**Building Materials and Construction**
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Module-06
Lecture-03
Strength of Concrete:
**Factors affecting Test Results**

Last lecture, we have seen how concrete strength is affected by various mix parameters. Now, this time we shall see what are the factors test factors, which affect the strength of concrete. Remember when we talked about earlier for the you know, in the introducary discussion on strength of concrete we said, both test parameters and mix parameters govern the strength of concrete.

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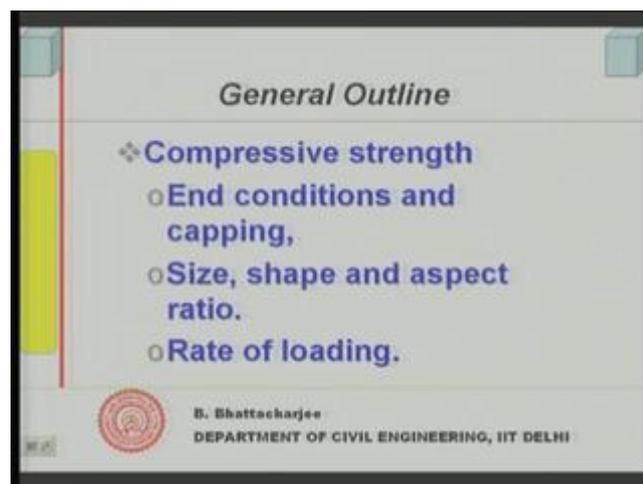
So, this lecture would we will start with compressive strength the factors those affect the compressive strength, measurements. Namely end condition and capping of the specimen size shape and aspect ratio of the specimen, rate of loading moisture condition etcetera.

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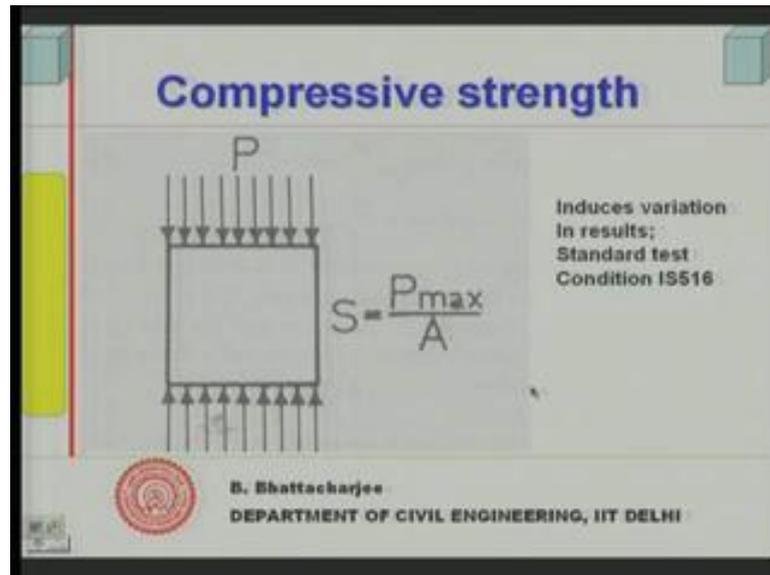
Compressive strength let us see how do we measure we apply uniaxially load into the specimen; you know, we are applying load only along this direction. And you know so, reaction from the bottom plates come from this side and the compressive strength, is measured at the P max the maximum load it can carry before failure divided by area of cross section of the specimen. Now, this test is there are variation possible due to various test parameters, as we shall see 1 by 1 various factors the way you apply the load, size of the specimen the specimen length to height ratio you know length to diameter ratio, rate of loading and several other factors.

So, 1 has to standardize the test procedure and compare you know for comparison of different results coming out from different mix. So, this is done as far as you know this variation, in results and therefore, we have standard test condition and that specifies in IS 456 as far as Indian condition is concerned, this is specified in IS 516. So, test method this test is described in IS 516. So, test condition induces variation in results and standard test conditions are given in IS 516.
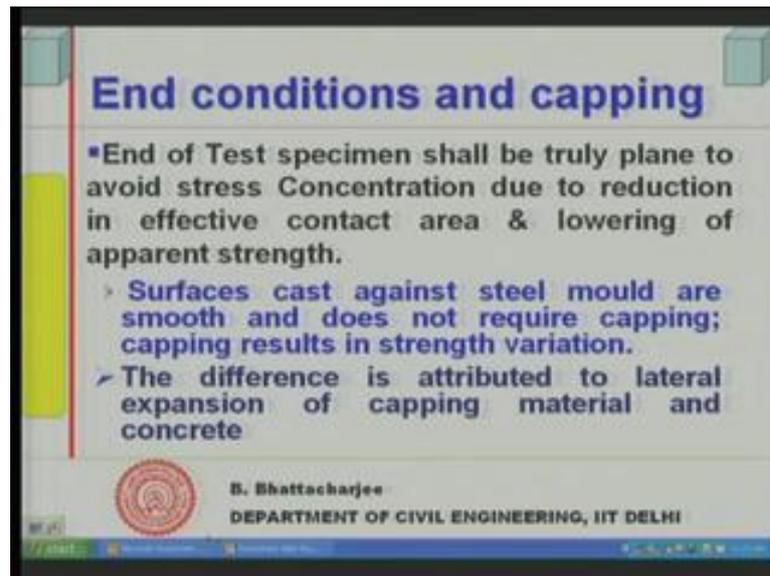
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A second view of testing them is not test not to test cube, but this is also a test suggested in IS 516 you can test part of the beam. Now, this beam once it has tested in flexure, we will discuss this flexure test or tensile test, for tensile strength later on, but once you have tested and failed. So, this is the failure plane where it has, failed the beam has failed and the bending test and the remaining portion, you can utilize for testing for compression. So, you can see load is applied on part of it this is d, this length is d and this length is d and this length is also d.

So, in other words it is a kind of you knows this dimension is same d, d. So, all this dimensions are same its almost like cube, most like a cube. So, you are testing this part of the beam for compression. So, this is also part of the standard test, but this is not very common more common is the cube test which we utilize for both quality control purposes and judging the potential of the mix, you know potential strength of the mix you know that we have that has gone into making of concrete.

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End conditions and capping

- End of Test specimen shall be truly plane to avoid stress Concentration due to reduction in effective contact area & lowering of apparent strength.
  - Surfaces cast against steel mould are smooth and does not require capping; capping results in strength variation.
  - The difference is attributed to lateral expansion of capping material and concrete

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So, first factor that affects we shall see that, end condition end of the test specimen affects the strength. Now, first thing is that it should be truly plane; you know, you are testing a cube and this you apply load through this surfaces. This surface should be truly plane, otherwise what will happen if you have some sought of undulation the load will be applied there and local stress concentration will be stress concentration would be there. Because effective area contact area is reduced and through this effective contact area then you are load transferring a load through a larger portion.

So, there will be stress concentration due to this undulation or if it is not truly plane, then contact area being less there will be stress concentration and this will induce reduction in the result. So, you will get apparently lower strength you know if it is not plain. So, it has to be plain; now, in case of cube what we do we cast the cube with in steel mode 5 surfaces are in contact with the steel mode. One top surface you know you cast like this with this surface all surfaces; this surface, this surface, this surface and the to this surfaces parallel to the screen are also finished also in contact with the mold. This top surface is the finished surface and which will normally have some sought of undulation.

So, what we do while testing we test such that this is facing the person testing; in other words, this you should be able to see the load will come on to the surface finished surface. So, this is what we do in case of cube of course; in case of cylinders we cast it in this manner cylinder we cast it vertically. So, load is also applied on to the finished surface, some time capping may be necessary you might put capping in order to you know take care of the variation due to the non planarity of the surface, but in other wise

people have seen in, you know during research what happens if you put some sought of capping material.

Now, this helps us in understanding the behavior also standard standardizing our specimen so, that is what it is. So, therefore, what we have seen surface cast against steel mold are smooth and does not require capping. Capping results in strength variation that is what we are going to see now. The difference difference is attributed to lateral expansion of the capping material and concrete.

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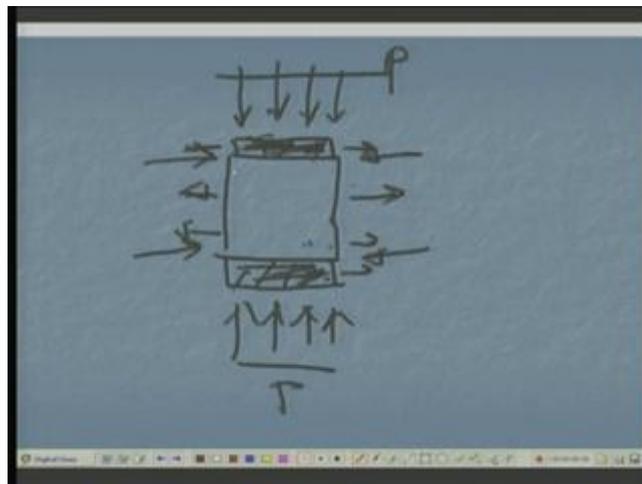
We shall see that; you know if you have your specimen like this and you have put a capping material let us say at the top some sought of capping material at the top and also at the bottom. Now, when you are applying load like this due to Poisson's effect there will be transverse movement of all this; you know, movement transverse movement due to Poisson's effect So, this will have a tendency to move. So, you have applied actually P load here, P reaction will come from there, but there will be transverse movement.

Now, this material the capping material here capping material here see relative movement between this capping material and concrete relative movement. If this movement of the concrete is restrained, if it is stopped if it is somewhat restricted by this capping material it will have some sought of effect and if it is not restrained or restricted by this capping material it will have a different effect.

The effect is something like this you know if you are applying a load from the other direction, then this is a situation of what is known as bi axial condition and in a bi axial

condition, strength would apparent strength would be higher in a bi axial condition apparent strength would be higher.

So, the difference is that is why the difference is attributed to lateral expansion of the capping material and concrete. You can see this happens now this is the results of several test specimen.

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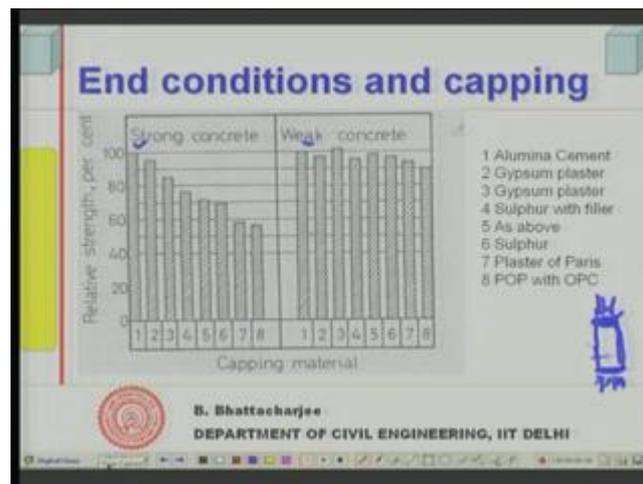
For example; 1 is Sulphur, you know 1 is alumina cement. So, this is alumina cement; now, y x is relative strength if we consider this as a strength for strong consider this as a strength for strong concrete. You know 100 whatever alumina cement can give you have done capping with alumina cement; that means, we have specimen cylindrical specimen of this something like this, which look like this and we have done a capping here and we did capping here and if we do capping here.

So, after capping the loads were applied loads were applied from both these directions loads were applied from both these direction. So, when you put alumina cement the strength that, we get we call it 100 percent. Now, let us look at strong cement strong concrete, you will find that gypsum plaster shows lower strength in alumina and so on. Similarly 8 is plaster of paris with OPC. Plaster of paris pure and sulphur and you know sulphur some filler, sulphur with another filler gypsum plaster different combination, different mix this might be this is also gypsum plaster.

So, you can see strong concrete the variation is significant; there is large amount of variation in case of a material in you know alumina if it gives 100 then, other something

else you know plaster of paris with OPC gives much lower whereas, in weak concrete this effect will relatively less, the effect of the capping is relatively less. We shall see why it happens we understand this as you go through the next slide.

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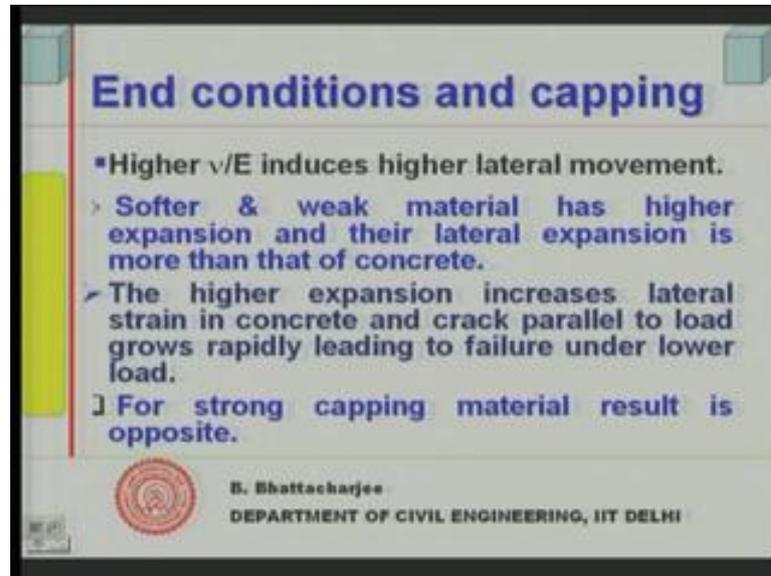
Now, what happens this depends upon nu by E; what is nu? Nu is the Poisson's ratio. This is E is elastic modulus. So, Poisson's ratio and elastic modulus. Now, what does what does it means if I have high Poisson's ratio then it will move laterally more you know the the stress induced along the lateral direction will be more divided by modulus of elasticity the strain along the lateral direction. So, this is a measure of the strain along the lateral direction.

Now, if I have a material the capping material which got high nu over E then therefore, it will move more at and therefore, it will restrain the concrete less. It will restrict the movement of the concrete less. So, higher Poisson's ratio to modulus of elasticity will restrict the concrete less and therefore, the strength will be lower.

On the other hand, if I have lower modulus of you know nu by Poisson's ratio to modulus of elasticity of the capping material then this will capping material then this will give what. If I have lower value of this will be stiff it will not move in the transverse direction and it will not allow concrete to move, it will actually induce higher restrain down to the lateral movement of concrete thereby apparent strength will increase.

So, let us see softer and weak material has higher expansion and their lateral expansion is more than that of concrete and as a result what do they do. This higher expansion increases lateral strain in concrete and crack parallel to load grows rapidly leading to failure under lower load. So, this value is higher it would mean that concrete will fail under lower load. Whereas, if it strong, if the capping material is strong then this will result in you know lower this will result in, higher strength of the concrete because a strong capping material, which has got low Poisson's ratio by E stiffness is less, E is high E does not want to actually deform. So, high E and also low value of Poisson's ratio does not transfer too much of strain, stresses along the transverse direction.

So, such material would itself will not deform laterally too much and it will actually oppose the because they are bonded together they are together and there is too friction and there is nothing more, because you have applied a high load P through it and friction will force is proportional to the normal. You know, when you apply high force the concrete cannot move, there is a kind of frictional force which will restrict a frictional force between the capping material and concrete and therefore, restrain lateral movement of the concrete will be restrained. If nu by E of the capping material is low, in other words if it is strong then it will result in it will result higher apparent strength of concrete.

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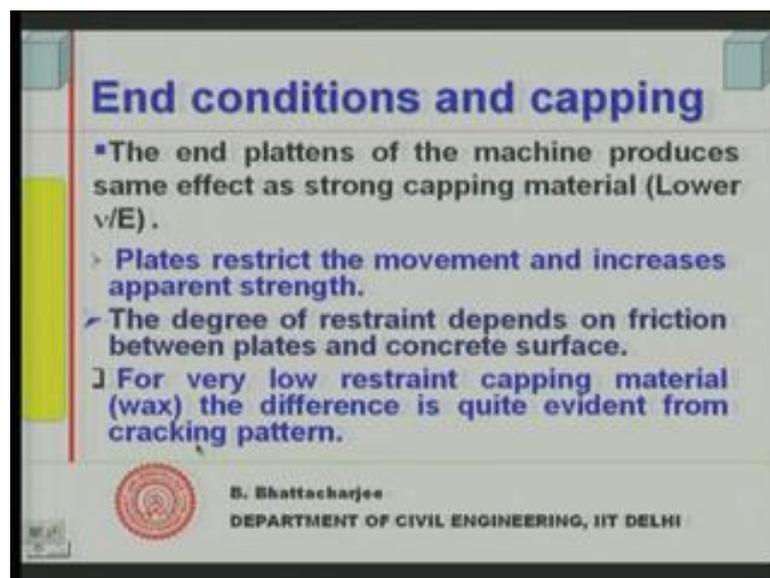
End conditions and capping

- The end plattens of the machine produces same effect as strong capping material (Lower ν/E).
  - Plates restrict the movement and increases apparent strength.
  - The degree of restraint depends on friction between plates and concrete surface.
  - For very low restraint capping material (wax) the difference is quite evident from cracking pattern.

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So, capping materials really affect the strength of concrete apparent strength of concrete high alumina cement therefore, shows low you know higher strength, which means; that high alumina cement shows higher strength amongst the material that we have seen.

Therefore if we use high alumina as a capping material you know it shows higher strength, which means that; it is quite stiff it has got low nu divided by E compared to all other materials like plaster of Paris etcetera. And that is why this variation that we saw. So, capping materials really affects the apparent strength of concrete this is 1 thing, but we need not apply capping all the time. So, what is you know why we are looking at capping material; we do use some time capping material, but that gives us a understanding that the restrain lateral restrain, is an important aspect as far as strength of apparent strength measured strength of concrete is concerned.

Now, come to the no capping material and come to the cube which is just been loaded under the steel plates. So, this is my concrete cube and this is my machine plates through which I am applying the load. So, they have machine plates now this plate themselves are usually steel and this plates affect the you know, produces the same effect as a strong capping material.

So, this 1 they produce the same effect as a strong capping material it has got lower nu by E. It would actually have a tendency to increase the strength of the concrete. So, and platen themselves, the machine platens the plates because you will apply load through the machine hydraulically or whatever way it is; now, this loads are applied through plates some plates which is which actually applies the load and this machine platen itself produces similar effect as the strong capping material.

These plates restrict the movement and increase this apparent strength. This degree of restrain depends upon the friction between the plates and the concrete surface higher the friction restraint will be more and of course, the friction itself is you know frictional force is a function of the load itself; for very low restrain capping material say wax the difference is quite evident from the cracking pattern.

Now, we shall see the cracking pattern which we have seen through photograph you know few may be 2 lectures earlier 1 or 2 lectures earlier if you remember we have seen the failure pattern of the cube now this becomes again apparent from the failure pattern observed in failure pattern observed
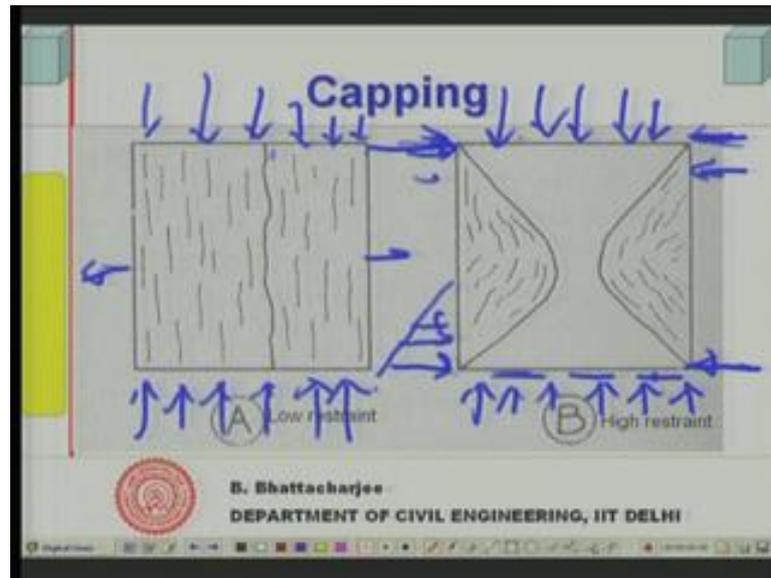
observed in 2 types of capping like if I put a load strain material if I put a load strain material you know the crack comes vertically straight away because I have applied load like this I have applied load like this and I have a low restraint low restrain means a soft. I have a low restraint; that means, I have a soft capping material.

So, it does not stop it does not restrain the concrete from expanding along this direction and therefore, the crack, parallel to the direction of loading as it should happen because we have said the failure mechanism of concrete cubes are tensile failure along the transverse direction. So, this strain it can reach early the ultimate strain this can reach early nothing is restrictin

g and throughout the specimen it can reach early the strain and therefore, you see vertical crack on fails at a lower load whereas, if you have a high restrain, same loading.

Now, this is not being allowed; you know the restrain this is not being allowed because there is a force coming by from the platen the force is coming by here and since the material, is connected this material is continuous. So, this force here which is transmitted through this will be also transmitted through some other material. So, although you are applying load like this and material is trying to bulge out in the transverse direction this bulging is restrained this bulging is restrained by a lateral force, which acts at this point the frictional force which acts at this point and in turn actually it will not allow it to bulge out.

So, strain would failure strain would would not be reduced. In fact, there are several failure criteria, several failure criteria for failure of concrete. You know stress criteria etcetera etcetera, but the most most well accepted criteria is strain criteria, 100 to 200 micro strain criteria; that means, concrete fails when it reaches, it is ultimate strain and accordingly

therefore, when the ultimate strain is reached in the in this case it will be reached early in this case it will be reached late and thereby you can see that, the failure pattern is also different and you remember we showed you a photograph earlier of actual cubes and this failure patterns were like this.

But as you go away from this point effect of this restrain reduces down and therefore, you see the effect is practically it remains up to certain distance. This because frictional force is applied here only at this surfaces, at this surfaces restrain frictional force is applied you know which does not apply allow it to bulge out.

Similarly, here only. So, this force gradually reduces down as you go from the surface of the cube, to inner side. And that is why, this this pattern is something like this. We will have more of it more understanding of it further.

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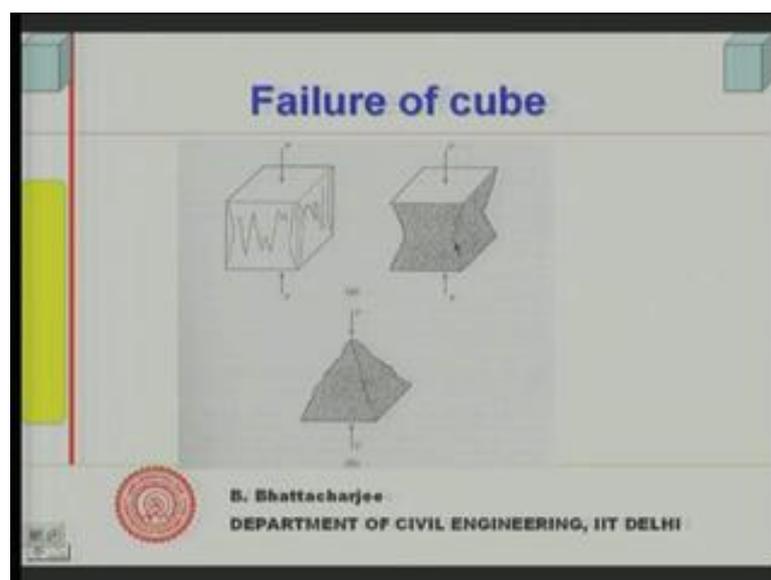
So, that is why we saw you remember that photograph and this is why, we saw the failure of the cube was something like this. The cracks you will see something of this

kind uni axial cube and you allow it to further crack into something like this you allow it to further crack further grow the crack and you will have something of this kind.

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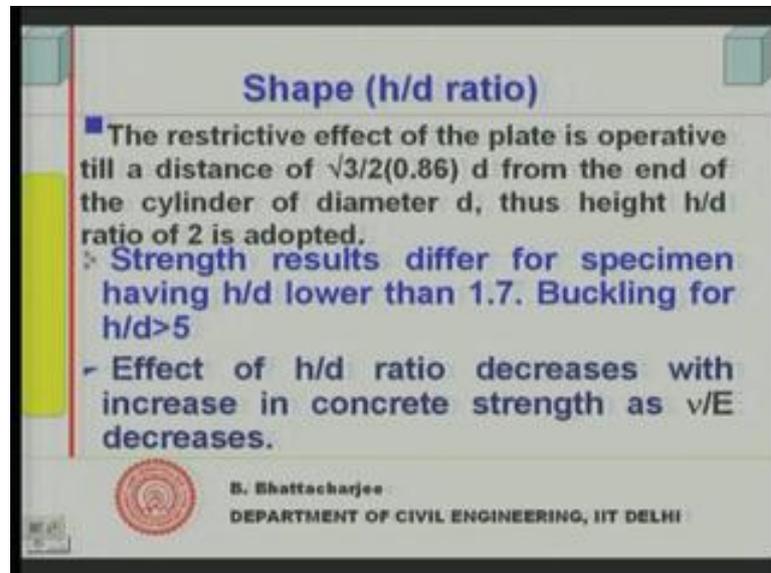
Now, this same effect of restrainment has some effect on the h by d ratio shape. So, far I talked about cubes and I also mentioned in 1 of the earlier lectures that, in India and European countries we will test cubes, but if you look at the North American or may be Japanese or some other codes they use actually cylinders. So, cylinders even our code permits IS 516 permits you to use cylinders, but this is not very conventional cylinder of length to diameter ratio length to diameter ratio 2; that means, length height is twice the diameter of the diameter.

So, how h by d ratio affects the strength apparent strength that is what we are going to look into. In case of cube this equals to 1 in case of cube this is equals to 1. So, shape of the specimen has got a role to play. all this idea puts us to the question that this is only you know cube or cylinder strength measurement, these are only relative measurements relative measurement; as we shall see that h by d affects the strength of the concrete apparent strength of the concrete. So, this only can be relative measure of strength potential of the mix and nothing else as we shall finally, conclude.

So, let us see now restrictive effect of the plate is operative till a distance of 0.86d from the end of the cylinder in case of cylinder of diameter d; same thing will go if it is a prism, you know instead of a cylinder if we are talking of prism of square cross section

same thing, same similar you can have similar sought of conclusion. Thus h by d ratio is generally we adopt a fix ratio of 2 h by d ratio of two, but if you have different h by d ratio same effect will be observed. Similar effect will be observed and this is been again, attributed to same platen effect as you call it the effect of the plate that we call as platen effect; Strength results differ for specimen having h by d lower than 1.7. Remember this cannot happen due to buckling, because buckling occurs at much higher h by d ratio.

If you have done a course on design RC design then you would know that, for length to side you know minimum dimension ratio of 12 and above we consider it to be not a short column, but a long column. So, therefore, this is below only h by d greater than 5 you have. You have buckling effect so, there is no buckling effect in such dimension 1 is to 2 or similar 1 we are considering, but strength results still differ from h by d lower than 1 point 7. This ratio decreases with increase in concrete strength as nu by E decreases. If I have a strong concrete its nu will be lower E will be higher and although, nu may not be much lower by E will be definitely higher. So, if nu by E decreases nu by E decreases if nu by E decreases nu by E decreases therefore, you know strength apparent strength would be higher, as we shall we have seen and this effect also tends to nullify somewhat because platen and the concrete their properties are nearly becoming similar.

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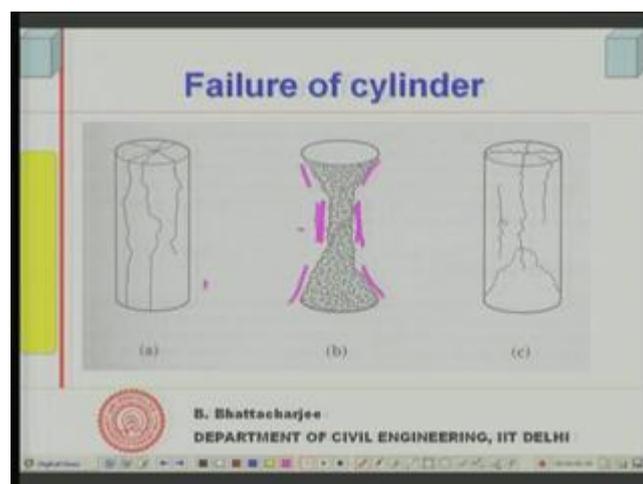
So, we shall see this effect; Let us look at the failure of cylinder we have looked through the failure of cube failure of cylinder is something like this. You see initial cracks could be something of this kind then if you have applied load now you can see there here again it is not vertical cracks or cracks started vertically at the centre. You have just vertical

portion. In fact, in this portion you do not have any effect on the restrainment due to the plates. So, platen effect is not there in this 1. In this zone there is platen effect and 1 would see that crack formation of this kind, crack formation of this kind 1 would see the crack formation of this kind.

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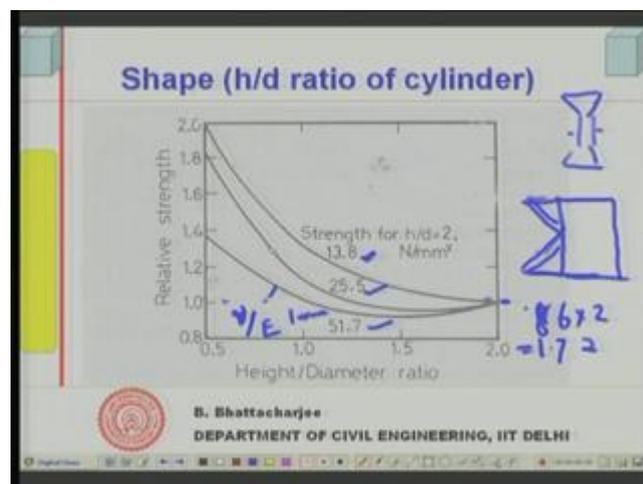
Now, this is the experimental results of height to diameter ratio. You see the strength strength if you see the strength 13.8 h by d ratio; this is for h by d ratio of 2 strength is 13.8 MPa this is 25.5 MPa and this is 51.7 MPa. Now, if I consider this as 1, 2; whatever I am getting at 2 as 1; You can see as I reduce down the h by d ratio the apparent strength actually increases, apparent strength increases the ratio increases why because the effect of restrainment. If you remember we said it is up to certain height 0.68d.

So, if I reduce down if this height is reduced you know initially if this is 2. So, restrainment would be there in some portion right up to this only 0.68d. So, some portion you know, 1 d because there will be some internal portion where there will be no effect of restrain and that is what we have seen in the previous. You know sketch that we had shown earlier because you had a you had a central portion where something like this and in the top portion something like this and the bottom portion starting like this.

So, in a standard l by d ratio h by d ratio 2 cylinder you have some portion where there will be no effect of platen effect no platen effect, but if I reduce down this height some cases would be there, where there will be super impression of the platen effect for example, if it is 8.86, 0.86 into 2 which would be 1.72. So, at 1.72 below 1.72 up to 1.72 onwards; there will be very little reduction in strength, but if you go lower and lower platen effect would restrict the transverse movement of the cylinder resulting resulting in increase in the strength.

So, when you go to point 5 there is a significant increase in strength and this effect tends to reduce, when strength of concrete increases the reason is because we said when the you know, if I have a stronger material it will have lower this will have nu by E this will have lower, I mean this will have lower nu by E because nu would have increased here increased. So, when you have lower nu by E it won't even otherwise it wouldn't move you know it would not have actually moved transversely or central movement itself wouldn't have moved much. So, the plate platen effect would be somewhat diminished there.

So, that is why you see it is much diminished whereas, in this case it is relatively high it is relatively high.

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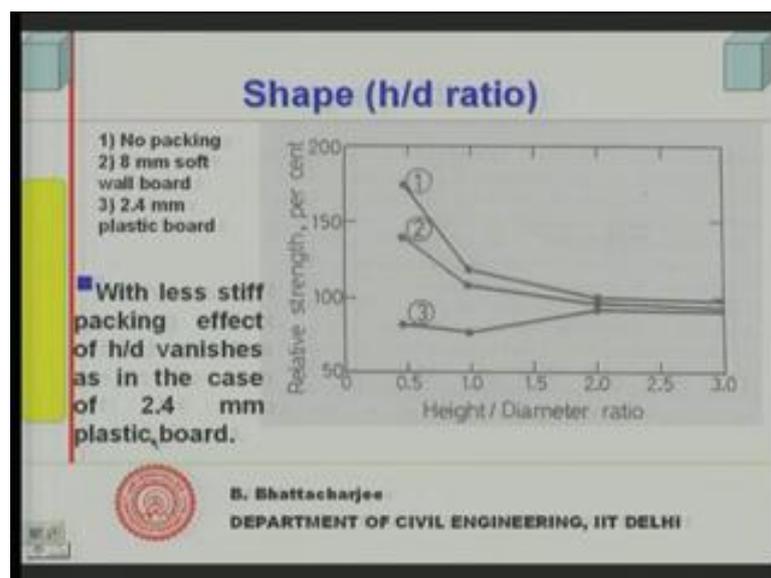
This was further confirmed by putting something like, by putting no packing put 8 millimeter soft wall. Board put 8 millimeter soft wall board like this 1. And when, you have 2 point 4 millimeter plastic board; that is, you know do not do not have practically platen effect was plastics which is very soft and it gave no effect of the no effect of the h by d ratio.

So, h by d ratio the loading of the strength again this is due to platen effect. So, we have seen that normal cube, you know cube shows a higher strength or failure pattern is like that because of the platen effect and capping effect. And capping effect is translated into platen effect the plates which restricts and if you put, plates you know something in between change the machine platens by some softer material you will find with soft material there is no effect of under strain.

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Shape (h/d ratio)

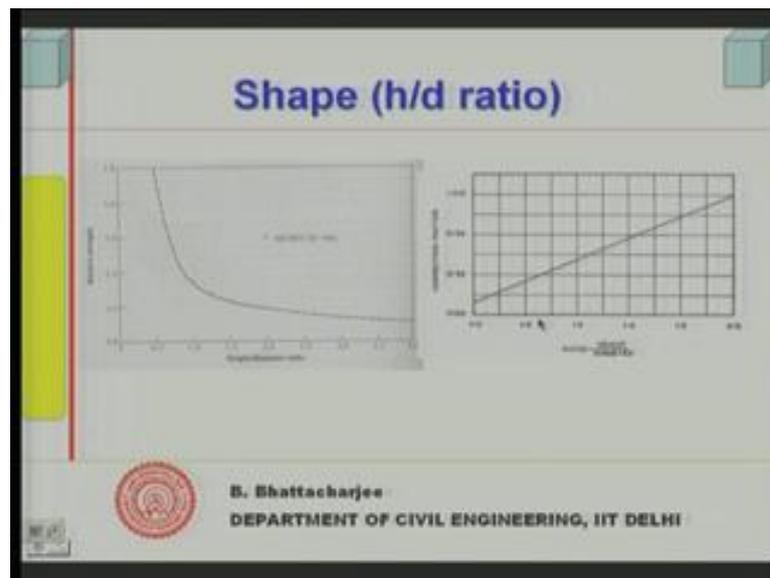| h/d ratio	Correction factor		
	ASTM	BS1881	IS 516
2.00	1.00	1.00	1.00
1.75	0.99	0.98	0.97
1.50	0.97	0.95	0.95
1.25	0.94	0.94	0.92
1.00	0.91	0.92	0.89

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So, with less stiff packing effect of h by d vanishes as in the case of 2 point 4 millimeter plastic board. This aspect has been considered in various code and therefore, say ASTM code or Indian code it takes in it allows you, to test cylinder for compression test even Indian IS 5 hundred and sixteen, but if you have a nothing less than 1 of course, is allowed you have to 1 to 1 is to 2. In special cases normally we test cubes sometime we can test cylinder, but then cylinder h by d ratio is usually 2. If you are testing anything else these are the conversion this is the factor actually for code test in situ testing, this is sometime we have to adopt this. And you know these values are useful in such situations.

So, you can see if I have 1 for this value when this is the h by d ratio for h by d ratio goes to 2 h by d ratio is equals to 1, the correction factor is 0.91. So, this would show higher strength. So, that strength should be reduced by 0.9. You know, since this shows higher strength when h by d ratio equals to 1 you have a strength which is higher, then what you would have found here, multiply by a fraction in order to bring down to this in other words what is being said here is it would be about 10 percent higher you know it would be nearly about, 10 percent higher this says nearly same values although, slight variation this 0.91, 0.92, 0.8.

So, codes normally allow testing cylinders with h by d ratio 1 to 2 and these are the correction factor this gives the least strength. As you go on increasing there is an increase and there is an further increase. So, it is something like that. So, that is the effect of h by d ratio on strength.

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The same when a curve form has given in IS 516 it is like t his you know here the ratio of h by d and correction factors which I mentioned for 2 h by d ratio is equals to 2 this equals to 1, for h by d ratio is equals to you know other values 1.0 this 0.91 etcetera, 8, 9 etcetera. Similarly ASTM C 42, 84; a gives you this sought of this is height by diameter ratio and this is relative strength. So, this is what it is.

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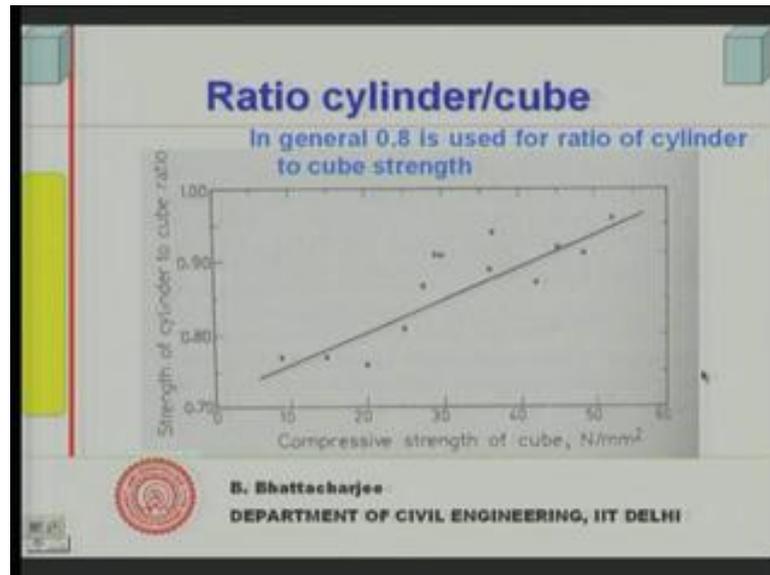
Now, cylinder to cube there are 2 issues involved. 1 of course, the volume it could be even different, but there is a difference there of course, not of the same shape there is a difference in shape. So, cylinder to cube there is a variation in strength, because some countries do we use we use cube and some other countries use cylinder. So, the conversion is generally required at times and this has been observed that, compressive strength of cube of cube if you plot on to the x axis. If you plot on to the x axis and this is the compressive strength of cube in MPa and corresponding cylinder strength.

Now, if you see this is the ratio this is the you know depending upon the compressive strength itself the ratio of cylinder to cube strength ratio would change. So, as the compressive strength increases this ratio also changes, but it fits into a good straight line if fits into a good straight line. Generally, what is done is we do not go into this kind of complexity although this ratio, is a function of the compressive strength, cube compressive strength of concrete itself, but what we do is we generally do not go into this complexity instead we use instead we use simply, 0.8 as a ratio of cylinder to cube strength.

So, what we assume is cylinder is about 80 percent you know or cube strength is 25 percent more than that the cylinder strength. Now, this we are talking of the cylinder of l by d ratio equals to 2 h by d ratio equals to 2. So, cylinder of h by d ratio equals to 2 we take 0.8 as a multilplying factor for cube strength to get the cylinder strength. And if you

want to do, other round increase the strength by 25 percent multiply by 1.2 to get the cylinder strength.

So, the it is 1 of the issue is of course, h by d, but the the shapes and also the volume of the concretes are different. So, both this put together makes it that it is about 0.8. So, that is what we have seen the age aspect ratio, how aspect ratio affect the strength of concrete. You know h by d ratio or end capping. Now, this end capping business of course is not very important in case of cube, but 1 thing has come to our understanding is that, we should put that plane surface on to below the platen.

So, we also know why the shape of the specimen the fractured shape of the specimen is as it is you know why it is like that, what we have like it is not a vertical crack, but the crack is inclined up to certain point and then, you get you get you know you get again inclination in case of cube cylinders you will have some vertical cracks at the center

So, nature of the cracks is also nature of the fracture planes are also explained by this phenomena, but capping situations are more important when 1 looks into the core strength, in situ core strength supposing you want to find out the strength of the concrete in structure then 1 has to do what is called code core testing. You take out a cylindrical core because we can easily drill, cylindrical core it is difficult to drill anything else.

So, cylindrical cores are drilled and then they are tested and there you might be using a capping and effect of end capping is important. There anyway we will discuss this possibly some time later on. So, at the moment let us see; what, are the other factors the next factor that, we are going to look into size or dimension of the specimen.

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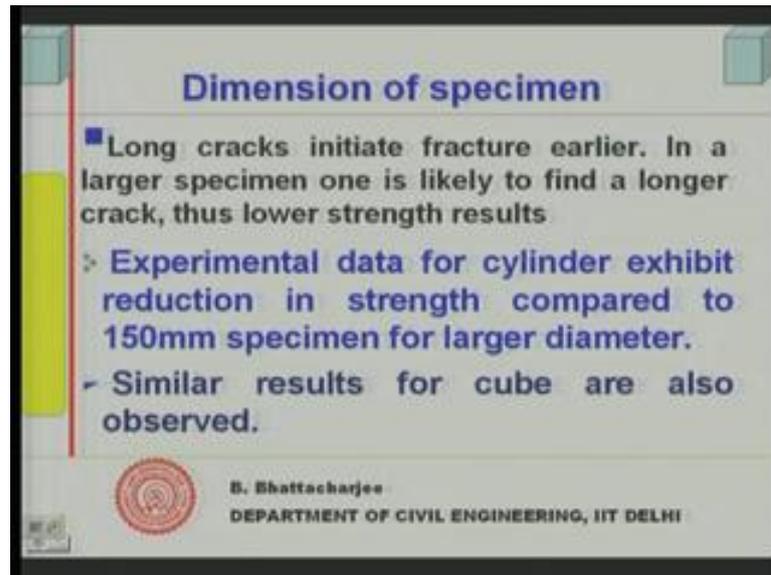
Well 1 of the explanation given you knows, there is a variation with the size of the specimen as we shall see. The experimental results have shown there is variation and 1 of the reasons that is given that, attributed to the size is that long cracks initiate fracture earlier and in a larger specimen 1 is likely to find a longer crack thus lower strength results.

So, if you the specimen size is larger and larger it has not been really related to the aggregate aggregate size, but it has been related to the size of the cube itself. It has been observed that, the higher cubes larger size cube shows smallest strength lower strength. And it has been attributed to possibility of finding a larger crack, in the larger crack in the bigger size specimen.

There is something called size effect in fracture mechanics, but this may not be necessarily you know although its similar because in small size specimens it is not very easy to find the size effect, but some results have shown that, larger specimen may likely to show somewhat smaller you know lesser strength than smaller specimen. Experimental data of cylinder exhibit reduction in strength compared to 100 millimeter specimen for larger diameter.

So, when you have diameter changes takes place experimental data shown there is a reduction, in strength and you have similar results for cube strengths also. Let us see, how this strengths looks like.

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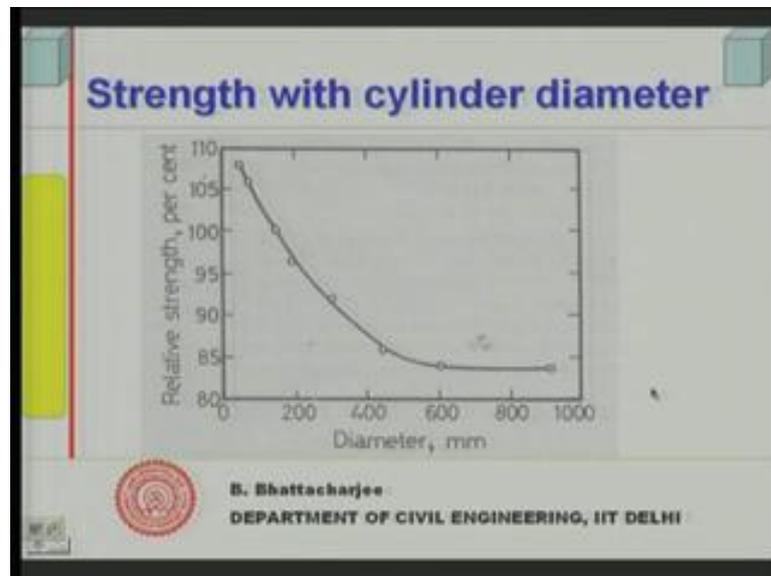
You see strength of the cylinder with the diameter is something like, this as you can see as you go on increasing the size beyond 600 millimeter of coarse diameter there is hardly any reduction in the strength, but before that there is a reduction in the strength l by d ratio has been maintained 2 throughout.

So, you have got diameter six hundred and corresponding length and you find that there is a reduction in the strength, but how much is the reduction if this is about 200. You know if I call this is for 150 millimeter actually is 1, the increase by lowering the diameter could be about 10 percent, even less than 10 percent and increase and lowering of the results to increasing it to 600 the strength results could be as much as 15 percent lower.

So, these are the significant lowering, but there is some lowering and of course, you can think in terms of think it about that, anything about 600 millimeter you know 1 millimeter diameter concrete cylinder is usually, you know impractical, but 200 even 250 is possibly possible, but that is also not very not very practical unless you have large aggregate size because, usually the cube size should be at least three times larger than the maximum size of the aggregate or cylinder size should be at least; you know minimum size dimension of the cylinder should be at least, 3 times more than the aggregate to make it representative otherwise, it is not representative of the representative of the mix

you have because supposing you take a you have 50 or 75 millimeter, 75 millimeter aggregate and you are taking a 50 millimeter core then, you will be leaving the large I mean; it might be simply the aggregate alone you might get all aggregate strength and if you are making cube, you will have to leave the large size large size aggregate and you will be ignoring their effect.

So, it is suggested that this minimum size of the specimen should be 3 times the size of the maximum size of the aggregate and you can see the effect variation is about, 10 to you know plus 10 percent to about minus 15 percent or may be 20 not even 20 somewhat below that.

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Let us see similar results, in cube cubes it has been observed that when you have cubes of the size cubes of the size seventy millimeters you get 10 percent increase in strength and 100 to150 it was seen that, there is no effect. So, you use 100 millimeter size or 100 and 50 millimeter size cube it is same use 205 percent reduction, 300 about, 10 percent reduction.

So, plus minus 10 percent variation due to size can be expected while testing concrete. Normally that, is why we have standardized this size, but it is many codes in the European codes many European codes actually, allow for testing different size of the cube different size of the cube, but you can compare a given size with the given size only; that means, 1 mix you make of 75 millimeter side length cube and another mix of

150 millimeter side length cube that is not comparable. So, you can compare after all they are meant for comparing the potential strength potential of a mix and thereby you can see that you know same size should be compared. So, size has got some effect this 1 must remember.

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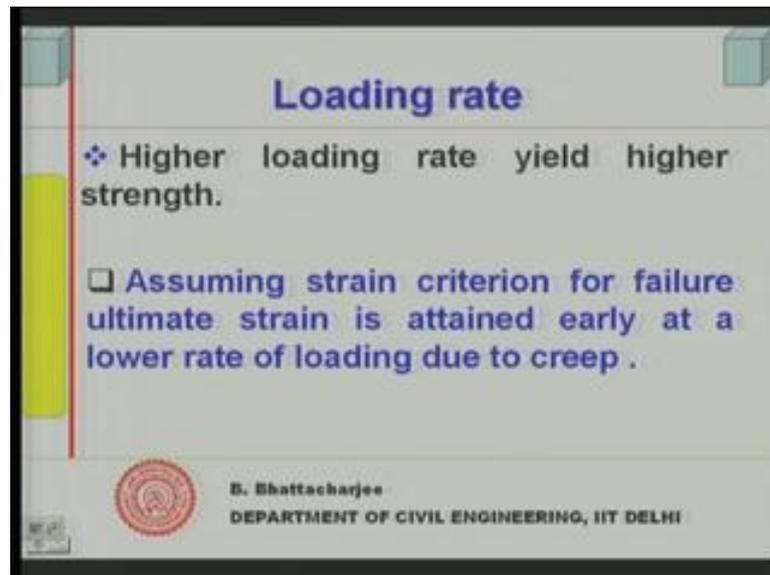
So, loading rate is other factor it seems it has been observed as we shall see through some curves that, higher loading rate yields higher strength. Higher loading rate yields higher strength and this is related to criteria of failure now, I just would like to highlight what we mean by this. There is something called creep of concrete. Now, creep is phenomena whereby you apply a load and keep the load constant, you find with time the deformation increases.

In other words, I can show you something like this I can show you something like this that supposing you have loaded a beam specimen.

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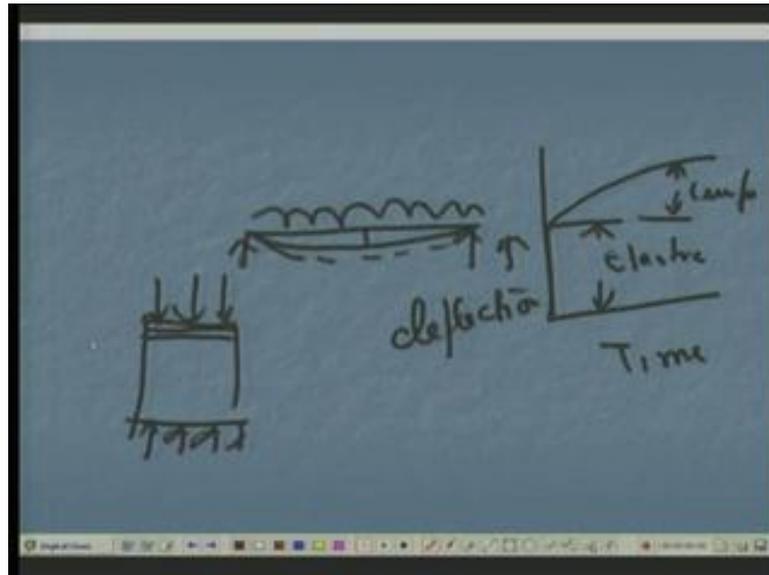
Supposing I have loaded a beam specimen, let us say with uniform load only and its deflection is initially something like this, with time we have not changed the load, but its deflection might go on increasing with time; that means, if I plot x axis time and this side the maximum deformation let us say deflection, maximum deflection I will find that, possibly instantaneously it will show some deformation and with time there will be some increase. So, this is nothing, but this is elastic deformation elastic and this is creep this is creep. We may not have time to look into details of creep, but this is the creep deformation.

So, this happens in case of concrete creep; that means, time even though you have not increased the load its deflection increases in case of, a beam strain increases in case of a you know, loaded cube specimen loaded cube specimen you will find you just keep the load. So, initially it might have just deformed this much, but this deformation will go on increasing with time. So, deformation increases with time and this phenomenon is known as creep.

So, actually I can quickly since you are not looking into details of this quickly I can give you an analogy, we can give an analogy. A creep is something similar to consolidation of clay takes very long time to consolidate same thing something similar, much lesser effect of course, in case of creep the gel water etcetera they are redistributed and thereby, results in deformation or deflection time dependent deflection which, although you have not increased the load.

So, when you have increased the rate of loading actually very quickly you have applied the load at a very fast rate. Therefore, the effect of creeping would not be there, but if you apply the load at a slower rate very slow rate then, what will happen the load is sustained for certain period of time and therefore, there will be creep effect.

So, this has this will result in addition of strain in the material and this has been attributed to lower strength at slower rate of loading. So, when you have higher rate of loading, you find the strength is apparent strength is higher whereas, smaller rate of loading apparent strength is lower and this because, as I mentioned the strength strain criteria for failure, which tensile strength criteria for failure which can be thought to be about 100 to 200 micro strain. This being constant under slow rate of loading slow rate of loading actually, the the strain will be reached at lower load and therefore, it will fail early ultimate strain will be reached at lower load and this will fail early. So, this is what has been observed and let us see, how the variation that has been observed.

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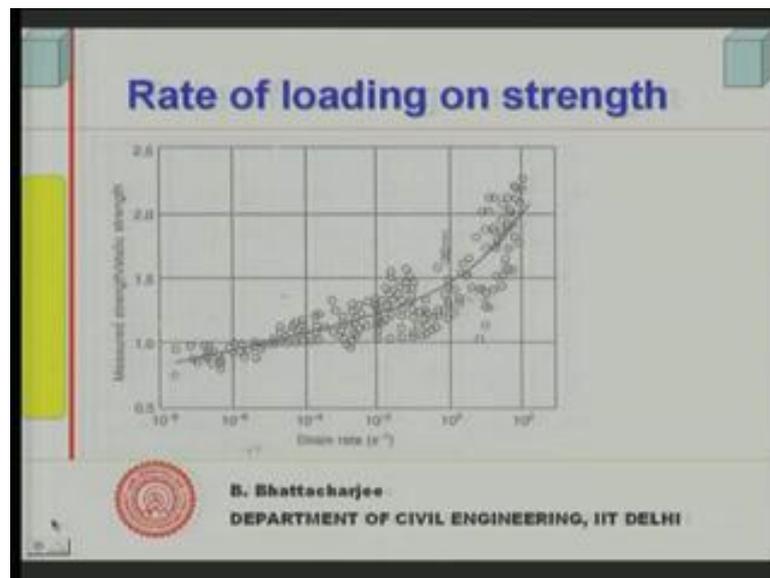
So, large number of specimen when tested you know you can you can test, you can test with strain control machine servo control machine, control the strain rate most of our machine of course, are you can control the rate of loading not necessarily all cube testing machines can have rate control. Sometimes it is controlled manually, but they can give you result because the rate of loading is an important aspect of strength measurement of concrete.

So, 1 has to maintain the specified rate of loading which has been standardized by the code. I will come to that, but some machines can control the strain rate and when, this was measured with this strain rate control machine. Now, strain rate per second you see this is 10 to the power minus 8 and minus 6 etcetera. So, as you go on increasing the strain rate of application of strain per second per second the strength goes on increasing.

So, measured strength to the static strength; so, the static strengths are measured at this kind of strength as you can see that, this something like about 10 to the power minus 5 strain per second. So, 10 micro strains per second at that kind of rate of loading normally we apply.

So, when you increase the rate of loading or reduce the rate of loading you see if you increase the rate of loading at 10 to the power 2 micros I mean 10 to the power 2 strain per second you can have a strength as much as twice of that 1 twice of that what you find it normal condition normal condition. This is strain rate of loading;

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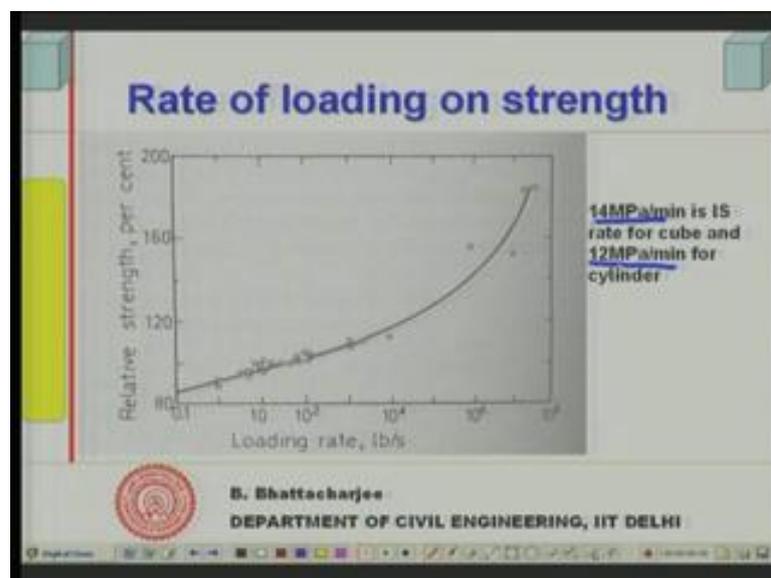
if you look at stress rate of loading similar sought of situation we will see and this is what, is the stress load of loading and it shows that it again increases exponentially this is of course, in pounds per second rate of loading pounds per second.

So, relative strength increases actually exponentially, but this aspect is important in testing and this parameter must be taken care of in testing of concrete. You know, in

laboratory quality control testing of concrete. In fact, all this aspect we have mentioned they are important while, laboratory testing of concrete it is been actually it is suggested in IS 500 and 16, 140 kg per centimeter square, per minute which is fourteen MPa per minute for cube. This rate has been suggested for cubes this rate has been suggested for cubes. This is the rate suggested for cube and for cylinder this is the rate suggested 12 MPa per minute.

So, you must the machine must apply the load at this rate machine must apply and it must be a machine capable of controlling the rate of loading. If it is not capable of controlling the loading and it is been done manually, well this may results in some sought of error in the measurement, but even very old machines are you know are capable of controlling this rate, cube compression testing machine are capable of controlling rate, only thing there should not be manual even mechanical devices they are capable of controlling the rate.

So, 14 MPa per minute is a Indian standard or even it is there elsewhere also and when, it is cylinder it is somewhat slightly smaller 12 MPa per minute. So, this must be remembered while testing concrete for cube strength testing concrete for cube strength.

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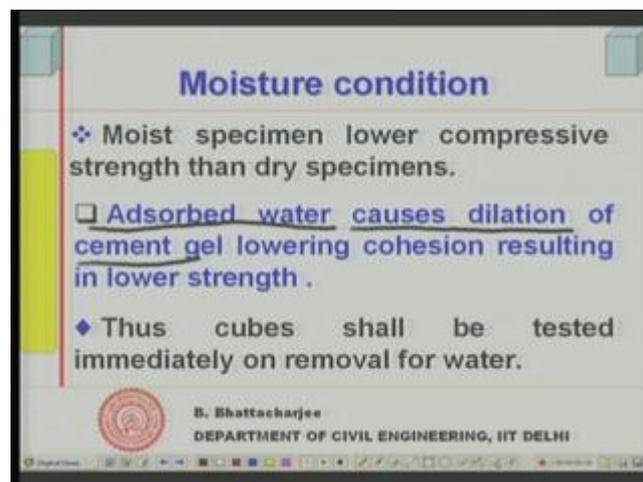
The next factor which is important for test conditions are moisture condition. It has been observed that, moist specimen lower shows lower compressive strength than dry specimen, It is interesting. In case of compressive strength, the lower moist you know moist specimen shows lower strength whereas, it has been observed if you are testing the specimen under tension which we shall discuss later on.

In case of tensile strength testing it is the other way round dry specimen's shows actually lower strength compared to moist specimen, but in case of compression test moist specimen shows lower compressive strength than dry specimen we will explain the reason, but before that 1 must understand that why therefore, code actually specifies the moisture condition that you cannot you got to test take it out not too much earlier, before you know testing you must take it out there is a time specified and preferably it should be tested, immediately on removal from mortar you can make surface dry ASTM actually specifies this.

Now, what happens why does it. So, why is it? So, the lowering of strength due to drying in case of tensile strength is been attributed to drying shrinkages. If you dry the specimen then new shrinkage cracks will come. So, when you are trying to test it under tension it gets lower, but that is as far as tension is concerned in compression the behavior is other way round.

So, what is the explanation; what is the explanation was given is something like this you know the explanation suggested is something like this. You have more adsorbed water now and this causes dilation of the cement gel; that means, cement gel gets separated you know, they are spreaded. Now, they are spreaded now because they absorb water goes between them and therefore, they can push them upward. If you withdraw the water they come closer and shrinkage drying shrinkage is because of that. In fact, when collapse of the gel layers takes place that could be shrinkage.

Now, when you have water and lot of adsorbed water is there this essentially means that, gel water will push the layers away and there is a kind of dilation. Now, this dilation results in lower cohesion between the gel; gel you know gel particles or gel layer and since there is lower cohesion lower cohesive force. So, there will be lowering of the strength, but the fact remains that the cubes shall be test you know, the moist cubes shows lower strength. So, this also needs to be standardized and therefore, the codes tell you that it should be tested on removal from removal on removal from. You know, on removal from water; the immediately after removal from water you should test this you should test this as quickly as possible.
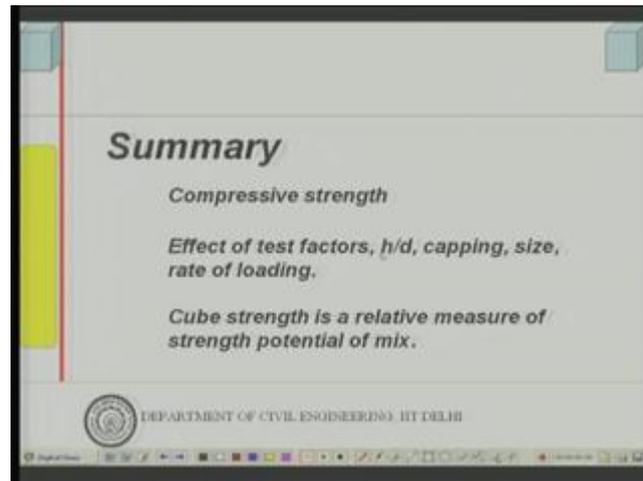
So, I think these are the test factors. Now, few issues become important the compressive strength, we have discussed what are the factors how do you measure the compressive strength. Now, we have seen that we can measure it on specimen and again let me reiterate, which I have stated earlier also that this measured strength is quite different from the strength. In the structure it depends upon; obviously, the mix parameters mix parameters, casting and curing of the specimens, but depends strongly on the test parameters as well therefore, this test is can be an indicator of the strength in the structure and correlated and, but can be very usefully you know, very effectively used for quality control purposes to find out that strength potential of the mix.

So, that is the first issue. So, we have seen that we can measure through cylinder as well as cube although, the Indian standard uses 15 centimeter cube and then, we have also seen that various test factors namely end capping h by d ratio size and rate of loading moisture condition all this affect. Let just repeating the same thing capping h by d ratio you know, this 2 factors are mainly because of what is called platen effect or because of the you know, effect of lateral. You know, the effect lateral movement because of restrainment of the or restriction to lateral movement this is because of the restriction to lateral movement.

So, capping which will restrict the lateral movement would actually show you a higher apparent. I mean, higher apparent strength compared to capping which does not restrict the lateral movement. The machine plate does this effect and this effect is limited to about 0.6 into the dimension of the specimen there by in case of cube it is overlapping, in

case of cylinder which has got h by d ratio more than 1.7. This is, some portion is there at the centre where there is no effect and therefore, cylinder fails at lower load and we understand that, it is about 80 percent apparent strength that, you get in case of cylinder its 80 percent of that, of the cube on an average although it is a function of the strength.

Similarly, the effect of h by d ratio is also function of the strength, but for our general understanding, we just you we of course, you know take a value or anything of that kind, but we understand the higher nu by E and lower nu by E of the capping material will have some effect on the strength of the concrete rate of loading is the other issue and this is important issue because rate of loading, while doing quality control in the quality control laboratory, 1 must control the rate of loading you have seen that, if you increase the rate of loading the strength can be even double, but that is very high rate of loading.

You know and small rate of loading of course, I mean you know a small rate of a slow, rate of loading failure can be at the lower load and this is been attributed to the phenomena of creep in case of concrete.

The last aspect that we looked into was the moisture condition and we have said that it is dilation of the gel system because of adsorbed water which, reduces down the cohesion it actually brings down the strength of the concrete. So, moist specimen shows lower strength compared to dry specimen in case of cube compressive strength. All this points out to 1 thing that, cube test or cylinder strength results that we get, are simply a relative measure of the strength potential of the mix.

So, It can be correlated to the strength of the structure, but you have a good high cube strength is you know high cube strength may have a good strength of the structure or may not be that is a separate issue that will depend upon the compaction. And curing etcetera, condition at the site itself, but cube when done in a standard manner; when done in a standard manner we have standardized. We have seen that, all other things are standardized moisture condition has been standardized rate of loading has been standardized to 140 kg per centimeter square per minute or 14 MPa per minute.

The capping condition or platen condition in case of cube has been standardized with plane surfaces remaining in contact to the cube, rate of loading has been standardized all other things have been standardized. The cube strength gives you a relative measure of the strength of the concrete. Let us this is important because that, is why this is being

repeated that it is only a relative strength potential of the, relative measure of the strength potential of the mix.

So, nevertheless this is the 1; this is how we do quality control this is how we do quality control and this measure that we take this value is used also in design because we can correlate this to the correlate. This actual strength in the structure and in design we take a value of 0.15. We assume that, cube strength is about 60 percent of that of the strength in the structure actual strength will vary. So, these are the compressive issues related to compressive strength; we can next time, we can look into the other aspects of concrete strength namely tensile strength etcetera and modulus of elasticity. So, with this we can conclude this lecture.