Concrete Technology
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Lecture - 18
Mix Design of Concrete: Packing Density, Rheology

If you recall from last you know last 4 lectures on mix design of concrete, we generally talked about the principles of mix design. Then, we looked in to several simplified methods. In the last lecture of this module, we shall be talking about some recent concepts such as packing density rheology and applying them to mix design principles.

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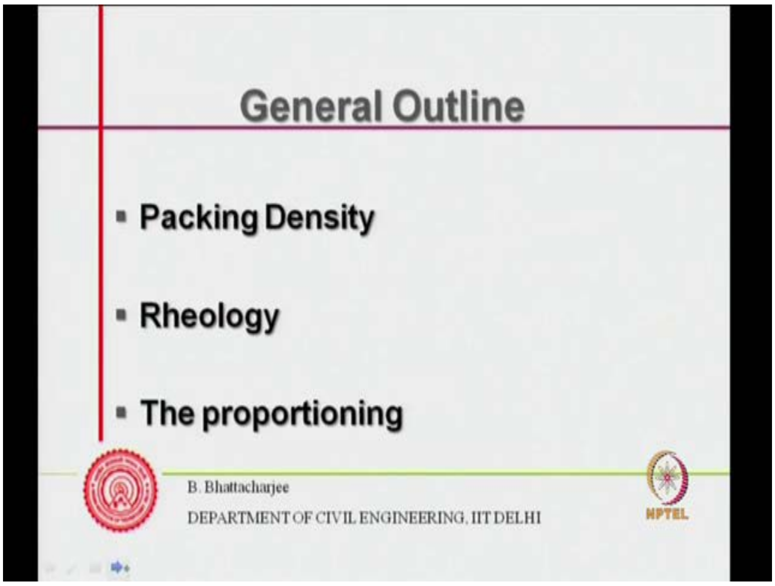

So, general outline of our discussion should be packing density, then rheology followed by the proportioning involved in them. Now, you know you remember that we discussed earlier. Also, concrete is a particulate system bonded together, it particles bonded together and in fresh state wet paste and aggregate systems form the concrete. That is in the fresh state, largest coarse aggregate particles are packed together with interstitial voids.

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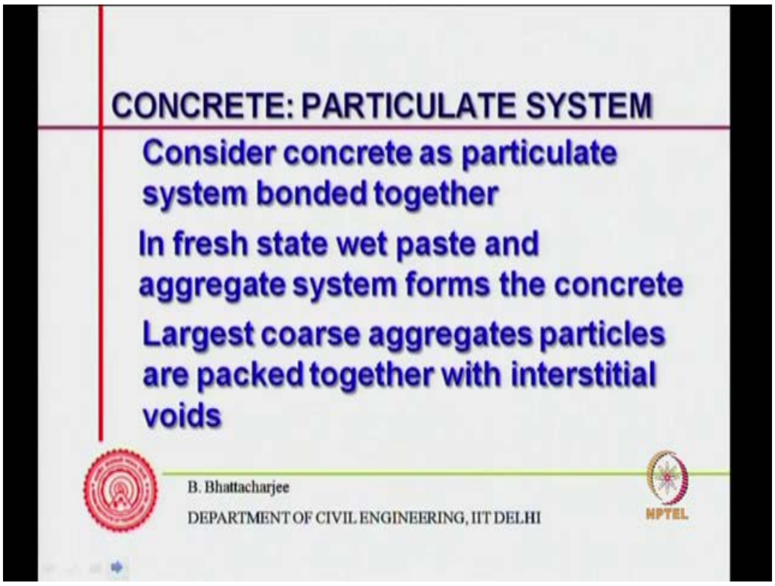

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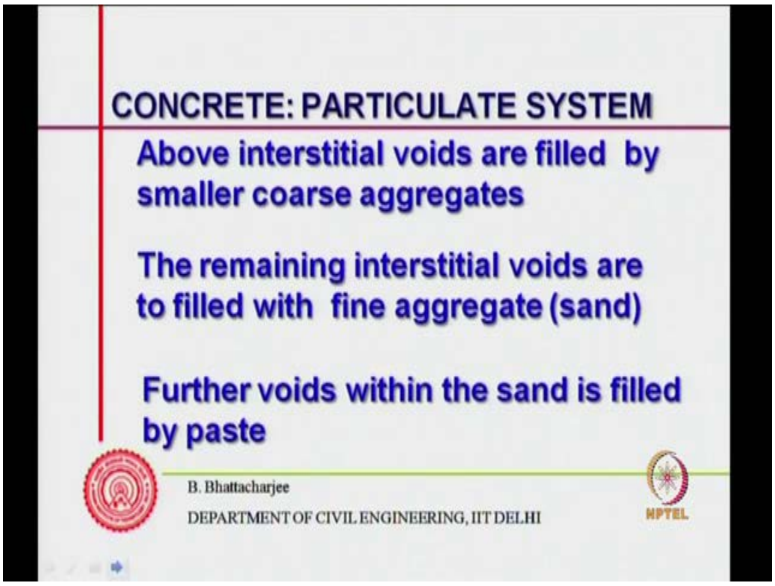

These in state interstitial voids are actually filled with smaller coarse aggregates and the remaining interstitial voids. Now, between the largest sizes particles of coarse aggregates are filled with fine aggregate; quite often, they would be natural sand or car stone etcetera as we have discussed earlier. Now, that is further voids, which are there within the sand. Then, it is filled by cement or cementations paste or powder and water paste. So, that is what the concrete is and you look at it for example the same.

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So, this is your aggregate system, a few of them. Let us say and let us just arrange them in a slightly different manner. Arrange them in a slightly different manner. We get it. This is the coarse aggregate. They get arranged in this manner.

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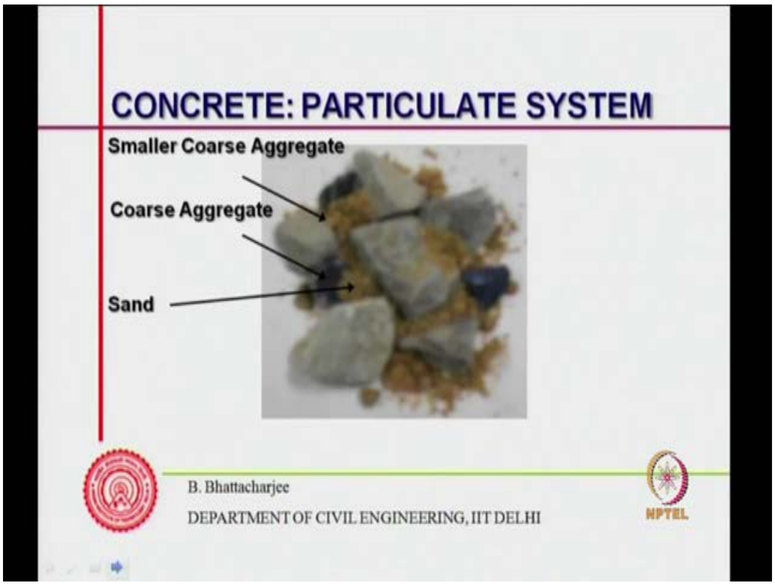

Then, the black ones as you can see they are the finer aggregate. Now, the interstitial voids are filled with you know. So, this is the this is the finer of the aggregate system black ones. Now, still there is a gap within. You filled in it some sort of fine aggregate, which in this particular cases sand.

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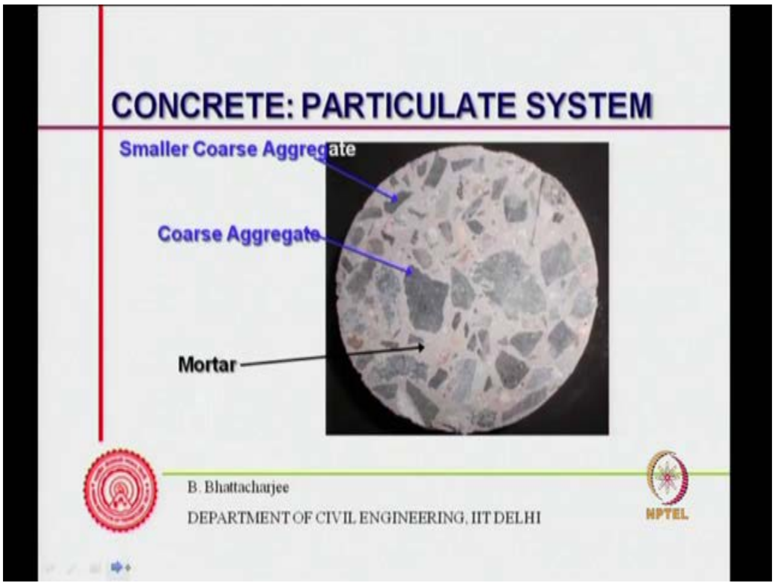

All this put together mix the concrete at the hardened state, which will look like this, which will look like this. So, you see, in this one you can see larger size coarse coarse aggregate and the finer, relatively finer, relatively less coarse, smaller coarse aggregates, they go into the interstitials and rest all is filled with moderate system.

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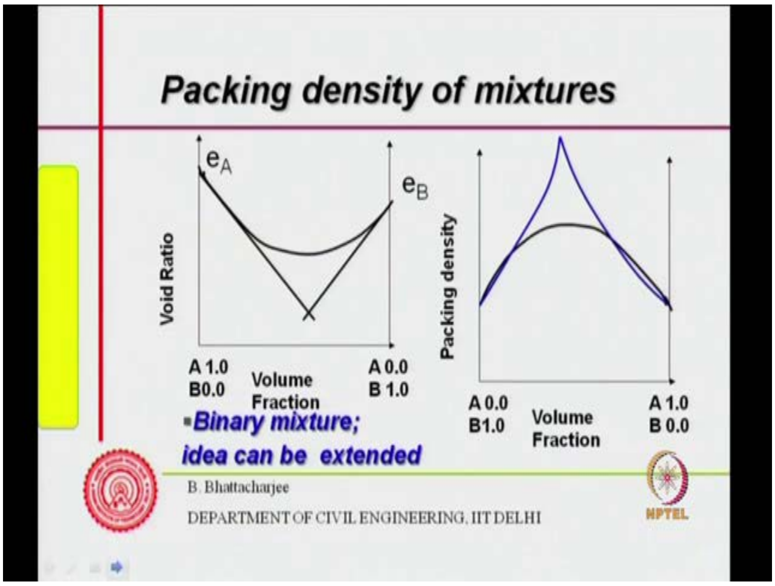

So, you see the packing of the particulate system that is very, very important. If the packing is good, you will require less paste. We talked about this earlier also. We talked about the concepts of packing density if you recollect from module earlier one of the earlier modules.

We talked about binary mixtures. We said that if we have 2 aggregates A and B, we mix in some volume. You know some proportions of their volume say A is 1 to 0 and correspondingly, B varies from 0 to 1. You remember the void ratios we said that e A is the void ratio of A and e B is the void ratio of the B.

When you mix them together, theoretically speaking the void ratio should reduce down as the proportion volume fraction changes. There is a minimum point and real situation is the void ratio where you see in this manner. But, minimum is less same corresponding to the straight lines that has been shown. This is what we have discussed earlier also.

Correspondingly, packing density we define as the volume of the solid alone divided by the overall volume. This would increase correspondingly depending upon the fractions of a particular aggregate from pure A to B. As we vary pure A to pure B, so first you have pure A and the left hand side, then you add some amount of B. Therefore, combination of A and B volume fraction will change.

When A is 100 percent, B is 0. When B is 100 percent, A is 0. This is what we have discussed. This we have discussed earlier and packing density becomes maximum. Somewhere in between where void ratio is minimum, the theoretical curve is shown in blue. The real one will be you know with the one shown by black. This is because of what is called particle interference loosening effect and wall effect etcetera etcetera that we discussed.

So, this is the situation of binary mixtures. This can be extended to multi party mixture. The volume fraction at which the packing density is maximum or the void is void ratio is minimum. One can determine from this kind of consideration and some theatrical models are actually available.

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This models of course, you know is not very easy to use because the material properties or aggregate properties that has to be all available. For example, F.de Larrard who has actually postulated a number of such models empirical equations, but a simpler procedure we can actually follow in normal coarse, in coarse of mix proportioning of normal mixtures.

So, let us see what are those simpler experimental procedure thing is that you pack the aggregate mixture with each aggregate in definite proportions. You can use mass proportions here because it is very difficult to control the volume. So, use different proportions mass proportions and then pack them in a container whose volume is known.

Now, this container volume may be v and u 1 would have to measure this by water replacement method. That means if you fill in this one with water; find out the mass of the water by 2 difference of difference of 2 weights empty container empty empty container and the container full with water.

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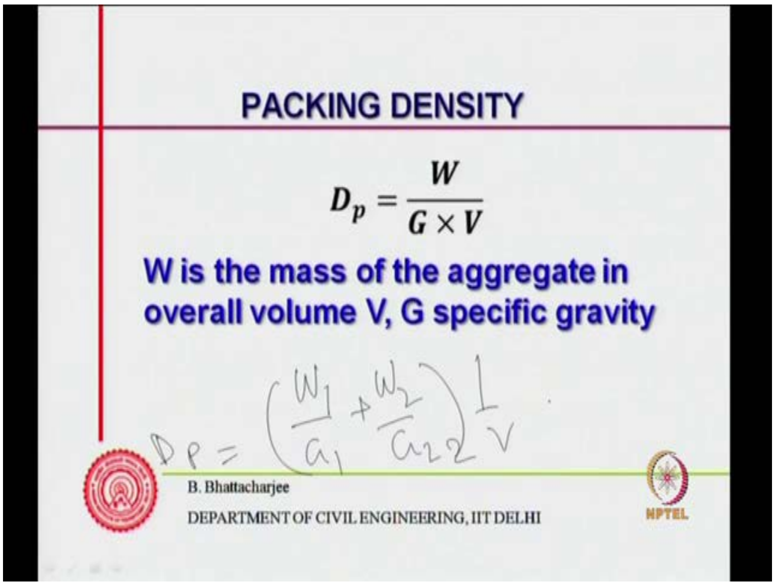

This volume is V. The difference of them will give the mass of water and from which you can really find out the volume V. Now, you packed the aggregates in right kind of proportions that you have decided to put in together. If the total mass is W or for a given mass, it is W G is the specific gravity, if it is both coarse aggregate, their specific gravity should be known same, which could be same. So, the packing density will be simply given by W by G, which gives the volume of the solid. W is the mass of the solid. G is the specific gravity.

So, W by G is the volume of the solid divided by V, which is the volume of the container. It will give you the packing density. When you are mixing 2 of them together, volume of each individual 1, you can find out sum total of each individual component divided by the overall volume V will give you. So, it can be written as simply it can be written as you know W 1 by G 1 plus W 2 divided by G 2. W 2 divided by G 2 1 by V, so that is will be your d P.

So, this is how you can find out it W 1 by G 1. For example, for example, I can I will just rub this off and tell you this should be actually G. This should be G 2 and 1 by V. That will give you the packing density. When you are mixing them up in some definite mass proportions, so in this manner actually, you can find out. Actually, you can find out packing density.

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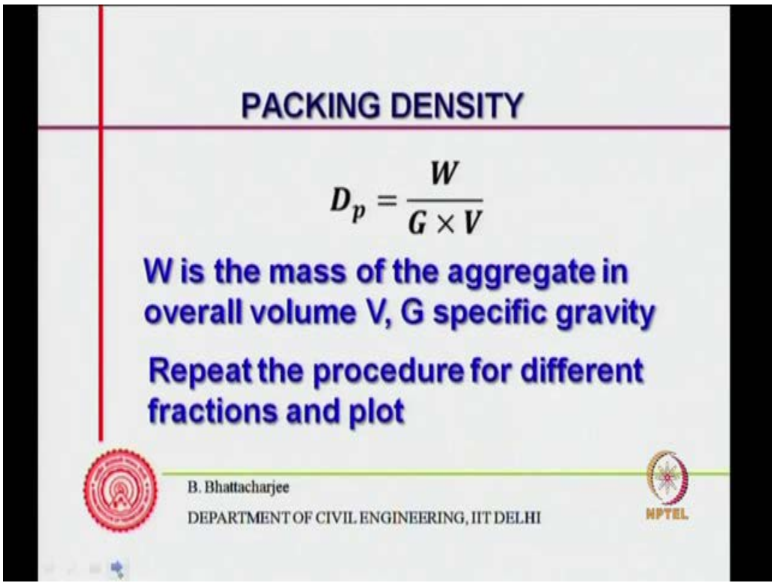

You can find out packing density corresponding to any proportion. Repeat this procedure for different fractions and plot. Such a plot would look like this. Such a plot would typically look like this.

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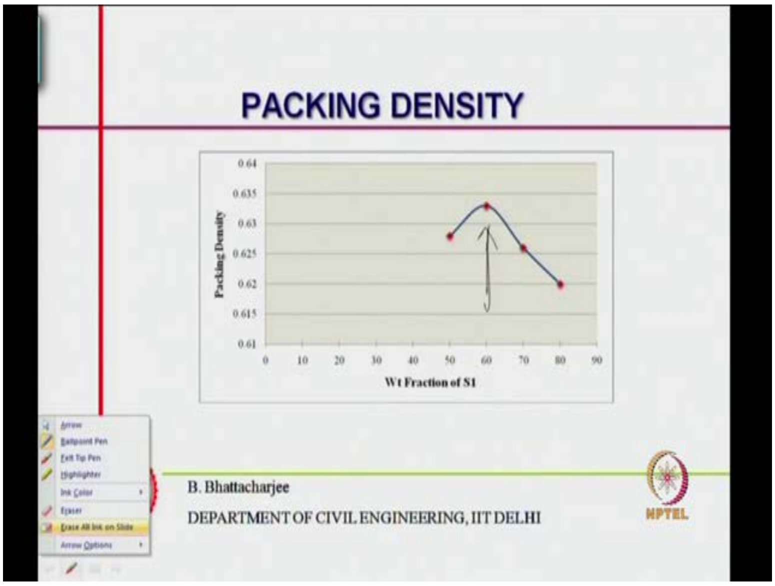

For example, here we have got weight fraction S 1 of S 1 particular, let us say fine aggregate sand. It was S 2 is the other one. So, as the weight fraction of S 1 increases the packing density, we measured and calculated. As I just mentioned, you find it is maximum at some point, maximum at this point; it is maximum at this point.

So, a 60 percent of S 1 and 40 percent of S 2 may give you the highest packing density. So, it is a simple experiment. You can do this experiment with your do this you can do this experiment with your aggregates. Determine the packing density of any 2 aggregates assuming that they belong to a small range of size. So, that is how it is.

So, this was the case of example of packing density measurement or measure packing density. So, what you do is since you are found out 60 and 40 is the best combination, you can choose 60 and 40 and make this as your fine aggregate in the in the case of the fine aggregate. For example, I talked about, typically what you will have you will, normally I will say that you are dealing with 20 mm down course aggregate.

So, you will have 20 mm down up to 4.75. Then, there will be another set of aggregate, 10 mm down up to 4.75. This is the 2 coarse aggregates. Now, find out the best proportions for the maximum packing density of these 2 coarse aggregates. Let this mixture be M12 for 2 coarse aggregate 1 is m s a 20. Another is m s a 10 mm. Now, these proportions, then you mix them up in this 2, this proportions that is whatever proportion. You find out is best, which gives you the best packing density.

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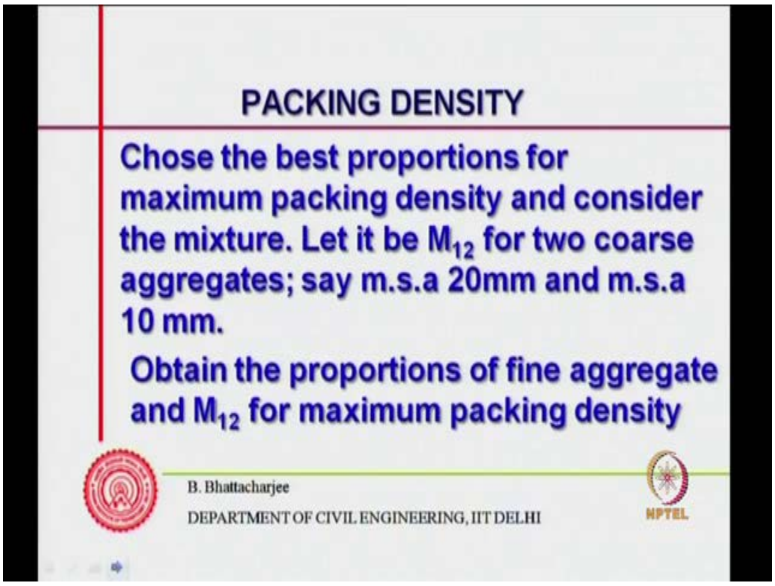

Then, use this mixture as one of the aggregate and fine aggregate as another. If you have more than 2 fine aggregates, mix them up, find out the best proportion for the highest packing on maximum packing density. Choose that proportion of the fine aggregate. Choose that fine aggregate. Similarly, choose the best coarse aggregate. Normally, fine aggregate will be only 1 coarse aggregate. There may be 2. I am talking of normal strength concrete, high strength concrete or other kind of advanced concrete. It might have some one difference sort of thing.

So, a normal strength concrete, 20 mm and 10 mm, you will have 2 different generally. Typically, in Indian scenario, you will have 20 mm and 10 mm, 2 aggregates, you mix them up. Find out the proportions of 20 mm and 10 mm for best packing density. Then, this use this mixture together with fine aggregate and find out the maximum packing density that will be the proportions of 20 mm down 10 mm down and the fine aggregate, which gives you the maximum packing density.

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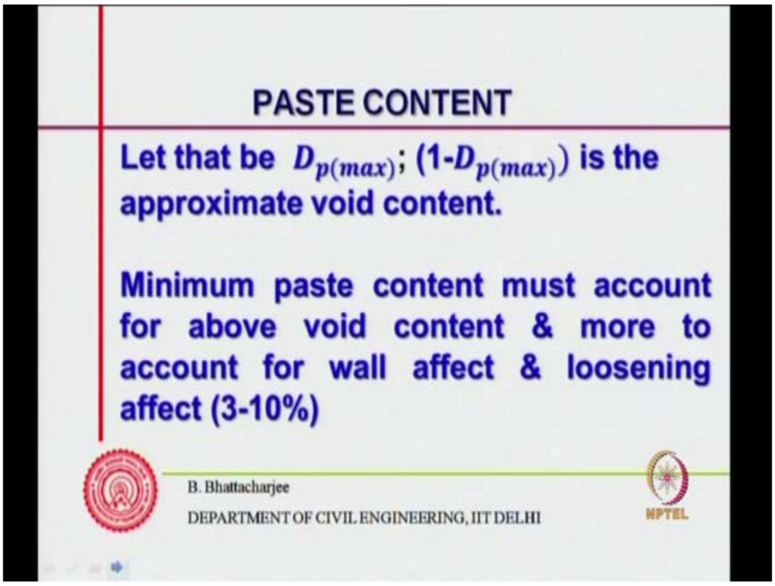

If there are more aggregates, you can repeat this procedure for each 2. So, consider them binary each 2 and 2 of them. Then, another 2 of them and combine them together. If there are more of them, you can actually go on repeating this procedure. It will become generally cumbersome. If there are too many of them, typically you will have 2 coarse aggregates, 1 fine aggregate and using this process, you can actually find out what is a best combination of the coarse aggregate. Both the fractions are mixed together and fine aggregate. Both the fractions are mixed together.

So, once you have found out, now you can look into the paste content. So, let us say D p max is the highest maximum packing density. So, 1 minus D p max is appropriate. You know it is the approximate void content in the mix. If I mix them well actually, void content will be higher. This is because you know that is because of wall effect and loosening effect and all that as we said when the paste goes inside; it will push the coarse aggregate. It will it will cause some sort of interference in the packing of the coarse or aggregate. Therefore, it will cause loosening. Besides that, the paste particles of paste that is cement etcetera will not pack very well close to the boundary of the coarse aggregate.

So, you have wall effect and loosening effect. This actually pushes out, which you have discussed earlier. Now, such effect would cause actually you know dispersion of that coarse aggregate more 3 to 10 percent. This also I mentioned earlier in one of our earlier lectures. So, it means that minimum paste content must account for the ever void content that is 1 minus D p max and more to account for wall effect and loosening effect. So, 3 to 10 percent more that is dispersion is 3 to 10 percent. So, what you can do?

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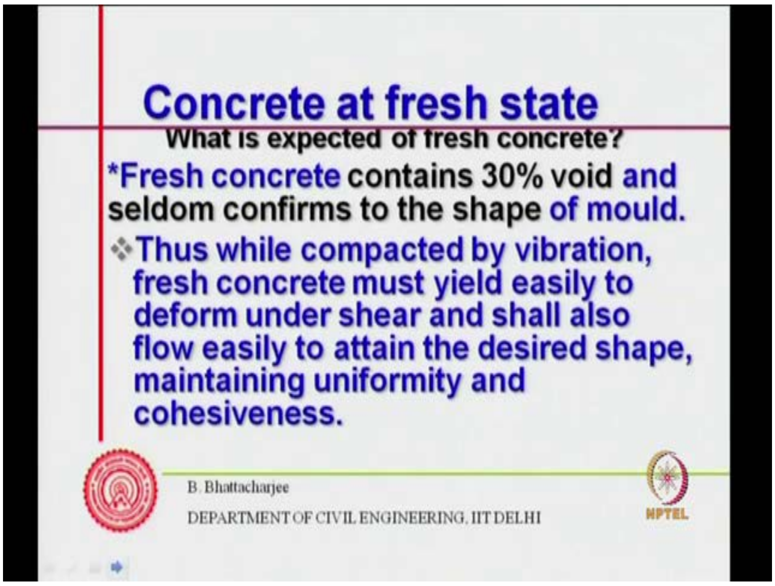

You can actually you know you can take about 10 percent more void. You can take about 10 percent more paste. So, let us go back to the slide again and so 1 minus 1 minus D p max into 1.1. That should be your minimum paste content in the system because 10 percent it will have it will cause dispersion of the coarse aggregate.

So, 1 minus D p max into 1.1, 10 ten percent more that will be the minimum paste content. I mean it could be somewhat less, but conservative way, you can start with 1 minus D p max into 1.1 and that is the minimum paste. This is 1 issue of how much paste you need for to have properly compacted concrete. The other issue related to gives the consistency of the paste itself to look at that you should look at what is expected to the paste concrete. What do we expect to the fresh concrete?

Normally, I am talking of again normal concrete. It will contain around 30 percent void. It does not conform to the shape of the mould. Therefore, we compact it by vibration and when you are compacting with vibration, it stands on a hit. So, it must actually yield easily and move and deform under shear and shall also flow easily to attend the desired shape.

At the same time, it must maintain its uniformity and cohesiveness particle. Reality distance between you know it must remain uniform that means larger size particle should not go at 1 side or paste should not you know move or move a way to another side. So, they should maintain their uniform mixer and cohesiveness. It should look similar coming from the same source. So, that is what it is. So, that is what should happen. This is what is expected from the fresh concrete.

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So, we must look into that. Therefore, shear stress strain behavior of fresh concrete because we said that while compacting, we apply some kind of vibration and under the vibration, it is actually subjected to a kind of shear stress. A given particular shear stress will start moving. Then, it will start in fact; you know the mobility the flowing would start. So, you can look into this behavior of fresh concrete.

Now, if you look at flow, flow of fluid takes place against frictional resistance offered by immediate next layer. If flow is occurring 1 layer, you see, if you can consider pipe flowing pool at the boundary velocity is 1, but at the center, it is maximum. So, if I consider a small layer in between the layer closer to the boundary of the pipe, it will actually exert a kind of frictional resistance to that layer, which is closer towards a center.

So, in case of liquid flow, this is what happens. The frictional resistance is offered by 1 layer to the next layer. Immediately next layer, which is in contact with the layer, there is a velocity gradient normal would be existing. In case of e laminar flow, in the transverse direction, in case of a laminar laminar flow, now what is the relevant property? It is viscosity.

So, actually shear stress is proportional to velocity gradient. The constant of proportional is the viscosity. So, that is in case of liquid. Now, we are talking of concrete or similar sort of thing, which is actually in plastic state. If you recall, we have also talked about that concrete is in plastic state. Now, a solid has got a definite shape and volume liquid does not have a shape although it has got a volume. The gas of course, does not have even a definite volume.

So, we will confine ourselves to liquid and solid plastic is something between. So, plastic it does not have you know, it may have a definite shape, but under stress, it would lose that shape. Its shape will go on changing. Therefore, concrete is actually in plastic state. It is not a liquid state because it is not flowing on its own not solid. I am talking of fresh concrete, not solid in the fresh state because it does not have a definite shape. Once it is hardened, it becomes solidified. It means solid once it sets, it becomes complete solid hardening. Of course, it is related to strength.

So, it becomes solid. So, before it becomes solid, it is in plastic state. So, you got to apply some stress. When it starts actually deforming, then that property is important. The subject through which we study this flow behavior of plastic material, we call it rheology. Now, cohesiveness of concrete must be maintained. It should not segregate. This property is governed by tensile strength of fresh concrete. If the tensile strength is low, particle will separate out. So, tensile strength is important.

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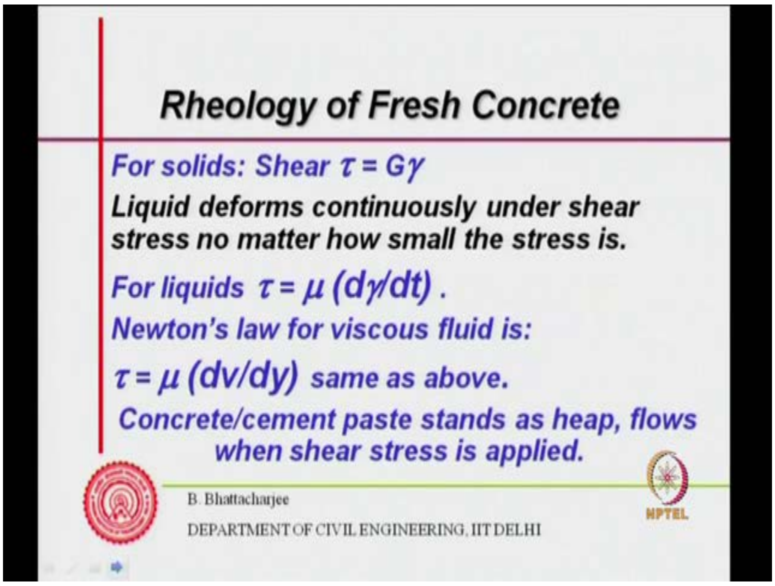

It will be governed by tensile strength of fresh concrete. So, we are looking at rheology; that subject, which deals with flow properties and shear stress for solid. You know we are just distinguishing the solid for solid shear stress is propositional to shear strain. The constant of proportionality is the rigidity modulus. The liquid deforms continuously under shear stress, no matter how small the stress is even without the stress. Actually, it will deform and shear stress is propositional to viscosity multiplied by shear strain rate. This is because I said velocity gradient velocity gradient you can actually express in terms of shear strain rate and that is Newton law for viscous fluid.

So, essentially you know tau is proportional to viscosity to d v d y and d v d y can be written as t x you know d x by d y and d x by d x by d y. You know this can be written as d x d y d t. This is nothing but shear strain. So, d gamma d t, this can be written as so strain rate. So, it will be actually strain rate, so same as you know. So, new viscosity is the property, but then in case of plastics, all this will happen in case of plastic, all this will happen. You know in case of plastic, all this will happen after cretin point of load application. In other words, after certain stress has been applied, it flows when shear stress is applied. So, up to shear certain shear stress, it does not actually move, but beyond that it starts moving.

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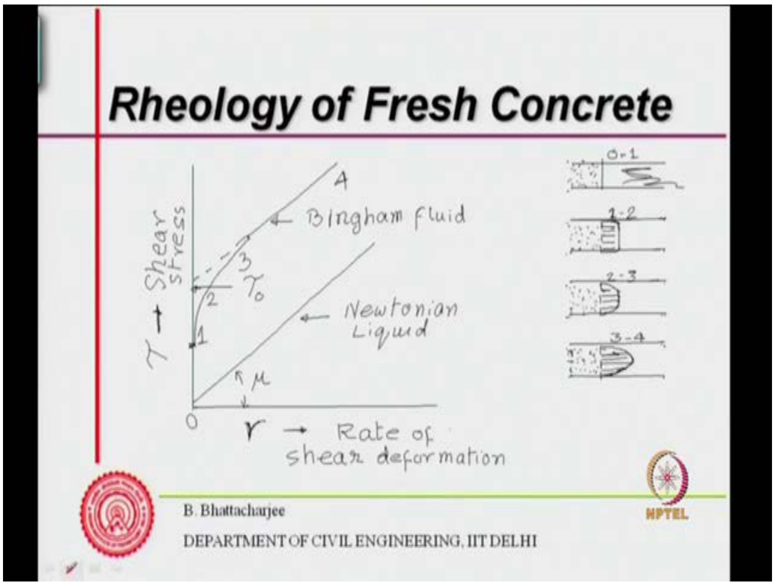

So, if I look at this therefore, if I look at this particular situation, this is for solid. This is for solid up to this level, up to which actually, it will not it will not it will not move, it does not, it does not move actually, if it is up to cretin point. It does not move and beyond this point beyond this point beyond this point up to this point. It does not move and beyond this point 1 up to 1, it is actually behaving like a solid.

It is behaving like a solid. It is behaving like a solid up to this point. It behaves like a solid. This is behaving like a solid 1 to 2. It started some sort of flowing and 3 to 4, I mean as a typical Bingham fluid, not necessarily concrete. So, from 3 to 4, it behaves likes a liquid and your velocity profile are like this.

So, you know solid, there is no velocity profile. Velocity is constant here along this direction, velocity here and velocity everywhere is same here. The velocity increases. Then, this here again, it is constant and 3 to 4 pure liquid velocity profile is parabola. So, this is Newtonian liquid, for which you know 3 to 4 behavior is from the beginning. This is mu.

Mu is the rate of strain shear deformation and shear stress. The Bingham fluid is 1 up to certain stress. It does not show up any moment any mobility 1 to 2, it shows this kind of mobility 2 to 3, it is like this and 3 to 4 again, it behaves like liquid. So, shear stress versus shear you know rate of shear defamation shear stress rate is shown and that is what it is.

So, concrete in plastic state or cement paste in plastic state can be modeled something similar to this one. If I extend this line, this point, this is called yield shear stress. This is called yield shear stress. This is called yield shear stress. So, if I extend this, this point is called yield shear stress, tau 0. So, it is called yield shear stress tau 0. So, 2 properties are important tau 0 and this slope. This slope is the mu viscosity. So, Bingham fluid or something similar kind of concrete would show yield shears stress. Then, it will show some sort of plastic viscosity. So, these are rheological properties of concrete rheological properties of concrete.

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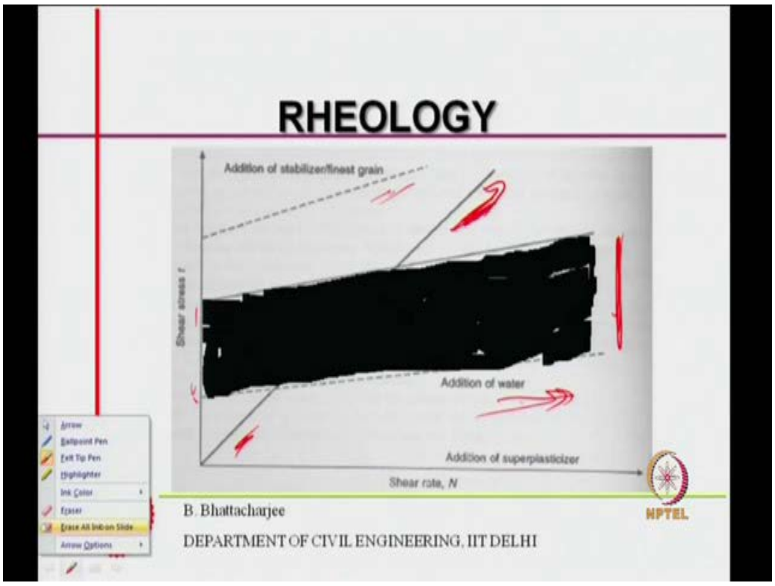

If you continue to look at it, you know we will find that addition of water increases viscosity. So, normal concrete will be somewhere here addition of water actually causes increase you know viscosity. I mean increase in what you call yield shear stress is here. It would lie somewhere there. As you add water more addition of water, it increases the shear strain. It actually increases.

So, liquid Newtonian liquid, it is somewhere here addition of super plasticizer or something you know, so or some grain stabilizer or grain, they were somewhere here. So, concrete would be somewhere something like this. This is your Newtonian liquid is somewhere there.

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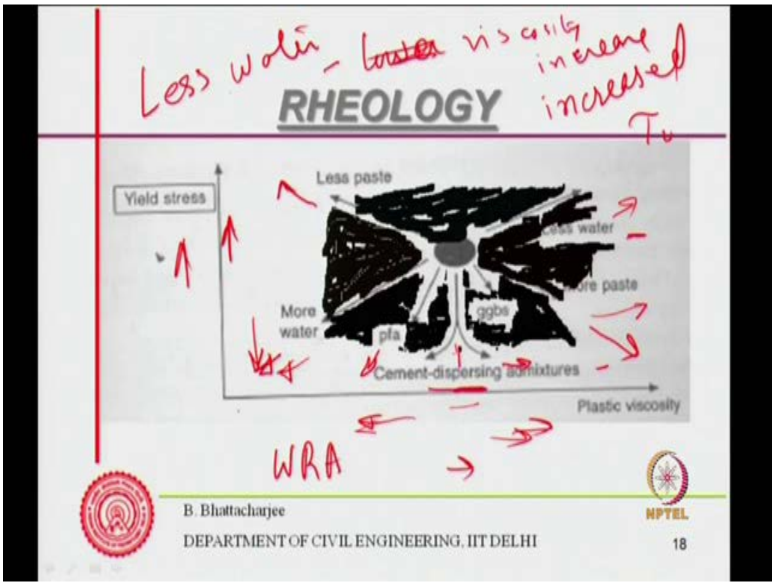

So, this is what it is. If you look further onto this 1 concrete, if you add g g b f s or dispersing a mixture of viscosity increases, you know in this manner viscosity cement dispersing admixtures. So, if I add admixtures, plastic viscosity can increase or decrease, but yield shear stress definitely decreases.

So, if I add plasticizer or water reducing agent, if I add water reducing agent, some of them will increase the plastic viscosity. Some of them will reduce the viscosity, but definitely reduce down the yield stress. This is the plastic. You know about viscosity. So, if I plot plastic viscosity versus yield shear stress fine particles like you know, if you add water, they go along this direction. More paste will also move along this direction. You know some case of more water, more paste, less water, it actually increases the viscosity.

So, less water, less reduce water, lower viscosity lower lower viscosity reduced water less water increases the viscosity increase as well as increases the tau 0, increase tau 0. So, yield shear stress increases, so lower the water yield shear stress increases viscosity also increases and more water. You will have lower yield stress more water goes like this lower yield stress and lower less space. It actually viscosity reduces, but the yield shear stress increases.

So, what we see is see more paste. Of course, it causes plastic viscosity to increase and also reduction, you know, it is along this direction. More paste results in this direction.

So, we can see actually if we pulverize fly ash, it actually reduces your yield shear stress stress like you know reduces the viscosity also like fly ash or g g b f s you know.

So, what we see if I add more water less water, if I reduce the water, if I reduce the water, actually my plastic viscosity will increase. The yield shear stress will increase, lower paste viscosity will decrease. The yield shear stress will increase, more water viscosity decreases, yield shear stress decreases more paste more paste.

If I put in yield shear stress decreases, but viscosity increases. So, you see I can actually manipulate because I need least yield stress least pressure. I should be applying before it starts moving. It must not have too much of friction. So, mu should be as low as possible. Mu should be as low as possible, not too much of friction. So, therefore, you can look into these rheological properties. Therefore, role of paste becomes very important paste and water because g g b f s p f a etcetera, they also go into paste admixture. Of course, it has the biggest role in all this issues.

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So, the role of paste, we can quickly look into. Water makes the cement plastic, by progressive addition of water, air filled voids are occupied by water. If you recall, I talked about basic water content sometimes which is a chief, when all their voids are isolated by water.

So, all air bubbles get actually isolated and that corresponds to you know air bubbles becoming isolated within the interstitial space of cement system. Water coats all the cement. So, all open air voids are isolated by water to air bubbles. This corresponding consistency is what we call it normal consistency.

So, therefore, water in the paste is very, very important. I must have sufficient water above normal consistency. If I had higher water content, it makes the paste softer with greater dispersion of cement particles. I should have sufficient paste to fill in the voids. We have seen that more the paste actually of course, has some effect on the viscosity, but they reduce down the initial stress. Also, I must have sufficient paste in order to disperse the aggregate. That is the first thing and the paste itself should have sufficient water content, so that you know it is it is it is it it has you know ease of flowing.

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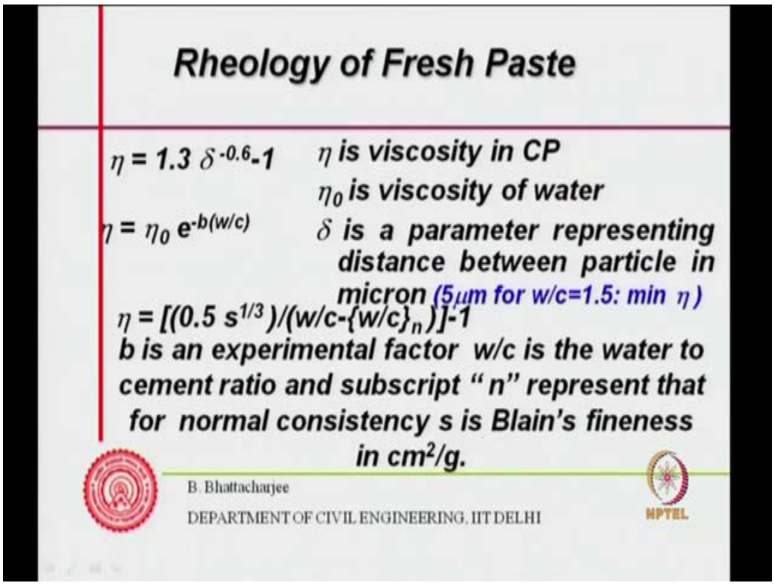

Now, viscosity can be related to dispersion distance between particles. Also, they can be related to water cement ratio. Let us see how they are related viscosity of cement paste mu 0 is viscosity of water delta is a parameter representing distance between particle in micron 5 micron for water cement ratio of 1.5 and that corresponds to minimum mu.

So, you see mu viscosity can be related to water cement ratio and also to also to some experimental factor b. You know water to cement ratio and n represents for normal consistency s is blain's fineness. So, this s is blain's fineness. This is water cement ratio for normal consistency. If you add more water, then this that is the difference you know if you add more water than this.

So, this term would actually you know more water, this term will reduce above normal consistency. This term will reduce. If this reduces, viscosity will actually you know first of all blain's fineness finer viscosity will increase. This term is reduced viscosity. It would increase minus 1. Of course, it is very much there outside the bracket. If this is actually according to this formula, if this is you know it is very large, lot of water, this term will tend to 0 and viscosity will be nearly 1, which is near to the water. So, whatever it is, this viscosity can be related by through this kind of empirical formulas.

So, what do we understand is it is related to the type of cement? Of course, it is also related to water to cement, but we are talking of the cement paste only water to cement. How much is the water in the cementitious cement water or powder system that is what governs the viscosity of the paste itself. In case of concrete, it will be water content. If we say with the total mass or volume of the aggregate and concrete system, so water content is what we governed in a viscosity.

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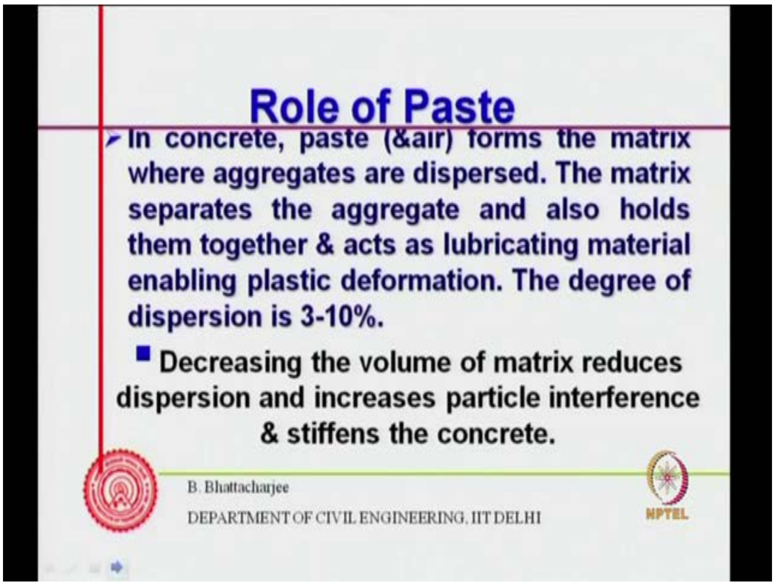

So, in concrete, paste and air forms the matrix where aggregates are dispersed. The matrix separates the aggregate and also holds them together and acts as a lubricating material an enabling plastic deformation. The degree of dispersion is 3 to 10 percent that is what we said. Therefore, decreasing the volume of matrix reduces dispersion and increases particle interference and stiffens the concrete.

So, role of paste is very important just by the way normal concrete, the paste content would be around 30, 32, and 33 percent. If you look at more flowing concrete, it might go to some around 37, 38 percent like self compacting concrete, you have much higher paste. The paste itself should be flowing. This is very important.

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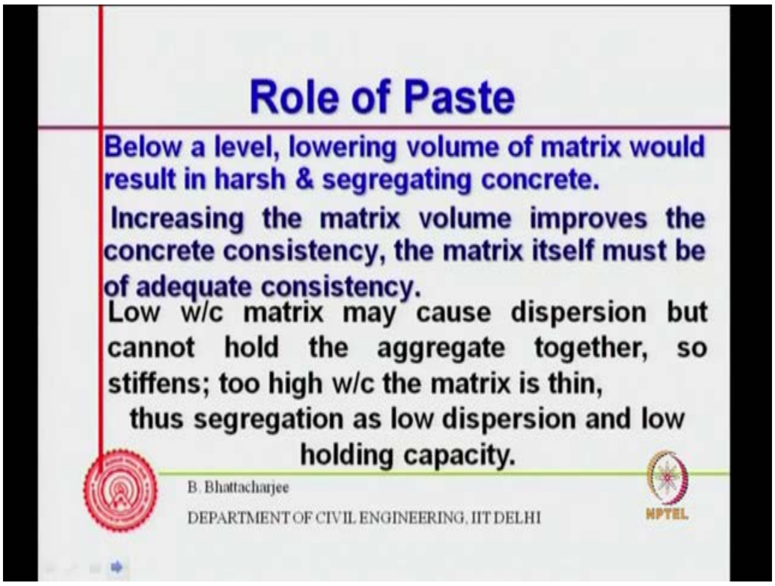

So, below a level, lowering volume of matrix will result in harsh and segregating concrete because segregate will not be held together. They will move away and increase in the material volume improves the concrete consistency. The matrix itself must be of adequate consistency. So, it increases the consistency.

Low water cement ratio matrix, I am talking only about the paste. Therefore, that side, the water cement ratio comes in low water cement ratio matrix may cause dispersion, but cannot hold the aggregate together, so stiffens; too high water cement ratio matrix is thin, so water moves out. So, segregation of water, actually bleeding would occur as low dispersion and low holding capacity.

So, the proportions of you know water in the matrix that is in the paste and powder. You put together all kind of cement and other powder put together blush is thus very, very important. This is because if it is too high, it be may thin and water might run away. If it is too less, then it cannot may not be able to hold the aggregate system.

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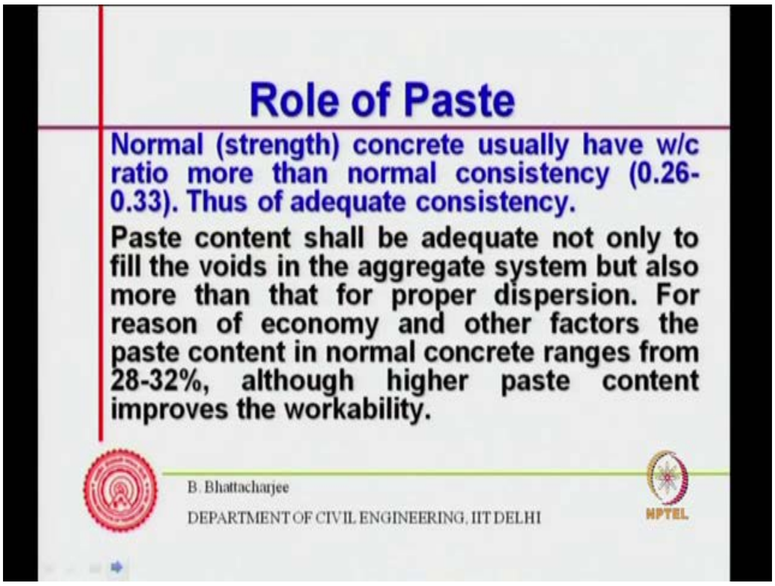

So, the water is the most important aspect. Normal concrete of course, will have water cement ratio more than 0.262, 0.33, which is actually normal consistency. Thus, you will have adequate paste, will have adequate consistency. It is in high strength concrete. You know you have to look into this paste content shall be adequate not only to feel the words in the aggregate system, but also more than that required for proper dispersion for reason of economy.

Another factor is the paste content is normal concrete ranges from 28 to 32 percent. All the higher paste content improves the workability because paste content cement has thus the costliest material. So, that is why, people who have tendency to keep the paste content to its minimum and a mix proportioning would be done accordingly.

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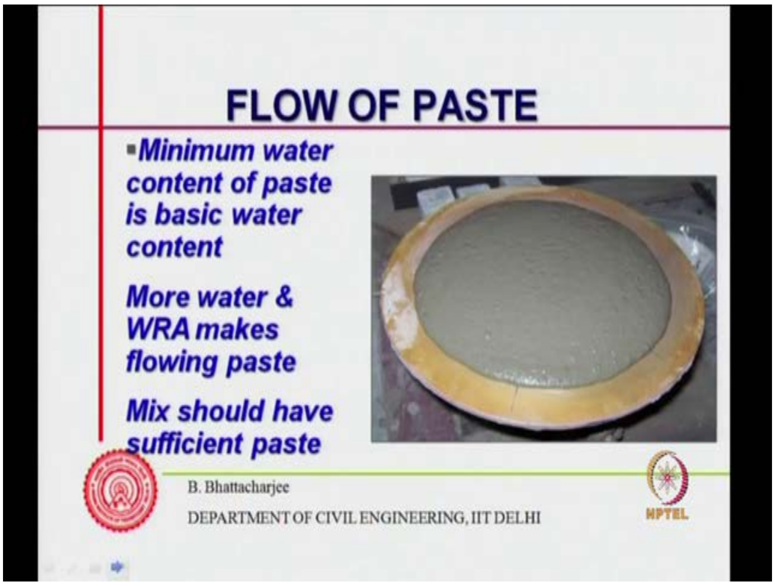

So, minimum water content of paste is that is basic water content. We talked about more water makes and water reducing agent makes flow in paste mix should have sufficient, paste mix should have sufficient paste. This shows a paste flowing paste, just flowing paste. So, that is that is what it is.

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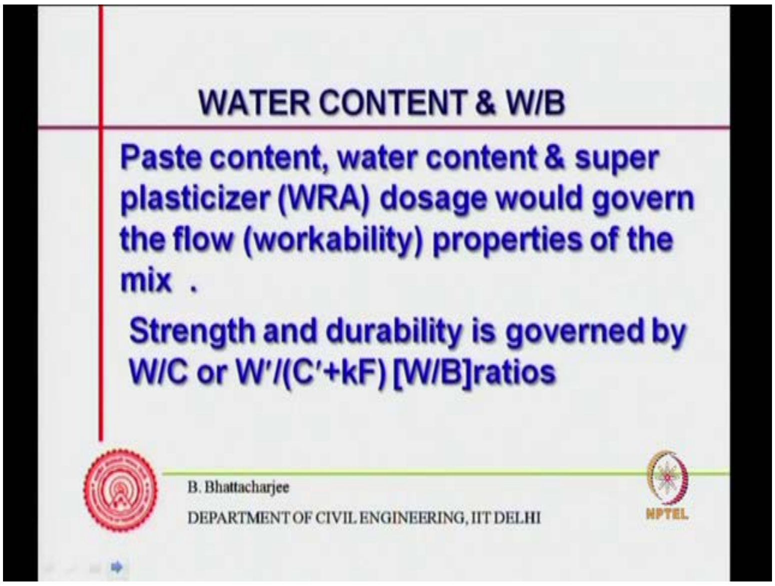

So, water and sufficient paste, now paste content, water content and super plasticizer dosage would govern the flow properties of the mix that is we have understood from our discussion. Now, strength and durability is governed by water to cement ratio or you know changed water to cementitious plus some.

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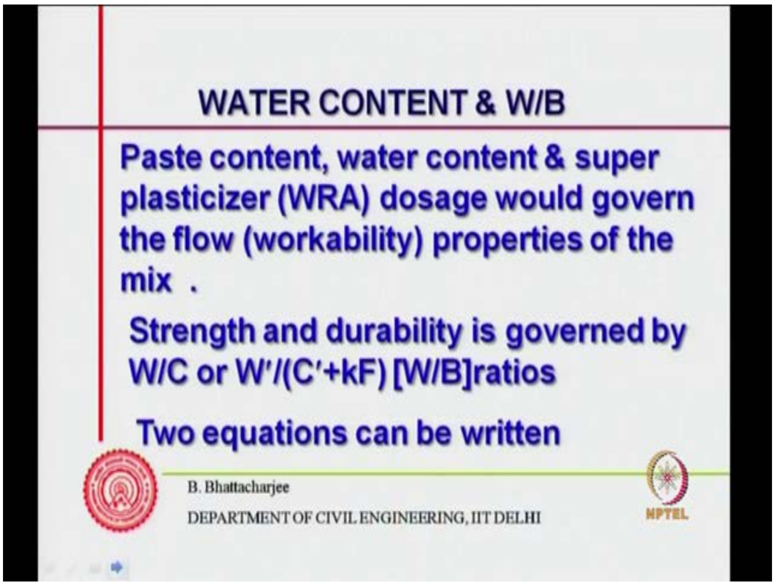

We have seen earlier that you know water to bind related to somewhat related to water to bind ratio. This we have seen earlier. We can write 2 equations based on this how the equations are like this.

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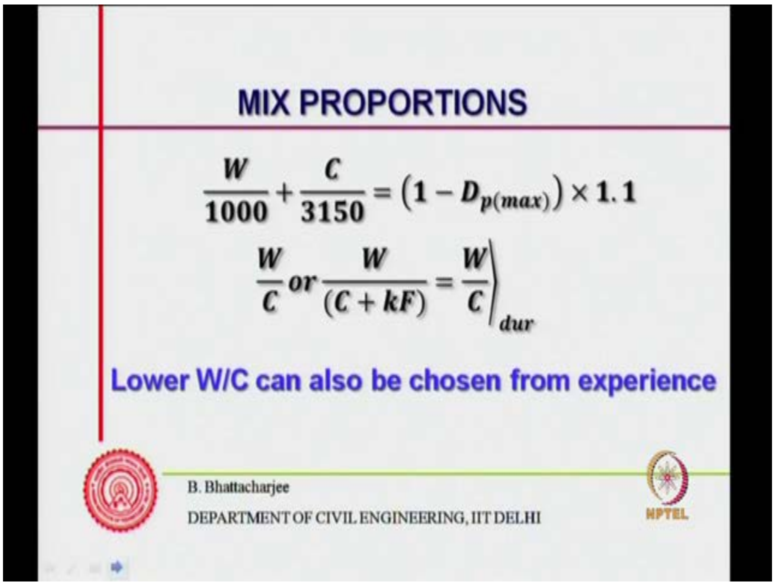

First of all, if I am trying to get the mixed proportion water volume of water plus volume of the cement must be equals to 1 minus the D p max that I have determined earlier into 10 percent extra.

So, the paste content must be minimum paste content. This this is an equation related to minimum paste content. That is related to packing density. The other equation of relating to water and cement is related to strength. If I do not know a relationship between strength and water cement ratio, I can start with water to cement ratio required for durability as we have done in Indian standard method practice 1, 0, 2, 6, 2, and 2009.

So, I can start this as W by C or W by C plus k F k. You can take as 0.3. To start with, that must correspond to the durability maximum water cement ratio permeable permissible for durability. You can take from experience as well like 1, 0; 1, 0, 2, 6, 2, which we have discussed earlier. So, you have a relationship for water cement ratio from durability and strength. You have another relationship from the packing density and paste content require. So, 2 equations water and cement can be determined.

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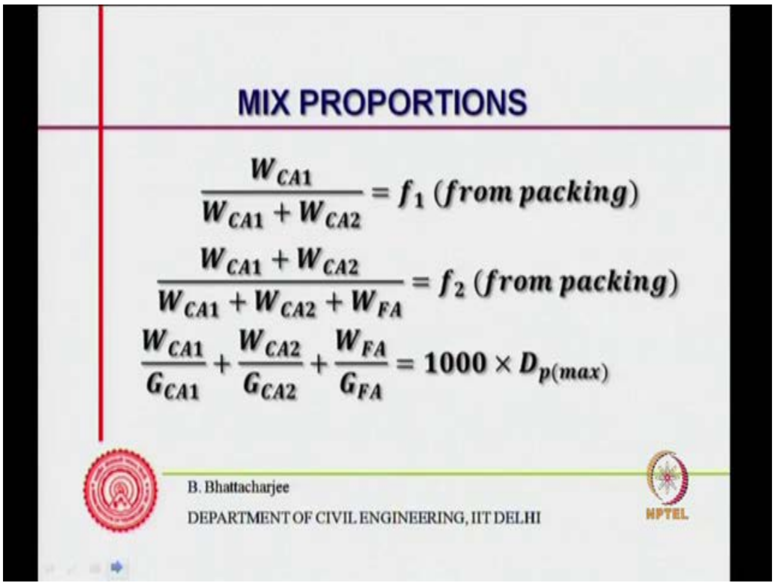

Now, you need to determine the other proportions from packing density coarse aggregate. What is a fraction? Of course, aggregate 1 in the total coarse aggregate system that was known to me f 1 from packing best packing optimal packing. Similarly, the fine aggregates or the total coarse aggregate proportion of course, aggregate in the total aggregate system, which I can call at f 2 is also known from packing density. Lastly, the total volume of aggregate system must be equals to the packing density itself.

This is because volume the solids pure solids that is volume the coarse aggregate 1 coarse aggregate 2 plus fine aggregate must equals to the packing, you know packing density. This is because that is the volume in 1 meter cube. I am talking of all this proportions in 1 meter cube like we have done earlier k g per meter cube content of aggregate system.

So, I have 3 more equations. I have 3 more unknowns W C A 1, W C A 2, W F. Aggregate content coarse aggregate content per meter cube of concrete and coarse aggregate 1 content of per you know per meter cube of concrete specific gravity must be the input like we have done earlier. So, you can see that I have got 5 equations. I have got 5 unknowns. They can easily be solved.

You do not require a big matrix or anything to solve that you know you do not require them. W C can be solved from the previous equations. These 3 equations will give you simple W C A 1, W C A 2, W C A 3. So, I have got the mix proportions of concrete using this constant. So, these 5 unknowns are known and that is the mix proportion.

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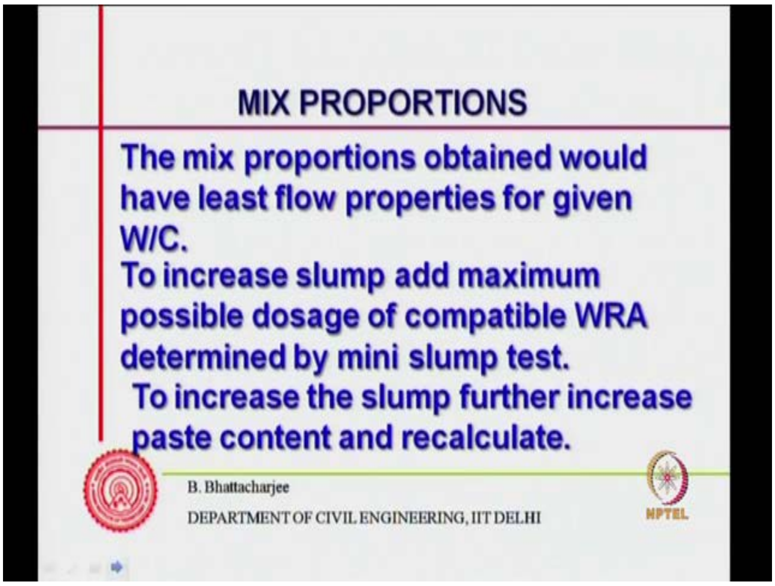

This mix proportion obtained would have least flow least flow properties for W by C. This is because I have taken the minimum paste quantity for given W by C or W by binder to increase slump at maximum possible dosage of compatible WRA determined by mini slump test. So, this is the starting point. This was the starting point for workability. It will give you measure the slump and find out that this is a right kind of slump you require. If you did more slump well, you cannot do without that paste content.

This is because otherwise you will have voids in the system. So, if you need more slump which normally would because this will be least slump; add possible dosage of compatible water reducing agent. That should be determined from mini slump test. You want to increase some further at maximum. You will get some slump.

You want to get more slumps. You add the paste content and recalculate the whole thing. So, it follows for earlier discussion of different mixes and methods that we talked about. How do you find out the optimal dosage of or the compatible super plasticizer or water reducing agent? You do mini slump test mini slump cone.

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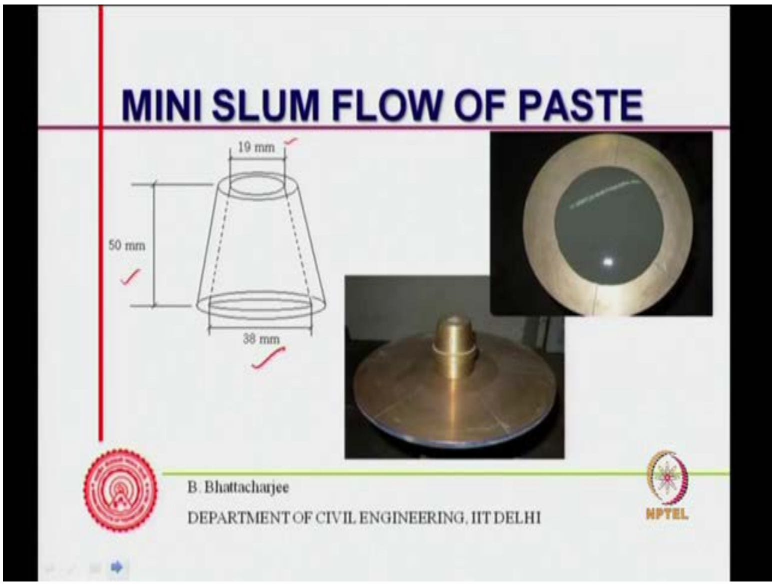

It looks like this. You can see that it is actually, you can see that it is actually 38 millimeter, 50 millimeter, 19 millimeter you have. It looks like this it sound the platform as shown and once you have filled it in lift, it almost like our slump find out the slump flow. This slump flow for the given paste because you have water to cement ratio. You have determined water content cement. You know water in the cement quantities; you have determined their proportions are known mix or cementitious material.

It can be extended to all cementitious combination. Actually, water I mean cement, fly ash etcetera or cement and water. So, make the paste as you desire for the given water cement ratio and add different dosage of water, high range water reducing agents, super plasticizer, hyper plasticizer, whatever you call it and find out the flow.

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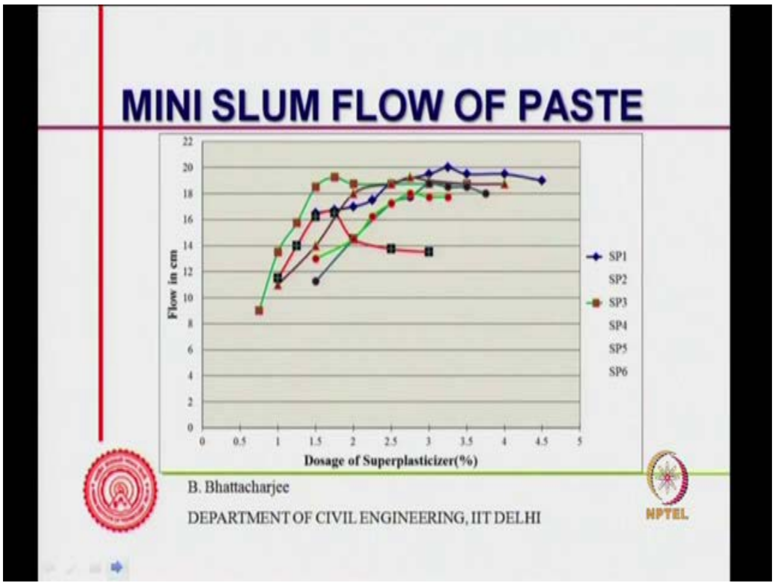

Now, this flow can be actually measured. So, you can see in this particular example. There are 6 such super plasticizer voids used to a particular cement system cement system. You know particular cement plus another cementitious material system, You can see the flow in centimeter goes on increasing, but there is a point of you know maximum point beyond that it is not really increasing. So, this is for super plasticizer 1, 2, 3, 4, 5, 6; super plasticizer has been plotted here.

Now, the optical dosage would be somewhere there and for this super plasticizer optimal dosage will be somewhere. You know the red one, it will be somewhere here. For each one, you can find out what is the optimal dosage. Now, this optimal dose for maximum dose you can apply because beyond this, by addition of super plasticizer, it does not show any further improvement in flow. So, this this dose as you have obtained from this experiment of mini slump, it should not exceed the limit that has been actually specified by the manufacturer. This is because then you will have all kind of negative effect.

So, the maximum obtained from here or the maximum dosage specified by the manufacturer, whichever is lower, you can put in that because high of the super plasticizer, you are using without any strength loss aggregation or such thing. It would minimize your cement consumption and that reduces the cost and also adds to sustainability.

So, therefore, we should like to use as much as super plasticizer or water reducing as possible to minimize our cement consumption. Find out by mini slump method what the best super plasticizer is. The best super plasticizer is the most compatible and will be one which gives you maximum flow with mix dose right. So, similar kind of test, one can determine.

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One can determine the particular super plasticizer. Then, at this super plasticizer to get the slump, you need if you need still higher slump, then you have to increase the paste content, which means that you will increase water cement and correspondingly, the super plaster plasticizer dosage also. There is strength calculate. You know want to find out whether it satisfy your first trial mix, you started from you might start from durability point or from experience as it is done in 1, 0, 2, 6, 2.

You have discussed earlier and shown as an example earlier. Also, you actually cast trial makes you with another water cement ratio. Let us say 0.05 less than the durability or you might still cast another 1.01 less than the durability. So, 3 water cement ratios or water cementitious ratios, as you wish, you might cast you know for your control mix.

Of course, it will be water cement ratio, but if you are using fly ash, then you can either you use the DOE method. You use the Indian is 2, 6, 2, 1, 0, 2, 2, 6, 2, method whichever way you like fly ash business, you can add. So, you can add 2, 3 water cement ratio strength determined 2, 3 water cement ratios to identify what is a water cement ratio.

So, trial mix will be 2, 3; similar to 1, 0, 2, 6, 2, which are quite rational and check. Of course, the cement content for durability requirement should not be less than the cement content. Specify this WC dash k F. Pozzolana can be calculated by as doe method. Earlier, we have discussed or it can also be calculated from 1, 0, 2, 6, 2. So, you see therefore, complete mix proportion, you can obtain complete mix proportion. You can obtain from the packing density concept and also using the idea of rheology as such today till date, it is difficult to model the rheology part from from your like theoretical understanding of concrete.

So, you can apply some idea basic idea. Obtain your mix design packing density method has been actually proposed. As I told you, the parameters required for the aggregate systems are fairly complicated because you have to determine all those properties of the aggregate. So, parameters associated with the aggregate, if you want to if you want to use the formulae, which I have arrived, but for the normal strength concrete mixer. So, one might do it for very high strength system. Still, one may be doing.

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So, if you want to do it for you know normal concrete, and then the procedure that has been just mentioned is a good procedure. So, what we have discussed? So far, we have discussed packing density concepts, which we have earlier also discussed with reference to aggregate. We have just tried to show you an example how you can use this concept in normal mix design practice.

If you are doing high strength concrete, then of course, or very high strength system, then this has to be done with much more vigor city. Then, what has been discussed here? The properties required for each individual type of an aggregate that has to be actually you know seen and understood and measured. Then, we also looked into rheology concepts namely the properties, rheological properties of concert. Then, we have discussed about how to do mix proportioning using this order of concept.

So, this is not right. Now, still there it is not, there in any code or anything of that kind or any guidelines for practice and so on. But, one can adopt this sort of practices especially, if one is looking into you know systematic procedure for development of normal strength concrete as well as can be extended to the high strength concrete. Also, I think with this actually, our discussion on mix design finished the summary of this particular lecture is packing rheology concepts and mix design. If you look at the whole module summary, then what have we looked into? First of all, we looked into the basic principle of mix design.

If you recall, we talked about we had a diagram. When we say the strength is a function of water cement ratio most of the mix design procedure follows that, then you know workability or such thing is governed by essentially the aggregate type their packing their shape and so on, so forth. That rating is related to the packing density and etcetera. Based on the workability and the water cement ratio, we will get actually the water content and the cement content and absolute volume remaining constant.

We actually find out the total aggregate content find to coarse aggregate. Aggregate comes from the grading or their packing. So, this is what we discussed in the beginning followed by Indian standard method DOE method British practice. Then, we discussed the ACI method. Lastly, today we actually discussed some concepts, modern concepts and how they can be put into practice in case of mix design of concrete. So, this completes our module 5 and thus ends it. Thank you very much.