which has a prescribed length you apply a force and you are able to estimate under flexural tension what is the strength of the bond itself. Now, you will have to be careful the bond wrench should not deform you should have a sufficiently stiff bond wrench that does not deform as you are applying a force that can foul with your measurements and typically the value at which the weight that is required to cause failure, the weight that you will be hanging or the force that you are going to be applying at the end of the lever arm is actually small.

So, control in this test is what is essential; we do this in a very simple way, we hang bucket here and have sand filled in the bucket because often if the bond is not good you can get failure even when you just hang the bucket and add maybe a mug or two of sand. So, it is a test that requires a little bit of a control. You might have brick units that have good bond strength, there you need higher forces, but you can also have situations I was talking to you about the wire cut bricks. Wire cut bricks have very poor bonding with the mortar particularly because they have low water absorption and no frog on the unit itself; we have seen that the bond strength there- the flexural tensile strength normal to the bed joint is very low.

So, you can you should be careful in the rate of application of the load, the level of load the resolution at which we are applying the load and control the entire system as you are applying this. Variability is something that you will have to deal with here, it is an interesting test we do not have an Indian standards that deals with this, but we do have the ASTM standards and some other codes that give a system that you can follow for the bond wrench test, you are required to do at least 12 such tests right because of the variability.

Now, as you can see if you can change the clamping arrangement you can use the same stack and keep shifting the joint that you are actually examining. So, I could use the same stack examine this as the first joint, that as a second joint, that as a third joint and if possible that as the 4 joint. So, you can if you make a stack that is sufficiently high you can get about 4 tests from the same stack and then you also try to reduce the variability that way, because it is the same mix and the same unit in which your same stack within which you are getting a few tests being conducted.

You will expect failure; you expect failure at the mortar-unit interface right or you can have failure inside the mortar itself. So, if the tensile strength of the mortar is low you can have the failure within the mortar, but if the tensile strength of the mortar is good and is higher than the joint tensile strength you can have failure in the interface itself, you can have an undesirable performance where the mortar has good tensile strength, the interface has good tensile strength, the unit has poor tensile strength, you can have a situation where are part of the brick unit is ripped off in the test.

So, you can have any of these three failure planes; failure plane can be within the mortar if the mortar tensile strength is the lowest. You can have a failure plane between the mortar and the unit that is the interface that is failing that is the joint that is failing or you can have failure in the unit itself, where the unit tensile strength is lower than the joint tensile strength and the mortar tensile strength which is not a desirable situation to be in because what is failing is the brittle material of the composite.

So, you can then estimate what the flexural tensile strength of the of the bed joint itself is you need to consider the fact that there is some pre-compression and the pre-compression there is no additional pre-compression being applied, but just under the self weight there is going to be some compressive stress in the setup. So, the stress due to compression is actually removed from the estimate of the flexural tensile strength. So, you will be able to measure the estimate the applied moment divided by the section modulus of the cross section that you are examining and reduce the stress due to pre compression due to the self weight itself. So, that is the bond wrench test.

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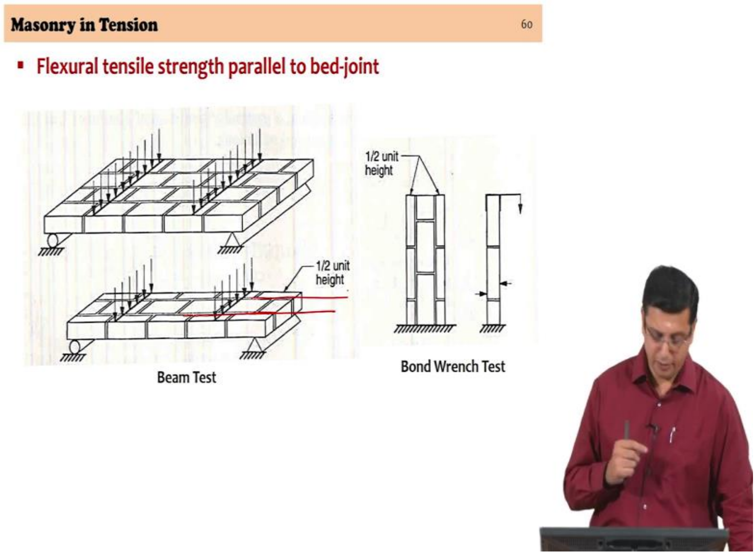


But if you were to estimate the flexural tensile strength now parallel to the bed joint, if you want failure of the unit to happen in the bed joint with failure due to torsion and shear induced due to torsion how do you do that. So, there are modified tests to estimate flexural tensile strength parallel to the bed joint, if you remember the previous case flexural tensile strength normal to the bed joint a beam test was being carried out right. A beam is just a stack of bricks subjected to bending and you get tension acting on the bed joint normal to the joint itself.

But in the modified test in the flexural tensile strength parallel to the bed joint test you do not use a single stack of bricks, but you use a small wallet- you make a small wall referred to as a wallet and you can then subject it to two point bending tests as we had seen earlier, but now because of the bending you will appreciate that in these joints; in these joints as the wallet bends those joints will be subjected to tension or shear inducing tension parallel to the joint itself. So, this test is something that can help you estimate what the flexural tensile strength parallel to the bed joint is, but interestingly you can carry out a modified bond wrench test.

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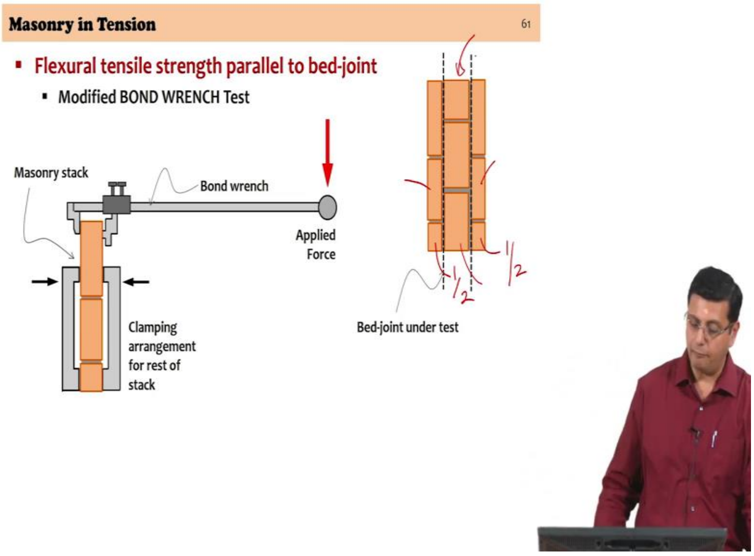


And in the modified bond wrench test what we are actually doing is everything remains the same, but in the wallet that you create, the wallet is no longer a stack of bricks, but a stack a small masonry wallet that is created by full units and half units right. So, you have one set of full units and on the two sides one set of half units and then this is the front elevation of the setup of the wallet, you turn it around place it within the setup and then you are actually subjecting those two joints into tension.

So, you are clamping you are clamping the middle, you are clamping this middle layer at the top and from the top and wrenching it, the clamping arrangement holds these two portions and hence you are subjecting the joint that is shown with dotted lines to flexural tension parallel to those two joints right. So, modified bond wrench test can also give you this estimate of the flexural tensile strength in masonry ok.

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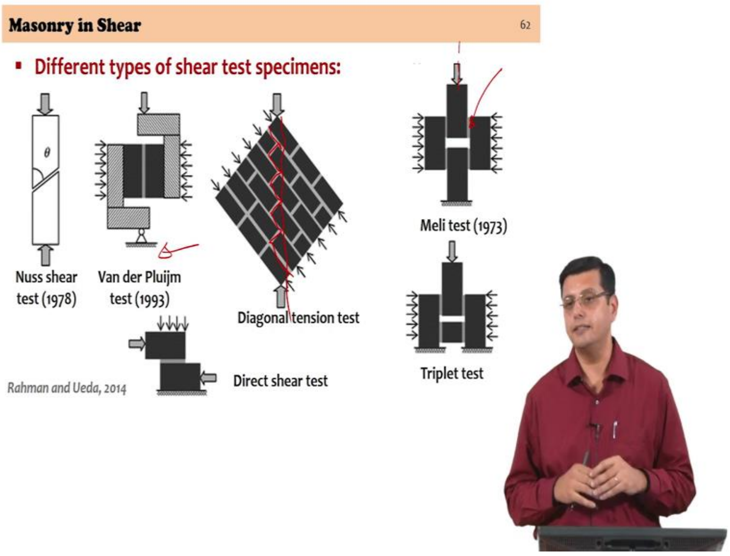


To conclude, we will be dealing with masonry and behavior of masonry under shear extensively in a few modules from now. But if you need to be able, if you need to estimate the shear strength masonry what options do you have and what kind of care should you take in adopting values and adopting test methods to arrive at the shear strength of masonry.

So, this is an area that has received significant research focus, but that is also and you have different test methods that have been prescribed in the literature and across different countries codes you have different methods to test the shear strength of masonry and that is primarily because that is pure shear is hypothetical. So, to be able to estimate just the shear strength is definitely a challenge, but then what is important is to understand what strength are we talking about here right, are we talking about the joint shear strength or are we talking about the shear strength of the masonry as a composite ok.

Now, the reason why that matters is you might have a situation where the failure may not necessarily happen in shear in the joint, it can actually rip through the masonry units. So, the type of shear failure here is classified as line failure and a stepped failure; stepped failures taking the profile of the joints whereas, the line failure just rips through the unit. We will be examining these in detail, but you will be surprised to know that you can have different tests to actually carry out this sort of a test. So, this is as I said received research focus for decades now, there are several of them the first one that you see here is you are subjecting a stack to compression and under that you get a failure surface which is because of the shear failure in the material itself.

You have another test which is quite popular where you are trying to subject a two masonry units jointed with the mortar between the two; subjected to shear and you expect failure in the masonry joint, either at the interface of the unit and the mortar or between the mortar and that gives an estimate of the joint shear strength. So, this is a test that is used quite extensively.

There is another test referred to as the diagonal tension test where the depending on the strength of the masonry unit and mortar that you are looking at, the strength of the mortar and the strength of the interface itself you can have different failure mechanisms here. The failure could actually go through the joint as a stepped failure or it could actually rip through the entire panel itself.

So, again if it actually rips through the unit with the line failure versus if it actually failed in the joint the characterization of the joint strength could actually come from a test such as the Van der Pluijm test whereas, in the Van der Pluijm test is not going to be able to successfully give you the strength in shear of a masonry panel if a line failure is going to be resulting.

So, we will examine this in detail when we look at biaxial stresses due to shear and compression; however, I am giving you an overview of the different tests available. Again there are two tests here- were looking at a triplet test because you have 3 units that are being subjected to shear and you see that the joint that is of interest is the joint that is between the 3 units that you can see here. Shear is induced in the shear loading is induced in the central unit. However, pre-compression is also provided; that is the joint is not under zero compressive stress it has pre compression levels that you can regulate and provide, we will examine that in a little detail.

So, triplet test and a and a modified version of the triplet test here called the Meli test and then while in the triplet tests there are 2 surfaces that are subjected to shear. So, it is a double shear test if you will permit whereas, the direct shear test is where 2 units are being subjected to shear force and it is a single joint that is being examined in the direct shear test.

We will examine in detail, you have interesting research works that are examining a comparison between the different estimates of shear strength, because of the different tests the problem as I said is to be able to create pure shear in the joint or pure shear in the masonry which is not which is not simple in any way. And many of these would have a further component because of the eccentricity of the loading and can foul with the estimate of the strength that you are able to get from any of these tests.

So, when you idealize, it is easy for us to show an arrow that is sitting right along the center line of the brick, but it is not a point load there, you actually have a contact surface, you have a finite length of the contact surface and then you have a finite length of the reaction surface. So, ultimately you can actually have eccentricities that are causing some moment to come at the joint along with the shear load (shear force) that you are subjecting the joint two. We will examine two of these, we will examine the triplet test and the diagonal tension test in detail in the next class.