Building Materials and Construction
Dr. B. Bhattacharjee
Department of Civil Engineering
Indian Institute of Technology, Delhi

Module - 5
Lecture - 2
Fresh Concrete: Role of Mix Parameters

Continue with the first concrete in this lecture. Today we shall look into role of mix parameters.

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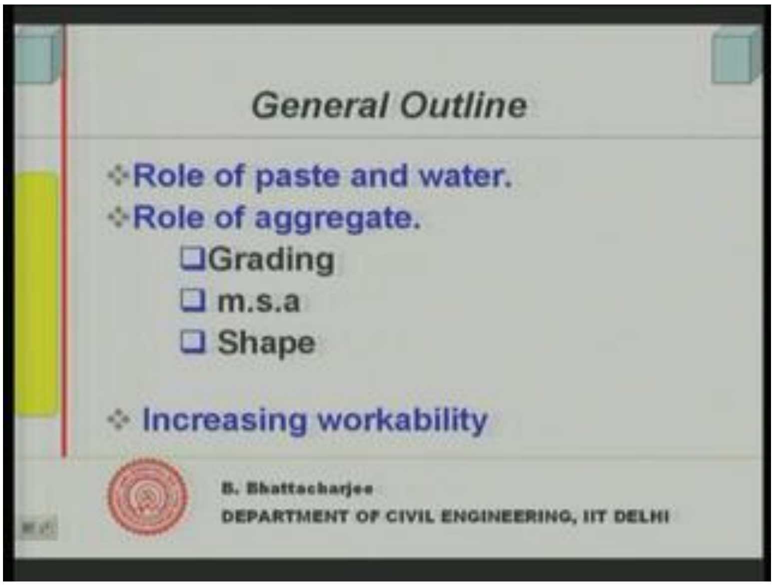

General Outline

- Role of paste and water.
- Role of aggregate.
  - ☐ Grading
  - ☐ m.s.a
  - ☐ Shape
- Increasing workability

B. Bhattacharjee
DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

What are the mix parameters? First is the paste and water. Then, next we will look into role of aggregates. And in aggregates we have grading. We will also look into effect of maximum size of aggregate and their shapes. Also we will look into how to increase workability, how 1 goes for any increasing workability. So, this will be the general outline. So, let us start with role of paste.

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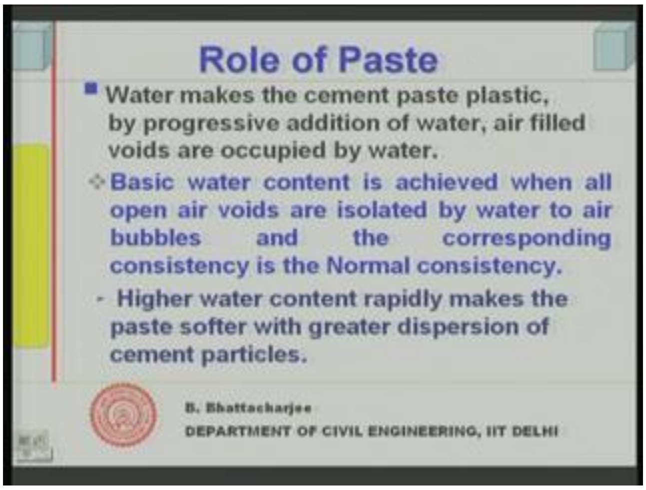

Role of Paste

- Water makes the cement paste plastic, by progressive addition of water, air filled voids are occupied by water.
  - Basic water content is achieved when all open air voids are isolated by water to air bubbles and the corresponding consistency is the Normal consistency.
  - Higher water content rapidly makes the paste softer with greater dispersion of cement particles.

B. Bhattacharjee
DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

When we add water to the cement it becomes plastic, otherwise cement is a solid which is in a dry condition; it is not moldable it will not deform low just like that. So, to make it plastic what we do; we add water. And as progressively we go on adding water, originally dry cement particles are air filled. The voids or interstitial void space between cement particles will be filled with air. And this air filled now spaces are now gets filled by water. And as they get filled by water, gradually you know a stage comes initially all the surfaces of the cement particles would be dry, as you add water some surfaces will tend to become wet.

Air of course, initially forms a kind of open continuous channel or connected air filled system. As you add water this connection gets disrupted, because water fills up and air filled voids tends to become isolated. And a stage comes when all the open air voids are isolated by water and they become air bubbles. This water corresponding to and the corresponding consistency is something close to normal consistency.

So, normal consistency we have defined in case of cements. And this corresponds to the state where, water has been is just sufficient to isolate the air bubbles. In fact, it is not totally air free; the voids will still contain air bubbles and they will be isolated, they are independent closed pores where air bubbles are filled. And the ratio of air to water at this stage is about 1 to 7 and this is called basic water or the water corresponding to normal consistency or this corresponds to normal consistency that has been defined.

Now if you add more water to it, it makes the paste softer rapidly and generally disruption of the cement particle takes place. So, that is the mechanism when you add water to the cement and progressively go on increasing the water content. Now let us see what happens to rheology of fresh concrete.

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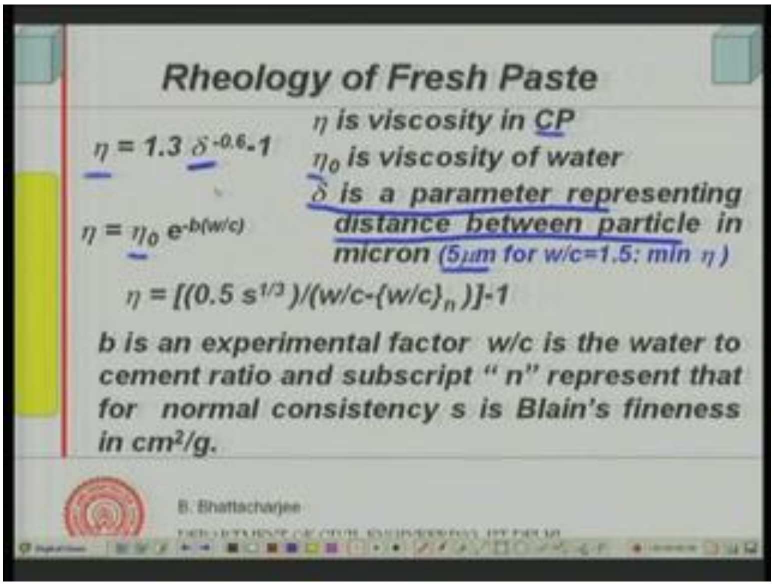

Rheology of Fresh Paste

$\eta = 1.3\ \delta^{-0.6} - 1$

$\eta = \eta_0\ e^{-b(w/c)}$

η is viscosity in CP

η_0 is viscosity of water

δ is a parameter representing distance between particle in micron (5μm for w/c=1.5: min η)

$\eta = [(0.5\ s^{1/3})/(w/c-\{w/c\}_n)]-1$

b is an experimental factor w/c is the water to cement ratio and subscript " n" represent that for normal consistency s is Blain's fineness in cm²/g.

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We have discussed earlier the rheological parameters and the yield shear stress and the viscosity. So, we can look into the viscosity; nu is the viscosity, delta is a parameter which defines particle dispersion, it defines parameter representing particle dispersion, as we can see now delta is a parameter representing distance between particle. So, as I add water, distance between particle will go on increasing. And as this delta increases from this equation; this is viscosity you can see that as delta increases viscosity will reduce, because delta to the power minus 0.6. So, if I increase delta nu will reduce and it reduces till possibly a distance between the cement particle becomes 5 micron. Any distance beyond this any addition of water and further dispersion beyond this of course, does not cause further change in the viscosity.

So, we can see that viscosity reduces. Therefore, flow will increase, flow will improve, this is of course, nu in centipoise nu the viscosity in centipoid and this comes here in 1 of those equations nu 0 is the viscosity of water. Similarly, you can see that this nu increases with and decreases with water cement ratio. As I increase the water cement ratio, this is exponentially related to nu. Higher the water cement ratio since this is e to the power b, b is an empirical constant into w by c. So, if I go on increasing w by c, nu will reduce right and exponentially it will it will reduce exponentially.

So, higher water to cement ratio in case of paste causes; whether dispersion, more dispersion and also it causes reduction in the viscosity. So, water cement ratio is a factor in case of paste, which causes reduction in viscosity therefore, improves the flow ability. This is even from common sense this is understandable. The other important factor is the surface area or particle size distribution of the cement particle. s stands for Blain's fineness we can see that s stands for Blain's fineness which means; is the specific surface defined in terms of earlier we defined in connection with cement, this is centimeter square per gram it is the specific surface.

So, as the specific surface increases the fineness of the cement increases, specific area is what it is the surface area per unit mass. So, if the surface area per unit mass increases; that means, it is finer the finer particle has more surface area compared to course particle area. So, as the surface area increases, the finer particle sizes are finer and finer, then this viscosity will have a tendency to increase the viscosity will increase, this increases the viscosity increases and this has got some relationship with water cement ratio also.

This is the water cement ratio for normal consistency. If you have more water cement ratio then normal consistency, you can see that the viscosity will reduce. So, this is a more generalized equation, relating both water and cement ratio and the fineness of the cement. So, higher the water cement ratio with reference to the normal consistency, because if you have normal consistency water this would be very, very you know this term would be 0, this term would be 0 and this is actually very large.

So, therefore, viscosity reduces as I increase the water cement ratio beyond the normal consistency and it increases with fineness of the cement. So, it increases with fineness of the cement and reduces with increase with water cement. So, flow ability would be better for higher water cement ratio and also for coarser cement range, final cement will require more water to become plastic actually. So, that is the idea. So, that is what it is alright. So, this factors actually governs the rheology of fresh paste.

So, water cement ratio is the main aspect and of course, the fineness of the cement plays a role in the flow ability of the cement paste. Paste itself must be flowable, because if you see all other materials are you know coarse aggregates and fine aggregates; they are dry materials and on their own they will not be have much mobility. It is the paste which should be there. So, what does actually paste do?

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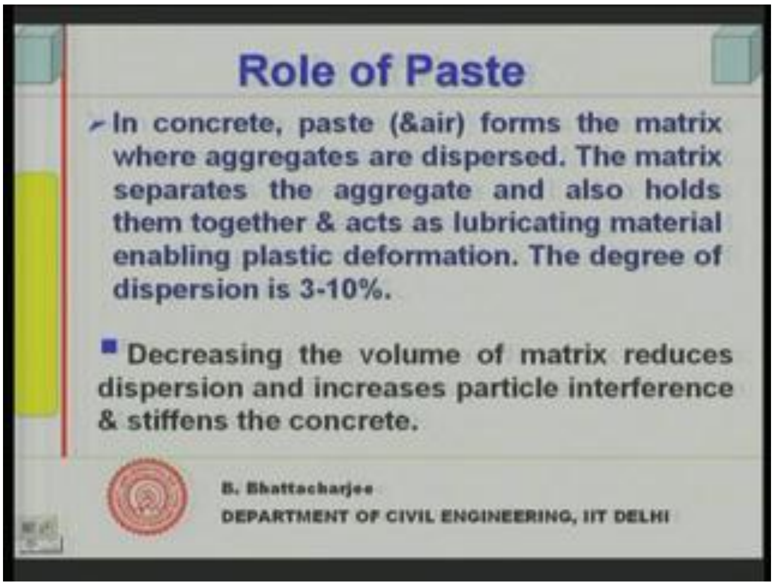

Role of Paste

- In concrete, paste (&air) forms the matrix where aggregates are dispersed. The matrix separates the aggregate and also holds them together & acts as lubricating material enabling plastic deformation. The degree of dispersion is 3-10%.

- Decreasing the volume of matrix reduces dispersion and increases particle interference & stiffens the concrete.

B. Bhattacharjee
DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

If you see the role of the paste in case of concrete paste of course, it will have a little bit of air in it, forms a matrix I may call it as a matrix in which the coarse or fine aggregate are the inclusion. So, this forms a matrix where aggregates are dispersed; they are the inclusion and they are dispersed. The matrix separates the aggregates and also holds them together. So, this aggregates are separated from 1 another by this paste which is inside in between and it holds them together also, it binds them together, even in fresh state it holds them together and acts as a lubricating material enabling plastic deformation.

So, therefore, paste is a main; is most important part as per as workability or you know deformability and mobility of concrete is concerned paste is the most important part. It is the 1 which holds the aggregate together, it disperses them together and then gives you a lubricating material enabling plastic deformation. This degree of dispersion of course, is not very large never more than 3 to 10 percent; that means, you know the volume find out the distance between aggregates before paste was added and after paste was added, this increases in the distance from original distance; mean distance to the increased distance is not more than 3 to 10 percent.

So, dispersion is not more than 3 to 10 percent and therefore, this is important, but the paste you know is important to have paste and sufficient paste so that, it can take care of the dispersion also. So, if you decrease the volume of matrix that is the paste, dispersion you know it reduces the dispersion and it will increase the particle interference resulting in stiffening of the concrete.

So, matrix must be sufficient. That is what we understand that, matrix must be sufficient to hold the aggregates together and also ensure dispersion of this aggregates together. Now, matrix itself must be capable of flowing itself, it should have low viscosity so that it can move. So, that is the first fundamental; matrix must be of low viscosity; it should be able to move itself, deform itself, should be capable of plastic deformation and for that you need a water cement ratio more than the consistency situation. And it should be sufficient to hold the aggregates and also cause their dispersion so that, there is an ability for the concrete to undergo plastic deformation. So, that is the role of the paste.

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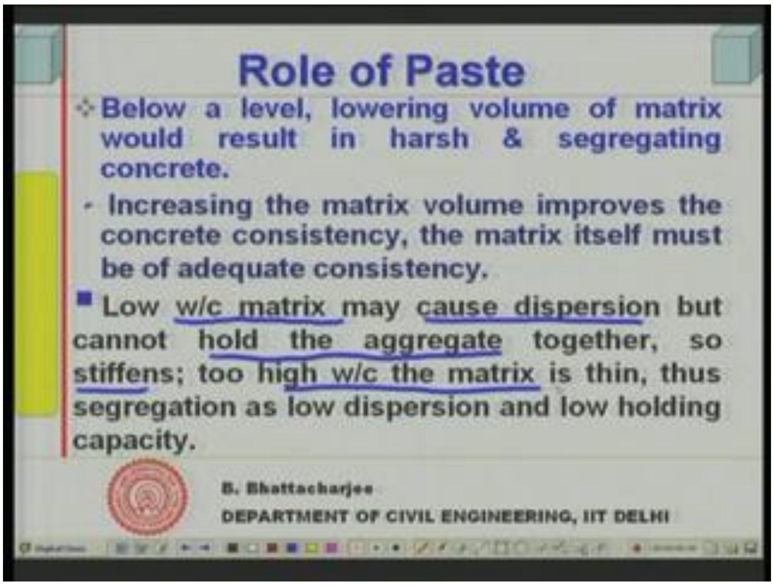

Role of Paste

- Below a level, lowering volume of matrix would result in harsh & segregating concrete.
- Increasing the matrix volume improves the concrete consistency, the matrix itself must be of adequate consistency.
- Low w/c matrix may cause dispersion but cannot hold the aggregate together, so stiffens; too high w/c the matrix is thin, thus segregation as low dispersion and low holding capacity.

B. Bhattacharjee
DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

Continue with the role of the paste; if we lower below a level the paste content, if you lower the paste content below a lower level, if you lower the volume of the matrix it results in harsh and segregating concrete, because if you have too much of if you have low paste the aggregates will be left alone, they will not be held together. So, they can segregate very easily. So, and that is the point actually.

So, this is the next stage; increasing volume matrix on the other improves concrete consistency and matrix itself must be, that is what I was mentioning that, if you increase the matrix volume, it will improve the matrix consistency I mean the concrete consistency or workability, but at the same time matrix itself must be adequately consistent.

Low water cement ratio matrix may cause dispersion, but cannot hold the aggregate together. So, if you have low water cement ratio, you know water to cement ratio; that means, the matrix is dry, it may cause dispersion. If you put sufficient quantity it will push the aggregates apart, but will not hold the aggregate together, because it itself is also dry. And therefore, it will stiffen. Too high water cement ratio on the other hand; the matrix becomes too thin, it is flowing very thin and not enough to hold the segregation is there. So, there will be segregation and could be form of bleeding and no dispersion is and you know and low holding capacity. So, it cannot hold and therefore, there is a possibility of dispersion. So, low water cement ratio is a problem, high water cement ratio, very high water cement ratio is also a problem.

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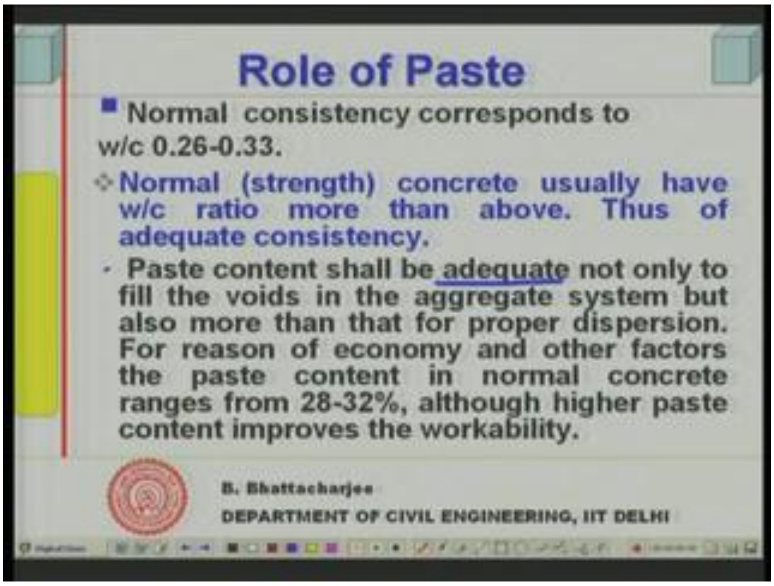

Role of Paste

- Normal consistency corresponds to w/c 0.26-0.33.
  - Normal (strength) concrete usually have w/c ratio more than above. Thus of adequate consistency.
  - Paste content shall be adequate not only to fill the voids in the aggregate system but also more than that for proper dispersion. For reason of economy and other factors the paste content in normal concrete ranges from 28-32%, although higher paste content improves the workability.

B. Bhattacharjee
DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

Continue with the role of paste incidentally normal consistency corresponds to around water cement ratio of 26 to 0.26 to 0.33. And you know in normal strength concrete, as sometime we might have define characteristics of concrete structures grade of concrete starting from 20 m p or M 20 to around 40 or say 50 or so on. The water cement ratio is usually more than this 0.26 usually it is more than this value. So, normal concrete normal strength concrete not very high strength, we are talking of normal strength concrete. The water cement ratio is usually higher than this value.

So, this is generally you will have adequate consistency. Well, paste content should be adequate. This is clear that paste content shall be adequate; this should be adequate paste content; that means; matrix must be sufficient now you understood. So, it should be sufficient to fill in all the voids in the aggregate system, but also more than that for proper dispersion. So, it should be more than what is required to fill in the dry volume, you know interstitial space between aggregate when they are compacted alone.

So, it is the amount of paste required is more than that is required to fill the interstitial space of the aggregate, when they are compacted alone. So, you need more, because there will be dispersion as you introduce space into the concrete you know. So, they will cause dispersion of the aggregate particle and therefore, you need more right you need more. But for reasons of economy and of course, factors like shrinkage etcetera, we cannot have too much of paste content to have high paste content is good, because it will give me workable system. But we cannot have too much of paste, because cement is the costliest material in normal strength concrete compared to let us say aggregate, you know coarse aggregate as well as fine aggregate and water.

So, therefore, if I make if I make if you use more paste more cement will be going into it, for a given water cement ratio more cement will go to it and therefore, it will be costly. So, I really cannot increase the space content in normal strength concrete very, very high, I have to control it. So, therefore, from point of economy and also it can cost shrinkage and other secondary effects. So, therefore, we do not want too much of paste in the or cement in the system and therefore, normal concrete the paste content ranges from 28 to 32 percent. Higher paste content will improve the workability, but we do not do that because as I said the economy will forbid as doing that.

But in certain special concrete it will do, example very, very high strength matrices very, very high strength matrices not of 20 30 order of 800 or 250 more than 200 you know the reactive powder concrete; there the paste content of course is relatively much higher, but that is a separate issue. But also in self compacting concrete the paste content is much higher where I need lot of flow, but then paste does not consist of cement alone it consists of cement and other cementitious material. Therefore, both economy and other secondary effects all are taken care of when we are we use high amount of paste content.

But in normal concrete what we were discussing at the moment; this is about 28 to 32 percent and we do not use too large paste content. This you will recall that we said that aggregate constitute about 70 percent of the concrete system, in the beginning when we define concrete right. So, that is the role of paste. Now let us look into the role of aggregate.

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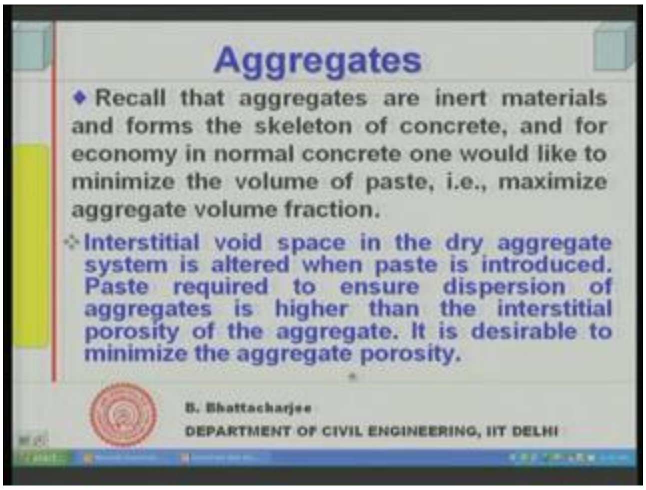

Aggregates

- Recall that aggregates are inert materials and forms the skeleton of concrete, and for economy in normal concrete one would like to minimize the volume of paste, i.e., maximize aggregate volume fraction.
  - Interstitial void space in the dry aggregate system is altered when paste is introduced. Paste required to ensure dispersion of aggregates is higher than the interstitial porosity of the aggregate. It is desirable to minimize the aggregate porosity.

B. Bhattacharjee
DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

Well aggregates are inert material. They should not react, they usually they do not react with you know take part in hydration process and should remain inert even in the future life, otherwise durability could be a problem. So, generally inert material bulk of this material that forms a concrete and provide a strength and stability to the concrete system as we have mentioned earlier. So, they are inert material and they form generally skeleton of the concrete if I may say so. And for economy normal concrete, 1 would like to minimize the volume of paste; that is what I mentioned and maximize the aggregate volume fraction.

So, that is what it is 1 would like to do that.

Now, interstitial void space in the dry aggregate system is altered when paste is introduced, we said that this happens, because you know is because of particle interference. Or if you introduce a new material into the pore space or interstitial pore space of larger size particle, a point comes when they start pushing the larger size particle itself; it is called interference particle interference.

So, paste also causes some sort of interference and therefore, this void system space in the dry aggregate system is altered, it is actually increased. And then paste required to ensure dispersion of aggregates is higher than the interstitial porosity of the aggregate; that is what I mentioned. So, what I need; I need the paste which should be more than that existing into the aggregate system alone when packed. So, if; that means, minimum level is a void content of the paste itself. I mean aggregate itself aggregate system, itself it will be more than that.

So, if I reduce down the void content of the aggregate themselves, then the paste content I can reduce. So, to reduce the because for reasons of economy we would like to keep it as low as possible, with adequate workability. We would like to keep it as low as possible for adequate workability. You know just the maximum level is that required for workability. So, but I would like to keep it as low as possible for a given workability. So, I must have a good packing of the aggregate system such that, its voids are minimal so that, you know aggregate porosity; interstitial porosity is minimal and that is what we like to do. So, aggregate porosity should be minimum.

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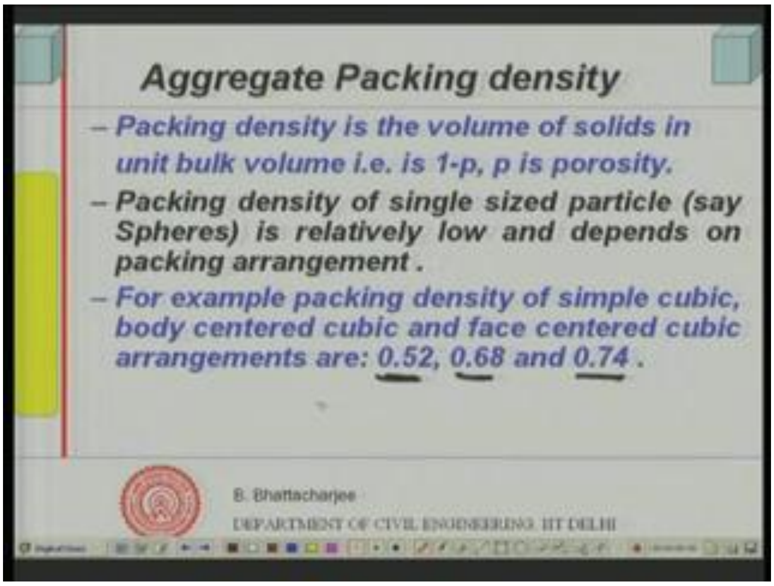

Aggregate Packing density

- Packing density is the volume of solids in unit bulk volume i.e. is 1-p, p is porosity.
- Packing density of single sized particle (say Spheres) is relatively low and depends on packing arrangement .
- For example packing density of simple cubic, body centered cubic and face centered cubic arrangements are: 0.52, 0.68 and 0.74 .

B. Bhattacharjee

DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

So, aggregate should pack very well. And this can be this can be expressed in terms of what is known as packing density. This is this can be expressed in terms of what is known as packing density. Packing density is nothing, but it is the volume of solids in unit bulk volume. Total volume if it you know unit total volume of the solids; that called packing density and it is nothing, but 1 minus p where p is the porosity, you know p is the porosity interstitial porosity of the aggregate. So, 1 minus interstitial porosity porosity is the packing density.

So, we would like to maximize the packing density so that, p is minimized. And if p is minimized I need p plus something amount of paste. So, if have minimized if I reduce the p therefore, paste requirement will also will reduce for a given workability. So, role of aggregate is therefore, to provide a skeleton system which gets dispersed into the matrix, but should have a low porosity, should have a high packing density. How do we achieve that?

If we look at packing density of single size particle, you know if we look at packing density of single sized particle, say just 1 unit size say spheres, then they would pack to you know single sized particle, they would simply pack to a relatively low packing density, even if it is sphere then relatively low packing density. And it depends upon its packing arrangement. For example, this is a simple cubic arrangement it will have a characteristics porosity of about 48 percent. In other words the packing density of about 0.52, we shall see that, so simple arrangement.

But supposing I have better; let us say body centered cubic arrangement or face centered cubic arrangement, then I have better packing density. So, but, you see this there is a limitation, I cannot go beyond with single sized particle the porosity which is nothing, but the volume of voids present you know here divided by the total bulk volume; that is ratio actually and that ratio is for a given single sized particle is relatively quite high, the porosity is quite high you cannot reduce it. Whatever may be the size of this particle, irrespective of the size of the particle porosity remains same, because you can make size finer or coarser because it will remain same, because relative volume relative total volume you know relative volume of the pores divided by the relative total volume I am interested in.

So, relative volume of this volume divided by this volume, similarly in another case if I have smaller particles, in that case the pores are here this relative volume or I may use another color, relative volume you know relative volume of pore to the total volume or porosity; they would remain same, irrespective of the size of the particle. So, that is important. If you have single sized particle, you will have porosity similar irrespective of the size of the particle, it will depend only on packing. As I mentioned in the packing density of simple cubic, body centered cubic and face centered cubic arrangements are 0.52 0.68 or 0.74. 1 can theoretically calculate this.

If you are looked into crystal structure you know school days you know arrangement of crystals this is also there in those case. So, we can see that if I have you know if I have a simple cubic arrangement, irrespective of the particle size, irrespective of the size of the particle the packing density is 0.52, irrespective of the particle size it is point 0.68 for body centered cubic and for face centered cubic this is 0.74. So, particle single particle size will always give this.

So, it is not single particle size definitely, not a very efficient thing to do. Actual packing density of course, in case of sphere of single size lies somewhere between 0.5264 and 0.74 0.2568 and so depending upon what is the arrangement. So, you cannot feel improving it very much, because 0.74 is a specific type of arrangement which you never get. You can get actually theoretically it is possible, but actually that is the maximum theoretically maximum, but you get it much less packing density with single size.

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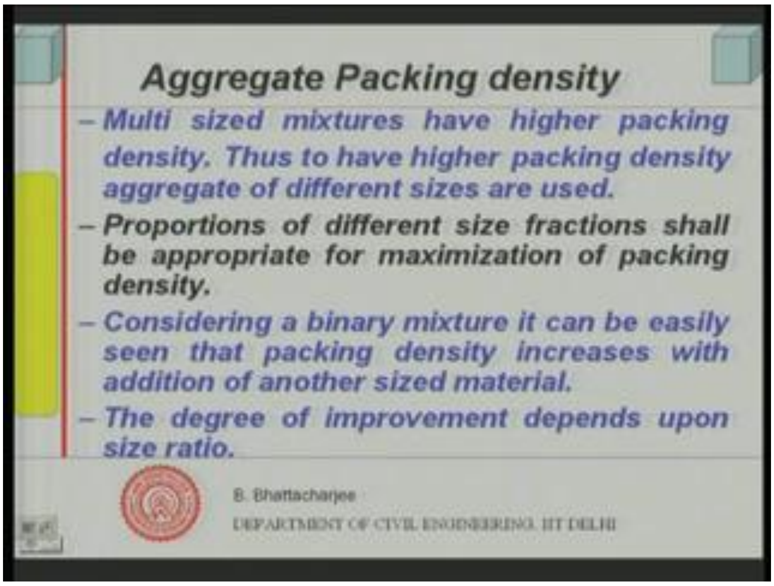

Aggregate Packing density

- Multi sized mixtures have higher packing density. Thus to have higher packing density aggregate of different sizes are used.
- Proportions of different size fractions shall be appropriate for maximization of packing density.
- Considering a binary mixture it can be easily seen that packing density increases with addition of another sized material.
- The degree of improvement depends upon size ratio.

B. Bhattacharjee
DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

But supposing I add another size to the same single sized particulate system, this will improve the packing density, because the finer size say original was larger size, now I put a finer size; the finer size will go into the interstitial pores of the original coarse size and resulting in reduction in the voids paste right. So, if you want to get higher packing density, then we should actually use aggregate of different sizes. If you want to get higher packing density we should use aggregates of different particle sizes and that is what we actually do in practice.

The proportions of this different proportions of this different size fractions shall be appropriate, because we just cannot add anything to anything any proportion and you will get improve it, now there is a you know inside an sudden rules you must do according to sudden rules and that is how you can maximize the packing density. Now we will look into the case of a binary mixture and we shall see how this packing density increases. We will see the binary mixture and we will see how this increases.

So, we will go to the binary mixture and we will see how this increases. So, we will, this degree of improvement also depends upon the size ratio. So, you go to the binary mixture and see how this packing density increases with another sized material and degree of improvement of course, depends on the size ratio. We shall see that next.

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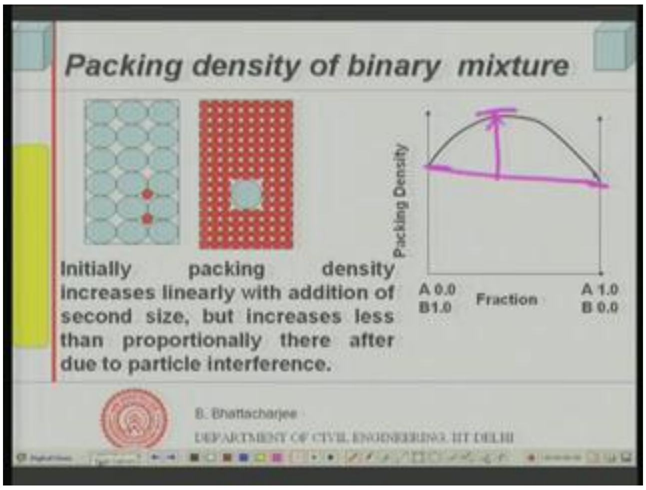

Packing density of binary mixture

Initially packing density increases linearly with addition of second size, but increases less than proportionally there after due to particle interference.

B. Bhattacharjee

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Consider this case: supposing I have got a singled sized particle as shown here, single sized particle you know it is all same sized spheres. Let me say nearly rounded all aggregate. Now, I add to this fine particles. So, where it will go; just little bit very small amount, then it will go into the interstitial pore space. You know this red ones are the fine particles that I have added into the system. So, they will go into the pore space interstitial pore space of the large particulate system.

If I go on adding further then of course, they will go on filling and it will sink down the voids, because they are going into the interstitial pore spaces. But time will come that the original packing of the large size aggregate will be disturbed and that time they would get separated further, because this fine particles have come and they are trying to occupy the space within that. So, this is called particle interference. So, the rate at which the voids are reducing will now diminish. Let me repeat; first of all we have got all large size particle, you put very small amount of fine size particle. It will go into the interstitial space you know pore space of the large particle, without disturbing the large size particle. So, voids will reduce.

Now, next what will happen; it you know next actually if you go on increasing it further, it will the finer particles they will tempt to go into the pore space between the larger particle, but they will try to push this larger particle apart. So, this is called particle interference. So, rate at which voids would be reducing would get now reduced. Initially it will reduce the voids, voids would reduce at a higher rate with increase in the finer particle, but if you go on further finer and finer particle you will not get reduction of voids at the same rate.

But, when you are adding too much quantity of this fine particles, then fine particles will start dominating and actually pores, because if they are more than this voids space available, then they will be separately as an separate material. So, void space within the fine particles will now add to the voids. So, in other words if you look at packing density; packing density will initially decrease, but its rate of decrease you know rate of decrement would reduce. There will be a maximum and then it will start increasing. We can see that, let us see we can see that how it occurs.

See supposing I have got from the reverse side, when too much of fines are there, I have a situation like this too much of fine and I add too much of fine it was full and I will just add this material here 1, you know remove some of this and put a large size particle as this. So, in such situation when too much of fine is there; little bit large sized particle 1 just for large sized particle I have added. This volume is of pure solid volume. So, it will reduce down the voids. In other words, packing density would increase. So, when I start from I started earlier from I started earlier from coarse side particle added fine particle.

Supposing I have large fine particle from the other side and I just remove some amount of fine particle put across particle, void will again reduce packing density will increase. I go on doing this, this will occur in the same manner, but after some time the packing occurs the fine particle will be disturbed by the larger particle. The result is something like this. The packing density versus fraction curves would be something of this kind, you know supposing A and B; this is larger 1 is let us say A say this is A and this red ones are B. So, A; I increase go on you know B was 100 percent here I go on increasing A. So, the packing density will initially increase, but the rate of increase is not linear, it goes on reducing down the peak is reached and it follows like this.

Similarly, if I start from this side I have got all large particle, then the small particle I go on adding a little bit, packing density will increase they will be maxima and there will be a reduction. So, what we observed from this is; packing density increases linearly with addition of second size, but increases less than proportionally there after due to particle interference and you know there after it increases. So, there is a maximum point of packing density. And at particular proportion, we will get maximum and by adding 2 particle size you can reduce increase the packing density.

If you go back again to the earlier 1 if you go back to the earlier 1 again will see that packing density of B was here, will see that packing density of B was here actually you know packing density of B was here and packing density of A was here. So, as you combine 2 materials packing density is actually improves, it is much higher than both of them you know, it is much beyond much higher than both of them. So, by adding 2 different particle size, we can actually improve the packing density.

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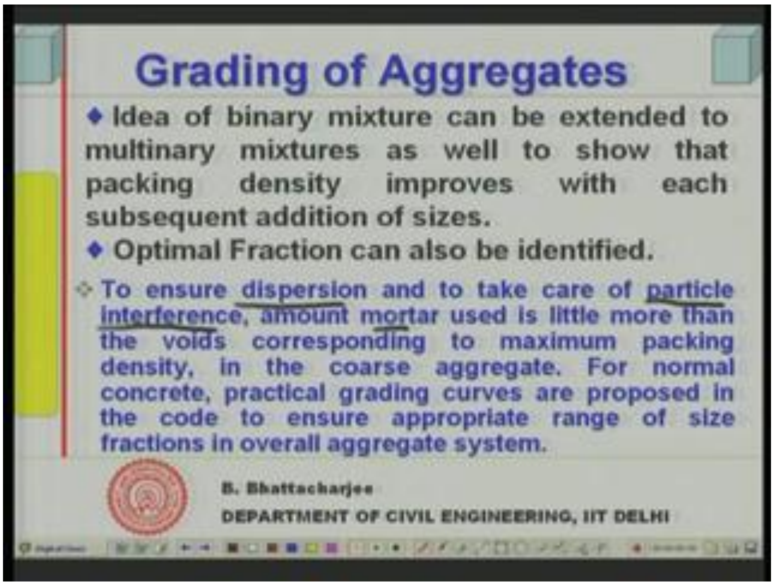

Grading of Aggregates

- ◆ Idea of binary mixture can be extended to multinary mixtures as well to show that packing density improves with each subsequent addition of sizes.
- ◆ Optimal Fraction can also be identified.
  - ◇ To ensure dispersion and to take care of particle interference, amount mortar used is little more than the voids corresponding to maximum packing density, in the coarse aggregate. For normal concrete, practical grading curves are proposed in the code to ensure appropriate range of size fractions in overall aggregate system.

B. Bhattacharjee
DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

If you repeat this for many particle sizes the packing density you can maximize. So, you can increase the packing density from binary mixture to trinary mixture packing density will still increase and if you multinary mixture the packing density will increase in a significant manner. So, each subsequent addition of sizes actually will increase the packing density. So, that is the idea. So, therefore, you should have large.

So, that is why we use several sizes of aggregates in concrete to reduce down the packing density so that, our paste content required for a given volume is less. We can identify the optimal fraction as we have seen, by some simple equations 1 can identify, but overall if you have a multinary system it becomes a complex thing, requires certain experimental factors experimental determination of certain factors. We can identify, but we do not do that actually, because this theories we have not really clearly developed, of late only there are certain models available on packing density.

So, what we do is; we use what is known as practical grading. So, practical gradings we use actually instead of using. So, this we said that we can do it, but theoretically we do not do it to ensure dispersion and to take care of particle interference etcetera. This is another issue; the mortar used should be more than little more than the voids corresponding to the coarse or aggregate, maximum density of coarse or aggregate. Paste should be more than the void space in the all total aggregate and the paste and sand that makes the mortar, mortar should be more slightly more. In mortar actually the coarse or aggregate gets dispersed therefore, mortar should be slightly more than that of the voids in the course or aggregate system.

So, in case as I said in normal concrete what I do is; we use practical gradings, you know these are proposed and practical gradings which are proposed in codes and for basically we cannot model it for packing density etcetera, it is there are lot of you know lot of complexity involved varies from place to place. So, at the moment the practice is to use practical grading curves for normal grade of concrete, although there are mix designs based on packing density as well.

Now, we are available in literature, but common practice is to ensure that your aggregate falls into a right kind of particle distribution, because that would give you good kind of packing. So, the ranges of particle size distribution that is proposed and this we call aggregate grading. So, range of sieve fraction of overall aggregate system is proposed.

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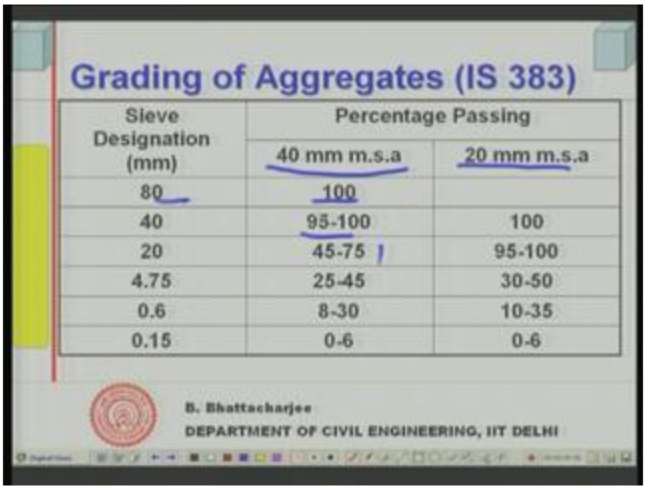

Grading of Aggregates (IS 383)

Sieve Designation (mm)	Percentage Passing	
	40 mm m.s.a	20 mm m.s.a
80	100	
40	95-100	100
20	45-75	95-100
4.75	25-45	30-50
0.6	8-30	10-35
0.15	0-6	0-6

B. Bhattacharjee
DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

For example, IS 383 is the code Indian standard code is IS 383 and there this is for all in aggregate. When your sand and aggregate combined, this is a kind of grading suggested whereas, say for grading suggested for 40 mm maximum sized aggregate m s a stands for maximum size aggregate. 20 mm maximum size aggregate. So, it should pass through 80 mm sleve 100 percent 40 mm etcetera. So, it tells you that, it must by sleve analysis actually you do it, you do it by sleve analysis, we have nominal sleve size square sleve size and 90 to 100 percent should pass through 80 millimeter 80 mm square sleves. So, you know and because they are not the spherical particles, they are any can be irregular crust etcetera.

So, this through this sleve analysis results gradings are confirmed right and this is the suggested grading that should proposed grading, one should follow in case of all in aggregate as per IS code.

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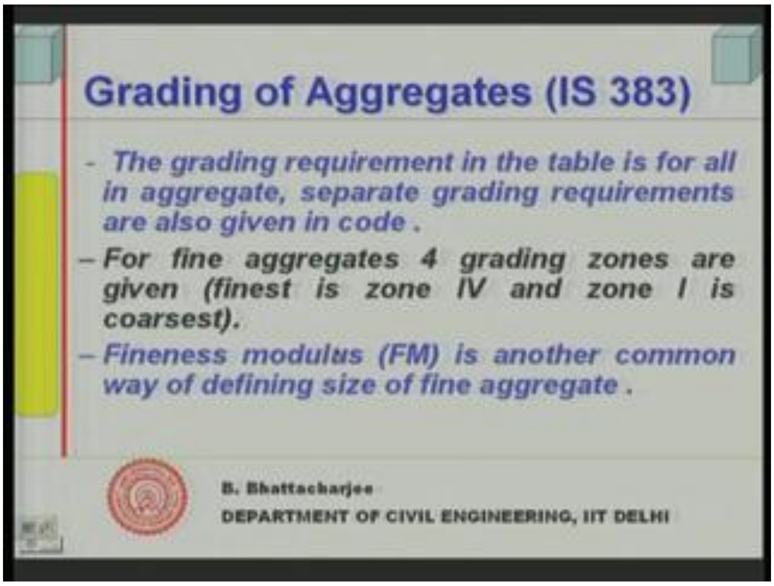

Grading of Aggregates (IS 383)

- *The grading requirement in the table is for all in aggregate, separate grading requirements are also given in code .*
- ***For fine aggregates 4 grading zones are given (finest is zone IV and zone I is coarsest).***
- *Fineness modulus (FM) is another common way of defining size of fine aggregate .*

B. Bhattacharjee
DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

Similar grading curves are available for coarse aggregate alone or sands, you know these are given in the same code, it is given. I just picked up 1 to show you the as an example to give the grading and, but details are available in the same code right. Now for fine aggregates, the code defines for grading zone. You know finest is zone 4 and zone 1 is the coarsest. So, you defines it defines actually 4 zones, zone 4 and zone 1 2 3 4, 4 is the finest maximum fine particle and 1 is the coarsest.

So, fine aggregates that is usually sand or crust sand or whatever it is river sand or land sand, this gradings are defined. The 1 table I showed corresponds to combined aggregate, but you cannot separate. In some places you might come across what is known as fineness modulus of sand, because fineness modulus also defines like, like the zone defines the sizes of the sand fineness modulus also defines the average size of the sand, average sieve of the fine aggregate, in terms of sieve number average sieve number. So, it is that is how we define. Just let us look into the fineness modulus.

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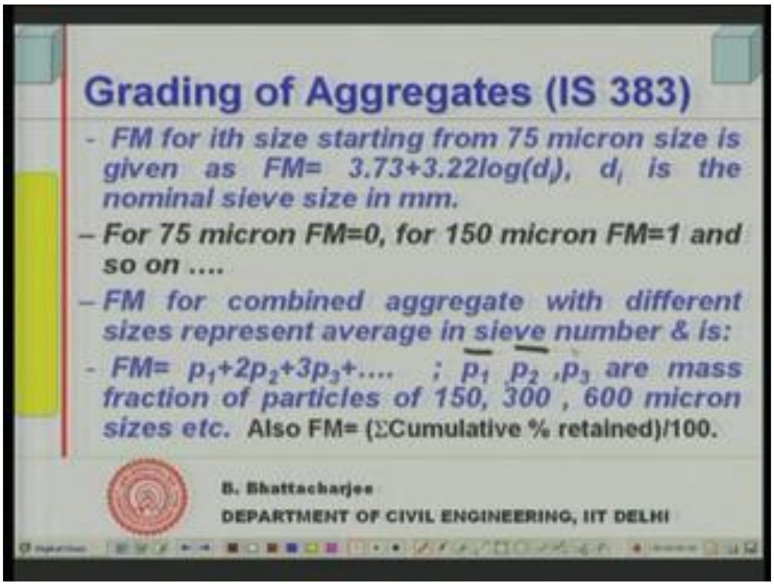

Grading of Aggregates (IS 383)

- FM for ith size starting from 75 micron size is given as FM= $3.73+3.22\log(d_i)$, d_i is the nominal sieve size in mm.
- For 75 micron FM=0, for 150 micron FM=1 and so on ....
- FM for combined aggregate with different sizes represent average in sieve number & is:
- FM= $p_1+2p_2+3p_3+....$; p_1, p_2, p_3 are mass fraction of particles of 150, 300 , 600 micron sizes etc. Also FM= (ΣCumulative % retained)/100.

B. Bhattacharjee
DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

Fineness modulus of ith size starting from 75 micron, size is given as 3.73that is an expression very simple expression. And if you put d i is equal to 75 micron here, here d 1 you know you will find this value equals to 0. If you put 150 micron because our sieve coefficient is 275, then 150 micron is coefficient this is called coefficient, multiply by 2 you get the next sieve size 150, multiply by another 2; 300 600 120 1.25 1.18 millimeter that is and 2.36 nearly above 2 and so on, because they got change from the British unit to the SI or you know what you call MKS or CGS unit. So, therefore, there are slight differences, but usually nearly about 2.

So, sieve coefficient is 2 and log 2 you know is 0.3010 multiplied by 0.322 will give you 1. So, d is as this is 75 this is equal to 0, if it is 150 this will be equals to 1, if it is 250 300 this will be equals to 2 and so on. So, as the sieve size increases, nominal sieve size increases you know the fineness modulus increases by 1, 2, 3 etcetera. For example for 75 micron fineness modulus is 0 for 150 micron fineness modulus is 1 and for 300 micron it will be 2, for 600 micron it will be 3 etcetera.

So, in a way fineness modulus for individual sieve size; it corresponds to the sieve numbers, starting from the bottom most sieve right, which is 0. FM for combined aggregate that is for sand which has got all or sand or even for total aggregate you can use for any combined aggregate, this is given as a weighted average size. For example, it is given as p 1 2 p 2 3 p 3 etcetera, where p 1 and p 1 p 2 p 3 etcetera this ones are the mass fractions of particles in 150 300 600 micron sizes.

So, p 1 means the particle fraction in 150 micron passing to 300 retain in 150, I mean passing to 100 retained and passing to 300and similarly p 2 is passing through 600 retained 300 etcetera. And if you some this up this will give you p 1 2 p 2 3 p 3 etcetera that will give you the overall fineness modulus of the overall fineness modulus of the aggregate system. Well, by algebraic 1 can show that fineness modulus, same thing can be calculated as cumulative percentage retained. Sum of cumulative percentage retained in each sieve divided by 100. You know if you cumulate total sum of cumulative percentage retained in each sieve.

So, you know the cumulative percentage retained in number 1 sieve, number 2 sieve from the top largest size, the next sieve the cumulative percentage retained with that retained in the previous sieve and this sieve and so on. So, if you sum all of them up and divide by 100 you get FM, because this will algebraically will be same to this. So, this is the measure of average size in terms of average sieve number. So, that is what is fineness modulus, sometimes this is used to denote the fineness of the aggregate like zone 1, zone 2, zone 3, zone 4.

So, we have seen that grading of aggregate is important, because if you have different sizes in the right combination, then you can reduce some of the packing density. So, and we do control it through grading.

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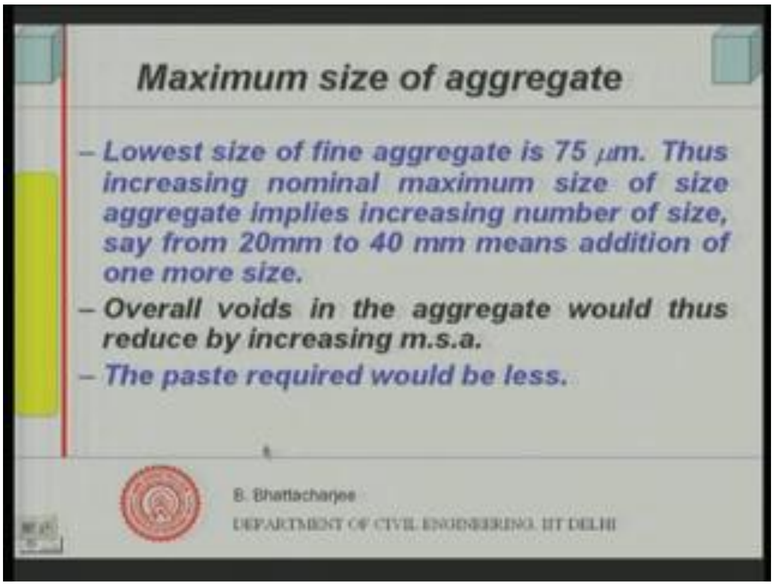

Maximum size of aggregate

- Lowest size of fine aggregate is 75 μm. Thus increasing nominal maximum size of size aggregate implies increasing number of size, say from 20mm to 40 mm means addition of one more size.
- Overall voids in the aggregate would thus reduce by increasing m.s.a.
- The paste required would be less.

B. Bhattacharjee

DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

Next aspects about the aggregate role of aggregate is the size of aggregate. Lower size of fine aggregate is 75 micron. So, least size is 75 micron, I do not have anything lower than that then I will go to cement or cementitious sizes. So, 75 micron is the lowest size of aggregate. So, if I want to increase the aggregate packing density, I will have nothing lower, but if I know that if I make this aggregate from binary to trinary, trinary to protonary etcetera and increase the number of sizes, then packing density improves. So, if I increase the maximum size of aggregates of the higher side, I am now increasing 1 more size. Therefore packing density will increase.

So, maximum size of aggregate if I increase packing density will increase. So, nominal maximum size of you know aggregate implies that, increasing number of size sieve size number of size from you know from 20 to 40 millimeter means addition of 1 more size. Therefore, what will happen this will ensure that my packing density has increased. So, increasing maximum size ensures that, I increase my packing density. So, overall voids in the aggregate would thus reduce by increasing m s a. The paste required would be less. That is the idea. The paste required would be less. So, that is the role of m s a.

So, 2 things we have seen so far; 1 the grading of aggregate, that is, you know proportions of various size fraction and they are important, also maximum size of aggregate that is number of size fraction that is important. So, maximum size of aggregate actually improves the number of size fractions.

Aggregate shape is a next issue.

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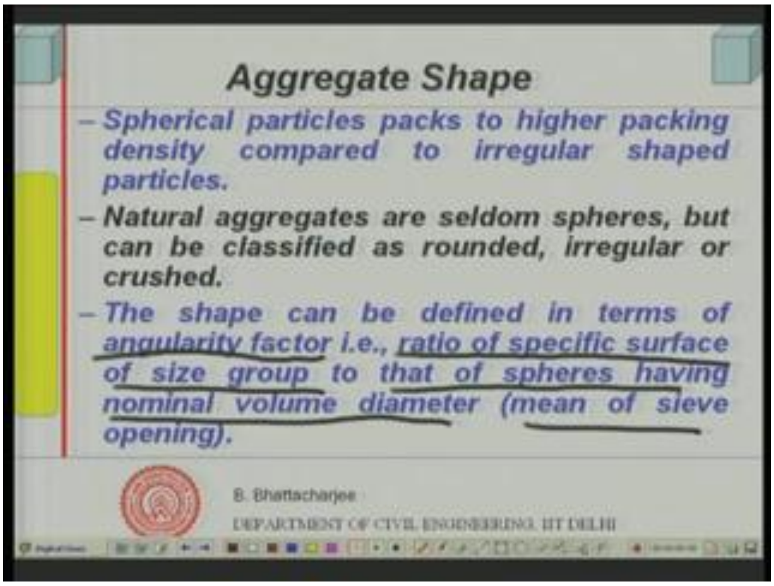

Aggregate Shape

- Spherical particles packs to higher packing density compared to irregular shaped particles.
- Natural aggregates are seldom spheres, but can be classified as rounded, irregular or crushed.
- The shape can be defined in terms of angularity factor i.e., ratio of specific surface of size group to that of spheres having nominal volume diameter (mean of sieve opening).

B. Bhattacharjee
DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

This must be understood very well, because there can be little bit of confusion sometime. Spherical particles packs higher packs to higher packing density compared to irregular shaped particles, this is important. Irregular shaped particles do not pack to good density; spheres would pack to good packing density higher packing density. If you have also say irregular they will have lot of voids within in the interstitial voids within them. Natural aggregates are of course, thought spheres definitely, but they can be classified as rounded you know rounded gravels natural gravels of course, will be rounded. If you get it from river bed they will be all rounded, because of abrasion that has gone in natural abrasion that it would have gone in. So, that will be rounded because through abrasion.

So, natural stones you know gravels if you collect them they will be rounded. So, rounded aggregates are natural like that. Same, similarly river sand would be rounded, even land cored sand would be rounded sought of natural ones would be rounded. But if you have crushed, they are unlikely to be rounded, because they will you know crossed means they are failed in the frailer plane in the weaker slain and the crushed ones are not rounded. There can be regular shapes in between somewhere.

So, basically we will classify generally for all our purpose rounded and crushed later on sometime, but it could be rounded, irregular or crushed. So, 1 can define them as rounded, irregular or crushed. 1 of the ways there are several ways of if you trying to define the people have tried to define the shapes in several ways, various indexes has been used. But 1 of the ways that I would like to introduce here is say in terms of what is called angularity factor, generally given by Loudon somewhere in 1950s.

Now, this he defined as a ratio of specific surface of size group to that of spheres having nominal volume diameter, means the sieve opening. Let me repeat; first you find out you do sieve analysis and by permeability test you measure the specific surface of that particular size group. You know the sieve size, so you find out the specific surface, that is centimeter square per gram or you know equivalent unit in square per pound or whatever it is. And also from that you find out what is the equivalent diameter, divide this by the nominal sieve diameter.

Now, this is a measure of the angularity, this is a measure of the angularity. Higher this value it means your surface area is large compared to the volume. For spheres this equals to 1, because surface area is you know to volume diameter they will give you same identical. Now here you calculate out the surface area and then try to find out the diameter of equivalent sphere, this diameter will tend to be large as you will have large surface area, you know surface area per unit volume and then try to find out the equivalent diameter.

So, for irregular shape surface area is more therefore, corresponding diameter will be more. So, angularity factor is defined in terms of the specific surface of the actual aggregate divided by the nominal sieve size and that is higher value means it is angular, higher value means it is angular higher value means it is you know less spherical. So, that is what 1 would say.

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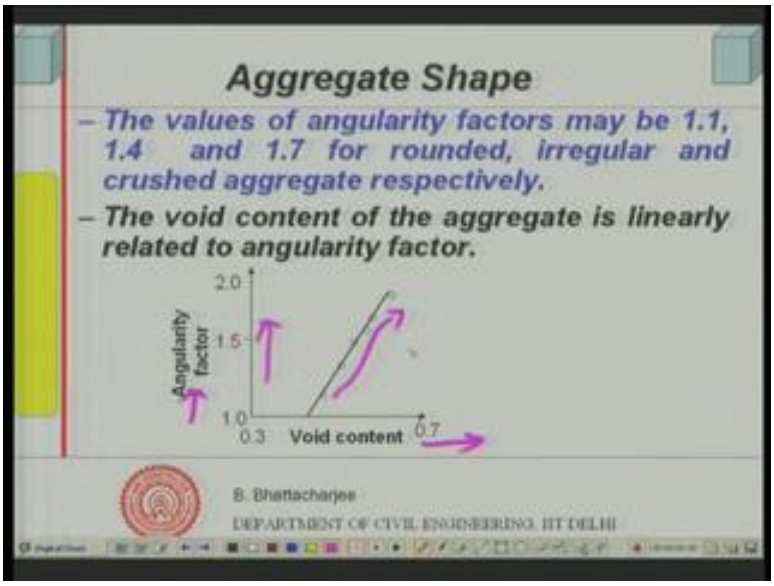

Aggregate Shape

- The values of angularity factors may be 1.1, 1.4 and 1.7 for rounded, irregular and crushed aggregate respectively.
- The void content of the aggregate is linearly related to angularity factor.

B. Bhattacharjee

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So, for example, you can see the values are 1.1 1.4 and 1.7 for you know for 1.1 1.4 and 1.7 for rounded, irregular and crushed aggregate respectively, it is from measurement at some sizes there could be slight difference, but it should be understood that for rounded aggregate this value is less, for crushed this value is much higher the angularity factor is much higher. So, that is the idea. And if we now look at the void content of the aggregate, people have measured this void content with this angularity factor and they observed that, we say linear relationship this we say linear relationship. So, this side if I plot void content, if I plot void content along this side say 0.3 to 0.7 angularity factor increasing along this direction. So, for 1 which is in perfectly sphere and some data’s are here. So, you will see that as my void content you know angularity factor increases void content increases.

So, rounded aggregate packs better, crushed aggregate will pack to lower packing density. Therefore, you need possibly more paste content rounded aggregates require less paste content. So, rounded aggregates will require less paste whereas, crushed aggregate will require more paste. In other words, you know workability associated with the rounded aggregate would be better, it would require possibly less water in concrete as we will see some time later on in the context of mix design. So, aggregate shape is an important issue.

So, 3 aspects we have seen; 1 the grading, you know fractions of different sizes. Second issue is the maximum size of the aggregate, that is, number; number of size that is involved. So, that is m s a and third we have seen the shape. So, this 3 are the major factor and they govern the paste content and therefore, they govern that is the role of the in workability or consistency of concrete. Higher, higher, more number of sizes and higher m s a right kind of grading proportions of each size is proper and rounded shape will give you better workability.

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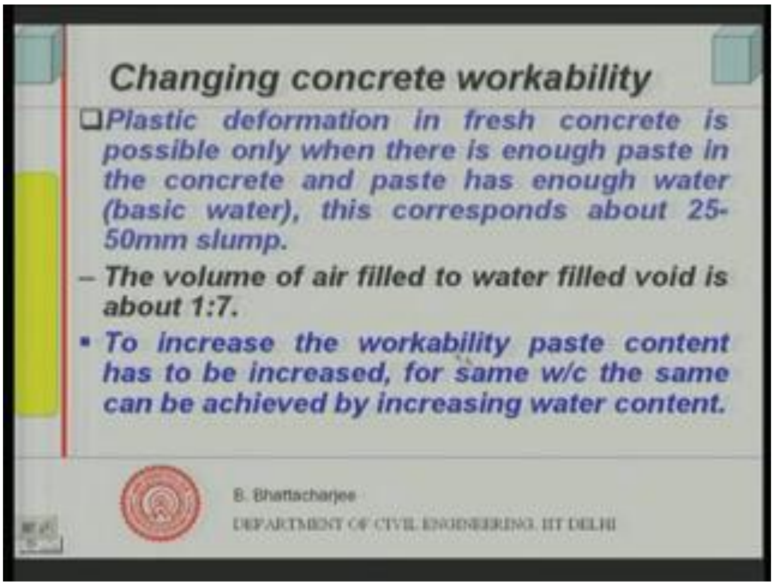

Changing concrete workability

❑ *Plastic deformation in fresh concrete is possible only when there is enough paste in the concrete and paste has enough water (basic water), this corresponds about 25-50mm slump.*

– ***The volume of air filled to water filled void is about 1:7.***

- *To increase the workability paste content has to be increased, for same w/c the same can be achieved by increasing water content.*

B. Bhattacharjee

DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

So, we can now look into how do we change concrete workability, this so far we have talked about only normal strength concrete and we have not talked about concrete with what is known as admixtures special additives, which you can add to improve the workability etcetera. So, normal concrete the 4 ingredients concrete; that is the cement, the water, a fine aggregate fraction and coarse aggregate fraction. So, with this concrete, if I have seen what is the role of the paste water and water to cement ratio and the paste and then we have looked into role of various aggregates.

So, we have looked in the role of component, we have not looked into anything, where by adding some additives we can improve the workability etcetera. So, let us look at how do we change the workability if I do not have any admixtures right. Plastic deformations in fresh concrete, is possible only when there is enough paste. This must be understood. By this time it must be clear that there must be enough paste in the concrete and the paste itself must be consistent, at least must have enough water that is initial basic water, you can have higher water that is fine. So, this basic water that is corresponding to the normal consistency nearly same has been observed. So, this you know this should be there.

Now, normal that would give you the normal consistent paste and normal consistent concrete normal consistent concrete has slump of 20 to 50 millimeter. So, normal consistent concrete will have a slump of which has sufficient amount of paste into it and paste itself is sufficiently consistent, that sought of the concrete will have 20 to 50 millimeter slump. Let me just point out here, you know in the context of concrete we shall see in terms of when you do mix design, that in mix design process we initially determine the water to cement ratio from strength criteria. When we discuss further about the strength, we will see that strength is mainly governed by water to cement ratio.

So, you fix the water to cement ratio from strength criteria. Then from workability criteria fix the water content. The idea is very simple; for given water to cement ratio if I increase the water content I am actually increasing the paste content. By increasing the water content as well as by increasing cement, because water to cement ratio is to maintained constant, that I cannot change. If I increase simply water my paste will increase, but strength may reduce. So, I keep the water to cement ratio constant and you know water to cement ratio constant and then increase the water.

So, quite often we understand in mix design that, water content governs the workability of concrete, but that is for a constant water to cement ratio. The water to cement ratio has to be fixed, then water content has a big role, because you cannot increase the cement, then if you increase the cement consistency of the cement paste alone, consistency of the cement paste itself will go down. So, if you increase the water, maintain the water cement ratio, both water will increase cement will increase and in the process actually workability will increase strength will remain same. So, this is important issue

So, to change actually to change what I should do; I should actually increase the paste and I also already mentioned that, volume of air filled to water filled void in case of a consistent mix in case of consistent cement paste is 1 is to 7. I just mentioned again repeatedly, because consistent cement has to be there. To increase the workability paste content has to be increased for same water cement ratio, as strength has to be maintained same right and this can be done by increasing water content. And that is what we do in case of mix design.

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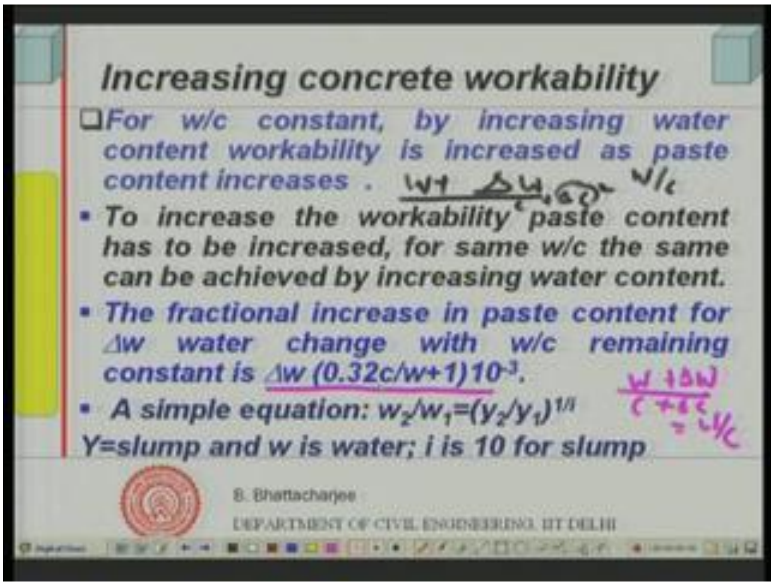

Increasing concrete workability

☐ For w/c constant, by increasing water content workability is increased as paste content increases . $\frac{w+\Delta w}{c+\Delta c} = w/c$

- To increase the workability paste content has to be increased, for same w/c the same can be achieved by increasing water content.
- The fractional increase in paste content for Δw water change with w/c remaining constant is $\Delta w\,(0.32c/w+1)10^{-3}$.
- A simple equation: $w_2/w_1=(y_2/y_1)^{1/i}$

Y=slump and w is water; i is 10 for slump

$\frac{w+\Delta w}{c+\Delta c} = w/c$

B. Bhattacharjee

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For water cement ratio to be constant right, by keeping water cement ratio constant, increase the water content water workability increases as paste content increases. That is what I mentioned. Therefore, how do we do; what we see is supposing I have I increase delta w increase the water, I said that I can increase my water content say by delta w. I must keep my water to cement ratio constant, otherwise my strength will be disturbed. So, supposing I have added delta w amount of water, my water to cement ratio is to be constant. So, w divided b delta w divided by c plus delta c, this must be equal to w by c. So, c delta c also there will be an increase in cement content also.

So, I must increase my cement content and because I must increase my cement content you know. So, I must increase my cement content w plus delta w divided by c plus delta c should be equals to w by c if, I have to maintain water cement ratio. And using this algebraic, if I try to calculate out what will be the increase in the paste volume, the formula will give me this. The formula will give me this because; delta c can be replaced in terms of w by c and delta w. And if I you know use just a little bit of arithmetic I will see the volume fraction of increase in paste will be given by this 0.32 c divided by w, where 0.32 c is the specific volume of cement, because we know specific gravity of cement is 3.15. So, 1 by 3.15 is this into c by w plus 1 delta w into 10 to the power of minus 3.

So, if I add a little bit of water, I actually increase the paste content by this much fraction you know volume of fractional increase in the paste content is given like this. So, that is what we actually do in practice. A simple equation has been proposed for increasing the workability for increasing the workability. This is called a k factor method does not matter, but let me explain this equation. This is this can be used supposing w 2 is the slump or any other consistency measure, usually slump will be etcetera, w 2 is the water content for the slump of y 2. So, y 2 is the consistency measure, w 1 w is the water corresponding water. So, w 2 is the water content for w 2 is the water content for y 2 slump, w 1 is the water content for y 1 slump.

Then w 2 by w 1 is equals to y 2 by y 1 divided by 1 over i, where i is an index depends upon the method of measurement of consistency of concrete, say slump could be 1 of them Ve be etcetera. So, i for slum p is 10, i for slump is 10 for Ve be it is different, compaction factor the equation becomes slightly different and so on for each you can 1 can define, but I have just taken in case of slump. This is a simple equation through which you can find out how much water should be there. Supposing you know w 1 is the water for your y 1, that is, slump equals to 50 millimeter. Now you have to find out the slump for 100 millimeter, so this is 100 and what should be the water that you can find out from this formula, i for slump is 10. So, using this kind of relationship actually 1 can find out what is the water requirement. We might discuss this a little bit more in connection with mixed design.

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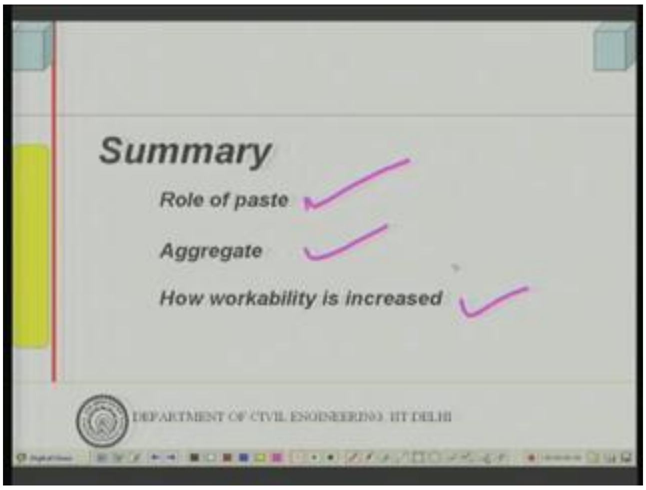

Summary

Role of paste ✓

Aggregate ✓

How workability is increased ✓

So, therefore, we will summarize our discussion. What we have discussed is so far is the role of paste. The role of paste we have understood the role of paste. We have understood the role of paste. We have understood the role of aggregates and how workability is increased. So, we have understood the role of paste, role of aggregate and how workability is increased. This we will use again in context of mixed design. I think that would summarize all our discussion and end our discussion.

Thank you for hearing.