Concrete Technology
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Lecture - 37
Special Concrete: High Strength Matrices and SCC

Welcome to module 9 lecture 2. So, in the last lecture we looked into high strength concrete, some properties we had introduction principles etcetera etcetera and some properties. Today, we will look into some more properties and then basic you know issues some stress, that we do for workability and related possible mix design scenario, mix proportioning scenario and then self-compacting concrete. We will just introduce today.

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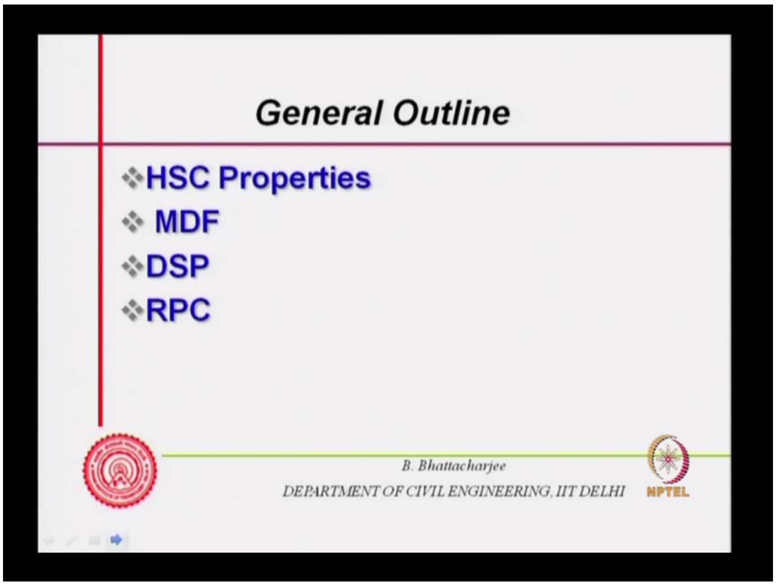

So, that is outline of our discussion today is H S C high strength concrete properties, M D F macro defect free matrices, because other high strength matrices, we will look into today and then D S P densified with small particle and reactive powder concrete and just introduction to self-compacting concrete. So, me of these we will look into today.

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So, if you recall in the last class, we just said that high strength concrete has got high modulus of elasticity and low fracture toughness because, area under the curve is low and then it has got very good durability by enlarge, most of the cases it has got very good durability.

It has got improved mechanical properties most of it and then fracture energy, then stress intensity factor they are better but, not proportionally better and c f, these are the micro cracked zone, dimensions of micro crack zone ahead of tip of advancing crack that is the a Fire property is of course suspect that is where we stopped in the last class and then, gain fracture mechanics related properties, these are smaller than the normal concrete.

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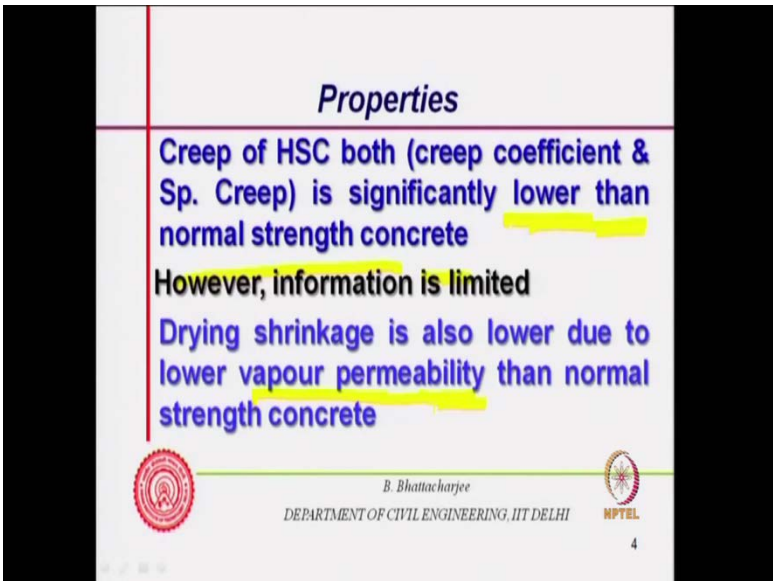

Let us look into other properties such as creep. Now, creep of high strength concrete both in terms of creep coefficient or specific creep, if you recall when you discussed about creep, we defined creep coefficient as well as both specific creep and both are actually significantly lower than normal strength concrete. Now, as we have discussed earlier also, that actually creep is relatively less understood, you know its mechanism is relatively less understood, here also seems to be there is a limitation of information and also limitation of understanding.

So but, what we understand is creep is lower. So, normal strength concrete significantly lower. But, we have somewhat better understanding of shrinkage and that is what we have seen earlier also. You know when we talked about shrinkage in general, the drying shrinkage amongst there. We classified the shrinkage in various classes' chemical shrinkage, autogenous shrinkage and drying shrinkage. You know we classified them all of them plus 16 k and drying shrinkage all we classified, drying shrinkage is lower because, of lower paper permeability than normal concrete because this is lower. So, vapor cannot get out because dense structure, dense microstructure low capillary porosity less water cement ratio. Therefore, vapor permeability is lower.

So, it does not get dried so easily dried you know vapor does not move out of the system therefore, it has got better drying shrinkage properties, it is lower drying shrinkage is lower. So, creep is lower, drying shrinkage is also lower.

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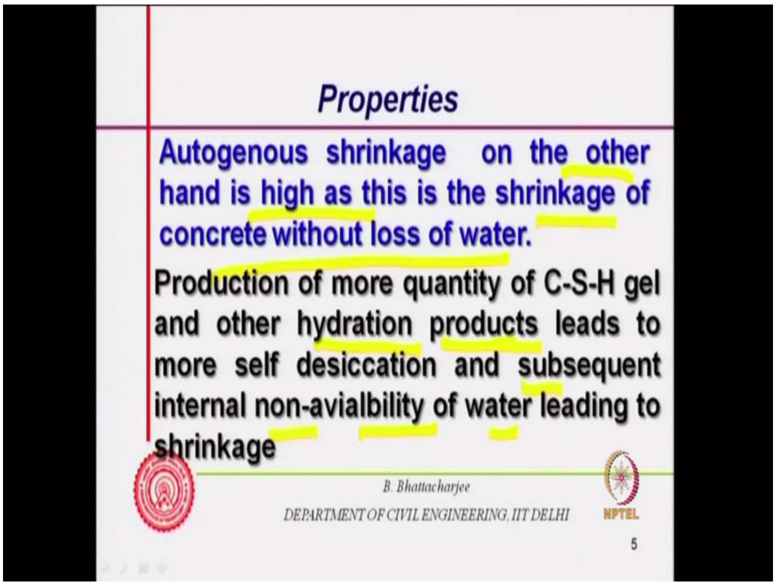

So, this is an advantage in terms of you know usage. But, this is not same with autogenous shrinkage on you know because this is higher autogenous shrinkage is higher, you know as you can remember it is higher, because this has nothing to do with the loss of water. If you recall, you know remember, we discussed that this is the shrinkage that occurs in silt specimen, this occurs in silt specimen and largely related to.

When you have a silt specimen, there is no drying, nothing is going out. Chemical shrinkage was related to volume changes right chemical shrinkage was related to stoichiometric volume changes. Autogenous shrinkage is related to in a silt specimen shrinkage do occur, there is no drying, nothing is going out but, because of the self-desiccation process water is lost in the system and this water loss causes some kind of system you know shrinkage, because there is empty pores with dry empty pores will be there and which means that in the gel will loose some water into those new pores or that would be empty pores that is there and as a result there would be shrinkage. So, this is very much there.

Now, this is related to production of more quantity of C H S gel because more you produce C H S gel and other hydration product is more and the water will be consumed. So, low water cement ratio anyway your space is less. It is a dense structure but, hydration products would be forming more hydration, C H S gel will be forming silica fume reacting with calcium hydroxide, it also would form more C H S gel and water is consumed in all the hydration process. It all occurs in the presence of water and therefore, this leads to more self-desiccation and subsequent internal non-availability of water in the pores leading to shrinkage. So, autogenous shrinkage is more and this is of course, a concern in case of high strength concrete like I said, fire properties are concerned, autogenous shrinkage is also a concerned.

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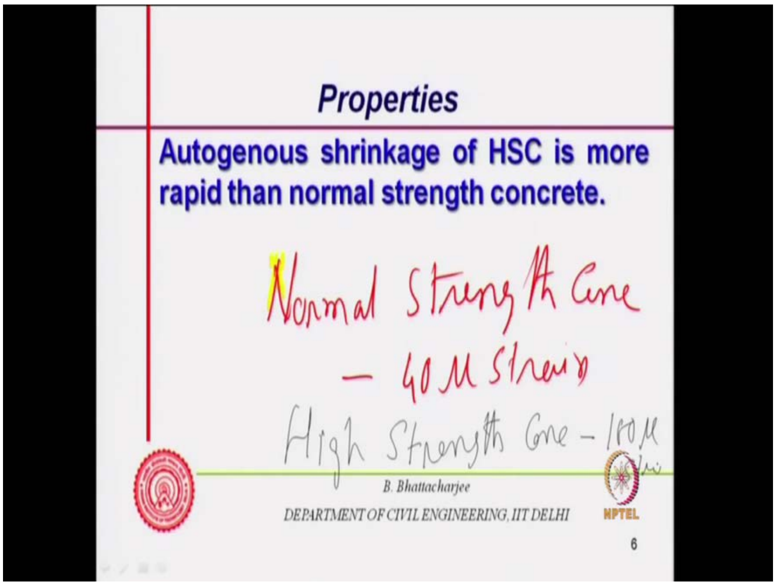

So, more rapid it is also more rapid then the normal strength concrete. So, during the time during which your normal strength concrete will let us say show 40 micro storm strength, say normal strength concrete might show normal strength, concrete may show, may exhibit 40 micro strain same time high strength concrete may show 100 micro strain. So, at a given time, so it is much faster also. So, not only it is more, it can be faster also. So, therefore this is surely one aspect, one must look into right 1 must look into in case of high strength concrete.

Of course, it has got implication in the design and therefore, it design implication could be quite prominent now you must understand. The high strength concrete would be used you cannot you do not use them in all structures high performance concrete you may not use them in all structures.

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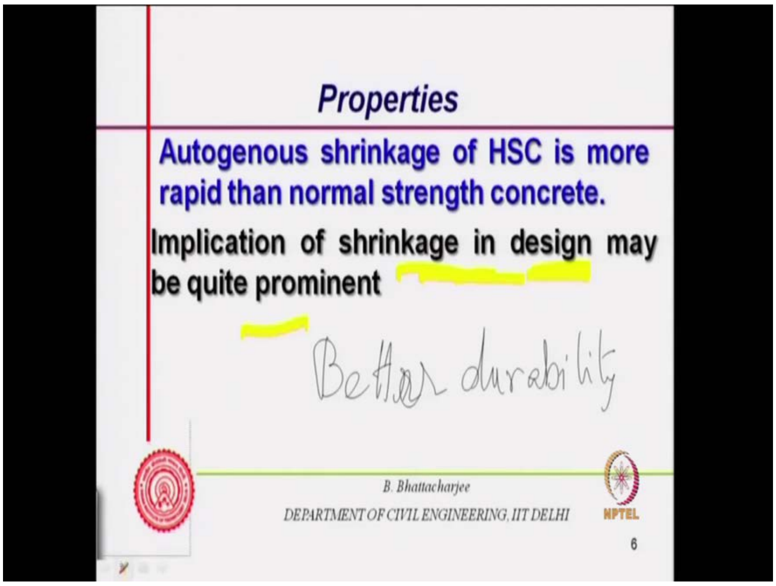

In case of high strength concrete of course, it has got implication in the design and therefore, it design implication could be quite prominent now you must understand. The high strength concrete would be used you cannot you do not use them in all structures high performance concrete you may not use them in all structures.

In last class, we have seen that it has got better durability. So, you might be using simply high strength concrete or high performance concrete from the durability point of view because it is the dense structure. So, the places where this is likely to be used are tall buildings, long span bridges or in extreme severe condition and there those tall structure, we know that shrinkage is got a kind of importance in tall structure, taller structure for example, patrons tower in Kolalampur is also in high strength concrete, the Bombay, Bandar, Worli link it uses high performance concrete you know and some of the flyovers in Mumbai, J J hospital flyover I think it is that you know is one of the flyovers, there we used high strength concrete 70 M Pa, 75 M Pa, 90 M Pa and so on, or 100 M Pa concrete.

Now, they are being used in such structures where they it may be worthwhile to use them or for that matter the new airport terminal in Chennai is using 60 M Pa plus m 60 grade concrete or something of that kind.

Now, these are the structures where you are using them and some of those are long span bridge which are pre-stressed the shrinkage could be an issue therefore, one has to think about their implication in design or tall buildings as we said they could be you know they might have their implication in design as well.

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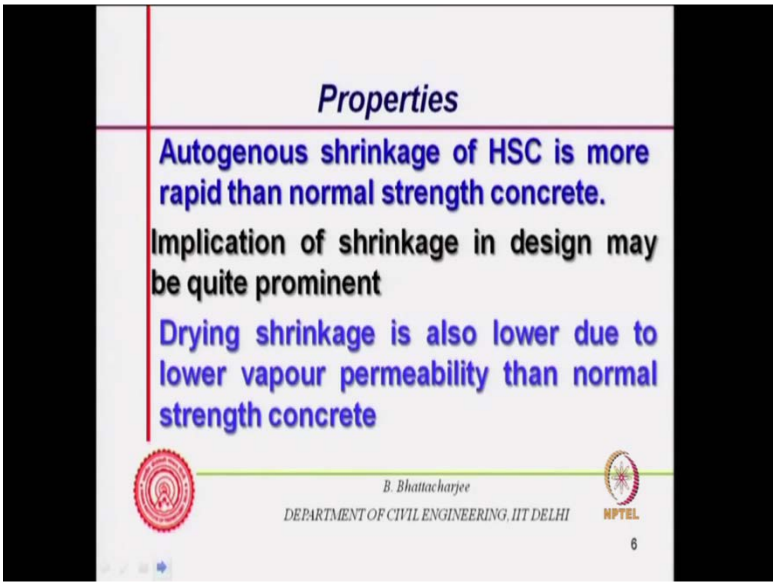

So, one must look into this therefore, this is important but, drying shrinkage is lower as we have already said, this is because of lower vapor permeability then normal strength concrete. So, drying shrinkage is lower, autogenous shrinkage is higher that is because of you know this no water can get out of it. Therefore, dying shrinkage is generally large for low vapor permeability but, autogenous shrinkage is higher.

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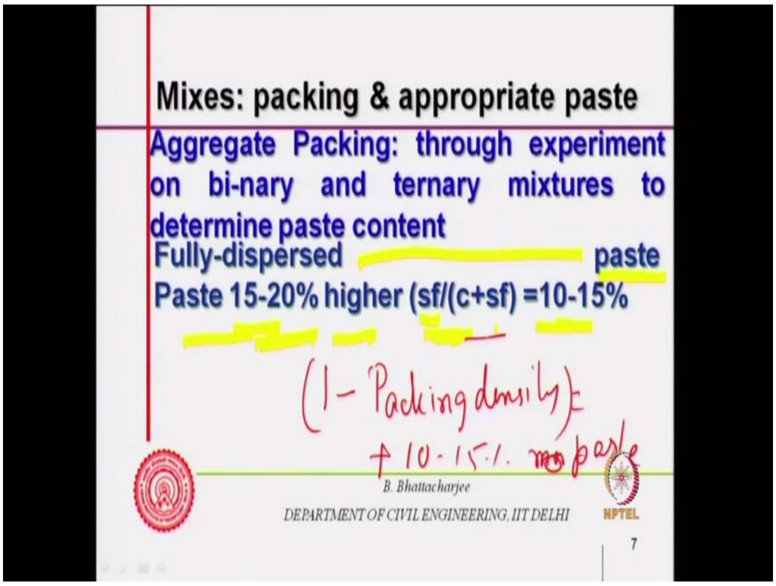

If you know the mixes that you should be doing that should look into the packing density and appropriate paste. Now, while talking about mix proportioning earlier, we said that you know you remember we talked about packing density of aggregate system. So, you look into the packing density of aggregates system and then put appropriate paste quantity aggregate packing through experiment better and binary ternary mixture to determine the paste content required you can follow it up follow to assume that there will be fully dispersed paste.

So, paste 15 to 20 percent higher right for silica fume 10 to and silica fume generally is 10 to 15 percent not 15 percent it could be 10 percent is a good amount. So, 15 to so, you have actually 1 minus packing density, I do not remember what I used but, just let me put it 1 minus packing density gives. You know whatever value you give, multiply this by about or plus 10 to 15 percent extra paste, extra motor extra paste, we have to add paste. So, paste here in higher strength concrete could be somewhat higher and silica fume content is this in very high strength material.

So, just see that it is workable to make it workable paste content would govern the workability as we have discussed earlier. So, it might be 10, 15 percent or even less depending upon what is the kind of workability one desires. So, you can determine the paste content and by packing density

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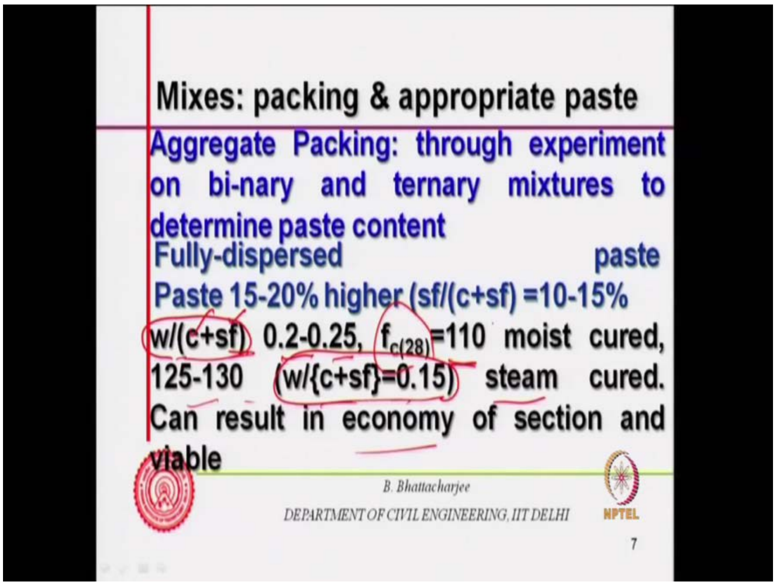

So, you can determine the paste content and by packing density. So, you can determine the paste content and by packing density for water to cement silica, cement silica, you know water cementitious ratio. What we are saying cement plus silica fume because lightly it is silica fume. Which is used in high strength concrete bearing between 0.2, 2, 2, 5 f c that is 28 days compressed strength might be 110 for moist cured situation that is you know and 125 to 130 if it is 1 water toes water cementations ratio being 0.15 steam cured or heat cured and this can result in economy of the section and viable dimensions could be smaller. So, you see you can use about, somewhat higher amount of paste obviously the cost will increase cement silica fume everything is going up but, remember here the volume the mass base is silica fume content total cementitious material may, may not increase significantly because silica fume is highly reactive and its pozzolanicity is quite high.

So, paste 15 to 20 percent higher could be there depending upon the workability requirement silica fume as a percentage of total cementitious should be around 10 percent maximum 15 percent water to cement ratio 0.2 to 0.25. We will get around 110 M Pa concrete that is generally the range but, one has to design this material. You, know design this material and you can have moist cure but, if you cure you can go to slightly higher lower water cement ratio and get a strength of 125, 130 and dimension of the section will reduce and therefore and if you have pre-stress you can imagine you get 120 M pa concrete and your pre-stressing it is it can dimension could be significantly low and economy can be achieved even though the cost of the material.

Will be higher and it could be viable situation and in the tall or long span bridges may be this is very common, very long longer span. Earlier we could go with m 45 rate of concrete in the deck pre-stressing 45 to 50 if we are doing pre-stressing we could have got to about 120 meter span of pre-stressed concrete bridges where this high strength concrete you might even go to longer box girder segmental construction you can actually go to about 120 meters somewhere in 1970’s the bridges those where constructed with m 45, 50 grade of concrete pre-stressed concrete, box girder. You know, double cantilever construction may be suspended span or centrally hinge later on they could go to 120 meters spans. But, this could be much 150 meters span and so on. So, 40 and very high strength system might even take it to 200 mm 200 meter like reactive powder concrete can take it to 200 meters spans over bridges bridge decks can be also of high strength concrete and so on. High performance concrete so there one might use this and this might be economically viable.

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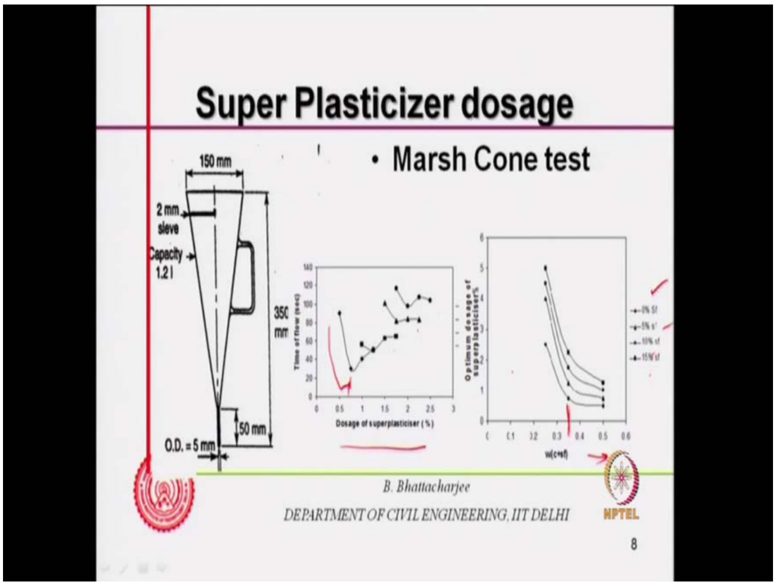

I have already mentioned the places where there have been used now, just plus before that little let us look into this is very important component what is the packing density issue determine the packing density of oliver aggregate system if you want to optimize your paste content and the cost therefore, and the super plasticizer compatibility is another issue one of the test used by lot of people is the mass contest originally meant for you know the mining engineers, they use for I think crude oil to find out their flow ability.

So, mass cone looks like this and you fill this material in a given way to 1.2 liter capacity, fill it in a given way dimensions are something of this kind and then time required to m t this was found out were time flow for certain period of time you can find out the other it will look like this. So, in this axis you can say time of flow for certain quantity of the material fix quantity of the material or complete m t because difficult.

So, you might do it in the paste and dosage of super plasticizer you can change and you can see the time of flow reduces as you increase your super plasticizer dosage. So, if the time is low it means flow is better and for different super plasticizer you might get this kind of values might choose a suitable super plasticizer based on this and then optimal super plasticizer content for different silica fume content 0,5,10,15 percent has been plotted here. So, you can see that optimal super plasticizer content is somewhere for the best for the water cement ratio point cementitious ratio of about 0.35 is somewhere here. So, for various water to cementitious ratio as you go on increasing, you do not have to increase the optimum super plasticizer dosage remains same.

So, you can find out the combination of optimal super plasticizer that you require for the best most compatibility super plasticizer that you determine form here. So, mass contest you can actually determine I am not going to detail in to this but, actually using mass contest. Actually you can find out, which is the best super plasticizer and what is this optimal dosage.

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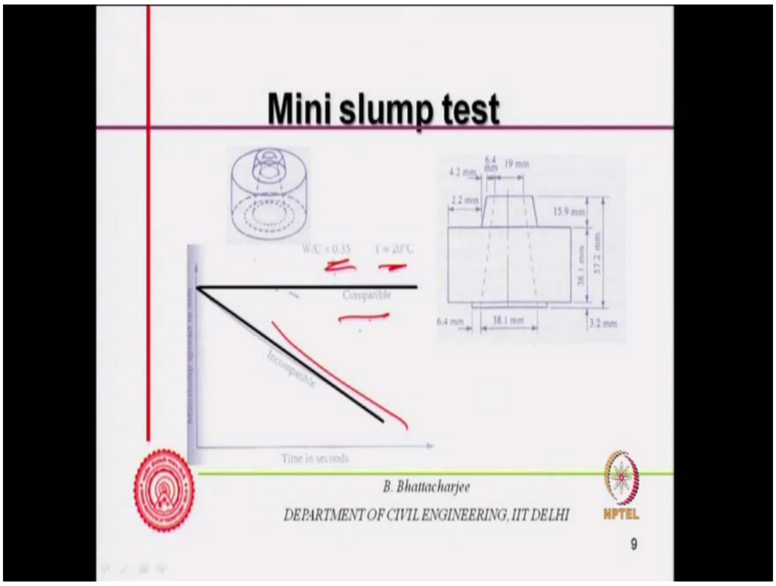

Similarly, you can use slump cone test you know mini slump test we talked about mini slump test earlier same mini slump test. You can do use we just talked about this earlier mini slump we can do and compatibility. You can determine depending upon different time after just mixing if you determine the slump flow which time you know for a given water usually people have been doing for water cement ratio of 0.35 and 20 degree centigrade and if this is actually reducing down that is the you know the flow total quantity of flow in millimeter the spread in millimeter if it will uses with time then this is not compatible but, if it no if it remains constant for certain period of time then it is actually compatible.

So, details I am not discussing using mini slump test you can find out compatibility and also using marsh cone test you can find out the best most compatible, most suitable, super plasticizer. With your paste and then find out the optimal dosage for each percentage of silica fume and water cement ratio. Water cementitious ratio you are dealing with and use that actually.

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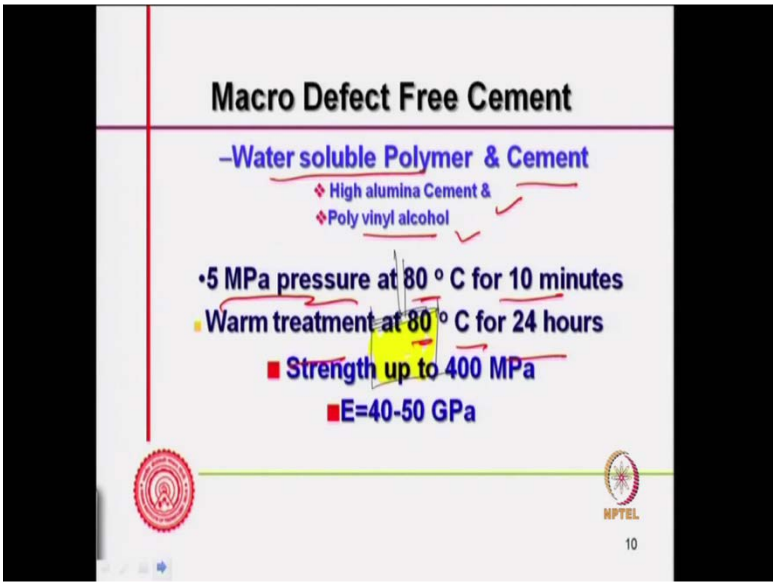

So, selection of super plasticizer is very important so, that was related to high strain concrete and high performance concrete. Now, where they are founder use high performance concrete H P C or H S C as I told you examples are peternousavada all the tall buildings these days tallest buildings this day many of them are using actually H S C. In India I told you Bandar World link sea link many flyovers and buildings in Mumbai, they have used greater than, you know more than m 60 concrete, new airport terminal building in Chennai that also part of it use m 60 grade of concrete it is the signature bridge tower bridge in Delhi, may be it is also using some part of it is high strength concrete so many places this is the m 60 grade concretes etcetera using worldwide this is become quite popular and useful material so with that we of course, finish our discussion on high strength concrete you can now look into the other high strength matrices and one of them is macro defect free cement.

Now, what is it water soluble polymer as I told you know you can apply high pressure you can high apply pressure on to the paste you can apply high pressure on to your paste high pressure on to your paste you know you can apply high pressure on to your paste high pressure on to your paste. If this is the piston let us say and apply high pressure on to the paste which is their pressure on to the paste which is there and as you apply high pressure on to the paste you can increase the strength.

Supposing, I do not you know you know it is very high pressure and I do not want to employ that kind of high pressure, quantity employ some kind of lower pressure then, it is been observed that material like this high alumina cement poly vinyl alcohol and if you apply some pressure you know these are basically this is p b a is water soluble polymer and some form of cement and apply some pressure and 5 M Pa at 80 degree centigrade let us say 5 M Pa pressure at 80 degree centigrade 5 M Pa pressure at 80 degree centigrade for 10 minutes and then give warm treatment at 80 degree centigrade for 24 hours and result is a very strong material. So, strength could be compressive strength could be as good as 400 M Pa and its modulus of elasticity could be 42, 50 G Pa. So, this is macro defect free cement so, this is another high [symmetric] but, this is of course, kind of not readily available it is a factory produce system and been used for electronic, substrate ceramics and such places.

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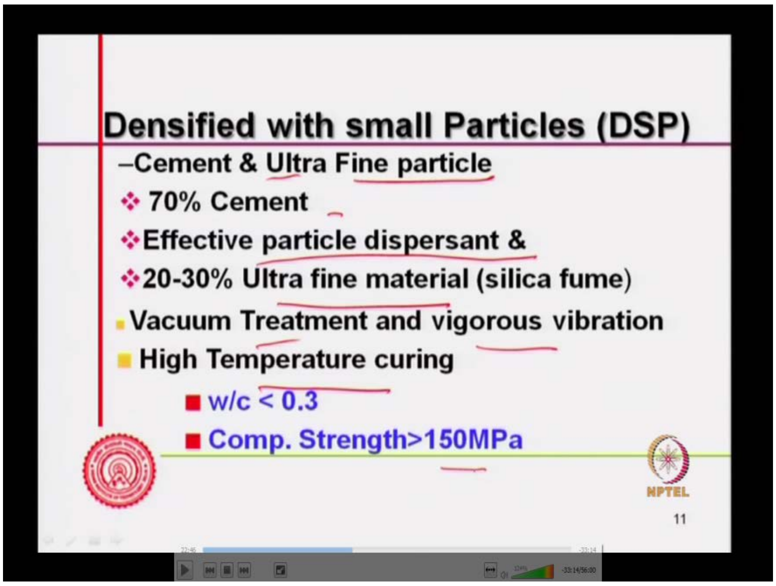

So, this is the high strain matrix, very high strain matrix you can see this is one the other one is densified with small particle D S P and, this is also cement ultra-fine particle and use a kind of effective particle dispersant same thing 20 to 30 percent ultra-fine material silica fume 70 percent cement and again give a vacuum treatment and vigorous vibration for dispersion. You know vacuum treatment and vigorous vibration for dispersion of this particular system and then you might do some high temperature curing after mixing with a very low water to cement ratio less than 0.3 where you can get a composite strength of the cement as greater than 150 M pa.

So, this is densified with small particle D S P cement and you can get strength as well as 150 M Pa or greater than 150 M Pa. Now, this can be used together with aggregate or sand you know course of fine aggregate.

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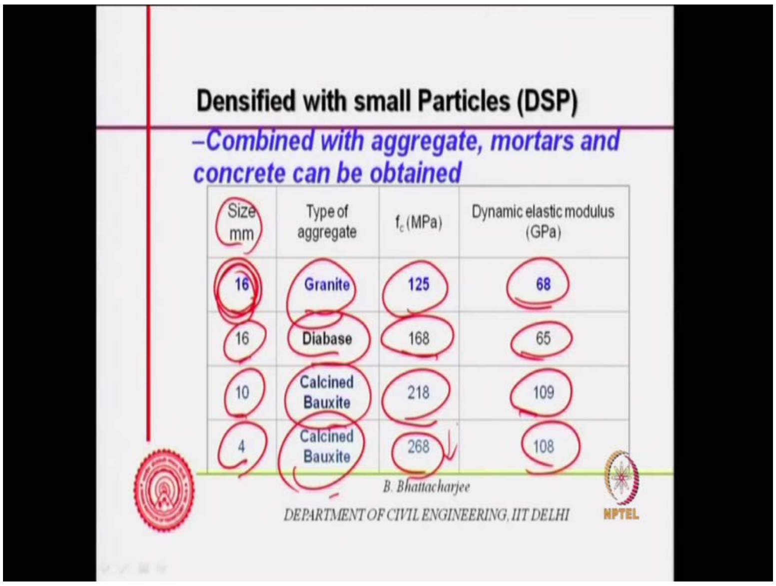

You can make mortar out of this or concrete and you can see the properties that you are likely to get. For example M Sa 16 maximum size of aggregate 16 granite aggregate you can get a compression strength of 125 M Pa and modulus of elasticity dynamic modulus of elasticity 68 use same size of M Sa use another kind of aggregate diabase. You get, 168 M Pa with this dynamic modulus around 65. You remember dynamic modulus we talked about dynamic modulus we determine it to actually by you know by actually acoustic or mechanical waves by impinging mechanical waves.

Now, 10 m m s a calcined bauxite aggregate type, this strength goes to 218 M Pa with the modulus of elasticity going to 198 g p a steel use finer one 4 m m aggregate that means no large aggregate coarse aggregate is missing calcined bauxite and strength is

268 M Pa and 108 is the modulus of elasticity. So, you can see that you can go to fairly high strain I mean quite high strain using this material when you are using aggregate.

But, M Sa higher obviously gives you lower strength stress concentration non-uniformity all that we talked about, because of that when you have finer and no coarse aggregate strength is much higher so the another kind of material which was developed original in France and possibly quite promising of the similar sort of high strength matrices is reactive powder concrete.

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Now, followed from this actually if I look at I will just come to the active powder concrete in a minute but, where can I use this D S P can we use in flooring you know high strength concrete I forgot to tell higher the strength of concrete you know abrasion resistance is very good that is what we have seen so, your high strength concrete will have a very good abrasion resistance.

So, you can use that in flooring you want still batter abrasion resistance D S P could serve good safe nuclear entrapment tooling and molding overlay over existing concrete as we pair material overlay over existing concrete as you know like kind of not repaired protective material protection material. So, it can give you good protection against thin layer making me good protection against external environment.

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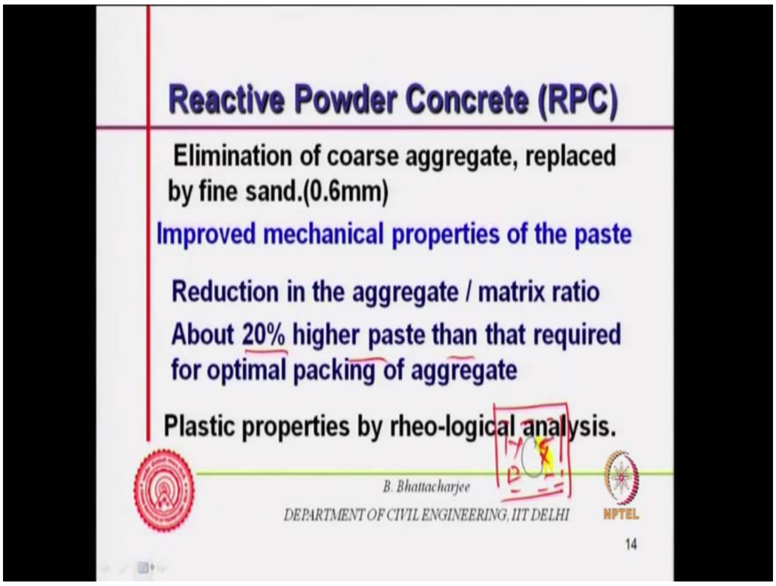

So, this is where D S P has been used and then I was talking of reactive powder. Reactive powder concrete we have seen while just talking about D S P that if as I eliminate out the coarse aggregate discontinue, when it discontinuity is vanishes and as stress concentration those effect actually vanishes and it becomes uniform material, homogeneous material, uniform material throughout by enlarge you know.

So, in this one coarse aggregate is completely eliminated and fine pore sand or steel powder maximum dimension 600 micron so, even the finer you know you are not using all fine aggregate sizes not going to 4.75 mm. So, it is reduced down further from 4 m m I talked about to now 0.6 mm and improve this mechanical properties is the paste is improved then, reduction in the aggregate to matrix ratio about 20 percent higher paste then that required for optimal packing of aggregate why is it so, to reduce down the shrinkage because, now it will shrink in bulk as I told you it will shrink in bulk that means it will change is size dimension in this manner and if you add an aggregate inside let us say if you add an aggregate inside, that will get compressed rather than any kind of stresses or cracks of the interface so, this will not be there this will simply this will not be there this cracks will not be there instead this will actually get compressed from all these direction because of bulk shrinkage. So, when you have higher paste content.

So, if you can if I just look at it normal concrete will have paste content around 30 percent or so 28 to 30 to 32 percent you come to pump able concrete you require more paste because of the flow characteristics and we will talk about a concrete called self-compacting concrete which will also need more paste because if flowability on or so on.

But, from the strength point of view you know like when you are looking at higher strength matrices again paste content increases. That is largely because we want to bring in homogeneity in one thing and then get rid of the interfacial you know shrinkage that is there because aggregates want shrink paste will shrink.

But, if the whole system is shrinking in bulk with a less quantity of aggregate inside the interfacial discontinuity or flow or cracking that would be relatively less right in the beginning before any load has been applied. So, use actually higher amount of paste then required for optimal packing. Now, you have to determine plastic property by throe rheological analysis in this kind of material.

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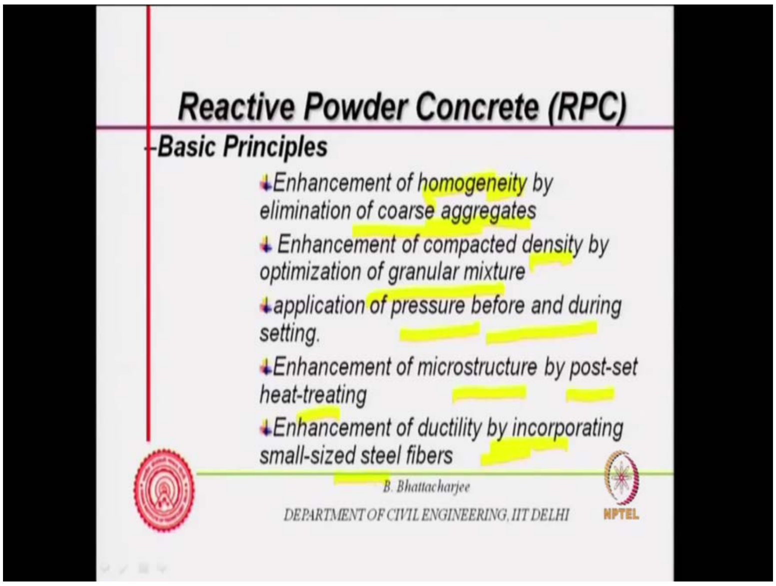

So, that is real you know this is how we get it reactive powder concrete, we enhance the homogeneity by you know enhance the homogeneity by elimination of coarse aggregate.

The compacted density by optimization of granular mixture see you have to do throe packing density scenario apply but, this is additional apply pressure before and during setting now this would ensure further compaction and if you are going to a very high as very high strength situation this will be recommended. Micro structure enhancement by post set heat treatment treating. So, you are actually doing you know all kind of combustion everything should finish quickly. So, you know micro structure is being enhanced by post set heat treating and if I want to increase the ductility of this material this material will be fully brittle but, as a material if I want to improve its ductility I might put in steel fibers or some other fibers particularly steel fibers should be useful find steel fiber but, the turban fibers there are and such things could also be good you know nana fibers for examples which have to be solved as yet. But, steel fibers fine. I know micro fibers small size fibers can improve its ductility property of the material as a whole.

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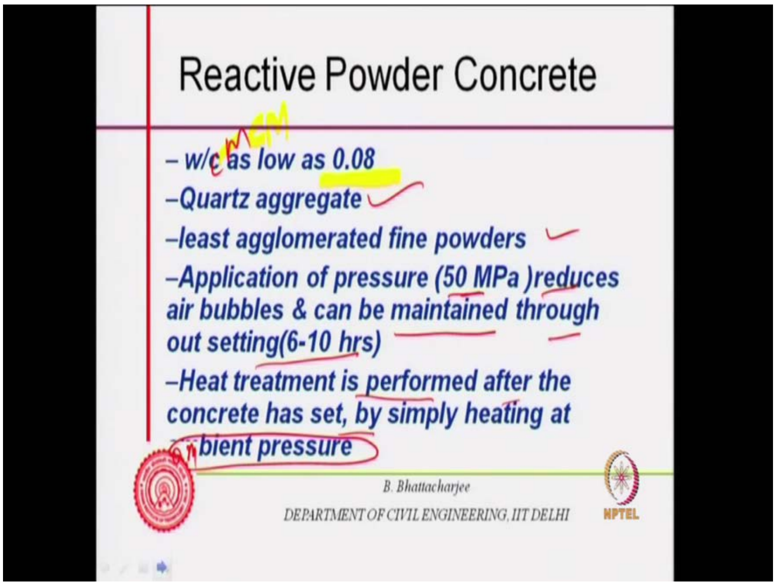

Now, this is one estimates of this one it could be as low as 0.8 water to cementitious ratio water to cementitious I will call it c m rather than c alone water to cementitious ratio c m quartz aggregate quartz aggregate quartz aggregate has when used powders have been fully dispersed least agglomerated and in the apply a pressure of 50 m p a to reduce air bubbles and you can maintain throughout setting of 6 to 10 hours heat treatment after the concrete has set simply by ambient pressure you know heat treatment at ambient pressure.

So, this is what reactive powder concrete and what you get you get something like this, there are two grades R P C 200 grade and R P C 800 grade. So, R P C 200 grade no pre-setting pressure equate none but, 800 grade unit 850 M Pa pressure that is what I was talking about heat treatment 20 to 90 degree and 250 to 400 degree out of plane situation may be the heat treatment would be there so, there is a pressure and also you know you might do a heat treatment at a higher temperature.

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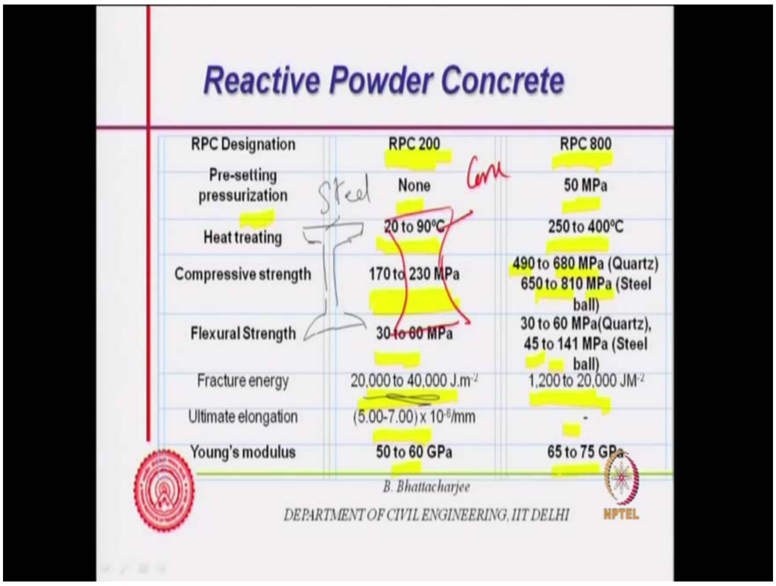

Obviously, the name suggest 200 grades 170 to 230 M Pa this one is 490 to 600 M Pa used in quartz all right if you are using quartz 0.6 m m down and if it is steel balls or steel powders then you can get as high as strength as 800 M Pa or 800 and 10 M Pa. So, that is why the grade name is 800 and flexural strength 30 to 60. 30 to 60 for quartz and 45 to 141 or steel now you see the potential of this material 200 grade first let us look at you know if I get 175,180 and pre-stress it.

So, it is one at least 150, 160 in tension as well as in compression that is the kind of load it can carry. So, the friction dimensions actually can be comparable to the steel sections and may turn out to even cheaper in some situation. But, remember it has to be precast you cannot make it in situ this has to be factory produce material it has to be factory produce material and in fact it has been shown some of the materials produced for example, ductile is so the similar principle its dimension could be will be almost similar for example, you have you have steel section of this kind I section and you can have concrete section of the similar kind having concrete this is concrete this is steel dimensions could be almost similar, to take same kind of loads.

So, you see this is this material has got an advantage let us look at other properties fracture energy is low it should be because, you know no stress strain curve is almost vertical. Basically, it is very brittle material if you have not added fiber and the steel lower. It is steel lower you know per meter square joules per meter square and ultimately elongation is low here it is very small.

So, there is hardly an elongation it is actually as high modulus relatively higher modulus of elasticity 50 to 60 G Pa and 65 to 75 G Pa. So, this material is potential this material has got significant potential actually and been attempted first I think in Canada and somewhere around 1990s it is actually original developed in France but, first pedestrian beach was constructed in Canada. Some around 1997 long span and then also in Parish a number of places actually some of this has been tried. As a structural material and commercial product like ductile which is possibly based on similar principle produced by Lafarge or there are similar other products by some other company. They are precast elements possibly are available but, this has to be factory produce totally in controlled condition otherwise you cannot produce this material. So, it has to be industrialized construction.

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But, the material has got big advantage if you're looking for very long span or very tall buildings they are it will have a big advantage the cost is also not you know it will be obviously higher than let us say high strain concrete and so on. But, looking at everything put together like by like compression if one does perhaps many cases this material also very viable at the movement of course, in Indian scenario I have not come across the situation where p c has been used but, it has got potential for very tall buildings and long spend bridges and so on. So, forth this is reactive powder concrete. So, last in our discussion today self-compacting concrete which are just introduced which are just introduced and discussed little bit today and discussed the rest of it in the next class.

Self-compacting concrete, how do you define well it is the concrete you know it is the concrete that is able to flow and fill every part of the corner of the form work even in the presence of dense reinforcement purely by means of own weight and without the need for any vibration and other type of compaction. So, it is actually it flows are originally developed in Japan in Europe. Basically, to get rid of vibration for two reasons, one the noise in a city you know vibration creates a lot of noise and therefore, you want to avoid that there should be no noise. Second thing is there is a cost for vibration. There is a cost for vibration and that cost can be eliminated both labor mainly labor cost and so on. So, forth that has to be eliminated.

So, basically, idea is that you put the concrete. It will flow like this you know you have put the concrete into the any part of the structure and it will simply flow. So, something like this as it shown so you have a slump cone test slump cone you have just lifted it and it will simply straight all around the places it will flow in all direction. So, it will simply flow therefore, flowability is the main concern of this one and it should be able to flow on its own now how can concrete flow. We have looked into pump ability and what we said was it can flow because only material that is flowable in such concrete is the water.

Now, if I have sufficient water in the system and also, some kind of dispersion. So, if you have some kind of disbursement then it can with you know if you want to put too much of water because only thing that is flowable in concrete system is the water. But, if you cannot put too much of water because that will not only increase the water to cementitious or water to cement ratio segregation of similar many other things will occur. So, you should have a kind of cohesiveness no internal separation. But, at the same time it should be able to flow.

So, it is the actually the hyper plasticizer 3 rd 4th generation water reducing agent very high your ultra-high range water reducing agent that made it possible actually for flow you know to make self-compacting concrete.

Now, we talked of polycarboxylate ether remember when we talked of admixtures we talked of polycarboxylate ethers which can disperse more because of their comb structure push the particle by static inderances. it is that kind of admixtures which is which actually made it possible to production of self-compacting concrete because they can if the normal quantity of water they can push the particle a part and give a lot of flow but, at the same time particle should be retained together they should they you know they should separate out so, me stickiness should be there so, me cases people use viscosity modified which we discussed again earlier. Some sort of you know sticking property which they have and therefore, both this admixture could mix self-compacting concrete possible. So, that is how actually it was developed in part of the Europe and Japan in the early days of its developed in 1980s

Now, let us look at requirements of cell phone compacting concrete first of all it must have filling ability fill all corners through flow all corners of the form work flowability ability to flow in the form without vibration no vibration I am not applying any vibration. So, it should flow in the form without vibration and because when we talked of compaction you remember the normal concrete will sell down attain the shape of the form work.

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So, I need some mobility and actually flow should be there, able to flow in the form changes position in the form without vibration here. So, that time we were actually enforcing them or ensuring them through vibration the mobility getting the shape of the mold so there is some amount of movement now here it should move on its own and actually getting the shape of the mold. It should be able to pass through narrow spaces such as rebar without blockage. So, if it is a self-compacting concrete must be able to pass through all reinforcement so passing ability.

So, filling ability, flow ability and passing ability, filling ability means it should spread and actually fill the place and then flowability means if require the space is there more you have put in. So, it should be able to flow and spread it because you might put it one place and it should fill all the portions. So, there is some flow is required.

Passing ability if there is reinforcement there it should pass through that reinforcement and should have good segregation resistance during flowing and also after it has come to rest so on. Segregation after rest means water should not bleed out while flowing stones or the coarse aggregate should not remain somewhere and the water or the paste should not flow away leaving the coarse aggregates. So, therefore, you know there should not be any kind of segregation or bleeding what so ever, before it has come to rest or during the flow.

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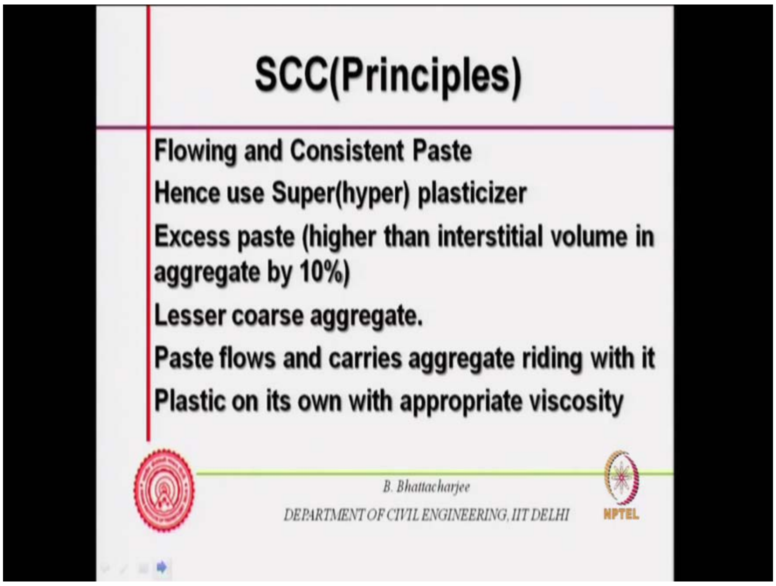

So, this is important and how do you attain this? How do you attain this? I should have a consistent paste and it should be flowing paste itself is showing you can just advance a little bit from pump able concrete what you talked about earlier. So, pump able concrete well you are putting pressures to move self-compacting concrete. You should be able easily able to pump no problem at all because, we are not talking of slump anymore 120 mm slump or 130 mm slump for the pump able concrete it is simply slump flow here as I showed in a photograph earlier and it should be flowable paste and consistent paste hence, hyper plasticizer use is must that is what I said and I must have excess paste higher than interstitial volume in aggregate atleast by 10 percent because as I said paste is the one which flows I will just explain through a diagram, later on this aspect more and lesser coarse aggregate obviously will be the reason.

You know have high paste less coarse aggregate and then paste flows and carries the aggregate riding it, riding with it you know aggregate will have a piggyback ride on the paste itself because they will be embedded in the paste and that is how you can make it self-compacting because aggregates are on likely to move or flow not they are going to fill in spaces. They will have their angular propose and hold it if they are alone but, it is the paste if they are embedded in the paste and then paste moves there should be also having a right onto the paste and then move and that is how it can be self-compacting well, plastic on its own with appropriate viscosity that means heel shear stress will be very little I talked about heel shear stress long back when we were talking of you know pump ability compaction on those issues and we talked of bingham model if you recall so, it should have it should be plastic it is on viscosity.

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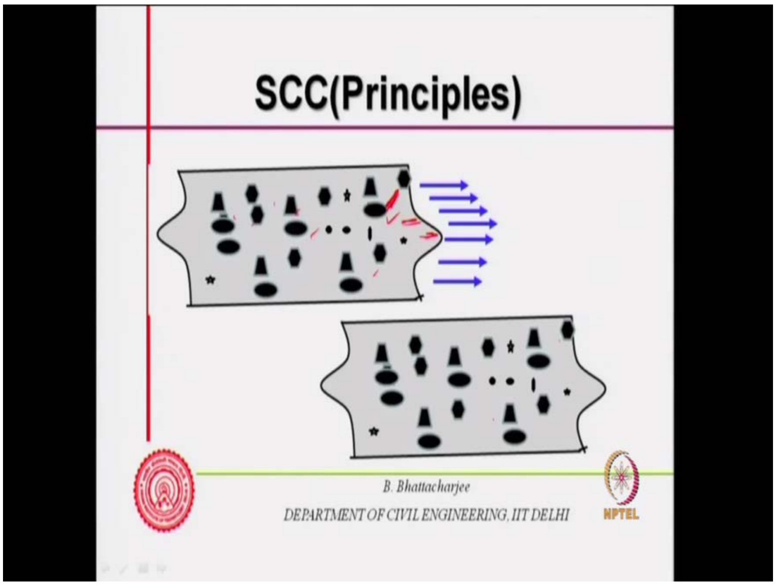

So, basically, you see if you look at this is your concrete, much less aggregate aggregation is much less this is your concrete actually lot of paste less aggregate now if it starts flowing whole thing flows it is actually the paste which flows and they remain in their position the you know the they should be relative should not be relative movement between this particle as it flows.

So, you can imagine you have a viscous paste which flows and you have some number of aggregates some number of aggregate I am saying just suppose you say paste and you made up a paste with a hyper plasticizer and adequate amount of water and hyper plasticizer it is able to flow.

Now, if you embed some aggregates onto it just push few aggregates onto it. Now, aggregate will also remain you know embedded in this position and if the paste has got stickiness, it will remain embedded in this position and then move with the paste itself so whole system on the paste moves and therefore, embedded aggregate also moves with it as if it is going to have having a ride onto the back of the paste. So, that is the idea that is the idea that is the idea that is the idea that is the whole principle.

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So therefore, you must have less coarse aggregate content coarse aggregate content is less in this kind of a system coarse aggregate content is less in this kind of system so as it flows as it moves out and moves but, then relative position remains same it does not change. So, after movement it should retain this same thing it should retain its cohesiveness.

So, after movement it should retain this same thing it should retain its cohesiveness therefore, this is the two these are the two issues in self-compacting concrete the paste content should be higher therefore, you have materials of course, physical properties of the material specific gravity grading etcetera are important particle packing density is very important you find out what is the particle packing density?

And then because you are using difference size of size aggregates and then as you pack it you know put lot of paste inside I mean put them inside you know you know larger paste matrix, and which should be the paste matrix volume, you can find out from the packing density you might do that same marsh cone test to find out the super plasticizer dosage determination of optimal one, and fresh properties of self-compacting concrete we measure by not by conventional slump test etcetera but, by slump flow spread, V funnel test, L box, U tube. We will discuss some of them and this of course, should be good if you can do it but, at the moment this is still in developmental stage so, yield stress and plastic viscosity.

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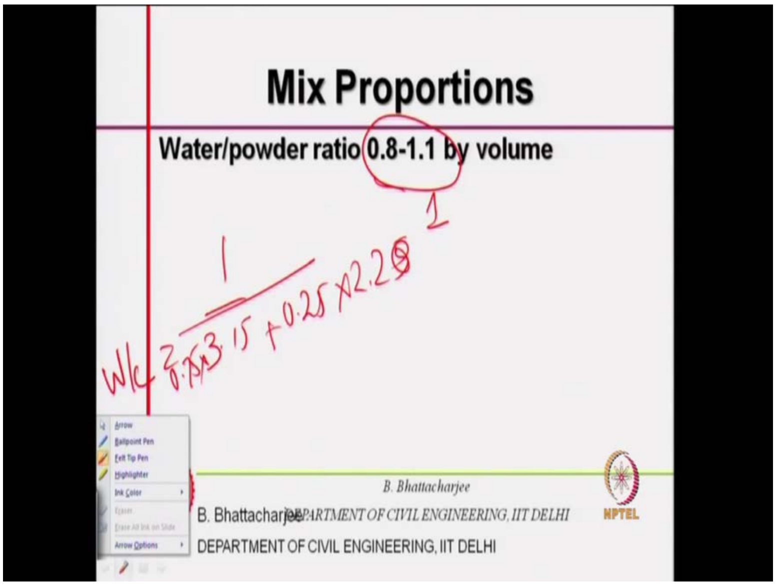

You see the proportion of the mix that would be there water to powder ratio you have sufficient quantity of water. So, volumetrically water to powder ratio is 0.8 to 1.1 volumetrically not mass bases mass bases it will be obviously much lower but, volume of water must be sufficiently high. You can see if this is you know water has got a specific revolt of 1.

So, multiply 1 by 1 divided by same, let us say pure cement then it will be 1 divided by 3.15 but, it will some cements, some fly ash because so, much of paste quantity you need in the system that you cannot have only cement we will have to have some kind of fila material large quantity because paste quantity you want to increase. So, fly ash or something so, you will have specific gravities depending upon the quantity of fly ash use, let us say 75 is fly ash and 25 percent is you know 20 percent is 25 percent is fly ash 2.2 and 75 percent is cement.

So, you can have the volume 1 is to 1, if this is equals to 1. Water cement ratio will be this much. So, you will get a strength depending upon this water to cementitious ratio. Now people ask, weather is it possible to make high strength concrete as self-compacting well this should be possible but, it would depend upon the right kind of mix sufficiently, high strength matrix. But, very high strength and self-compacting, well that would be a real challenge at the movement we are not talking of that kind of situation where only right.

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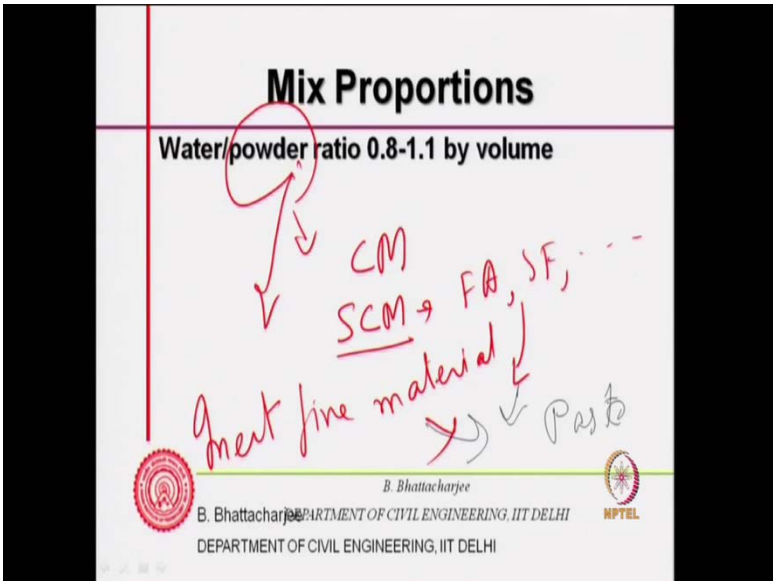

Now, talking of self-compacting scenario. So, the volume to powder to water to powder ratio now that is why I am talking of powder which might have when you when you know not cementitious alone not supplementary cementitious material not S C M like fly ash silica fume etcetera etcetra. But, we are talking of powder. Powder means even inert material inert fine material inert fine material, they should go into make all this should make into are required to paste.

So, in the paste you have water to powder ratio is very important because we have seen there is a there is a water content which may give us consistency which is what we you know what we call you know the standard consistency is the water which will be just isolating the air bubbles. But, you add you got to add more water here because you want real flow ability. Therefore the quantity of water to powder that is very important all particles must be looked into. So, air bubbles are isolated plus more because you want the flow ability of the system.

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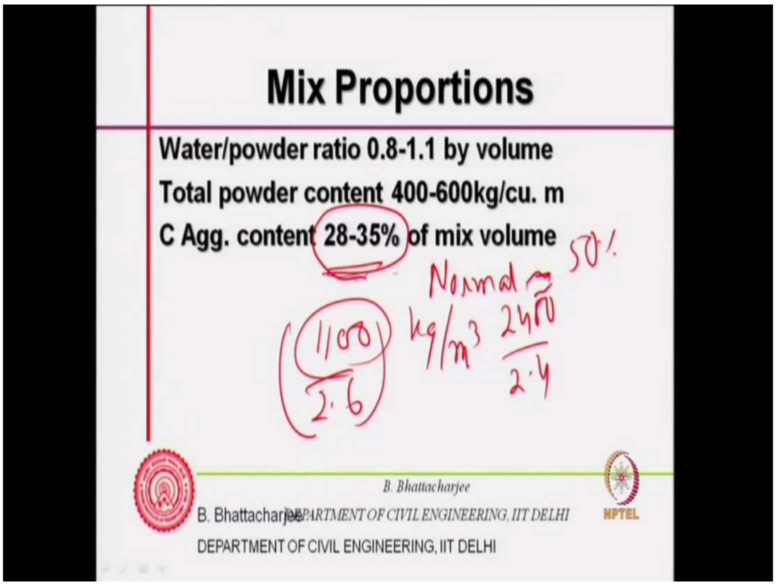

So, therefore water to powder ratio is the important issue and total powder content might go to about 400 to 600 kg per cubic meter the reason is very simple because you want sufficient quantity of paste that is what we have seen. So, you one sufficient quantity of paste this is 28 to 25 percent of mix volume.

Now, if you look at normal concrete supposing you have got about you will have about 1100 to 1200 or 11, 1200kg per meter cube of concrete the volume of you know mass of aggregate divide by 2.6 that is the volume of aggregate 2.6 if you divide and the concrete is 2400 kg per meter cube divided by 2.4. Let us say, you know stress gravity of the solid particle means something like this.

So, you can find out this will be nearly 50 percent in normal concrete, this will be nearly normal concrete, this is nearly 50 percent, coarse aggregate content would be nearly 50 percent in normal concrete coarse aggregate content could be nearly very close to 50 percent 45 to 50 percent but, here it is 28 to 35 percent because they got to have a piggyback ride on the paste or mortar coarse aggregate will have a ride on the mortar should flow and they are sitting on top of the you know mortar and as just enjoying their journey and go to the right position.

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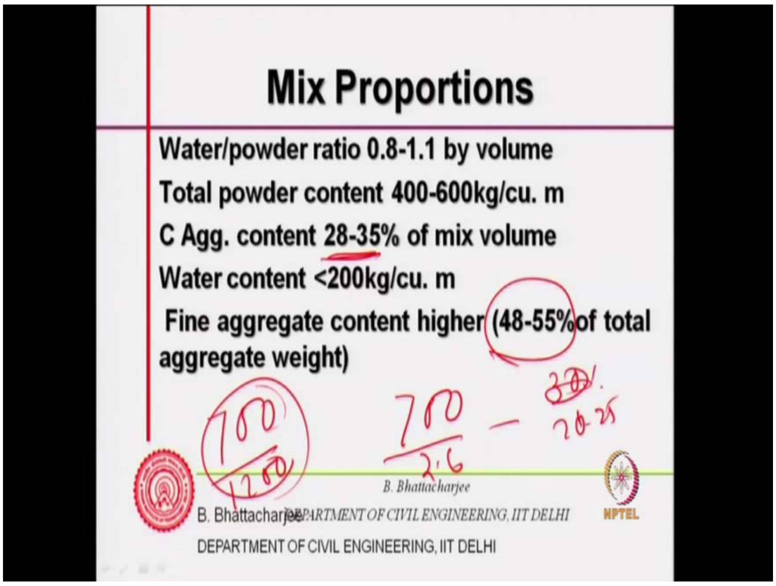

So, obviously the mortar content will increase mortar content will increase water content. Of course, around 200 k g per cubic meter depending upon the water to cementitious ratio but, water should be of the similar that means what you are doing you are not reduce in high strength concrete system you reduce the water too much to get the strength cementitious you keep saying so your water cementitious ratio is higher I mean sorry lower to get the strength here you need not may not go for a strength at the moment suppose you are not interested in the strength you can keep the water content high but, because you need water to powder ratio to certain level but, increase your powder content. So, paste content total you increase depending but, ratio of this water to powder or water to cementitious system would go on the strength.

So, water you do not reduce but, you still the plasticizer to make it flowable in high strength concrete you use the plasticizer cut down onto the water here to you are taking it to the full advantage of getting as much flow as possible. Fine aggregate content obviously will be higher because you know it normal concrete it will be around 700 and assuming in 2.6 as the specific gravity. So, the volume would be this much and the content same. So, roughly around may be 30 percent is 30 volumetrically this might be about less than 30, the 20, 25 percent in case of normal strength, normal flow aggregate or normal aggregate, normal concrete.

But, here mass base is 40 to 55 percent of the total aggregate weight much higher. So, in normal concrete will be 700 divided by let us say 1200 so this is less than this would be this you know this total aggregate total aggregate content is actually here the scent content would be higher because aggregate content is going out overall volume of the aggregate system is lower paste is higher cent would be send would be of this sort of sorry send would be of this sort of quantity.

So, send would be of this sort of quantities. So, that is how typically the fine aggregate. You know the proportions of the self-compacting concrete. So, we just introduced the self-compacting concrete in this discussion.

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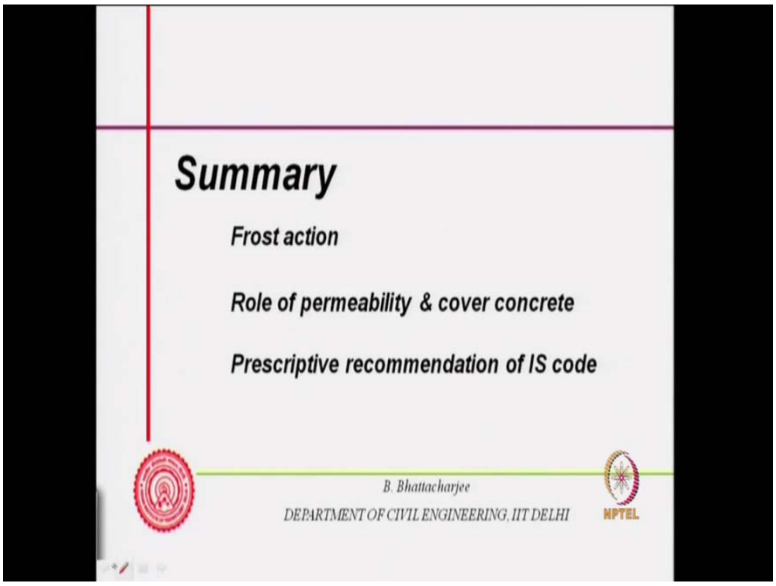

So, we can actually look into the summary of this particular one here summary you can look into what we have looked into.

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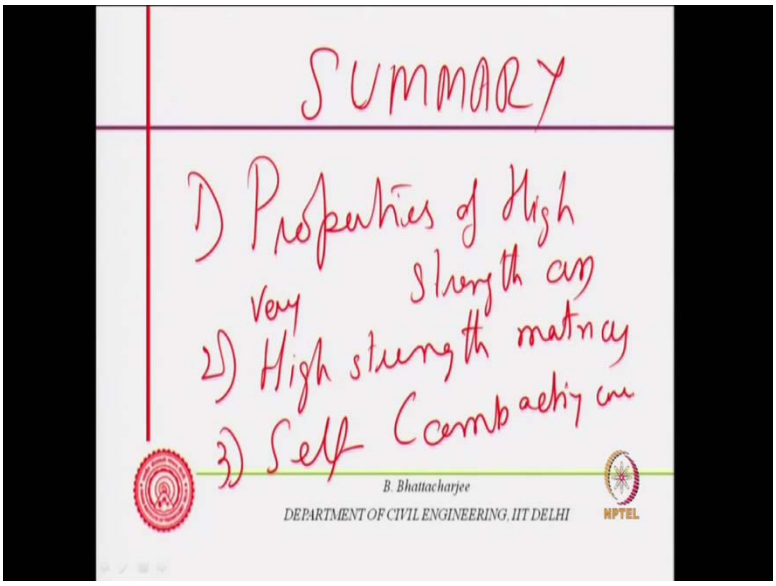

Summary what we have looked into number one we have looked some properties of high strength concrete, then we have looked into some other very high strength matrices, then we have introduced our self to self-compacting concrete.

In the next class, we will look into self-compacting concrete to start with and if time permits we will go to other concretes such as fiber reinforced concrete. So, with this I think we can we can conclude our discussion on this what we have seen is, we have seen high strength concrete basically from the beginning what is the principle and is history we also discussed a little bit of history of the self-compacting concrete today and the other high strength matrices.

So, and finally, we have come to the flowability the high performance one of the other kind of performance of the concrete that is your flow properties or compaction properties. Self-compacting concrete that is what we looked into so, with this actually we would like to finish this discussion.

Thank you.