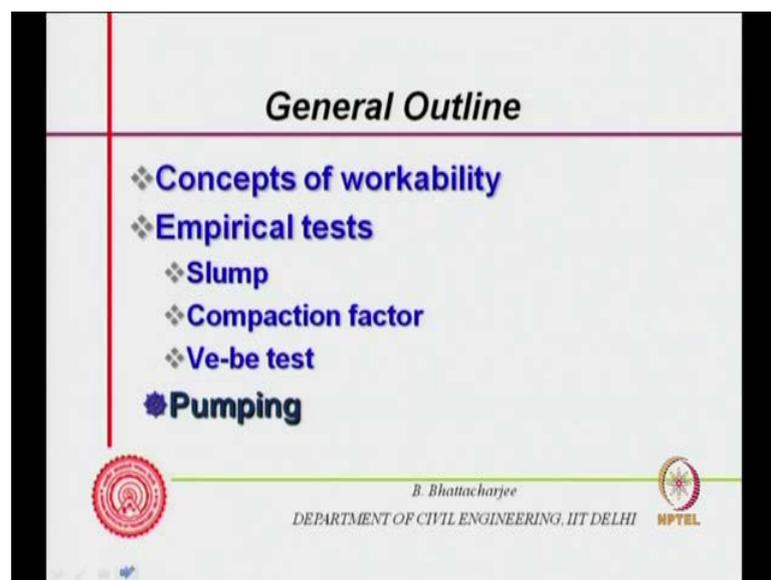


Concrete Technology
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Lecture - 21
Workability and Pumping of Concrete

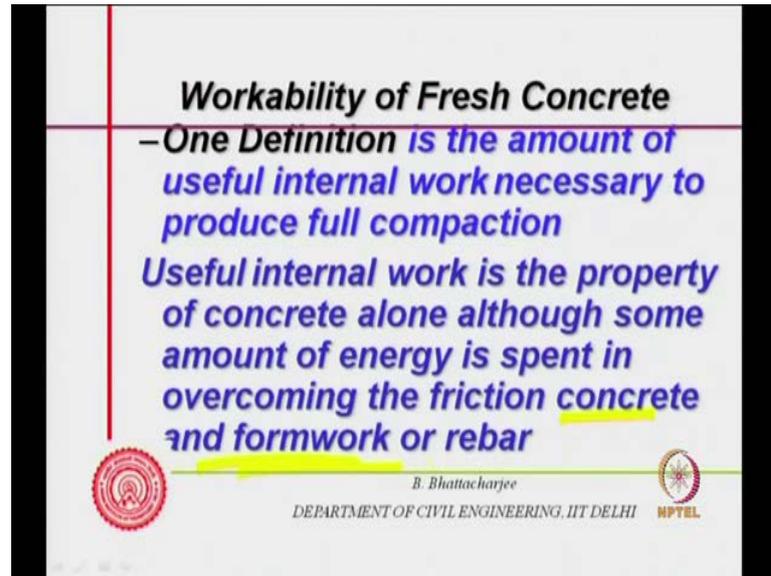
Lecture 2 of module 5, we looked into transportation of concrete bearing one technique that is pumping. You know pumping we just mentioned there, pumping of concrete. Pumping is more versatile than most of the methods because it can pump horizontally as well as vertically, but when I am looking at pumping I should also look at pump ability and which is linked to workability which you have not discussed so far.

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So, we will discuss about workability particularly the empirical measures of workability in this lecture, followed by, followed by pumping. So, we will talk about empirical test and then donate we will talk about pumping.

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So, let us look at what is workability of fresh concrete? One definition is the amount of useful internal work necessary to produce full compaction. You know it should be workable that means I should be able to make. As we discussed earlier we said that relatively not self compacting type, relatively less flowing concrete you know normal concrete as we have been using over years together.

Initially when you put the concrete in it forms a heap like like the soil does you know and you have got an angle of repose. So, particles are supported by other particles and you, it forms heap sort of, right? Maybe more flowing than soil, but it forms a kind of heap, and there is as much as 30 percent voids and this 30 percent voids we drive off by compaction usually through vibration, you know engineered compaction will be through vibration. Of course, the extreme case where you do not need vibration is a self compacting concrete which I mentioned earlier.

So, therefore the workability is defined as the amount of useful work required to produce full compaction and we also said that it does not confirm, seldom confirms to the shape of the mold. Therefore, you know there is some amount of mobility is also involved. So, workability is a useful internal work necessary to produce full compaction. Now, useful internal work is the property of the concrete alone although some amount of energy, although some amount of energy might be spent in you know in overcoming the friction of concrete and formwork etcetera etcetera or rebar and so on.

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The slide is titled "Workability of Fresh Concrete" and lists three components. The first component is "A. Compactibility i.e. function of the work done", with the formula $\frac{1}{2}(\tau_0 + \mu \sigma) \gamma_y$ written below it. The terms τ_0 and $\mu \sigma$ in the formula are underlined in yellow, and the handwritten text "Yield Shear" is written in yellow below the formula. The slide also features the IIT Delhi logo, the name "B. Bhattacharjee", and the text "DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI" and "NPTEL". A small number "4" is in the bottom right corner.

So, this is what we define workability as and it has then three components because what we are doing? We are its, it would be in a heap, it has to move and we have to drive out the air, at the same time it must maintain its cohesion. In other words you know relative material should not get separated from each other. So, the three components can be written as compactibility that is we should be driving out the air and the work done is to drive out the air would involve some amount of movement and flow.

So, if you recall the rheology of concrete which you talked about, we talked about yield shear stress and beyond which I have some viscosity and therefore, you know the stress at any point will be given by this yield shear stress, this is your yield shear stress, yield shear stress, yield shear stress plus coefficient of viscosity and a normal force. It will be a function of normal force, which will be a function of normal force. So, stress likes shear, like soil. If you do box shear, box shear test we will see that the amount of you know stress chain carb is the function of the normal stress that we apply.

The shear stress is stress it can resist and mu is a kind of coefficient of friction or viscosity, dynamic you know its plastic viscosity. So, stress could be this and this is strain, shear strain. So, half shear stress into strength we know the strain energy that is the kind of work done. So, you know there is a kind of strain energy that the material will absorb. So, there is a amount of work done. So, compactibility is a function of the work done which is half stress into strain and stress is yield shear stress plus the viscosity

and if you have applied any normal stress we will come to this sometime in the next lecture when you talk of compaction and little bit more and this is the strain. So, therefore, this is a function of the work done which is given as the strain energy which is half shear stress multiplied by the strain, half shear stress multiplied by this strain. So, that is it.

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Workability of Fresh Concrete

- **Three components**
- **A. Compactibility i.e. function of the work done $\frac{1}{2}(\tau_0 + \mu \sigma) \gamma_v$.**
- **B. Mobility i.e. function of (μ , τ_0 and m.s.a. D)**
- **C. Stability i.e., function of tensile strength**

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This is compactibility. So, this is how easily you can compact. So, there is energy required to actually cause some movement, some shears stresses, shear strain and that results in compaction. Mobility is the flow. So, I should be able to drive out the air and that is compactibility and if I want drive out the air there should be shears, you know if the shear, it should have been some kind of behavior. I should cross the yield shear stress and then it flows and then occupies most of the volume so that you know occupies the volume and air moves out.

So, therefore, that is related to work done. The mobility is a function of, is the flow, it is the flow because you said it does not conform to the more. Therefore, there has to be some amount of movement to attain the shape and this mobility is a function of mu again. mu is viscosity, tau 0 is again yield here stress and of course is function of the maximum size of the aggregate, maximum msa because larger one will easily move. The smaller one moves less.

So, workability actually has got so far we have seen two components. I said I should be able to compact it very easily and it should attain the shape and lastly the particle should not separate out from each other and that is basically a kind of stability or function of the, tensile strength of the fresh concrete. So, compactibility, mobility and stability, these three ensures that it will not segregate, it will remain same cohesive as it was and then it will move to the, move and you know it will be mobile to get, attain the shape of the, shape of the mold and I should be able to drive out.

So, the least work required would give me better workability, least energy I require. So, internal work required should be least and therefore, work required should be least. So, easily flowable, one should be more flowable and that is what it is? Now, these are the concept of workability. Now, easy if I want to fund, from fundamental principle if I want to come to compactibility, mobility, stability and generate a kind of workability function that would be really complicated because I need τ_0 , I need μ sigma and that too as a function of mixed parameters, concrete mix parameters such as cement content, water content, water cement ratio etcetera etcetera.

You know all those I mean water content, paste content and so many, so many factors could be there. So, from fundamentals to relate to those factors particularly mix proportion that is content you know water content, cement content, aggregate content, coarse aggregate content, m_{sa} maximum size of aggregate and any other admixture content and so and so forth. Relate this to τ_0 μ is not yet, we have not arrived at that kind of understanding till today as far as concrete science is concerned.

So, we have and and you know, but but then we need some measure for workability and that is you know we needed it for last 30, 40 years or 50 years or nearly, you know nearly 100 years for which concrete is being used. Therefore, some empirical test we have developed, some empirical test we have developed for comparing the workability of different concrete. Now, to both you know there are number of test actually developed and each test measured a thing. It does not matter all three component all right, all right. It does not matter all three components. So, relative comparison of different mixtures as far as there workability is concerned that is possible.

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Empirical measures of workability

- **Fresh Concrete Properties**
 - **Slump, Ve-be or Compaction factor Test**
 - **Yield Stress, Plastic viscosity.**
 - **Air content, Pump-ability and Density**

The method of placing, section dimension and amount reinforcement etc, decides the above property requirement.

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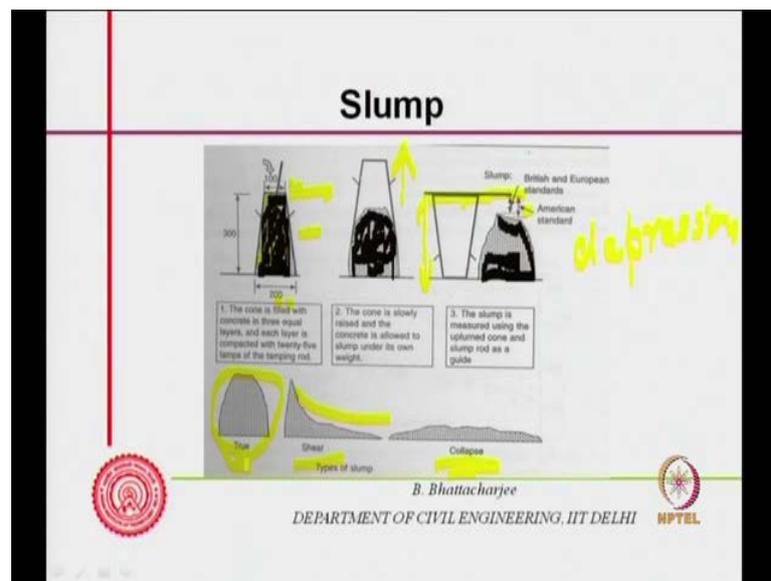
But absolute, when from fundamental principles we are yet to arrive at that understanding. So, therefore, we rely on some empirical test, all right? Empirical test, although some work has been done in 1950's or not (()) currently a lot of work done on rheology particular relate to flowing concrete. However, for normal concrete we need some empirical measures and these measures are like slump, Ve-be compaction factor test which are more popular, there are numbers, series of other test and yield stress and plastic viscosity will be rheological test actually.

At the movement we are not looking at them and air content, pumpability, density some are specific test related to fresh concrete. We are not interested, but today we are interested more in slump, ve-be and compaction factor test which are very common empirical test which I use. In fact this is most common, this is most common. This is used for dryer concrete and this can be used for some concrete which are in between, but this for example, fiber in push concrete.

One would prefer this test because where workability is very low or roller compacted concrete which is actually compacted by road rollers, you know earth moving machineries, there we do ve-be test with some modification. Put a surcharge on top because it is 0 slump, late practically no slump you will get it. So, you will come to those tests and this values of let us say slump or ve-be time or compaction factor value this depends upon the section dimension, amount of reinforcement etcetera etcetera.

How much is required that we will you know, so most of the normal strength concrete one would specify the slump. Sometime, of course ve-be a few of the you know practices might even include compaction factor. There are some other test, but we are not interested. These three are the most common test.

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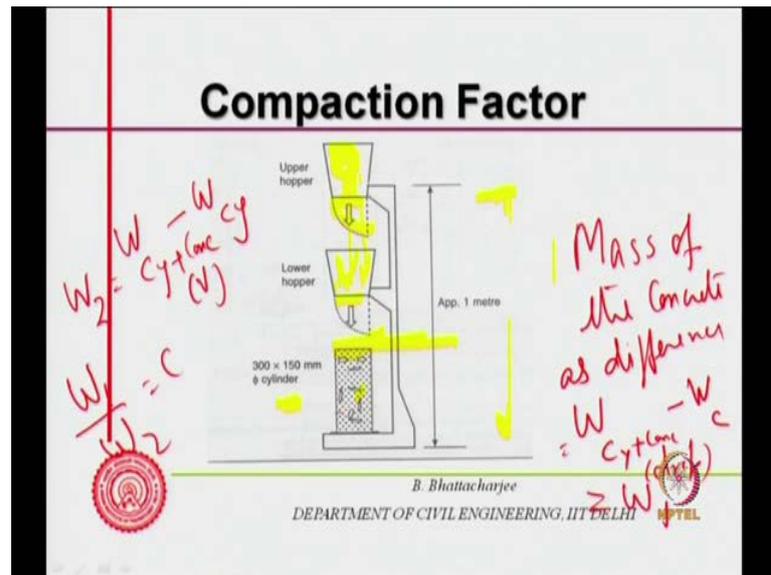
So, let us see what these tests are? For example slump test it was actually device by D A Abraham, it is Abraham slum cone and it is very simple. You place the concrete, pack the concrete, pack the concrete here in a cone which is dimensions are given 200 and 100 So, 2 is to you know one is 2 is 1 is this and this is 300. So, it is a cone, truncated cone and you pack the concrete in three layers, compact it in a standard manner. Lift this up, the cone up.

Now, concrete attains some kind of a shape like this after lifting up. Now, this difference is right from the top is British and European standard tells you the slump. American standard takes the bottom most one and one can take average. So, original height depression, you know depression is what you are interested in. Depression from this level, from this level to how much is the depression. That is called a slump; that is called slump; that is called the slump, right?

So, slump is measured using upturned corn and slump rod as a guide. So, this is the rod you put it in and take as a guide. Therefore, this is the slump. So, we can understand that if the concrete is flowing then slump will be very high. Every stiff slump will be very

low. So, you can in fact classify this is true slump, something like shear slump. This is you know this is just simply sheared off and collapsed slump which is actually flat. Normally, higher higher the slump flowing concrete will show this kind of a collapse behavior. Most of the ordinary concrete you know of the good old days, normal concrete would show this kind of true slump. So, this is one test.

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Compaction factor is other test where you have a hopper in which you feed the concrete in three layers. There is a gate here which you can open. So, you open it. The concrete just goes there. It is closed now. So, there is a kind of standard compaction you have achieved here by a drop. You know drop from upper hopper to the lower hopper. So, this is about a meter height. So, this is standard compaction you have achieved, so that you know if somebody might pack it in a different manner it may depend from individual person to person.

So, there is a standard, there is a drop. Through this drop we have got a standard. Some compaction you have achieved and which is, which will be more or less similar by you know it will be, it will not be as much as individual depended had this been not there. Then you drop the concrete into a cylinder, standard cylinder which is 150 mm dia by 300 mm height and it will you know excess concrete you travel it off from here. So, excess concrete travel it off and find out the mass of the concrete.

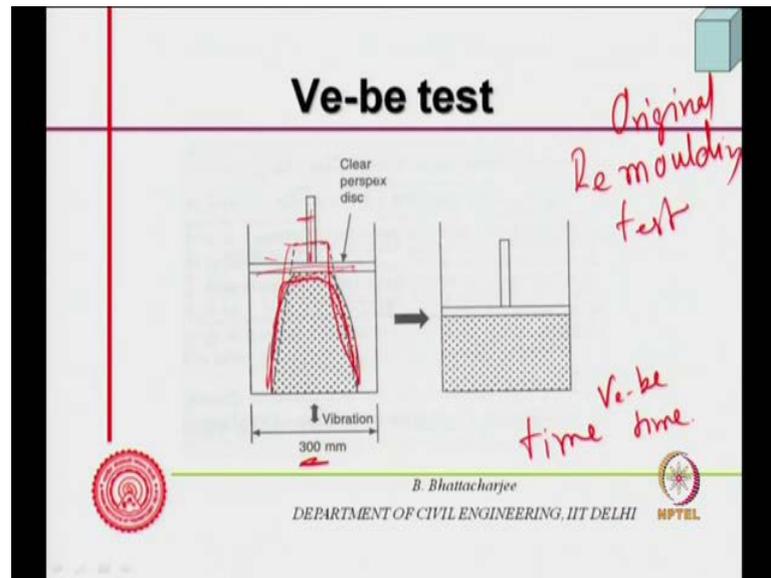
So, find out the mass of the concrete, find out the mass of the concrete. So, mass of the concrete, mass of the concrete as difference, as difference of cylinder plus concrete minus W_{cylinder} . So, you find out you know difference, this is mass of the concrete. Now, the volume is known or next what you can do? You can take this cylinder, put it in more concrete and then compact it in standard manner. So, compact it in a standard manner.

Let us say you know and then you will get this after drop, drop. So, this is, let us say let this one is W_1 and then similarly, you compact it in a standard manner, fill it in and compact it in a standard manner on a vibrating table and the you get W_2 is equals to $W_{\text{cylinder plus concrete vibration minus } W_{\text{cylinder}}}$. So, W_2 divided, you know W_1 divided by W_2 is we call as compaction factor. W_1 divided by W_2 we call as compaction factor.

Therefore, what we are doing? We are actually measuring concrete you know trying to find out by this standard drop the compaction of the concrete or the mass we attain by compaction divided by, so it is the ratio from the mass we attain by dropping it through a you know kind of a standardized compaction divided by full compaction under vibration in a vibrating table. This ratio we call as compaction factor. So, higher this value the ease of, you know quite easier to do the like more workable the concrete is for example, if it is water, it will be simply water 1.

If it is flowing concrete it will be simply 1, it will be simply 1. So, how easily it can gets compacted that is what it is. How it is easily you know it drives out the air that is what is seen, so in fact a function of compactibility. Well slump is a actually settlement under self weight. So, depend little bit on flow properties, little bit on flow properties you know under self weight how much it settles. So, basically we will depend upon actually angle of repose also, it will depend upon angle of repose also. A stiff concrete will high angle of repose while a flowing concrete will also somewhat related to flow, but this can be related to actually compactibility. So, compactant, compaction factor mostly maximum can be 1, but it is never 1, it is more than about 0.65 66 or 0.7 you know to about 0.85 or 0.9. So, compaction factor is like that, compaction factor is like that. This is another empirical measures say most suitable for laboratory situation, not field application of course not very easy.

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Ve-be test is the other test where it is actually variation of remoulding test. So, originally what was done was you have the slump cone, the concrete and then remove the slump cone, concrete might attain a shape like this, might attain a shape like this, right? Because there will be some settlement and then you put a piston here, in this case of course, clear perspex disc, disc piston sort of a thing. It is a disc basically and from this now you, this can be some weight here and you vibrate it, then it attains the cylindrical shape. So, 300 mm cylindrical shape, you know this cylindrical shape.

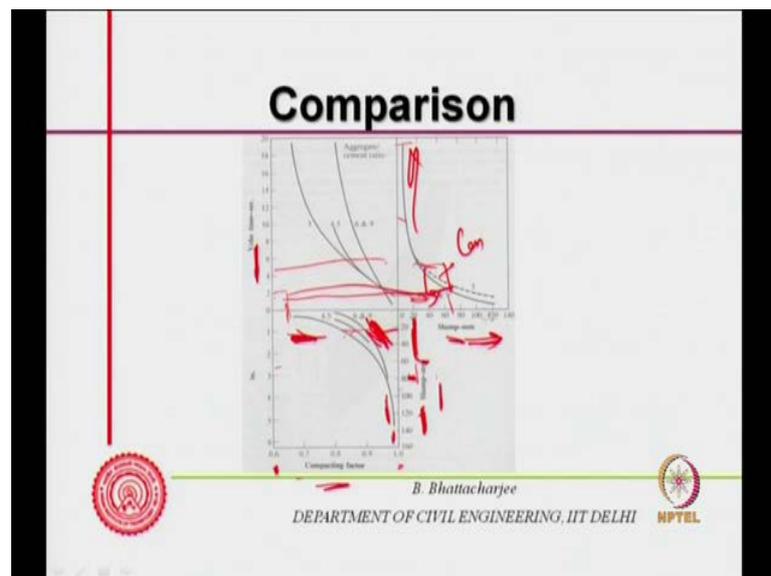
So, as soon as cylindrical shape is obtained the one can put off the stopwatch, you start the, start the vibration in a standard manner and as soon as it attains a cylindrical shape from this truncated cone shape or slumped trunk you know from a truncated cone shape, then too this time is measured. This is called ve-be time. Originally, remoulding test was done to find out the effort required to change from this shape to this shape. So, truncated cone shape to you know so original remoulding test. It is called remoulding test.

So, effort required for remoulding, remoulding test originally, originally. Remoulding test is the effort required to remould it from this truncated shape to a cylindrical shape that is called you know remoulding test, but now of course, it is measured in terms of time. So, and we call it ve-be time. So, this is actually higher the time, more effort you require. So, less workable the concrete is, lesser the time least effort you required. So, therefore, ve be test is related to this.

Now it is good for stiff concrete because stiff concrete will take longer time to attain that shape whereas the flowing concrete will quickly attain the shape and therefore, it may not be easy to measure it. All right, so this is, this is this is ve-be test. This is ve-be test and its gives you an kind of a, kind of a measure of mould ability because you are doing a remoulding test. So, the time require from remoulding from a given shape of truncated to slumped, truncated cone shape to our cylindrical shape, how much time does it requires.

So, therefore, time required for remoulding with a constant effort, all right? So, it is actually mouldability, moulding to a new shape that is what it talks about and relates somewhat to mobility, mobility; relates somewhat to mobility. Stability is the tensile is related to tensile strength of the fresh concrete, right? Stability is related, so should not separate out.

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All right, if you compare this three test we will see that here is the compaction factor, on this side is the ve-be time and here is the slump. So, compaction factor varying from about 0.6 to 1 and this side is a slump. So, you know when it is very close to, it is going towards near to 1, very high compaction factor means slump is also very very high, but the sensitivity of the compaction factor to lower ve-be time you know. So, this is I mean the ve-be time is less ve-be time here, lower ve-be time it is not very sensitive. If you

look from between slump and the ve-be time, slump higher slump you have very less ve-be time. Ve-be time is very less for high slump.

So, it is not ve-be time is not sensitive to high slump concrete, but is very sensitive for low slump concrete. So, when you have slump 20 if you know if that ve-be time change will be quite significant. So, ve-be time is good for stiff concrete, slump is good for relatively flowing concretes. Stiff concrete it cannot handle because if you look at the slump here for the stiffer where ve-be time is changing, the slump does not change much. So, it also depends upon aggregate cement ratio etcetera etcetera.

Compaction factor is somewhat in between. If the compaction factor change for high slump is very little, it is not changing and here also what is stiff concrete it is not changing, but it changes significantly in this zone where you have got relatively low slump and possibly relatively slow ve-be time as well. Relatively slow you know it actually is relatively slow, you know this is a slump and the compaction factor is in between you know, it is somewhere in between.

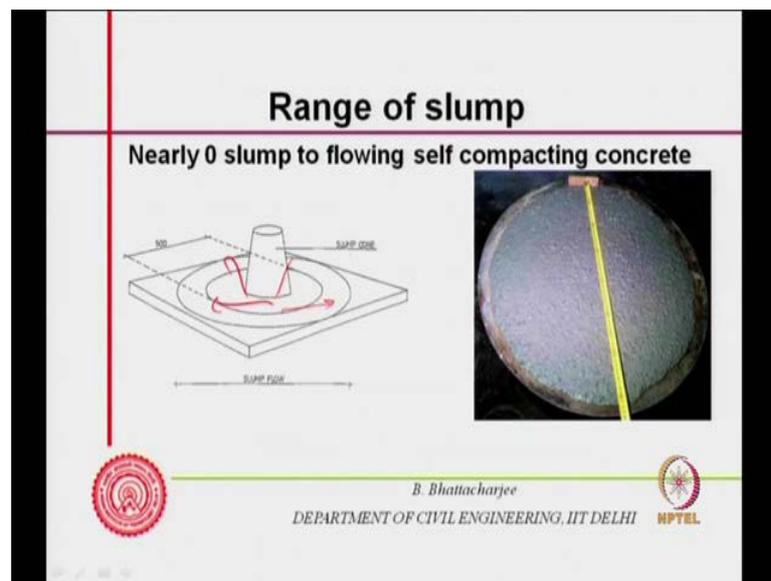
Compaction factors for example this slump 20 to 40 slump compaction factor is good or even 50, 60, 80 slump, it is quite good, but if you go to 20, 0 to 20 slump its change is very little. So, correspondingly if you see 20 to about 80 slump, this zone compaction factor is still good, compaction and correspond to about ve-be time of 2 to 4 seconds and so on and so forth. So, therefore what we find? For stiff concrete ve-be time is good, for flowing concrete slump is good, compaction factor is somewhat in between.

So, you can compare one with the other. One with the one, you know compaction factor with compaction factor only, cannot mix it up. So, I thus required workability is usually specified either in terms of any one of them. Most popular is of course, is slump because if its simplicity and ease of performing the test at site. Ease of performing the test at site, right? Ve-be is required where we are doing very stiff concrete such as I gave an example, for example, fiber reinforced concrete.

Introduction of fiber depending upon their l by d ratio you know this workability gets reduce because it is a kind of elongated, extremely elongated aggregate you are introducing. So, they actually disturbs the workability, tend to become stiff concrete. Now, such concrete you cannot measure with slump because you won't get any slump variation, but compaction ve-be time variation you will get it. Similarly, self compacting

concrete there is no question of using ve-be time or pumpable concrete no question of using ve-be time, not even compaction factor. So, it will be slumped and similar kind of thing. So, that is how we compare, that is how, that is how we compare, that is how we compare different tests.

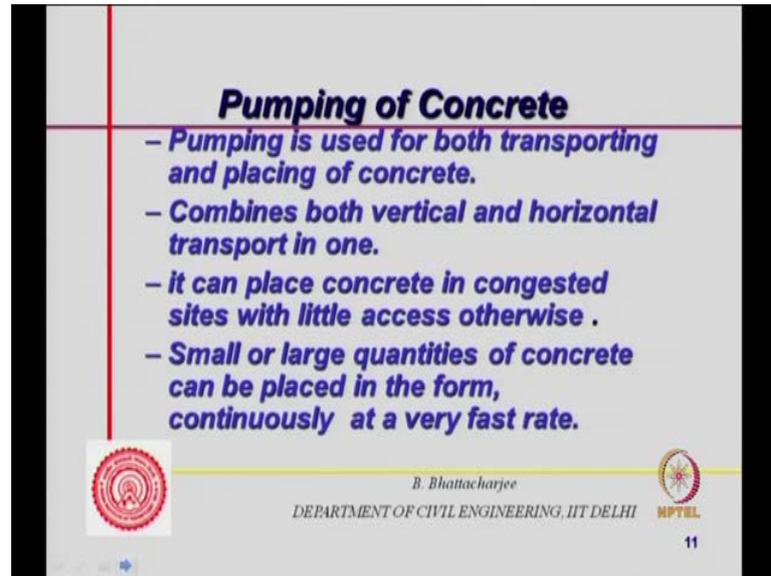
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If we see the slump you can have concrete today, you can have nearly 0 slump concrete to flowing concrete which is self compacting concrete, right? Self compacting concrete. So, there we talk in terms of slump flow. For example, you just lift it up. The slump cone, lift it up and this spread of the concrete we measure. So, as you lift it up the concrete will get spreaded along this direction and you can see that slump flow is measured.

So, you see the extension of the slump is in this term, in this you know, this kind of, this kind of test called slump flow. So, concrete is very versatile going from 0 slump roller compacted concrete to self compacting concrete. And I also talked about mini slump earlier. If you remember we talked of mini slump test in the context of a mixture, a compatibility or selection of that mixture etcetera. Mini slump test for paste, so thus, thus actually you know, that is essentially related to the empirical empirical methods for workability. As you can understand pumping of concrete, pumping will be related largely to the slump finally, you cannot do the other one, but anyway let us see. Pumping of concrete, issues involved.

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Pumping of Concrete

- **Pumping is used for both transporting and placing of concrete.**
- **Combines both vertical and horizontal transport in one.**
- **it can place concrete in congested sites with little access otherwise .**
- **Small or large quantities of concrete can be placed in the form, continuously at a very fast rate.**

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11

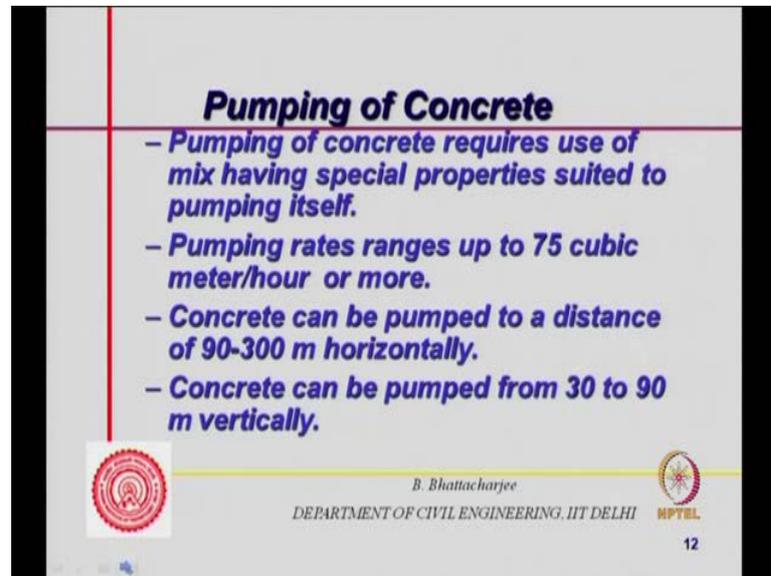
First of all let see how you know what are the pumps types, a little bit and then will go to you know pumpability of concrete itself and then mechanisms and so on and so forth. Now, remember any concrete cannot be pumped. Pumpable concrete is somewhat different than the normal concrete because only thing that can be pumped in the, you know only thing in concrete that can be pumped is water. Well paste also you can pump, but that is because there is water present.

So, as the water moves it takes the other materials with it, but then it should not go alone, leaving the solid behind. So, it should carry all the materials together with it and therefore, concrete pumping water is the one which is actually pumping, pumpable and the solid should be in such a manner that there is no separation of water from the same or water from the rest of it. So, therefore, pumpable concrete can be just not simply you know normal concrete proportioning. You might have to proportional them a little bit carefully, so that pumpable its, it remains pumpable.

So, pumping is use both transporting and placing of concrete. You can place straight away on to the mould and then it combines both vertical and horizontal transporting one, therefore, it is very versatile. And as I was mentioning a pump together with let us say ready mix concrete truck, agitator truck coming or the transit mixture coming and delivering your concrete and straight away into the hopper of the pump and from the pump straight away concrete goes to the mould, straight away it can go to the mould, so

quite a bit of advantage. Can place concrete in congested site with little access otherwise. And you can place actually small or large quantities of concrete in the form, continuously at a very fast rate. So, speed is also very very high.

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Pumping of Concrete

- Pumping of concrete requires use of mix having special properties suited to pumping itself.
- Pumping rates ranges up to 75 cubic meter/hour or more.
- Concrete can be pumped to a distance of 90-300 m horizontally.
- Concrete can be pumped from 30 to 90 m vertically.

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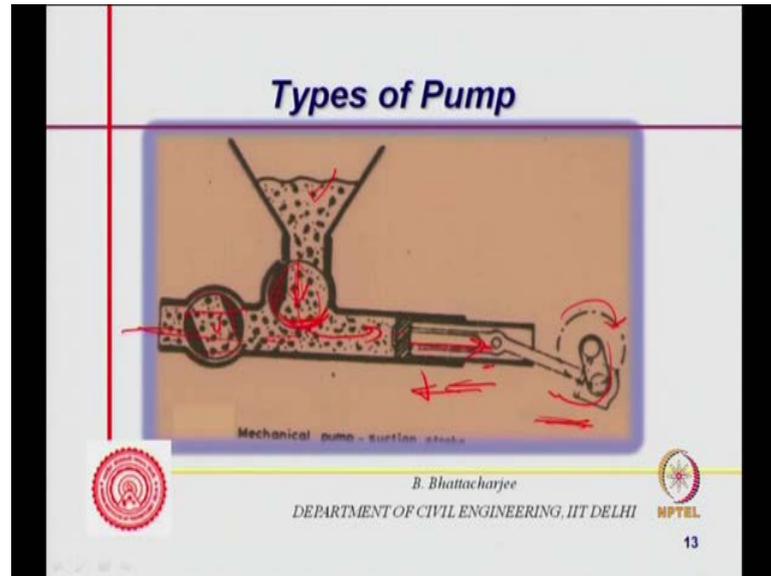
 

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It requires use of mix I mean special properties suited to pumping itself, that is what I was mentioning. You know it is just not I mean people, you just simply should not be thinking that concrete with a given slump, high slump is just pumpable. Well it is, high slump is a thing, but that is not necessarily the sufficient condition for pumping. So, one is to see because pipe might get choked. If the concrete is not proper pipe might get choked and more frequently it might get choked because water may just flow leaving the material alone.

Pumping rates ranges up to 75 cubic meter per hour or more. It will depend, current pumps might do much higher and you can pump concrete to a distance of 90 to 300 meter horizontally, may be modern pumps might be even doing better and it can be pumped from 30 to 90 meter vertically, but both you cannot realize together. So, either vertically up, if it is you know other maximum goes up to 390 meter may not be realized simultaneously. You will realize it somewhat in between.

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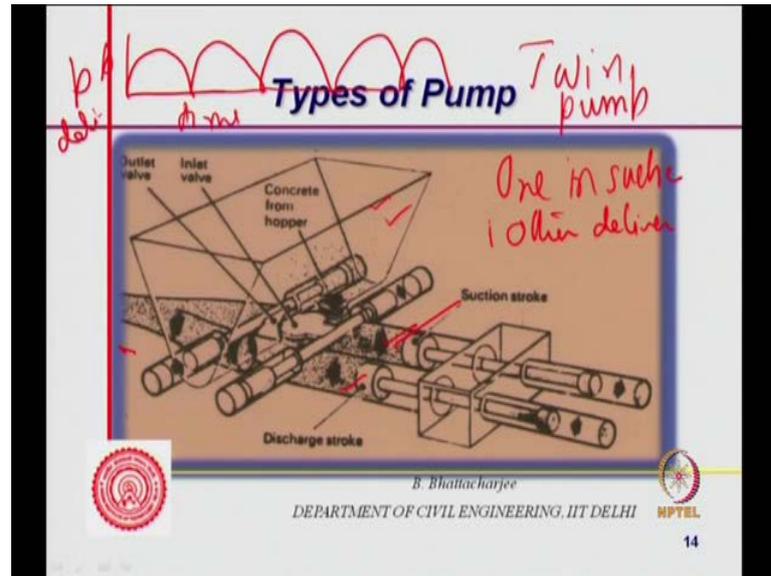


Types of pump, now most commonly used pump is reciprocating type. There are other types of pumps, but I will not discuss them actually and this is mechanically driven. This simply mechanically driven as you can see it is simply mechanically driven. You have a, you know reciprocating engine, the piston is here. The piston is here and we send a suction stroke. So, you have a hopper, you have a hopper on which concrete comes in and you can there is a valve, the circular valve.

Now, it is open, the gate is open. So, concrete can come in. So, it is a suction stroke and this there is another valve. Actually, it is, it will be, it is closed actually. Nearly, closed and the stroke is along this direction. So, it is a suction stroke. Stroking is along this direction. So, this is rotating along this direction, suction stroke and as the suction occurs, this gate is open, concrete come in and fills in this space. Now, the piston goes then in the delivery stroke as this rotates here, delivery stroke piston will go somewhere there. Simultaneously simultaneously this valve will come and close this portion and this valve will open up, you know this concrete portion will get a line.

So, it will be something like this. It will get the line and during the delivery stroke concrete will move out of the pump. So, it is basically reciprocating action and this is directly mechanical, but this system can be modified to hydraulic system and that is what is most commonly used. That is what is most commonly used; you know that is what its most commonly used.

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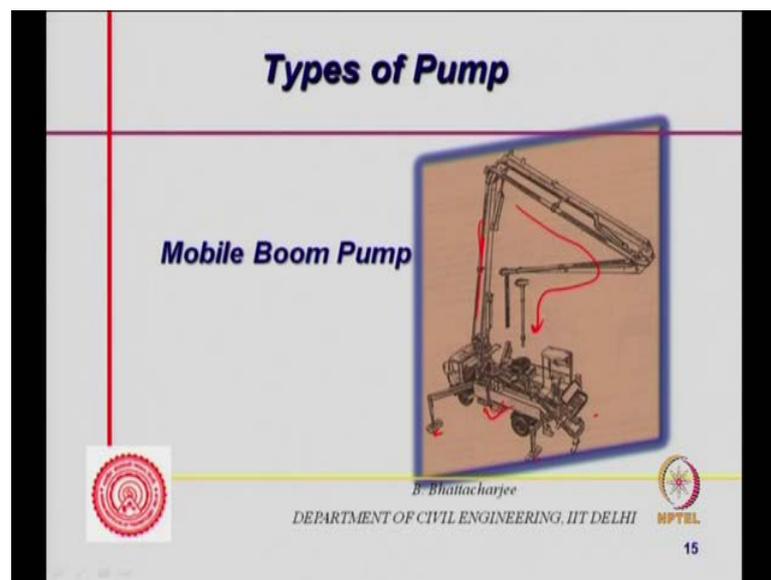
So, generally you will have; this is the hydraulic system. So, this is hydraulic. Now, the same piston is operating, but it is operating hydraulically that means your fluid you know is the one which gives the pressure and therefore, you would not have jerks and now there are twin valves because twin twin pumps you can see one and two. There are twin pumps, one and two. There are twin; two of them actually. So, what happens is this is a common hopper, common hopper and the valve is such, the valves are such that while this is in suction stroke this, let say this is in suction, the other will be delivery.

So, one of them is in suction the other one is in delivery and this is a hopper for collection of concrete, hopper for collection of concrete, so one, one twin pump, twin pump, one in suction, other delivery. Now, normally what will happen? Since, it is reciprocating pump if I plot the pressure for a single pump pressure will be like this. Delivery stroke in the pipe pressure and the pipe will be like this. Then this is the suction stroke, there will be no pressure, no delivery, delivery side there will be no delivery.

Then you will be (()) this will be another one. So, it is this pressure, at the pipe pressure with time, time; this side it is time, pressure with time. So, if I have only one pump this will be the kind of half rectified wave, but if I have two pump like this twin pump then I will have pressure in the delivery process in the delivery pipe, in the delivery pipe you know the pressure would be like this. So, concrete flow will be now our pull will be rectification actually, so you have something like this.

So, twin pumps are what is most commonly used and they are usually hydraulically driven, they are hydraulically driven, they are usually hydraulically driven, driven so that you have better control. The smooth, so that you know, so that it is all smooth. There is no sudden change. So, actually the wave sort of half wave rectification or full wave rectification we achieved with twin pump and does the delivery through which concrete will be actually delivered.

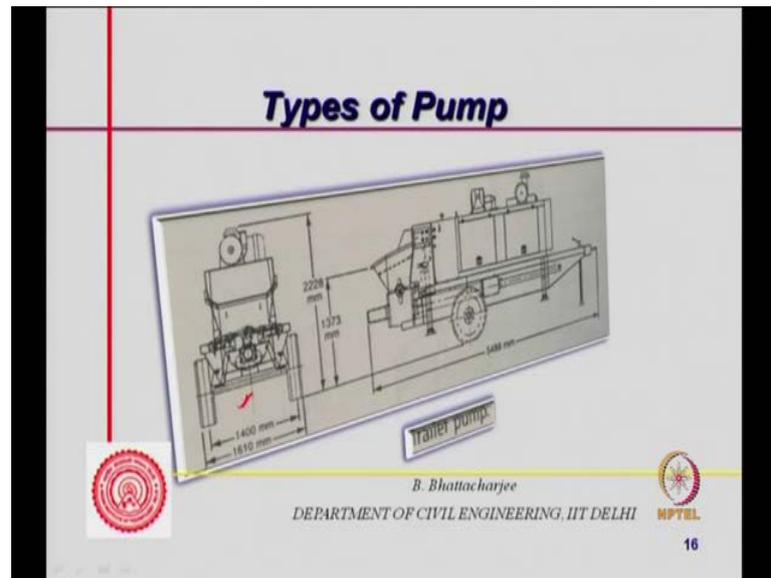
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There are other kind of pumps which we will not look into like peristaltic pump, which I think I will have to, we will have to skip because of time constraints that we have, but there are other kind of pumps such as peristaltic static pump, which are actually used in many laboratories you might have seen, (()) laboratories. So, squeeze (()) pump or peristaltic pumps were used sometime small pumps, but most commonly used is the hydraulically driven twin pump, you know same reciprocating type as I just showed.

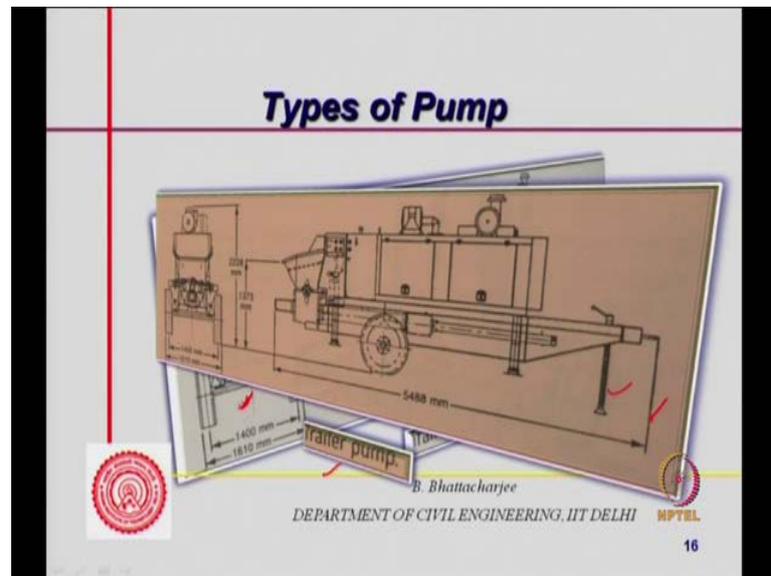
And they can be mobile boom pump for example it is like this. If you see this, it is on a truck, it is on a truck, it is on a truck. This is actually supported on the rigs, right and this is the boom and you can actually, you can actually deliver anywhere you like you know, so it is a mobile boom pump. It is a truck, mounted on a truck and can be transported, transported, the truck and come and you can just you know the same pump is just simply on a, so the, it is on a mobile boom. So, we actually can deliver wherever it, you know wherever it is required. So, that is the mobile boom pump same one.

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Then you have got trailer mounted pump. So, for example this is a trailer mounted pump you know pump. So, something like this, this is how it looks like, trailer mounted, mounted on the trailer on one side. So, this will be actually towed by, towed away by other vehicle, mounted on trailer.

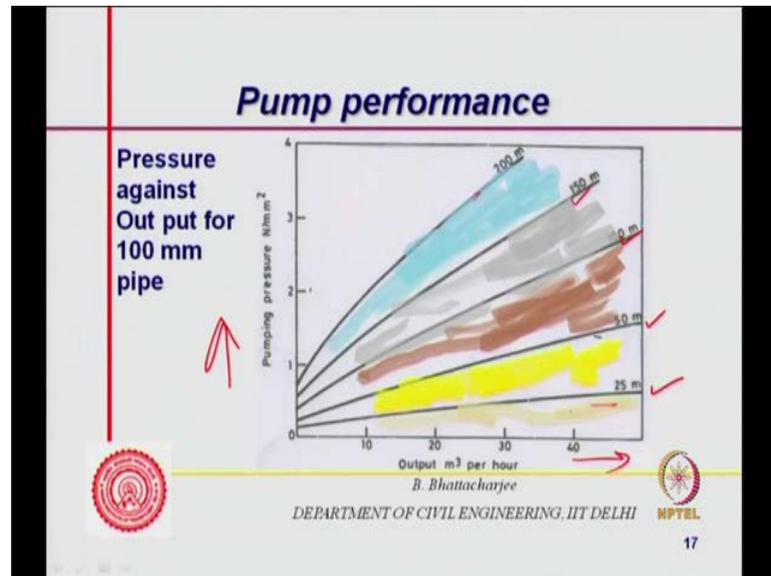
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And you can see from the other direction. So, this is the, this is the form essentially meant for you know towing it off and the pump is mounted there. So, you can have trailer mounted pump, trailer mounted pump or you can have pump which are truck

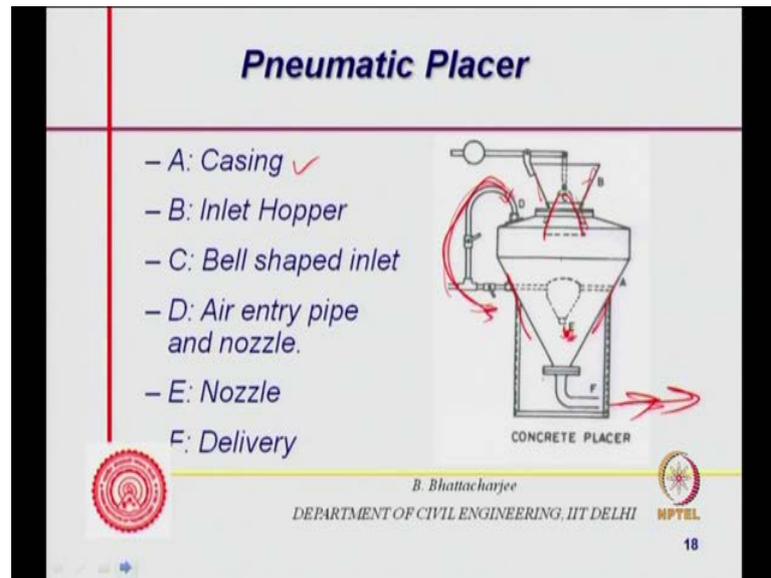
mounted and both are mobile. So, you can use them in conjunction with r m c, you can use them in conjunction with r m c very easily you can use them in conjunction with r m c very easily. So, that is so far as the pumps are concerned.

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Pump performances, well it is for a 100 mm pipe, output per hour as a function of pumping pressure. And this will depend upon what is the length you are pumping through. So, at 200 meter length the pressure required will be this much, for 25 meters pressure required is less. So, as the length increases length of pumping increases, pressure required will be high and it is also a function of higher the output, pressure required is high. So, this is one can understand pump performance from so therefore, you know the pump that you select will be based on what is the length one would like to pump and what is the kind of output. So, based on this pump capacity is actually selected.

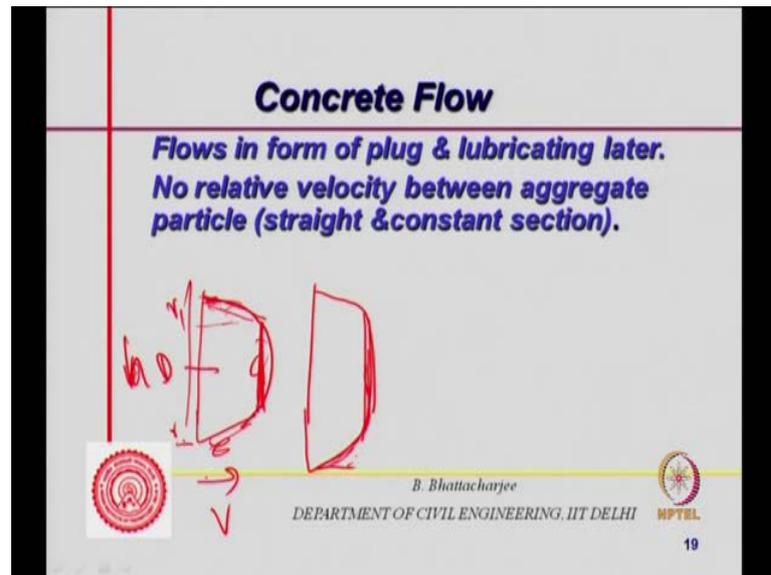
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Then, just we will come to the concrete a little bit later on, but pneumatic placers are used in some cases where actually it is the air, you know it is the air actually. Air which, compressed air which will be actually driving out the concrete. So, this is your pneumatic placers. So, you can see A is the casing, this A is the casing, this is the casing; B is the inlet hopper. So, B is the inlet hopper, this is the inlet hopper through which it comes, C is the bell shaped inlet through which actually your motor or concrete etcetera will come and D is the air entry, D is the air entry, you know this, this one is to the compressed air would enter, compressed air would enter, D is the air entry and E is the, there is a nozzle through which also you know air, air will enter. D is the compressed air will enter through this nozzle and F is the delivery pipe.

So, you have concrete enters from here, air under the pressure and it causes to move. So, dry, relatively dry air makes quite often (()) for example or similar sort of usage you can actually, one can used compressed air to drive the transport the cement mortar or even you know concrete or grout or similar sort of situation, not you know concrete dry, relatively dry not grout (()), relatively dry, but even grouts can be you know pneumatically placed through concrete. This is pneumatically placed through a pneumatically placed.

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So, this is not, this is not a very common thing, not in special cases only used. So, let us look at pumping and concrete flow. Now, we said that flows in form of a plug that we have seen when we were talking about, when we are talking about rheology of concrete. So, it forms, flows in form of plug and we shall see a diagram of course, and there should be no relative velocity between aggregate particles. Especially when your pipe is straight and you have constant cross section.

So, for constant straight pipe and constant cross section there should be no relative velocity between aggregate particles otherwise there will be segregation and concrete actually flows like plug. So, and the lubricating layer is there in the boundary. So, in other words if you remember what we talked about, what we talked about you know the velocity profile, it will look like this.

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Concrete Flow

- Flows in form of plug & lubricating later.*
- No relative velocity between aggregate particle (straight & constant section).*
- Lubricating layer near pipe boundary is essential for pumpability.*
- Compacting effect of pressure consolidates and forces grout out*

The slide includes a diagram showing a cross-section of a pipe with a central plug of concrete and a lubricating layer near the boundary. Hand-drawn red lines and arrows illustrate the flow and the effect of pressure. The diagram shows a central plug of concrete moving through a pipe, with a lubricating layer near the boundary. The flow is depicted as a series of waves or pulses. The diagram is annotated with red lines and arrows, showing the direction of flow and the effect of pressure. The text 'grout' is written in red above the diagram, and 'ε' is written in red below it. The diagram is signed 'B. Bhattacharjee' and includes the logos of IIT Delhi and NPTEL.

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19

There will be no velocity, at the boundary there is some velocity profile because there is a lubricating layer, but velocity profile. So, this is actually velocity, velocity V you know along the cross section. V be along this direction, h or cross section diameter you know diameter, so this is radius r and this is radius r . So, little bit of velocity gradient of the boundary, but there will be no velocity here. So, it actually, sorry it is like this. Actually, it will be like this, constant, more or less constant.

This has to be constant, but there is a lubricating layer there. You just have a look at that, in a minutes time, so basically lubricating layer and you should have a no velocity gradient. So, lubricating layer near the pipe boundary is essential for pumpability and that is important. So, compaction effect of effect of pressure consolidated and forces grout out. Now, I said that it will be like this. So, there is a compaction you know, the concrete gets compressed from both the sides.

Concrete gets compressed because it is moving the piston is causing it to move. So, piston causes it to compress, piston causes it to compress. So, when it compresses, when it compresses the water will force out. So, grout comes out. In fact grout will; compression grout will force out. So, grout goes upwards, grout forces out. So, compacting effect of pressure consolidates and forces out grout. So, material will come closer to each other, you know solid materials and some grouts will be forced out to the periphery. So, this is one action, this is one action, this is one action.

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Concrete Flow

- Flows in form of plug & lubricating later.*
- No relative velocity between aggregate particle (straight & constant section).*
- Lubricating layer near pipe boundary is essential for pumpability.*
- Compacting effect of pressure consolidates and forces grout out*
- Trowelling effect due to frictional drag at boundary pulls grout out*

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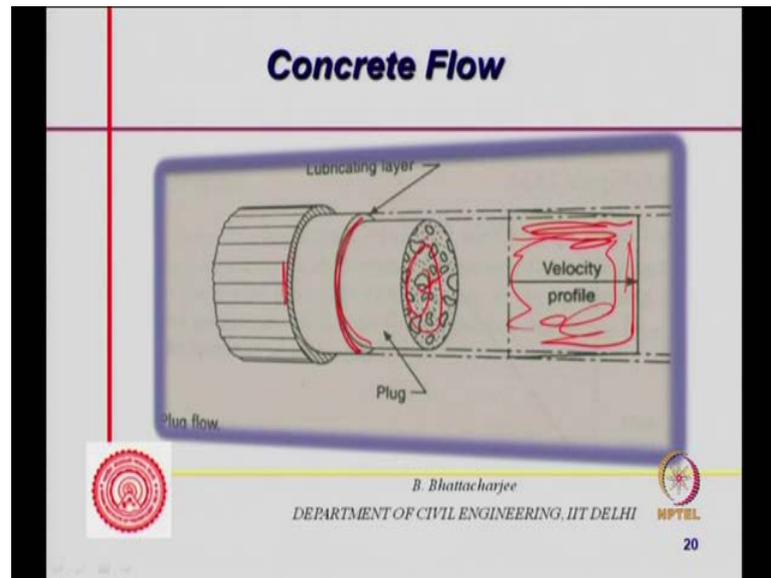


19

Next thing is trowelling action. So, when you trowell a concrete you know if you have seen, we would trowell a concrete, this is your concrete let us say and you do trowelling you do some sort of trowelling you know, just polish it. So, what happens? Trowelling actually brings out when you are water. Now, trowelling effect occurs here between the pipe boundary and the grout you know and the concrete itself. So, as it is moving as the relative motion you know pipe boundary is fixed, pipe is fixed, the material is moving, material is moving.

So, as it moves there is a kind of trowelling effect on the boundary. This frictional drive, due to the frictional drive and that also pulls out the grout. So, this grout goes to the boundary, the compaction, also compacting effect of pressure also causes grout to move to the boundary of the pipe. So, the pipe boundary if I have sufficient you know grouts available in the system they will go out to the pipe boundary. They will go to the end of the pipe boundary and creates that lubricating, create that lubricating layer and create that lubricating layer, create that lubricating layer, right? So, it will create those lubricating layer and that is what it is.

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So, velocity, velocity here there is a reduction, but in this zone it is all constant. So, velocity is constant in this zone, this remains fixed concrete. This is, this is actually, this is actually the friction layer, the lubricating layer. You know the lubricating layer will be here, this is the pipe boundary. So, pipe boundary, pipe thickness then the lubricating layer and then the plug that will be there. So, flow is plug flow. The flow is plug flow you know as we mentioned earlier and you remember that was in the Bingham state, not three four, just before three and four.

One is like solid, one to two like solid, two to three there is some kind of two to three is the plug sort of thing and three to four was actually a flowing like a liquid. So, here actually it would, should be best it would be between two to three that means it starts moving, you have a lubricating layer at the boundary, but the velocity, relative velocity between the particles even though within the plug is nearly zero.

(Refer Slide Time: 43:15)

Concrete Flow

- When mortar which has enough water and is sufficient to fill in all the voids in aggregate and is more to create lubricating layer it is said to be **SATURATED**.
- In Saturated concrete radial and axial pressures are same and fine content is important.
- Too much cohesiveness due to excess cement and fines may prevent formation of lubricating layer

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21

When we have sufficient mortar and which has got enough water and is sufficient to fill in the voids. So, first of all you must have sufficient mortar in the aggregate system and the mortar must have enough water in the fines which fills in the voids in the mortar itself and slightly more. This will create a situation where lubricating layer will form readily and this is set, the concrete in that case in the context of pumpability is called saturated. In saturated concrete radial and axial pressures are same that means pressure in this direction and in this direction is same.

You know there is pressure along this direction, uniform pressure in both transverse radial as well as in the radial as well as in the either in the horizontal or axial direction. So, they will be same, same pressure, same pressure all right? So, that is under saturated condition because the grout would have moved to the boundary from the lubricating layer and it is able to move. So, radial at this pressure would be same.

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Concrete Flow

- When mortar which has enough water and is sufficient to fill in all the voids in aggregate and is more to create lubricating layer it is said to be **SATURATED**.
- In Saturated concrete radial and axial pressures are same and fine content is important.
- Too much cohesiveness due to excess cement and fines may prevent formation of lubricating layer

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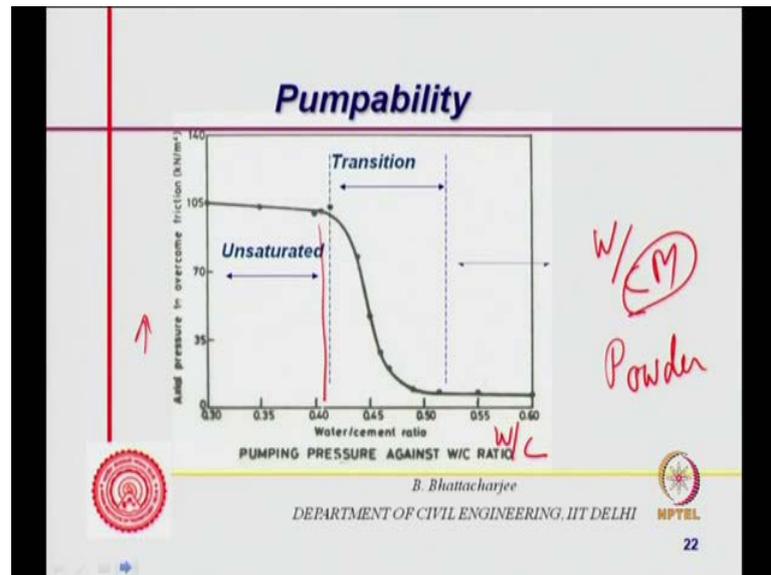


21

And too much cohesiveness of course, can result in too much cohesiveness due to excess cement and fines may prevent formation of lubricating layer. So, I must have a minimum fines content which is, which should be sufficient to fill in the voids in the mortar system or sufficient paste, I must have sufficient paste and slightly more than too fill in more than you sufficiently, sufficient paste which will obviously fill in the voids in the mortar sand system or aggregate system, but slightly more. In fact, you need more paste with lot more fines here. Fine means not fine aggregates, but finer below say 300 micron or 150 micron that, sufficient fine should be there.

So, that my lubricating can form because remember lubricating layer is formed because of the fine material present in the system and cement and very fine part of the coarse fine aggregate system forms this and that should form that lubricating layer. So, I might have cement or cementitious material or some sort of (()), fillers like limestone powder or you know fly ash is of course, is a very good material for that purpose because it is spherical in nature and it can fill in those, contribute to the paste content or grout content of the mix and thereby actually it mix the concrete more or less easily makes it saturated, easily makes it saturated.

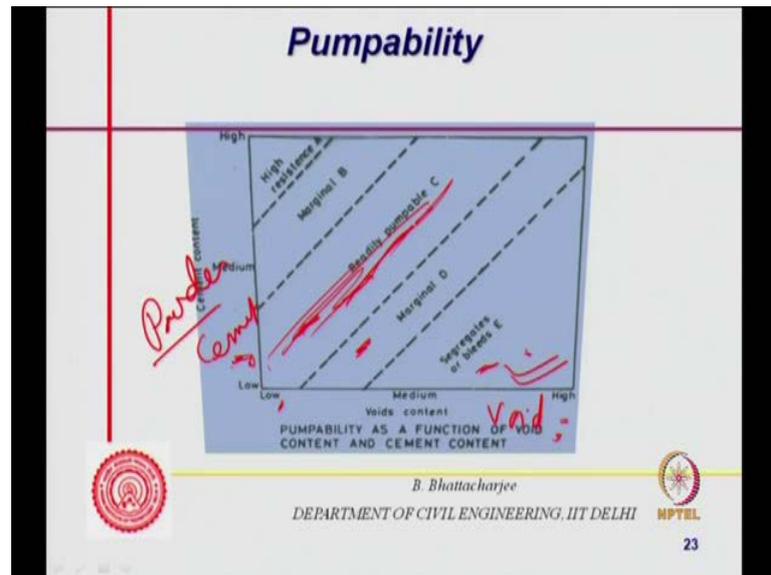
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Now, good old days there were no, when there were no fly ash and such things people did test and they looked in to say water cement ratio along this axis, water to cement along this axis and the pressure, pumping pressure. So, it was observed that when you have low water to cement ratio such as this, you are pumping pressure is very very high, so that you know we call it as threes, you can actually divide it into three zones. In the first zone your pumping pressure is pretty high, this is actually unsaturated situation because you have got less water, more of the solid in the water to cement ratio is low, right?

In other words, water to powder ratio is low that means water is more sufficient to fill in to make the paste flowable, right? So, I would not call it, see today I will call it cementitious may be C M cementitious material. So, water to cement ratio or powder, we might call it even powder. So, water to powders ratio if it is low it may be unsaturated. In other words sufficient lubricating layer may not form because lack of grout. There is an transition zone which is in between, transition zone which is in between where you know lubricating layer starts forming and when water to powder ratio is sufficiently high you have a saturated situation where lubricating layer rarely forms and your pressure reduces down. So, at it can flow at lower pressure, it can flow at lower pressure, it can flow at lower pressure.

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So, it is, if you see in another diagram for example, the void content versus this side is the void, void and this side is a cement. Of course, I will call it powder here, current days, current days we will call it powder. In good old days one would have called it cement. So, when you have got lot of voids in the system, high voids in the system and very little powder content the voids will be remaining and if you are trying to pump it will actually cause segregation and choking, you know it is, it is high void in the system, lesser powder material.

So, it will actually cause segregation or if you have too much of water in the system it can even cause bleeding, right? It can cause bleeding. So, this zone is not very good for pumpable, pumping because if you do not have sufficient powder in the system. It is actually the water goes out, it is actually the water tries to go out and if the pores in the system in the fresh concrete, pores in the systems are so fine that the water has got a you know it cannot, cannot filter out.

So, if it wants to go out it has to take the solid along with it, right? It, you know it is a, it is not a, you know it is not a kind of a reverse of filter. In a filter water goes out leaving the solids. Here, if the water has to go it must take the solid in. So, water cannot go out. So, what should happen? The pores in the system must be sufficiently fine, very fine and when can it happen, when you have fine particles, cement particles are sufficiently high and this interstitial space between those cement particle is such that water content just

cannot move out through them, cannot squeeze out through them under the pumping pressure.

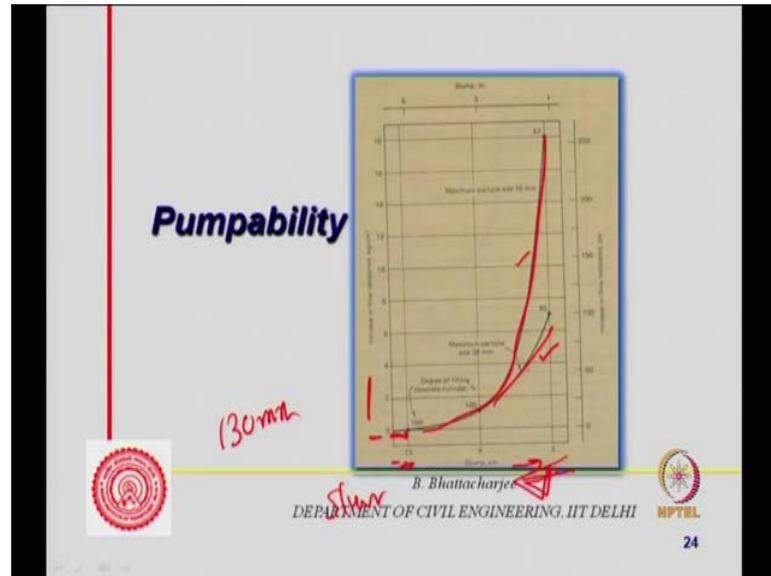
This, if it happens that way water will be going out leaving the powder. This can happen when we have too less particle or cement, fine particle or powder system in it. So, water will go out leaving the so you know sufficient fines, sufficient powder or cement fines, I am talking of cement or similar sizes material, if they are there they will ensure that the pore within them, interstitial pore within them is so fine water cannot go out, they will have to take it, take them together. If it is less then there can be segregation, that is bleeding can occur, pump water may squeeze out.

In between you can see that marginal, but somewhere you have, when you have a low voids in the system, lower cement it works out. It is readily pumpable and it is in this zone when there is you know compatible cement and the void in the system. So, void is, the packing is such the system, void in the system is sufficient and cement is also sufficient to fill in those places. So, there is a compatible zone in which pumping is, pumping does occur readily, but if you have too much of powder in the system what will happen is, you know it will offer high resistance.

Lubricating layer will form, but it will offer high resistance to actually flow because of too much of cohesion in the system. Therefore, there is a zone of pumpability in between. So, it has to have very fine or powder material sufficient, right? Sufficient powder material or appropriate, optimal amount of powder material which is more than the normal case, normal, it will have more paste in fact and flowing paste, but not excess water just flowing paste, sufficiently flowing paste.

So, that paste flows and it takes the aggregate also with it. So, water goes. It must take the cement with it and the powder, other powdery material with it. So, that paste moves as a, as a single entity and embedded aggregate also moves. So, you will have slightly higher paste quantity in pumpable concrete.

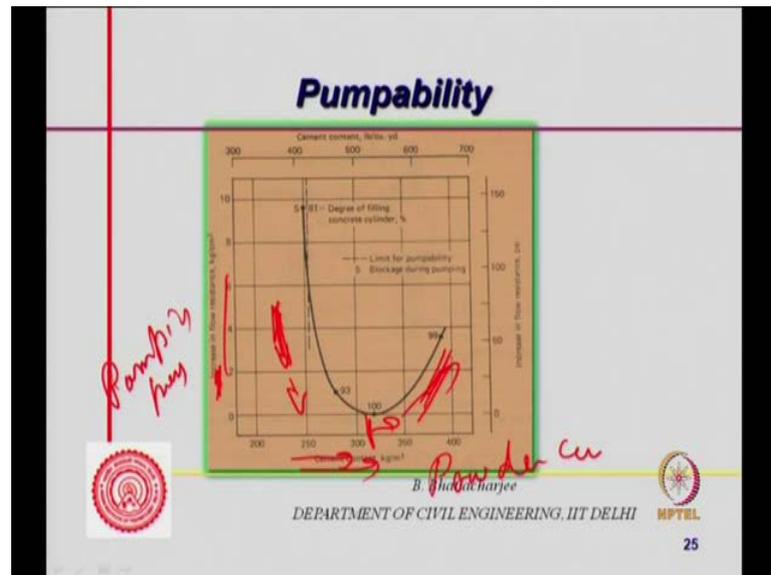
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Now, people have tried to relate this to slump and if you see in this particular diagram slump increases along this direction, you know slump increases along this direction. So, slump is here, more slump here and this is a pumping pressure. So, about 130 mm slump, here it is 130, pumping pressure is very small. Pumping pressure increases parabolically depending upon of course the aggregate size, aggregate size you know aggregate size, smaller sized aggregate, larger sized aggregate etcetera, etcetera. So, pumping pressure increases as the slump reduces.

So, one can say that somewhere around 120 130 mm of slump, you will be, concrete will be pumpable, but remember slump is one thing, amount of fines is also important. So, I can achieve this slump of course, with the admixture, but also amount of fines must be sufficient otherwise there could be choking. So, slump is an important thing. So, most of the time we actually define slump of pumpable concrete as 120 plus 120 plus may be 130 mm 40 mm in between. In fact IS 456 2000 also gives you the minimum slump required for pumpable concrete, somewhere around 100 or 120. I do not remember exactly, not really at the moment we are interested in that.

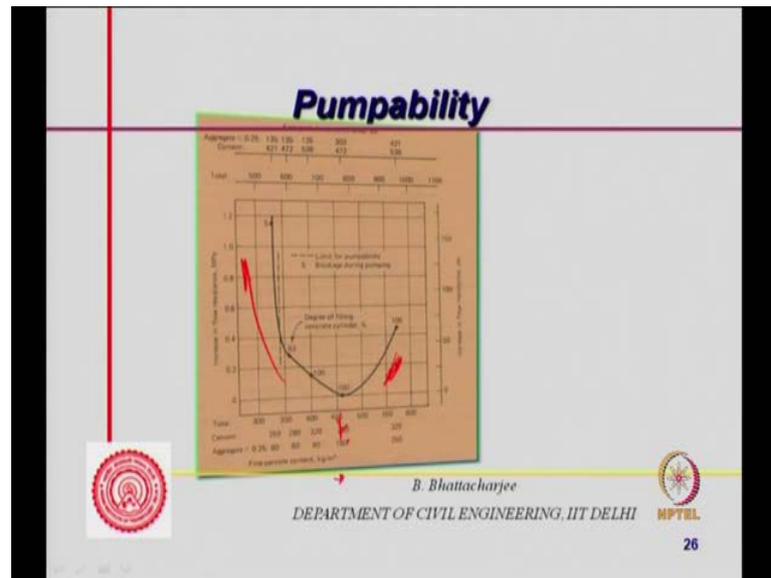
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But the fine contents if I look at, cement content in good old days this I can call it as powder content, powder content along this axis. So, if I increase my powder content there is an optimal point, beyond this if I increase my powder too much the pumping pressure, this axis is pumping pressure, pumping pressure, pumping pressure, so pumping pressure will increase.

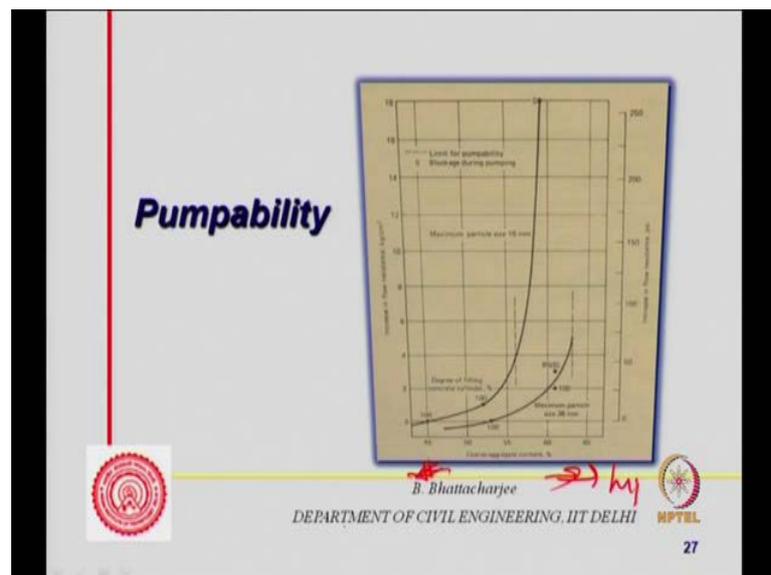
If I increase, you know it will increase and low cement or low fines, pumping pressure is also high, it reduces as I increase and further. So, I have an optimal quantity of the optimal quantity of the material, which material? The powdery material which will give me least pressure, like we mentioned earlier, right? Least pressure we mentioned earlier. So, that is it. So, we should have optimal fine content, so pumpability one must look at the optimal fine content.

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Similarly, one can look into the aggregate content, this will also give us since the fine content state has to be, powder content has the optimal correspondingly aggregate content is also optimal. So, you have got an optimal. If you have too much of aggregate, too much of aggregate less powder it will be not pumpable, pressure will be high and when you have too less of aggregate system, so then also again pumping pressure will be high.

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And then let us look at this is related to coarse aggregate content, similar sort of situation. Here coarse aggregate content is lower, here higher on this sorry lower on this side, high, high on this side. So, lower on this side actually you will find that you know it is, it is something similar concept. So, I think I will skip this quickly because we have something more to look into.

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Pumpability
- EQUATION FOR SATURATED CONCRETE

$$p = p_0 - \frac{4Rx}{D_i}$$

- p = pressure at a distance x
- p₀ = pressure at the delivery end of pump.
- R = flow resistance /area of pipe
- D_i = Internal diameter of pipe

$$x_{\max} = \frac{p_0 D_i}{4R}$$

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MPTEL
28

So, if it is saturated concrete in fact the pressure at any point at distance x, pressure at any distance x, pressure at any distance x can be pressure at any distance x can be related to, pressure at any distance x can be related to p₀ is the pressure, p is the pressure at distance x, p₀ is the delivery end, D_i is a pipe diameter, D_i is a pipe diameter and R is a flow resistance per unit area of the pipe. So, pressure at any distance from the delivery end, at x distance from the delivery end one can relate like this. In other words you can find out if the p₀ is known, if the pipe diameter is known and resistance, flow resistance per unit area of pipe is known which will be a function of the mix. Then one can find out what is a maximum pumping distance. So, x_{max} will be given by simply x_{max} you can obtain by p₀ D_i by 4 R. So, one can actually because when p is (()) to 0 you can find out what is the value of x, that is the x_{max}.

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Pumpability

- EQUATION FOR
UNSATURATED CONCRETE

$$p = p_0 e^{-4\mu k \frac{x}{D_i}} - \frac{\left(1 - e^{-4\mu k \frac{x}{D_i}}\right) A}{\mu k}$$

$b \geq 0$

- μ = coefficient of friction between concrete and pipe wall
- A = adhesive resistance, similar to yield stress .
- k = radial to axial pressure ratio

$$x_{\max} = -\frac{D_i}{4\mu k} \ln \frac{A}{p_0 \mu k + A}$$

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29

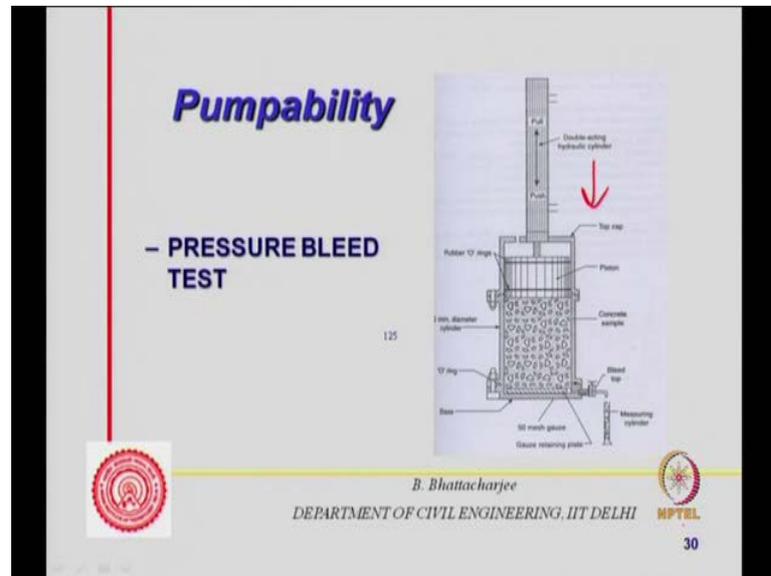
For unsaturated concrete there is one formula like that, there is one formula like that, but there is more complex, a little bit more complex, you have a coefficient of friction between concrete and the pipe coming in and also coming in adhesive resistance, similar to yield stress. Radial pressure to axial pressure ratio because radial pressure to axial pressure were same μk coming in here, it was same before, it was 1 earlier and this is the kind of formula. So, it is actually exponentially reduces, right and this is the kind of formula.

This A is the something adhesive resistance similar to yield stress. So, that is more complicated, but saturated concrete is what is desirable, right and this fraction, you know friction or the force, the the r resistance offered is a function of the concrete type and saturated concrete will have you know is is you can pump more through the saturated concrete. So, therefore x_{\max} you can find out even in this case given by this formula D_i over $4\mu k$ \ln you can simply put a p_0 equals to 0 and put p_0 sorry p equals to 0, you will get an expression for x_{\max} given by this simple algebra, there is no problem, put this equals to 0.

So, this is, this minus this take it on to the other side, take \ln on both sides, so it will become simply $4\mu k x$ by D_i and $\ln p_0$ plus you know this. So, you can actually get an expression and this will be, this will be simply \ln of all of those things. So, you can actually obtain an expression for this particular one. So, in fact this will be separated

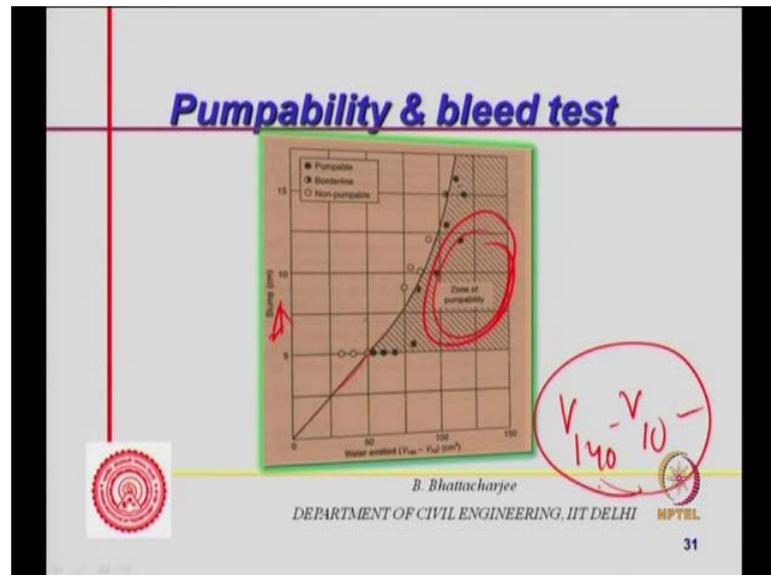
out. If you take, put this equals to 0, this goes to the other side, multiplied by mu k, so you can separate this out and simple algebra will give you this formula. I do not think I will derive this, it is very simple and anyone can do this.

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Pressure bleed test is the one test which is used for pumpability. Now, this equipment looks like this. You have a kind of tap here, bleed tap, that is the kind of a, you know there is a kind of mesh here; there is a kind of mesh, right? Mesh here, standard mesh. Here is the concrete and there is a piston through which we apply a standard pressure. So, apply standard pressure and then after you apply the pressure there is a mesh here which allows water to pass, but no solid. So, bleeding will occur under this pressure. Bleeding will occur. You measure the rate of bleeding, rate of bleeding or volume that has the water that has actually accumulated at 10 seconds to 140 seconds.

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And pumpability is related to pumpability is related to this pressure bleed test. In the x axis you have actually the V_{140} , $V_{140} - V_{10}$ that is the volume of water that comes out. So, if the water comes out, you know over a longer period of time initially if it goes out first 10 minutes plus 10 seconds is actually omitted out and it should come out in a slower speed. So, pumpability is readily defined depending upon slump.

This axis here slump, this line, so this is the zone of pumpability, readily pumpable zone where I have got sufficient value of $V_{140} - V_{10}$, you know this value is high and slump is corresponding to the slump. So, both slump and pressure bleed test can be used together in order to obtain the pumpability. So, this zone is readily pumpable. Of course, this is not a very popular test, most the people use slump and therefore not necessarily always high slump we will ensure you pumpability.

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Effect of Pumping on concrete

- *Drier consistency*
- *Increase In Temperature*
- *Slight increase in air content*
- *No change in strength or shrinkage, although aluminum pipes may cause loss of strength*

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32

Well, just to conclude our discussion, effect on pumping, effect on pumping of concrete, drier consistency. It tends to become dry. No negative effect actually. Increase in temperatures slightly because of the friction, slight increase in air content and no change in strength or shrinkage although aluminum pipes may cause loss of strength. If it is just aluminum pipes without any coating because aluminum can react with concrete, you know calcium hydroxide and all that, aluminum can react actually the concrete. (()) system, aluminate system can react with also concrete.

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Dos & Don'ts in concrete Handling

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33

Lastly, some dos and don'ts with concrete to end our discussion on transportation and all. For example, this diagram shows if it is a small mixer, you know you should actually load full, full load should be put on to the barrow, full load should be put on to the barrow, you know full load should be put on to the barrow unlike in this case, this is not the best thing to do, this not desirable. Half load on to the barrow, half load on another barrow. This will leave a stony batch this will have more paste, more mortar. It should be full load should be put on a barrow, because distortion of mixture machine will have a tendency to discharge larger particle in the beginning and finer particle at the end. Now, again this is not desirable.

I mentioned yesterday this kind of discharge is not desirable neither this, one thing is narrow and inclined. It should be actually desirable as a you know direct and then through a bottom opening large bucket, large bottom opening bucket, large bottom opening bucket and this is not, again this if you discharge, stones will come here, mortar will come there. So, narrow opening, very little will come. Here, stones will come here, mortar will come here; here the paste will have a tendency to come, aggregate will remain. Bottom, large bottom opening is always better, this is not good; this is not good. Yesterday, last class, last lecture also I mentioned same.

Large bottom opening is better. Dropping directly through a height is not desirable from a conveyor belt for example you might drop it through kind of suits or guides. So, this is also just we will, just to kind of strengthen our discussion which we had earlier. So, dropping of concrete, some do's and don'ts with concrete handling related to manual handling. So, I think with this we conclude our discussion on this particular lecture, the third lecture of the fifth module. We talk of workability, we talked of empirical measures of workability then we looked at pumping. Next lecture we will look at compaction and curing.

Thank you very much.