Design of Masonry Structures
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Module - 02
Lecture - 05
Masonry Materials and Properties Part - I

So, the second module starts examining masonry, particularly its constituents and understands what properties of the constituents contribute to the overall strength and performance of masonry as a structural typology. So, we will be examining the specific aspects, engineering properties of the constituents of masonry. And then understand, when you look at an assemblage, which is the masonry unit and mortar put together, bonded together; how is the behavior of this sort of a system affected under different actions, compression, bending; so, flexural compression, flexural tension, shear and a combination of shear and compression. So, this segment basically tries to understand, how the constituents determine the overall mechanical behavior of masonry.

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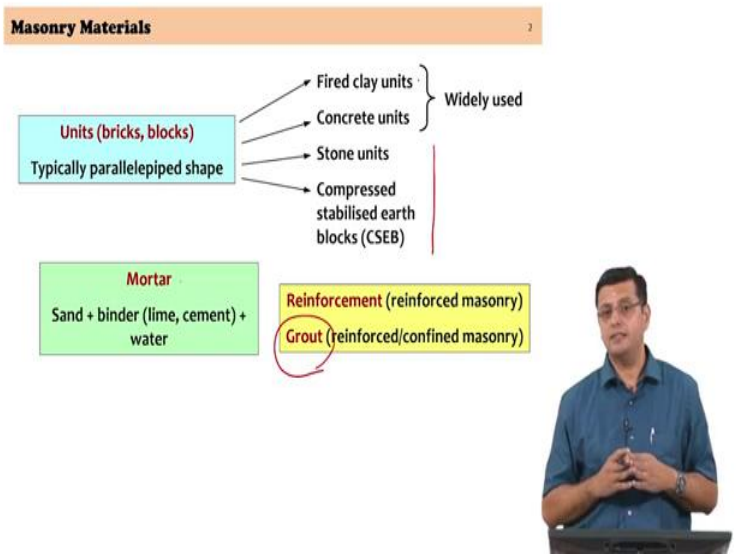

We have been examining over the last week, the different types of constituents, you have a brief summary on this slide. We are talking of different types of units that are possible, you can have fired clay units, you can have concrete units and these are the ones that are widely used as far as structural masonry is concerned. Of course, you have other types

and the list is not exhaustive; other types of masonry units- you could have stone masonry units, you could have sun dried compressed stabilized earth blocks, there is an entire spectrum and we have seen few of them in the earlier classes.

So, as far as the design of masonry in this course is concerned, we will focus on the use of fire clay bricks- hollow or solid and concrete blocks; typically, hollow concrete blocks with the possibility of introducing reinforcement in them. Of course, you need a binder, you need the mortar as the bed joint mortar that we are referring to, we are not looking at mortar as a render element which is plaster, but more so, as a material that is used as the bed joint mortar or the head joint mortar.

So, here it is a combination of sand, a binder; lime as I said is something that has been used in the past, but our focus is primarily on cement as the binder. And of course, sand cement and water together gives you the cement mortar, which is another structural material that goes into composing masonry. And then you have the two other elements that are introduced particularly when you are dealing with confined masonry or reinforced masonry which is the reinforcement itself and we have seen that you can have vertical reinforcement, you can a horizontal reinforcement, you can have the two in isolation or you can have the two together.

So, the reinforcement itself and the properties of the reinforcement needs to be known, but when you have reinforcement you need protection to the reinforcement and you need a method of shear transfer from the reinforcement to the structural masonry. And therefore, this is typically embedded in grouts also providing the necessary corrosion protection to the steel reinforcement.

So, you need to understand what is the property of the grout? And now you have the grout which is one material, within which the reinforcement is sitting and then you have the brick along with the, the brick unit or the concrete unit along with the mortar which is another material. So, it is really an assembly of the masonry unit and mortar, the steel reinforcement and the grout which are three different materials as far as masonry, as a structural material is concerned, ok.

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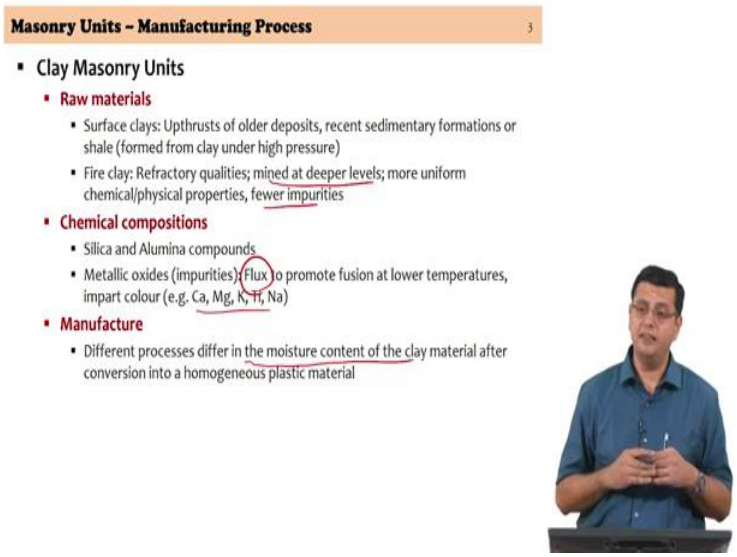

Very briefly it is useful to examine the manufacturing process, it is an industry that has a very large number of people who are employed, it is not a sector that is very well organized, particularly in our country. But we will focus on very few aspects that may give us an idea of how strength and durability may be affected in the use of structural, use of masonry as a structural material itself. So, raw materials as you know, clay is what is the material that would compose, clay brick units, very often we use surface clays.

Now, for refractory purposes, which is the regular use of fired clay bricks is for construction; is for construction of regular buildings, but when you are using these materials within furnaces, because of excellent refractory qualities you use fired clay bricks even for furnaces, as lining for furnaces. And for this, you need to basically take clay that comes from deeper deposits with fewer impurities, very often the surface clay would have larger proportion of impurities whereas, for refractory purposes you use what is called fire clay and they are typically mined at deeper depths.

The chemical composition, it is soil, it is derived from soil. So, it is primarily made out of silica and alumina compounds, you also have a significant distribution of oxides, different metallic oxides, but these are seen as impurities and you know that when you have these impurities, these impurities typically act as flux. So, when the firing process is happening, when the clay bricks are being fired the presence of these metallic oxides is useful as a flux and helps to create a stronger final product, And of course, depending on

the proportions of these impurities the color of brick also can vary, but typically we are talking of calcium, magnesium, potassium as the impurities in the oxide forms.

The manufacturing processes, there are different manufacturing processes, but typically the processes differ in the clay content, the moisture content present in the clay itself.

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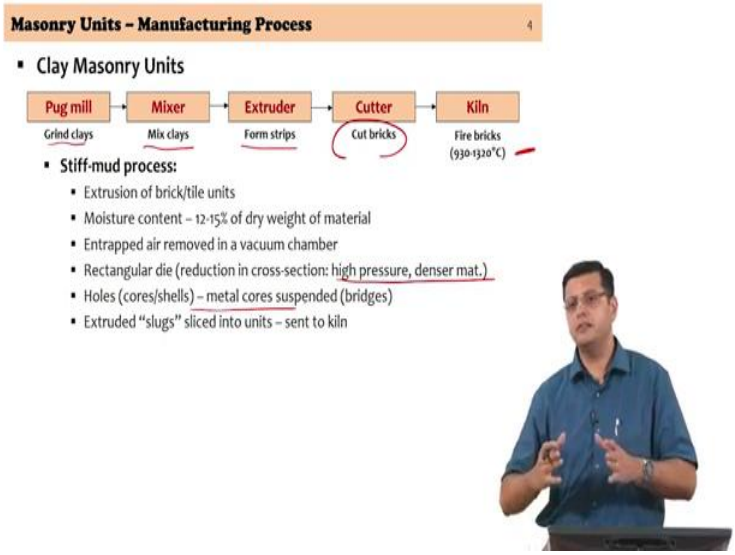

They are broadly classified into processes which recognize the amount of moisture present in the clay itself as you prepare it for the firing process. The workflow as far as creating these clay masonry units, you need to grind clay, you take you need to grind the raw materials, you take it through a pug mill to do that; typically it is not one single source of clay that is used, there is a tendency to mix clays.

So, you have different sources and then you mix it to get good proportion and good outputs. So, you have a mixer, which mixes these clays well and then, once it is made into a mixture with water, then have to give a form to it and extrusion is one method, another method is moulding.

So, you have these extruders which will create strips as the clay comes out or you mould them and fire them. So, as they come out from an extruder, you either cut and use these as wire cut bricks or you fire these bricks and when you fire these bricks typical firing temperatures are above 900 degree centigrade to about 1200-1300 centigrade.

So, as I said, depending on the moisture content in the clay along with the kneaded, along with water you have different processes. The stiff mud process as you can see the word ‘stiff’ meaning moisture content is on the lower side; the stiff-mud process it typically uses extrusion method to manufacture the bricks, the moisture content is typically of the order of 12 to 15 percent of the dry weight of the material itself.

So, it is taken into a vacuum chamber and of course, the kneading process of the clay introduces entrapped air. This entrapped air is removed, that is what also helps in formation of pores in the brick units and then these are also put into a rectangular die and under high pressure the material is densified. And if necessary, there are perforations created or you have; if you want to create divisions, particularly when you have hollow fired clay bricks, you can have bridges which can create partitions in the blocks and so on. So, all that is done within the die itself, these are then sliced and once you have the extruded wet clay with the necessary coarse or divisions, it is then is ready for the firing process itself.

Yes, your question is whether this is the process that is typically adopted within an industrial setup or in the unorganized sector. This sort of a process where you have extrusion as the process for creating the bricks and then cutting them, wire cut bricks are typically industrialized. The unorganized sector uses moulds and casts bricks. So, this would be more within an industrial setup rather than in the unorganized sector.

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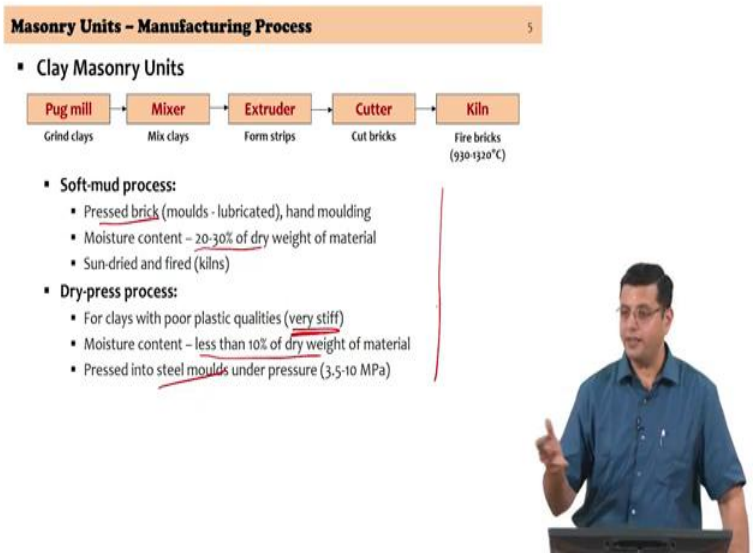

The soft mud process, again the reference is with is to the moisture content present. So, with about 20 to 30 percent of moisture content with respect to the dry weight of the material, you cannot use the extrusion process anymore. Because you have a softer clay and it can deform if you use the extrusion process and hence pressed bricks what are preferred when you use this level of moisture in the bricks. And this is where we are talking of moulded; these are hand moulded, the clays packed into a mould and then you get the brick which is ready for drying under the sun and then firing. So, this is typically what the unorganized sector would use to prepare the bricks themselves.

In situations where the moisture content is far lower than the two previous processes, particularly in areas where availability of water is the problem, you could have processes which are refered to as dry-press process. And these are very stiff clays and here we talking of less than 10 percent of the dry weight of material as the moisture content.

And so, these two processes, as against the first one that we were looking at, the first one uses the process of extrusion, the bricks are extruded and cut. So, you get wire cut bricks whereas, these two processes are processes where you have to mould the bricks. So, these are based on the use of moulds and they are actually pressed bricks.

So, we saw this type of brick that you can get, one with the frog which can be embossed as you manufacture it with the mould itself, the wire cut bricks are typically devoid of this sort of a frog. So, again you see that it is the moisture content in the clay that determines the kind of manufacturing process itself of the brick. So, once; in all the three cases, once the brick is ready, the wet brick is ready, you go and fire the brick.

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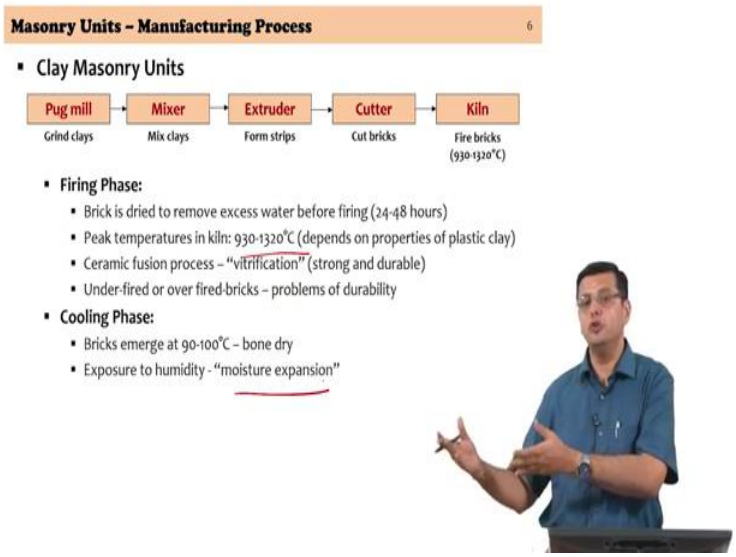

And in the firing phase and this is what imparts the strength to masonry-brick masonry, the firing process; before putting it into the oven right away you let it dry and this is sun dried. So, where it loses the excess moisture that is present. So, this excess moisture actually needs to leave the clay otherwise, if you put it right into the oven that is going to become steam and create problems for you in the strength gain of the brick itself.

So, this is sun dried and then you take it to the kiln and as I said we are talking of temperatures higher than 900 degree centigrade. And of course, depending on the different types of clays, the temperatures are regulated between 900 degrees to 1300 degrees centigrade.

However, the most important aspect is when you take the clay to a temperature of this order it undergoes a process called vitrification, ok. And that process of vitrification, it is a ceramic fusion process, this is what imparts the strength and durability to the masonry. Now, the word vitrification comes from vitro which is glass, which means because of the presence of silicas and the presence of metallic oxides, there is a fusion process of the silica compounds, and it is like formation of glass and that is really what gives strength to clay, to the clay bricks.

Now, if vitrification process is not uniformly occurring you can have poor quality bricks, might have bricks that are a very brittle or have non-uniform strengths, and that is why it is so important to have uniform firing of the bricks. Have you seen bricks which do not

have a uniform colour, black on one side and reddish brown on the other; That is simply, because of non-uniform firing. And therefore, the whole process of ensuring that the that all the bricks within the kiln are exposed to same range of temperatures, for the same amount of time is a very important part of the process.

Particularly when you have kilns that are, kilns in the rural areas and kilns which are not part of a thorough industrial process, you have firing that is done in a very informal manner. And wind during the firing process is sufficient to ensure that part of the bricks get fired properly, part get fired more than necessary and part less than necessary.

So, the variability comes one from the type of clay that is being used, two from the firing process. So, it is not only a problem of strength, but it is also going to be a problem durability, because water absorption properties are affected if the firing is not adequate.

Once the firing is completed you cannot use it immediately, these are coming out of furnace, they are left to cool down naturally; they are left to cool down naturally, they come out of the kiln in a bone dry condition which means there is no moisture left in it, it is inside the kiln for hours together. It comes out now bone dry condition, but there is moisture in the atmosphere. So, the bricks start absorbing moisture from the atmosphere.

Therefore, you should let the brick do that, if you immediately use the brick you are going to have problems in your construction. So, this phenomenon is referred to as ‘moisture expansion’, that when you expose it to humidity in the atmosphere, it will absorb moisture and expand to a certain extent. So, moisture expansion is an essential phenomenon and has to, you have to give time for this to occur, ok.

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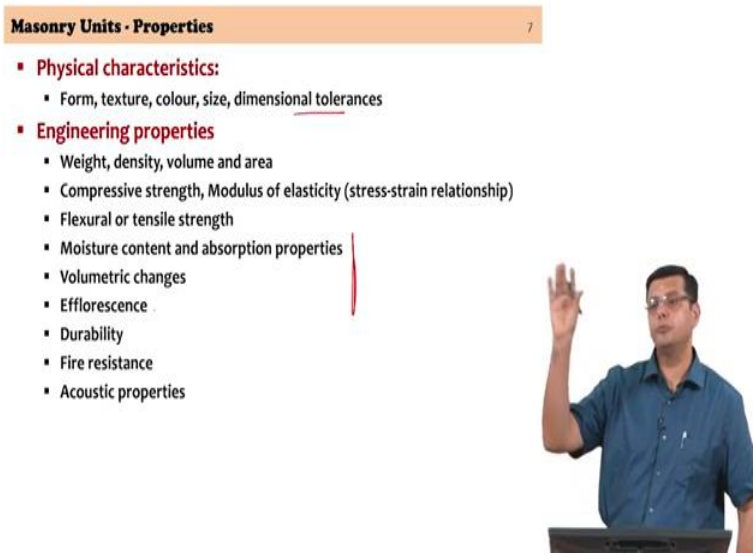

Now, in terms of the properties of masonry, we are going to be examining of few properties, but it is important to understand that aspects such as the overall form, particularly the overall form and dimensional tolerances are key to good quality construction. When we talk about of dimensional tolerances, if these bricks are coming out of a thorough industrialized process, you can expect a certain uniformity to the product.

But if these are coming from handmade moulding processes, you will have significant differences between the products of this moulding process itself. And there are limits that codes typically allow on how much variation is allowed from one brick to another within a lot. So, dimensional tolerances are important if you have warped bricks, if bricks have significant differences in their shapes, you are going to be using different quantities of mortar in different locations, which is not good, because more the mortar weaker is the masonry construction going to be and that uniformity is lost.

Of course, the engineering properties of interest vary from compressive strength to the flexural strength, flexural tensile strength, the modulus elasticity so, the deformability characteristics of masonry. And other aspects which affect durability; like the moisture content in the brick, the water absorption properties, changes in volume, efflorescence, other durability aspects, abrasion resistance for example, if you are using it for paving,

fire resistance and acoustic properties. So, we will examine a few of them to understand how the unit contributes to the strength of masonry itself.

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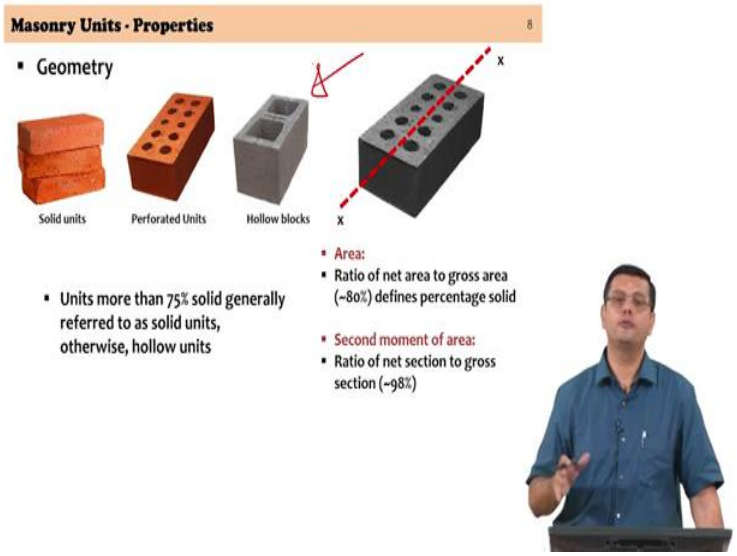

Fundamental aspect to be considered is the role of geometry. So, here we have examined that the unit could be a solid unit, it could be a unit with some cores. These are called cored units, some amount of perforations and it could be hollow brick construction; it could be hollow brick as the unit itself. How would do these differ as far as the structural mechanics of the wall that you are constructing is concerned.

By definition, if the unit has more than 75 percent solid cross section that is the perforation that you are creating are 25 percent or lesser, you refer to them typically as solid units, that might look like a paradox, solid unit is a solid unit, hundred percent solid. Why is that I am calling a unit which has a 25 percent voids as a solid unit?

It is interesting to examine the rationale behind this, and the rational behind does not directly come if you were to look at the area of cross section. So, if you were to examine, let us take the perforated units. These perforated units if the percentage of voids is less than 25 percent, I would still classify that as a solid unit. And if I were to classify that as a solid unit then you have a certain way in which you will make your calculations as far as area of cross section is concerned for structural design.

So, take that brick that we have been looking at, it is a perforated unit and you can see that it's cored, right. So, if you were to look at the area of cross section and examine the net area to the gross area, in this case it would be of the order of 80 percent, so it is about 80 percent solid. So, percentage solid is defined as the ratio of net area to gross area. Now where would this affect, the stresses under compression would vary, because the net area is lesser than the gross area, and 80 percent to 100 percent there is a difference, it is not insignificant right, you would agree with me.

However, if you were to examine bending properties; if you were to examine bending properties of this sort of a brick unit; if I were to examine the second moment of area as a geometrical parameter that defines the bending property, it is very instructive to note that this unit which has about 25 percent void is not very different from a solid unit.

So, if one way to examine the second moment of area and you take the net section to the gross section, you can calculate the second moment of area of the net section, the second moment of area of the gross section; the ratio is close to 100, which means these units really behave very similar, because of the geometry being comparable, overall geometry being comparable to a solid unit.

So, it is with this rationale that if the voids are less than 25 percent you can still classify them as solid units. For area of cross section, you would use net area for compression compressive stresses, but for bending you have literally no change in the way you account for the geometry. So, this is an important aspect that one must remember; however, when you are dealing with hollow blocks, it would changed significantly and you should be able to account for how much of your wall cross section is filled, how much of your cross section is left unfilled, ok.

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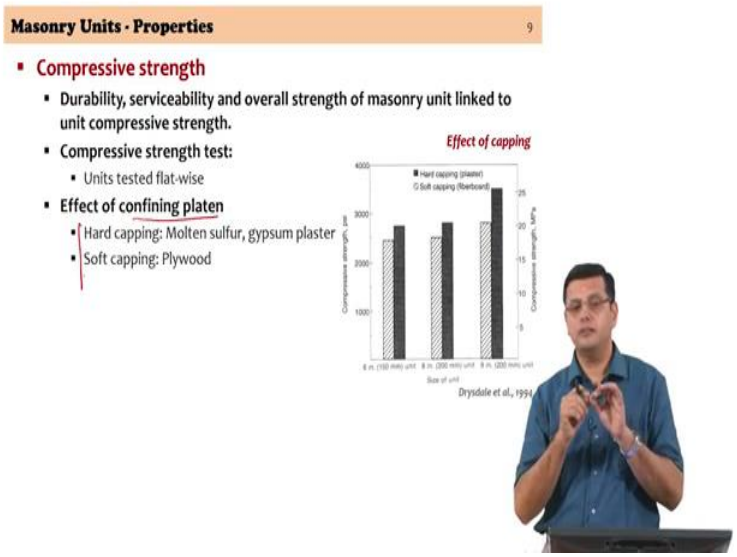

The compressive strength of the unit, what does the compressive strength tell us? how does it affect the compressive strength of masonry itself? Durability of the masonry construction, serviceability aspects of the masonry construction and the overall strength of the unit is linked to this parameter, compressive strength.

So, if you measure the compressive strength of the unit or if you know the compressive strength of the unit, it is that one parameter that is linked to all other qualities of the material; it is linked to the its durability for better the compressive strength, better will be the durability, better the compressive strength, better will it perform during serviceability conditions, better is a compressive strength, better is the overall strength meaning your tension strength will increase, your flexural tension strength will be higher, your shear strength of the units will be higher.

So, one parameter that can easily be correlated to every quality is compressive strength. Keep this in mind both are the unit level and at the level of the masonry assembly. And this is an important information, primarily because when you doing assessment of existing buildings, if you can get this one information, you are better placed than having no information for an existing building. We will come back we will revisit that point; however, the compressive strength of the unit is an important aspect.

How do you test the compressive strength of the unit? It is tested flat-wise. Now what is flat wise? It is the way the brick is actually used in construction- flat, so the largest

surface is placed facing down, so you test it flat-wise; however, a word of caution! If by design you are going to be placing the bricks on edge, you cannot use the flat wise strength of bricks.

So, you will have to devise, you will have to estimate the compressive strength of the brick unit, though it might not be significantly different from the flat-wise strength; it is essential that if you are, if you know that you are using the bricks flat wise in construction use the compressive strength define flat wise. If you using the bricks on edge or on end you will estimate the compressive strength in that format definitely, and that is in fact, the question of end restrains is definitely a cause for concern and there is a significant body of research that has looked into the problems that can arise because of end restrains, but that is something that you will have to deal with, because you know that the end restraints, because of the proximity of the loading head to the structural material along the height is a problem.

However, the research on this has shown that depending on the type of capping that you use, that is exactly the next point; depending on the type of capping material that is used on the top and bottom of the brick unit when you are testing it flat -ise, you can have different orders of effect due to confining, end confinement itself, but you cannot do away with it.

So, when you test these bricks flat-wise in a universal testing machine you will have, if you do not an intermediate material, you will have direct contact of the steelhead, the platen head on the brick material itself. So, that can cause confinement effect to the lateral bulging that occurs at ultimate loads, the load at which failure by crushing is actually happening in the brick unit.

So, this effect of confining platen has been examined and you can see the kind of conclusion that has been drawn, you can either use a hard capping or you can use a soft capping. Now the reason why we use capping, is the brick surface, the top or the bottom need not necessarily be completely flat. It is important that its flat, but the manufacturing process may result in undulations in the top and bottom surface. So, use a material that ensures uniform transfer of load from the steel platen to the brick unit itself.

You can use a hard capping or you can go for soft capping, we use cement plaster, cement mortar or sulfur, molten sulfur is being extensively used today or you use

gypsum plaster, you wait for it to harden and then test it. But, you could also use a soft capping like plywood and you see a significant difference between the use of soft capping versus hard capping.

So, this figure here shows you for different sizes of units, you can see that it is 150 mm, 200 mm and 200 mm unit, different types of units, when you use a soft capping versus a hard capping, the soft capping consistently gives you lower compressive strengths. A hard capping can actually interfere with the actual strength of the material and contribute to increasing the compressive strength or contribute more to the confining effects of the end platen.

So, this use of plywood something that is typically adopted, but if you have undulations you use a softer material; like gypsum plaster, plaster of Paris rather than cement mortar which can actually be rather hard with respect to the brick unit itself.

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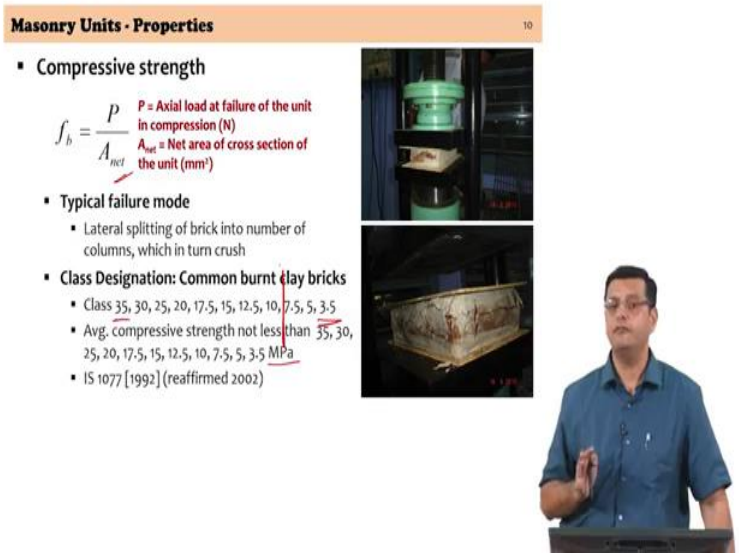

So, a typical test is shown here; a brick is placed in the universal testing machine flat-wise with plywood soft platens, soft end plates as the ones that are helping in uniform transfer of load and as you seen you use the net area of cross section when you are estimating the failure strength of the brick under compression. So, if you have perforations then you will estimate the failure stress with respect to the net area and not the gross area.

$$\text{Compressive strength of unit}, f_b = \frac{P}{A_{net}}$$

$$P = \text{Axial load at failure of the unit in compression (N)}$$

$$A_{net} = \text{ Net area of cross-section of the unit } (mm^2)$$

And the typical failure mode under compression, you have lateral bulging and you have splitting of the bricks into small pieces, small columns and that is when it crushes. So, axial compression leading to lateral bulging, because of the poison's effect is the way you would see the failure in these bricks themselves. As far as the designation of the strength of the brick, it typically follows the compressive strength. So, as you are very familiar, for concrete you have M20, M30, M35 and so on, where the characteristic compressive strength of concrete is used to designate the strength of concrete, the class of concrete.

Similarly, as far as masonry is concerned, the designation comes from the average compressive strength of masonry, and as far as the IS codes, Indian Standards are concerned, we typically have the strength of masonry going all the way from 3.5 which is the average compressive strength, 3.5 MPa to as high as 35 MPa. So, you see this entire range 3.5, 5, 7.5, 10, all the way up to 35 MPa.

I would like to point out at this stage that while the code for use of masonry as unreinforced structural typology permits this entire range; as far as reinforced masonry is concerned, a limit is introduced, requiring that the brick unit strength be least 7 MPa if the masonry is going to be reinforced. I will stop here.