Design of Masonry Structures
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Module - 02
Lecture - 06
Masonry Materials and Properties Part - II

Morning. So, we will continue looking at the properties of the constituents. We examined the behaviour of the masonry unit; we are focussing now on the clay masonry unit, the compressive strength of clay masonry unit as one single property that can be related to the strength of masonry, the durability of masonry.

So, it is one of those unit properties of significance and as you will appreciate towards the end of this component, masonry compressive strength; compressive strength of the assembly is again such a parameter which gives good correlation with every other strength property like tensile strength, shear strength and also correlation with durability.

So, we continue looking at the properties of masonry unit and then examine the properties of mortar.

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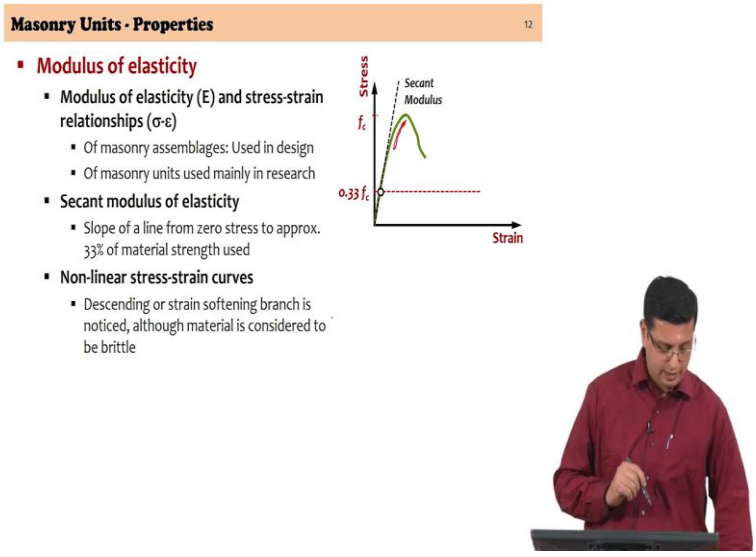

So, when we look at compressive strength; the behaviour under compression of the masonry unit is a property of importance, we are talking of the modulus of elasticity

under compression behaviour, of course. So, this as far as a property, comes directly from the stress-strain behaviour or the stress-strain relationship of the brick unit. Now, as far as the property of modulus of elasticity is concerned, while the modulus of elasticity of masonry assembly, the composite masonry, is a property of significance as far as design is concerned, we are interested in understanding the deformability of masonry and so, modulus of elasticity of the composite is a useful property as far as design is concerned. However, modulus of elasticity of the brick itself is not a parameter that we use so much within the design context. It is more from a research perspective that you would want to get the stress-strain relationship of the brick unit and then pull out the modulus of elasticity of the brick unit. So, this particular property is more a property that you might want to use when you are working in masonry research.

However, the modulus of elasticity is estimated through a compressive strength test and we were talking about a flat wise compressive strength test that is carried out on brick units. So, as you conduct the test, you would get a stress-strain curve for the behaviour in compression and if you are carrying out a strain controlled test, where the application of load is controlled in terms of strains, displacement controlled test setup, then you would be able to get the complete stress-strain curve from initial loading to peak to post-peak behaviour when the descending curve of the structural response can be captured.

So, assuming that you have the stress-strain curve of the behaviour of the masonry unit under compression, the secant modulus is what is used to establish the modulus of elasticity of the material. And for the secant modulus, the prescription is that you take one-third of the compressive strength of the masonry unit.

So, if you know the compressive strength of the masonry unit as f_c, then 33 percent or one third of the compressive strength is the point that you designate to be able to establish the slope of the line from 0 to 0.33 times f_c and you get the secant modulus, which would give you the modulus of elasticity of the material of the brick unit itself.

You know that the brick the material of brick is fragile and brittle. However, it does have a post peak response and that can be captured using a strain controlled test and even in the pre-peak zone, in this particular zone, you do see that there is some non-linearity in the pre-peak and a very minimal amount of ductility post-peak. So, it is a non-linear

stress-strain curve and a non-linear softening branch that you would observe as far as this material is concerned.

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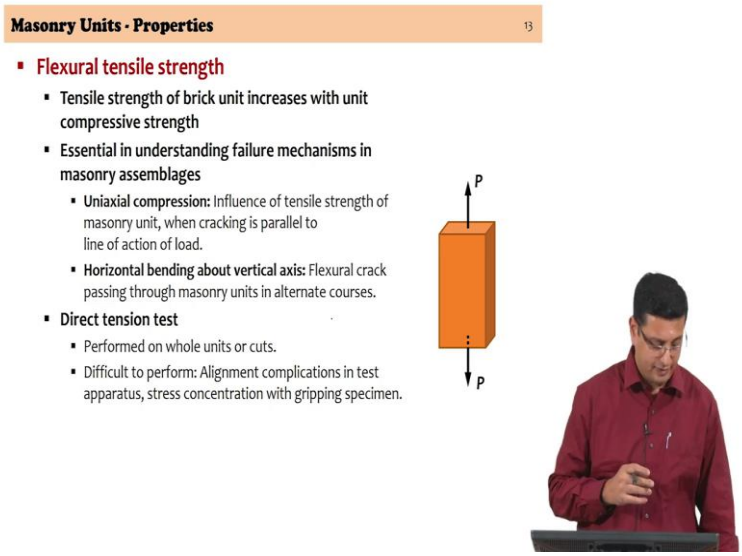

Moving on, tensile strength of the brick unit is another property that determines how the masonry is going to respond under different actions and combination of actions. So, whether we will be able to do a direct tensile strength test or not, we will examine.

However, the flexural tensile strength test is something that is of significance in bending behaviour of masonry. And, based on our previous discussions you will agree that very rarely would you put masonry into completely a tension kind of a situation, pure tension. So, the tensile strength of masonry from a direct tensile strength test is not really required, we can depend on the flexural tensile strength of masonry. So, it has a direct correlation with the compressive strength, better the compressive strength of the brick unit, better is going to be the tensile strength of the brick unit.

As I said, the way in which the masonry assembly composite, is going to respond to a combination of loads- lateral and compressive gravity axial, will depend on the tensile strength of the brick unit. So, the mechanism formation in the assembly particularly at failure is determined by what is the tensile strength of the unit.

If you subject the brick unit to compressive load, uniaxial compression, then you know that due to Poisson's effect there is going to be lateral bulging in the material and you

will have cracking forming in the brick unit and these cracks are parallel to the direction of load, that is how they would fail. We call that the crushing stage of the brick unit; however, the failure initiates by the formation of tensile cracks which are actually parallel to the direction of loading.

If you were subjecting the brick unit to bending about a vertical axis, take the brick unit and it is subjected to bending about a vertical axis, then the tensile strength of the brick unit is what matters in determining whether the crack in the masonry wall is going to split the brick unit or is it going to pass through the joint or the head joints itself right.

So, you have a wall panel and when you subject the wall panel to bending about the vertical axis, we have referred to that as horizontal bending when that happens whether this crack is actually going to split the brick or not split the brick because of a high tensile strength of the unit and follow the path of the joints is actually determined by how strong the brick is in tension.

So, under compression, it is the lateral bulging, the Poisson's effect which will cause those cracks and split the brick. So, the tensile strength of the brick matters even under axial compression. Under bending, it matters whether the crack in the wall is going to follow the joint pattern, the head joints, or is it going to split the brick itself.

So, the direct tension test is prescribed to get the actual tensile strength of the brick unit. However, there are challenges in carrying out this sort of a test, you might have a test specimen, but you know that brick units can be of different sizes- you can have the height of the brick varying if they are not a particular modular size. So, apart from that gripping the unit when it is subjected to direct tension is a challenge.

So, you have practical difficulties in performing this sort of a test. Very often, ensuring that the alignment is right, ensuring that under the gripping ends of this tension testing machine you do not have stress concentration and crushing locally of the bricks itself are problems that you will have when you are trying to carry out a direct tension test with brick units. Hence a direct tension test is not something that is usually adopted and we make do with the flexural tensile strength test.

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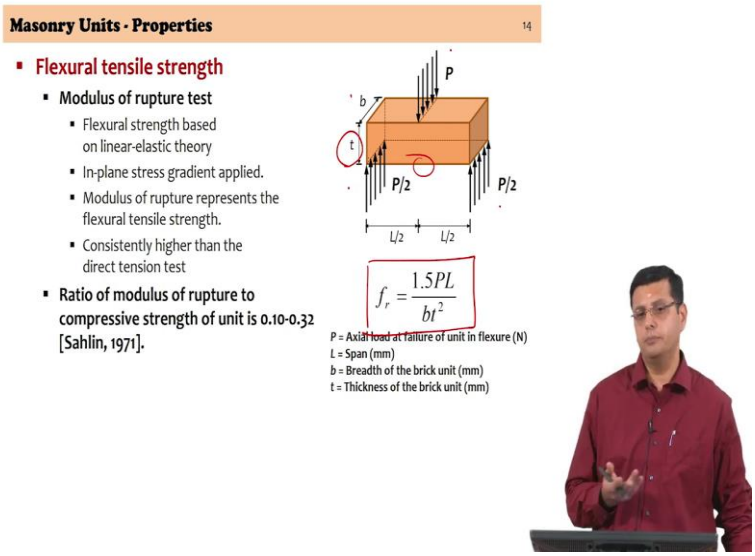

So, how do you measure the flexural tensile strength of masonry? The simplest test that can help us measure the flexural tensile strength is a modulus of rupture test and in a modulus of rupture test, it follows simple elastic theory. You are subjecting the unit to bending, you are assuming that the bending moment in the unit due to this external load is actually linear elastic. Failure occurs when the tensile strength in flexure of the edge fibres are reached and you get failure under flexural tension of the unit itself.

So, what we really do is a three-point bending test; you have two support points and one loading point right at the centre of the brick unit, it is again placed flat wise and tested. So, the bending moment in this case will ensure that the mid span has the maximum bending moment and that is where you should expect at the bottom, the bottom fibres to crack. So, it is a very straight forward test. The stress gradient that is applied will ensure failure occurs at the bottom fibre mid-span.

This modulus of rupture that you can estimate, from consideration of the moment divided by the section modulus of the cross section, is going to give you the flexural tensile strength of the masonry unit. The modulus of rupture or flexural tensile strength of the brick unit is given by,

Modulus of rupture, $f_r = \frac{1.5PL}{bt^2}$

P = axial load at failure of unit in flexure (N)

L = span (mm)

B = breadth of brick unit (mm)

t = thickness of brick unit (mm)

What is observed based on statistically relevant numbers of these tests is that the flexural tensile strength always turns out to be higher than the direct tension strength and this is primarily because of the fact that in a direct tension test the entire cross section is subjected to a uniform state of tension, equal along the entire cross section; whereas in a flexural tensile test it is the extreme fibres that are subjected to the maximum tensile stress.

So, the stress gradient is what is allowing for the further strength in the system, though you are interested in capturing what is the tensile strength of masonry. So, it is observed that you will, if you do this test, the tensile strength that you get of masonry is going to be consistently higher. Typically, if you take a ratio of the modulus of rupture by this test to the compressive strength of the unit, you would get ratio somewhere between 10 to 30 percent and that is a typical range for your use if you do not have data; a conservative estimate of 10 percent being the tensile strength of the brick unit if you know the compressive strength is a good value to begin with.

If you have actually got a values coming out of an experimental test, well and good; if you do not a lower bound value is 10 percent, which as you are aware even for a material like concrete we assume that the tensile strength is about 10 percent of the compressive strength. So, fairly all materials, all these construction materials which are weak in tension would have a tensile strength of the order of 10 to 20 percent or slightly higher. ok.

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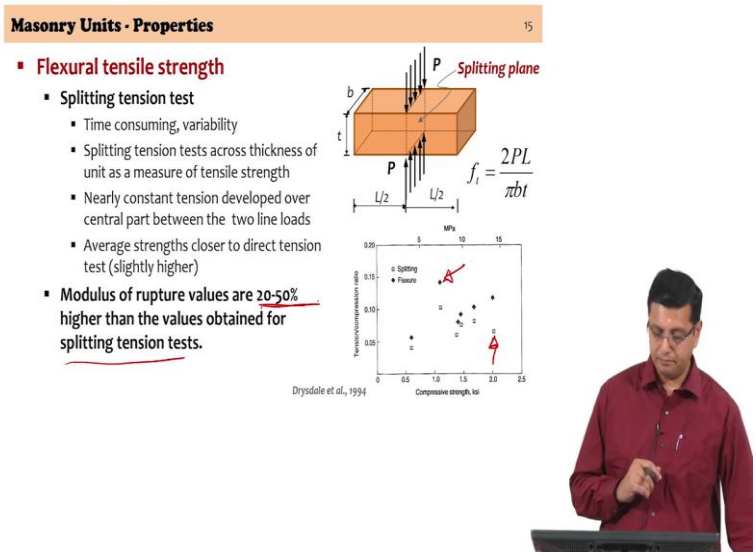

The flexural tensile strength test that is carried out by the three-point bending test is not the only way of estimating the tensile strength of masonry unit. You have the direct tension test, you have the three-point bending test and you also have another test called the split tension test.

The split tension test again is a test that is adopted in finding out the tensile strength of concrete. In concrete, we make use of cylinders to do the split tension test it is otherwise referred to as a modified Brazilian test. You can get, you are subjecting the cross section to compression; however, you will get the tensile strength because the compression load acting on a plane will split the cross section.

So, the split tensile strength test is carried out where you have, in this case you do not work with the cylinder you are actually working with the brick unit as it is. So, you place the brick unit and now you have to ensure that your loading plane and reaction plane are along the same line, along the same plane and you are subjecting it to compression.

So, you have the reaction plane, you have the load line and you are subjecting the plane what is referred to as a splitting plane in the figure to compression and this ensures that the entire splitting plane is subjected to uniform tension. So, under this test you will have the unit subjected to pure tension in that plane and will give you an estimate of what the tensile strength of the unit is.

Of course, you cannot take the, in this case because of the complexity in this stress distribution in that plane, dictated by the mechanics of the problem, the tensile strength is

not going to be P divided by b t, but needs to be modified and from theory of elasticity you get the split tensile strength of the brick unit given here as:

$$f_t = \frac{2PL}{\pi bt}$$

So, the problem with this test is, it is time consuming, you have to carry it out very carefully, you cannot have the load line and the reaction line deviating, controlling this test is difficult and therefore, it is time consuming and what is typically observed is that there is a large variability in the test results. So, you will have average values with significant scatter in the test results. So, this is again giving you a measure of the tensile strength and the two line loads ensure constant tension in the splitting plane.

Again, the average strength that you would get from a split tension test is closer to the direct tension test because of the fact that the plane is being subjected to uniform tension and does not have a stress gradient like in the flexural tensile strength test or the three-point bending test. However, the split tension test give values that are slightly higher than the direct tension test. It is quite interesting to observe that consistently with the flexure test with the three-point bending test you will get values higher if you are estimating the tensile strength of the brick unit.

So, this is a graph where you see the compressive strength on the x-axis with the ratio of tension strength to compression strength on the y-axis and you can see two sets of points; you have the points coming from the three-point bending test and the points coming from the split tension test. You can see that consistently at all compressive strengths you have.

So, you are using different types of units of different compressive strengths, you can see that the split tension test is going to give you a much more accurate estimate of the tensile strength of the unit, the flexural strength because of the mechanics of the cross section and the strength gradient will be slightly higher. And, on an average we are talking of 20 to 50 percent higher than the values obtained from a direct tension or a split tension test.

So, the in this information is something that you really need to keep in mind because if you are using the modulus of rupture value for masonry which is not in flexural tension, then you should know that the flexural tensile strength is going to be higher and probably

reduce the value in a way that you account for this difference between the mechanisms in which cracking of the unit is happening, ok.

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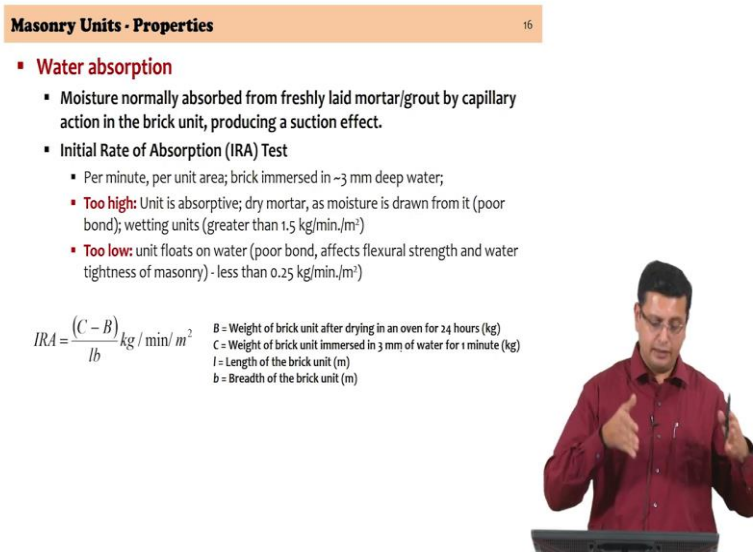

So, we examined the compressive strength and the tensile strength, water absorption properties of the unit is probably one very critical property of masonry units. It can foul the way in which the masonry gains strength, If due attention is not given during the construction phase or due attention is not given to understand what is the water absorption characteristic of the unit before even selecting the unit, right.

So, the water absorption is a parameter that gives you an indication of how well and how quickly is a bond going to develop between the mortar and the unit and this bond is essential for you because the strength of the assembly is established because of the bond.

So, you have moisture that is freely absorbed by the unit from the mortar. So, the moment you place course by course you are constructing brick, the moment you have your brick and then you put mortar on it, the unit has a tendency to absorb moisture from the mortar; mortar is plastic right and this also can happen if you are working with hollow blocks and if you are grouting the void in the hollow block the clay brick, the hollow clay brick or the cement block actually has a tendency to absorb water from the grout.

So, the grout and the mortar are sources of water and depending on the water absorption property of the unit it sucks up less or more water from the mortar. Now, this is a problem because if you take away water from mortar you are going to interfere with the hydration processes of the cement in mortar. So, what really happens and the effect of this we can examine if you have very high water absorption properties or very low water absorption properties.

So, one of the tests that are carried out to evaluate the water absorption property of masonry unit is called the initial rate of absorption test, right. And, this is very important because it is in the first few minutes that the most important water that is available with the mortar is taken away. It is not later how much of water can the unit absorb; in the initial few minutes when the bond is going to be established if critical water is not available for the mortar you will have a problem of bond.

So, what the initial rate of absorption test actually does is tries to establish in a minute right, in 1 minute per unit area, right you are you are working with one brick, so, you can estimates per unit area if you were to immerse a brick in a tray with about 3 millimetres height of water, how much water is being absorbed? So, you bring a brick unit, you have a trough in which you have got about 3 mm of water and you are placing a flat wise one surface down and you are measuring the weight before the weight after to check in 1 minute how much of water is this brick unit capable of absorbing. So, that the test lasts for a minute and then you make some measurements.

So, the initial rate of absorption is therefore, calculated as C minus B where C is the weight of the brick unit immersed in 3 millimetres of water for 1 minute. So, once you finish immersing it for a minute, pull it out weigh it, but before you do that you would have actually weight the brick after drying it in oven in an oven for about 24 hours. So, what you do you take the brick put it into an oven, leave it for a day; take it out, it is going to be hot. You leave it outside for sometimes so that it comes down to room temperature.

But, the other thing is remember we talked about moisture expansion. So, when you are going to be placing this unit in chamber and dry it for 24 hours it is going to lose all its moisture and the moment you bring it out is going to absorb moisture from the atmosphere. So, if you were to test the brick unit coming directly out of the oven you

will get a wrong value for the water absorption because you are biasing it now as having more water absorption whereas the moisture in the air will actually be absorbed by the brick anyway.

So, you allow for moisture expansion, let it come down to room temperature and then you carry out this test. So, once you measure B and C, C minus B over the area of cross section which is the length into the breadth of the brick unit will get you the value of the IRA represented in terms of kilograms per minute per metre square (kg/min/m^2). And of course, there are limits on this right and brick clay brick is notorious in water absorption.

If the IRA is too high, that it is absorbing too much of too much of water from the mortar, the problem that you are going to have is, the mortar will dry up. Now, if the mortar dries up the moisture that it requires for the hydration process is reduced and you will have a problem of bond you will have a problem of bond and this is in the first few minutes of laying it itself.

So, what is typically done is you, this is the reason why you wet bricks before you take it to the site for construction and typically if the water absorption rate IRA is about 1.5 kg/min/m^2 or higher you definitely have to wet your bricks otherwise you are going to have a problem of bond. Yes, your question is why 3 mm right. So, it is it is a test that is trying to replicate a condition at the site where I have a brick course and on top of the brick course, I am actually placing mortar.

So, it is really the surface absorbing water. I am not interested how much the in this test, I am not interested in understanding how much of brick itself is going to absorb. The surface that is in contact with plastic mortar is only that top surface or the bottom surface and that is why we are restricting ourselves to about 3 mm and of course, there is going to be capillary action with the wet mortar that is in contact with the brick unit itself.

Now, if you have very low water absorption you have another problem, the mortar is plastic and you have the unit which does not want to absorb water. So, what would happen in this case is the mortar typically has a tendency to bleed that is excess water in the mortar would actually come to the surface, this happens even in concrete. The phenomenon is called bleeding. So, there is a film of water that typically forms at the top and now, if a film of water is formed between the mortar and the brick unit you will have no bond.

So, too much water or either too much water in the mortar or too low absorption from the by the brick is problematic right and if you are looking at water absorption less than 0.25 kg/min/m^2 it is problematic right. In such situations you must have a way of ensuring that bond is developed that is tricky issue and if you remember when I was talking about types of clay bricks we refer to moulded bricks and wire cut bricks.

The wire cut bricks typically have this tendency of very low water absorption. So, you might have very strong bricks because of wire cut bricks, but you might have very strong very weak masonry because it will not be able to establish bond whereas the moulded bricks which maybe weaker in compression will have better overall strength in masonry because it can established bond very easily ok. So, this is this is an important parameter that really links the theory from the behaviour of masonry to construction.

The initial rate of water absorption is one parameter, but if you want to know how much is the brick going to absorb water as such because you have a durability problem if the brick unit is going to be soaking water. If it is very soaking water like a sponge that is again a problem because it is already porous, it is already porous.

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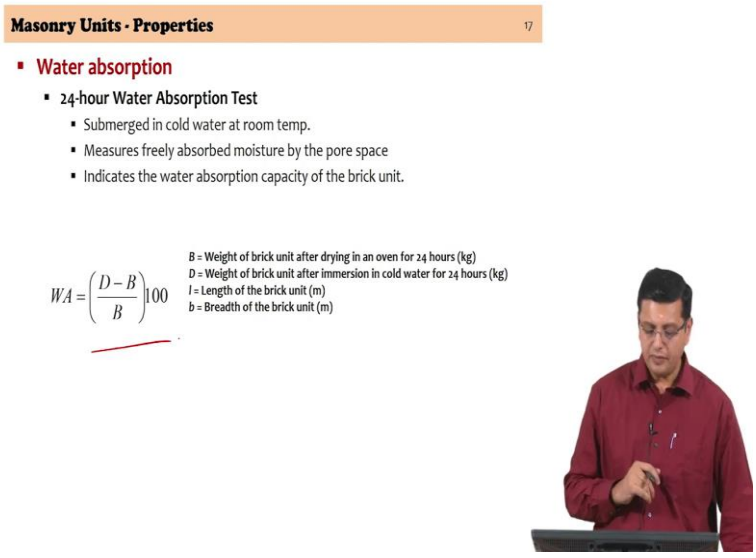

So, the water absorption test which is the typical test that is done, it is the 24-hour test where you are immersing, in this case you are going to be immersing the brick unit in water, because you want to know how much is the total weight of water that the brick unit can actually absorb.

In this what you really do is, you submerge the entire brick at room temperature, leave it for 24 hours; measure the weight of the brick before, measure the weight of the brick after and you get by percentage by weight of the brick how much water can be absorbed by the brick unit. Can you give, can you hazard a guess of what could be this number typically for hand the moulded bricks?

Student: 20 percent.

20 percent. It can be as high as 20 percent of the weight of the brick. What is the weight of a brick? Roughly, yes, 3.5 to 4 kgs would be the brick. If you have brick that is about 3 and half to 4 kgs and it is capable of absorbing one fifth by that weight of water, if you do not protect your brick masonry and if the brick is highly absorptive, it is during rainy seasons your masonry walls are going to soak up water right, it is a potential problem of durability.

So, here you require the weight of the brick unit after immersion in cold water for 24 hours and you know the weight before. So, finally, the water absorption as a percentage is calculated by D minus B by B into 100. So, this is established. Basically, what you are measuring is how much voids are present and how much water is freely going in and filling up all the pore spaces that are available. You get the overall water absorption capacity of the brick.

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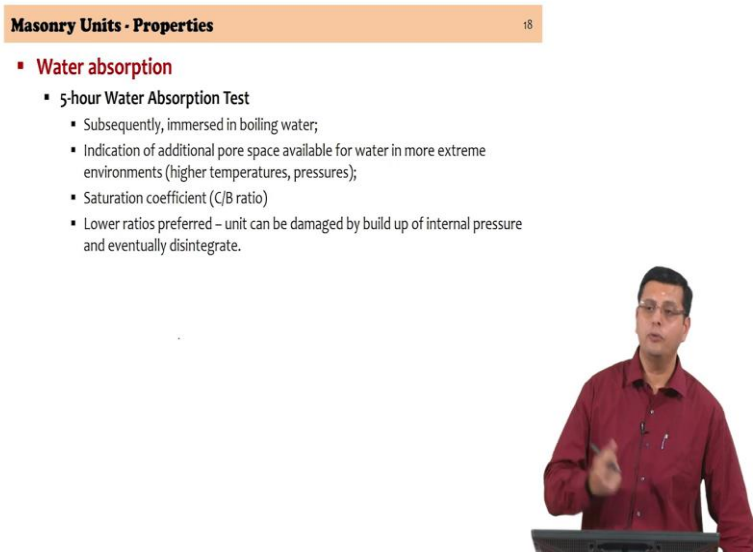

There is another water absorption test and this water absorption test is not so much for countries or at least the tropical regions, it is more for regions where you have extreme cold weather and warm climates during other times of the year, 5-hour water absorption test is done; where after you do the 20-hour water absorption test; where the water that can freely go into the pores and fill up the pores is being measured. In the 5 hour water absorption test what you are actually doing is you are immersing it in boiling water.

So, in this case you have pressure and water is entering the remaining pores under pressure. So, the smaller pores are going to get filled up when you do a 5-hour water absorption test and what really happens, what really this one captures is what is the additional pore space available the smaller pores that do not get filled up when water moves in freely.

In this case, you are under high temperatures and pressure water is going into these pores. This becomes important because in climates where you have very cold freezing temperatures, water gets into these small pores and then when it freezes there is change of volume and you can actually have micro cracks that are generated in the brick and with freeze thaw cycles. In freeze thaw cycles you will have brick deterioration progressing from day one. So, this is a test that is typically used to understand how durable is your brick that you have chosen for construction.

And, the value or the parameter that indicates how good the brick unit is referred to as the saturation coefficient, is a ratio that is calculated ratio that is calculated by the weight of the brick after the 5-hour water absorption test to the weight of the brick before the water absorption test.

So, this saturation coefficient is checked to see if you are going to have a brick unit that could create problems during freeze thaw cycles and the lower the saturation coefficient is the better it is because those micro pores interconnected micro pores are not there for build up of internal pressure and eventual cracking and disintegration.

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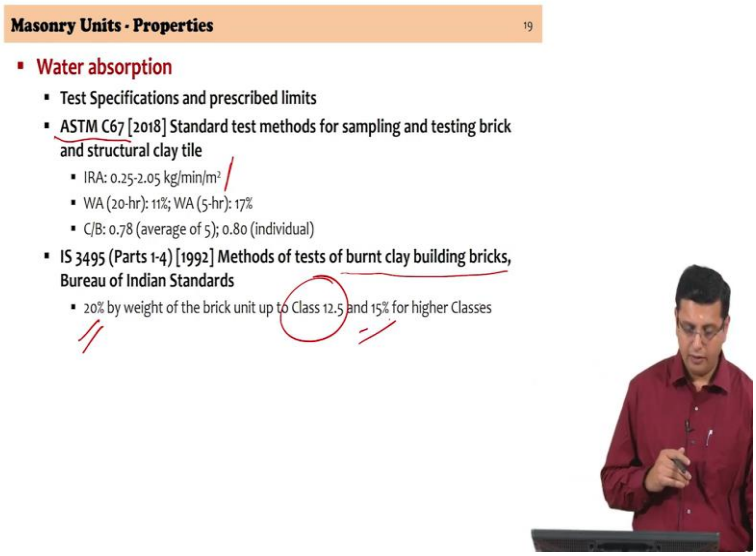

There are of course, limits and it will be instructive to examine what these limits are. I would like to point out that the IS code for clay brick unit does not have an a IRA test. The initial rate of absorption test is not in the IS code, we only have a water absorption test. The IRA test the 5 minute test is a test protocol that you can refer to the ASTM standards, the American standards and carry it out because it is a very valuable parameter.

So, the ASTM standard, ASTM C67, a code that refers to construction materials; in this the IRA range that is prescribed for clay brick is between 0.25 and 2 or just above 2, 2.05 kg per minute per metre square and you have limits on the water absorption and limits on the saturation coefficient as well.

The Indian code IS 3495 which talks about the methods of test for burnt clay brick and specifications thereof, actually allow 20 percent water absorption by weight as long as you are looking at classes of bricks from class 3 to class 12.5 and anything beyond class 12.5, the water absorption permitted is lesser which is 15 percent. So, the cap is 15 percent and 20 percent by weight, up to 12.5 and beyond 12.5 respectively. So, you see that as you go to higher strength it is better to have lesser water absorption in your bricks.

And, particularly when you have reinforced masonry you use higher strength bricks you do not want to create durability issues like corrosion of the reinforcement simply because your brick is actually soaking water right ok

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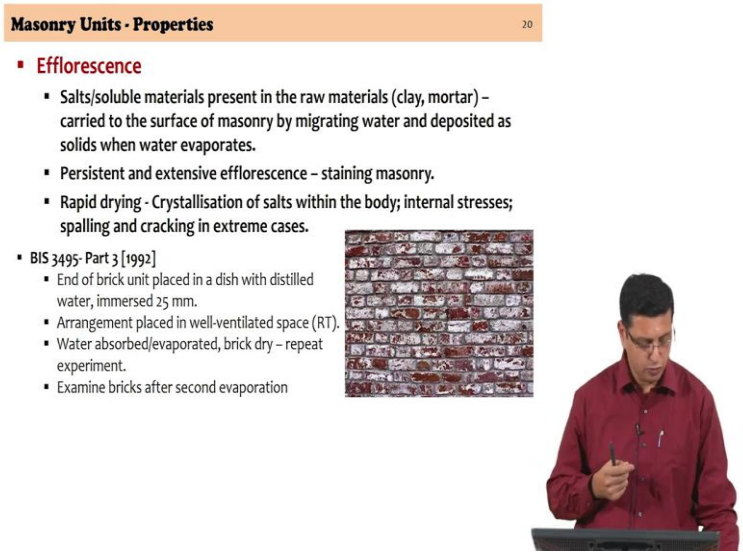

Another property which is more related to durability, but if not addressed over time, you can actually have a problem of strength reduction in the brick. So, efflorescence is another property that is typically checked and efflorescence you would have all seen masonry walls with white patches on them and most often you might not see it because the wall is plastered.

But, this sort of transportation of salts and deposition on the surface because of drying will actually be happening and if it is plastered you might not be able to see it so clearly. But, if it is unplastered wall where you have exposed brick work finish, you can gauge how much of efflorescence is happening in these walls because of transportation of salts. Now, where do you think these salts are coming from?

Student: (Refer Time: 35:43) water.

Water. So, you it the source of the salts can be two-fold. It could actually be during construction itself you have used water that has heavy concentration of salts which is the reason why tests on water are carried out during construction. So, that you do not have these undesirable salts.

So, one source could be the freshly laid mortar or the water that you use to actually wash the bricks or wet the bricks before construction. Alternatively, you can have capillary action from the soil and the wet soil can actually help in transporting salts from the soil

to the structure if you have deficient damp proofing courses or walls that are retaining walls in contact with moist wet soils.

So, what really happens is the salts and these are soluble salts, right, soluble salts. They can be present even in the brick unit itself. The manufacture of the brick unit itself. The brick may have impurities and we have seen those impurities that are present, that could be another source.

So, you have several sources and when moisture starts migrating due to capillary action, comes to the exterior to get evaporated, you have these salts that will start crystallizing on the surface. So, if you have heavy efflorescence you will have staining in masonry as you see in this picture. If it is light you might be able to even, it may be small stains, it can even go away quite easily.

Now, if there is sudden changes in temperature and spikes in temperature and there is rapid drying what will actually happen is those salts may not be able to reach the surface and will crystallize inside the brick cross section itself. In such a situation again crystallization causes volume change and internal cracks are formed you can actually have spalling of bricks if rapid drying and crystallization of the salts within the body occurs, ok. So, efflorescence is something that is a parameter that needs to be checked when you are studying, when you are selecting materials for the construction.

The IS code actually gives you a test method to check efflorescence. It i s simple test you actually have a tray in which the brick units are immersed and you wait for a few days the water has to get absorbed and evaporate. You refill and keep it for a few days till the movement of water has actually happened through capillary action and then you examine the brick surfaces.

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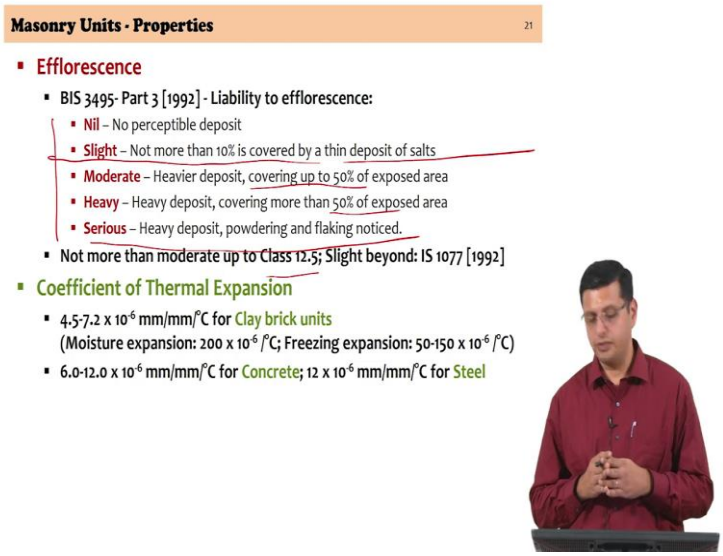

The classification of what you observe in terms of the efflorescence, in this case referred to as liability to efflorescence, you would look at five level classification: nil – you do not see any perceptible, you do not see any deposit, Slight - 10 percent of the area is covered by a layer of thin deposits, moderate covers about 50 percent of the exposed area, Heavy – very heavy deposits and more than 50 percent of the area is exposed and Very serious or serious- is when the so much of deposit that actually if you use your hand they flake you will get salts flaking and that is where or that is serious efflorescence.

And, as far as specifications are concerned up to class 12.5, only moderate liability to efflorescence is permitted and if you are actually going to strengths beyond class 12.5 you cannot go beyond slight. So, you actually have to make this check for the lot of bricks that you are getting for the construction.

Of course, another property that is of importance, knowledge of these properties useful is coefficient of thermal expansion. Yes, the question is about why are we classifying the liability to efflorescence of the brick when it actually has an influence from the type of water that you use. True, but this test is actually looking at how much of salts does that brick itself have, right.

So, if your clay had minerals and you did not know that they were present, if you do this test and of course, in the lab you are not going to be using salt water. I mean you are not going to be using water with heavy in minerals. You check the water that you that you

are going to be using and you are using distilled water. So, you are sure that it is free of salts. So, this is actually telling you whether the brick is of good quality or not.

The coefficient of thermal expansion these numbers are useful to know where we stand with respect to other materials that are used to create the masonry assembly. So, if you have clay brick units that you are using for construction you see that the range is not too far from the coefficient of thermal expansion for a material like concrete and steel. So, these are strictly speaking compatible from practical purposes in being able to put them together as a composite, ok.

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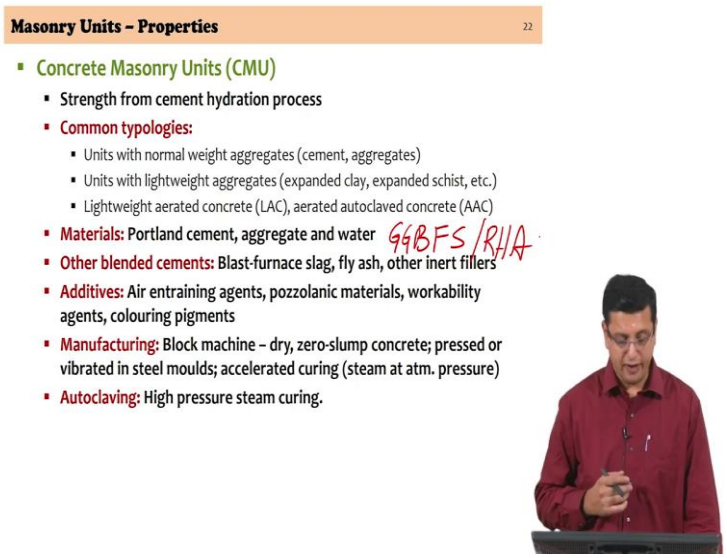

Just for completeness, the concrete masonry units are again the type of unit that you use for construction. You have different types of concrete masonry units. However, while in the clay brick units it is the vitrification process which is helping it gain strength. Here it is the cement hydration process that is helping the unit gain strength, that is the fundamental difference.

We have seen a few typologies in our introductory lecture you could have units constructed with normal weight aggregates, graded aggregates, units with lightweight aggregates- it could be expanded clay, expanded schist and other materials. You have lightweight aerated concrete, AAC or LAC as aerated autoclaved concrete as well.

Now, the materials typically used; You can use Portland cement, aggregates and water. But there is also a tendency to use other blended cement or combination of cements to reduce the quantity of Portland cement for several purposes. Ground granulated blast-furnace slag is something that is used quite a bit; slag cement and fly ash or rice husk ash (RHA) is again something that is used in replacing Portland cement. These are all inert and help in the process of hardening like the cement in the composite.

You also have additives that are used; air entraining agents to make it lighter, pozzolanic materials can be used, workability agents, colouring agents for pigmentation and so on. And, the weight is typically manufactured you have these blocks into which the zero-slump material is placed and you typically have moles that are vibrated. So, that you get they are compacted and curing accelerated curing is used either at atmospheric pressure with steamer atmospheric pressure or autoclave when you are using steam at higher pressures.

So, that is the typical process with which these are being manufactured in comparison to our clay brick which was fired, ok.

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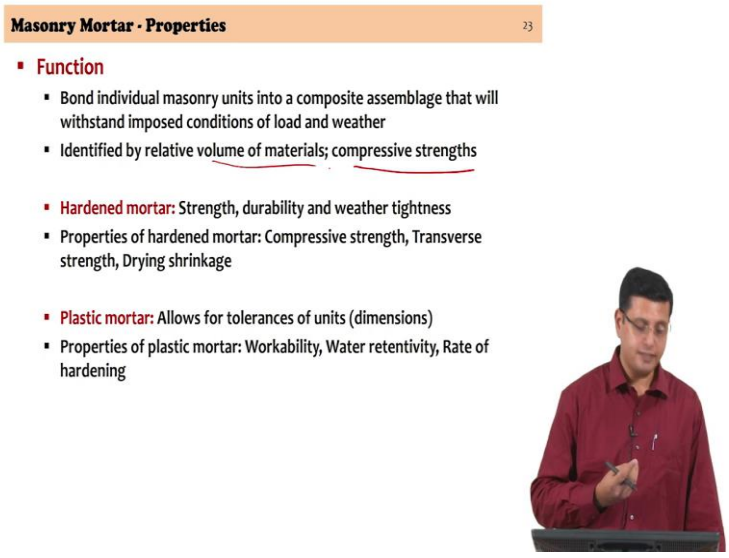

Let us move on to the other material which is part of the composite, the mortar and the function of the masonry mortar is to bind the units together. So, it is really to achieve bond between the units and to create a certain monolithic behaviour of the construction that you use mortar. The way we identify mortars like we identified bricks as class 12.5,

class 15 and so on, the mortar is typically identified by it is compressive strength like we do for concrete, but also by the relative volume of materials.

So, sometimes you might want to have additives like lime in your mortar and if you do not, then the composition is different. So, by the volume of materials 1:4 or 1:3 or 1 1:1:2 and so on versus the compressive strength itself. As far as properties are concerned when you have hardened mortar the compressive strength matters, the strength of mortar matters, the tensile strength of mortar matters. The hardened property the hardened mortar also ensures durability and water tightness in the masonry.

Compressive strength can be estimated. Transverse strength can be estimated. Drying shrinkage is something that you need to keep tab on, because if there is too much of drying shrinkage it can affect the bond and then it can also have cracks and the water tightness of the hardened mortar is lost.

As far as plastic mortar is concerned, the fundamental reason why we actually use mortar is because you will have undulations in courses. You will have undulations and the plastic mortar actually helps to overcome those undulations. So, workability, water retentivity and the rate at which the mortar hardens are properties that from the plastic state you are interested in capturing, ok.

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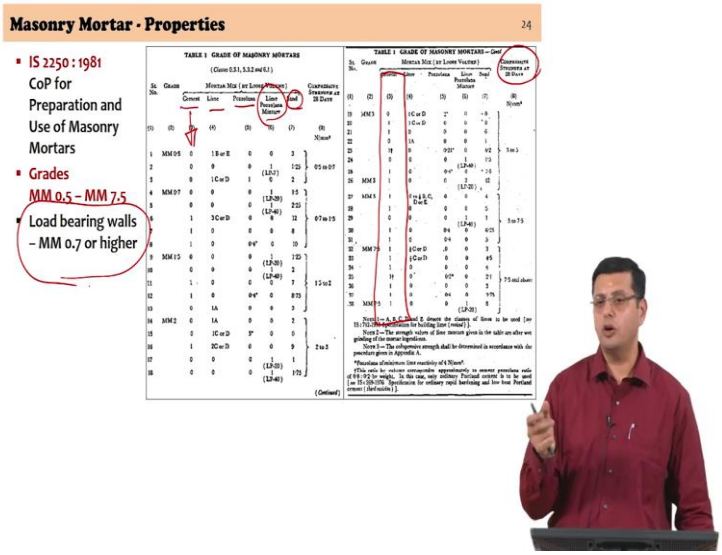

I would like to focus on a particular aspect here. What you see are tables from the code that regulates the preparation and use of masonry mortars, IS 2250 and basically tells you what is the grade of masonry mortar and as you see MM 0.5 would mean the compressive strength, the average compressive strength of the masonry mortar 28 days is 0.5 mega Pascals up to MM 7.5, where 7.5 is the compressive strength of the masonry mortar.

What you see in the table is the set of materials that are used to create the mortar- you have cement, you have lime, you have pozzolans, you have a mixture of lime and pozzolana and sand. So, these are the different compositions in the mortar and you can have varying proportions of these to regulate workability and strength of the mortar.

However, an important word of caution is if you look at the column for cement and the column for cement continues here you, just have one single column for cement right. But, as you know the strength of cement has what is available in the market, increased over time. You used to get 33 grade cement at one point of time 33 MPa being the strength, 43 grade after sometime and today you get only 53 grade cement, which means unless you are sure what strength of cement you are going to be using, you really cannot be sure about the compressive strength at 28 days.

So, theoretically you might want a MM 5 mortar, but if you do not know what cement you are using you can go completely off the mark and get a higher strength mortar. So, this is, I am flagging of a potential problem that we are facing today. As far as masonry construction is concerned you can see that if you are using load bearing walls you need a decent strength for you masonry mortar and we are talking of 0.7 MPa which is very low as a compressive strength and achievable even with lean proportions of cement to sand.

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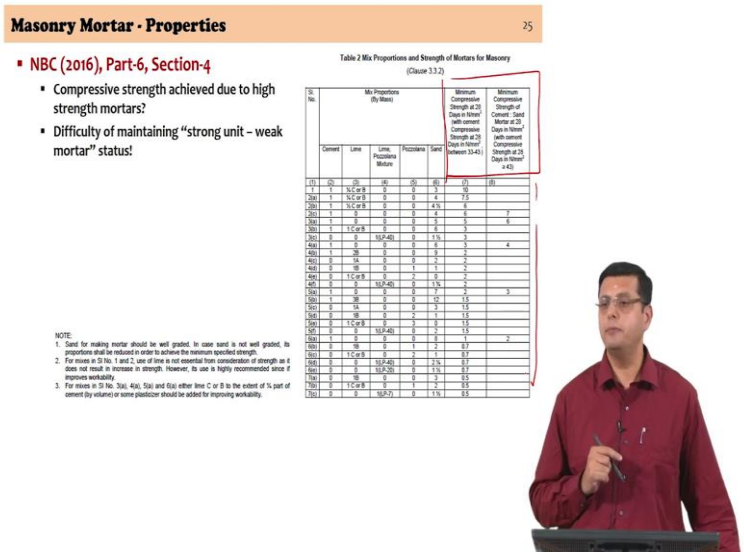

So, the recent version of the National Building Code 2016 which deals with the masonry constituents has specifically brought in a distinction between masonry mortars that are made with cements of strength 33 and 43 grade and cement strength 53 grade, which means your mortar strength can actually be higher if the cement grade is higher. So, this distinction, you need to keep in mind.

And, the problem is why are we so worried, if you get better strength material is better for you right, that is not the point. The point is about compatibility, you need a certain compatibility between the unit strength and the mortar strength and you need to be sure what is the compressive strength that is achievable with this mortar. Now, if you have a situation where the unit strength is lesser than the mortar, you have a change in the mechanics under compression and very soon we will be examining what happens to an assembly of masonry and units under compression.

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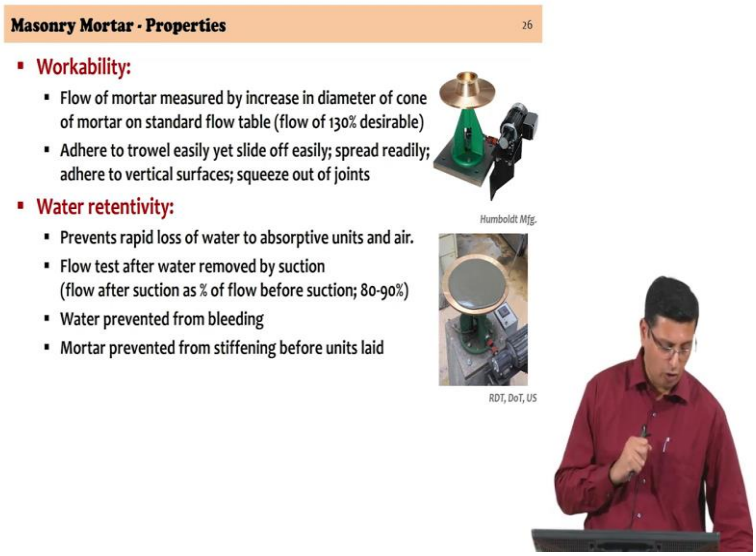

So, in terms of properties the workability of mortar is something that we keep tab on, you could do a flow table test and you expect that the flow is about 130 percent when you do a flow table test. The way you describe flowable mortar is that it should adhere on to the trowel that you use, it should be able to slide of easily from the trowel, it should be able to adhere on to vertical surfaces and the moment you put a brick you should see that it is squeezing out of the joint.

So, that is qualitatively describing the mortar, but that is how it should be. If it is anything different and not respecting these physical observations, your mortar may not necessarily have the necessary workability to help you with development of the bond.

Water retentivity is another important parameter. We talked about the plastic stage parameters that are of importance. This is essential to ensure that water is not lost by the mortar very easily. So, you do a water retention test and then you carry out the flow table test again after carrying out the water after removing the water from the mortar and you expect that the flow after the water is removed, flow after suction as a percentage of the flow before suction is about 80 percent or 90 percent.

So, the point is, you do not want water to just come off from the mortar, separate from the mortar and this will cause a film to form as the mortar is gaining strength, you really want the water to be available for the hydration to be completed. So, if this happens then the mortar is going to start hardening and the bond gets affected, you need the water for the hydration process.