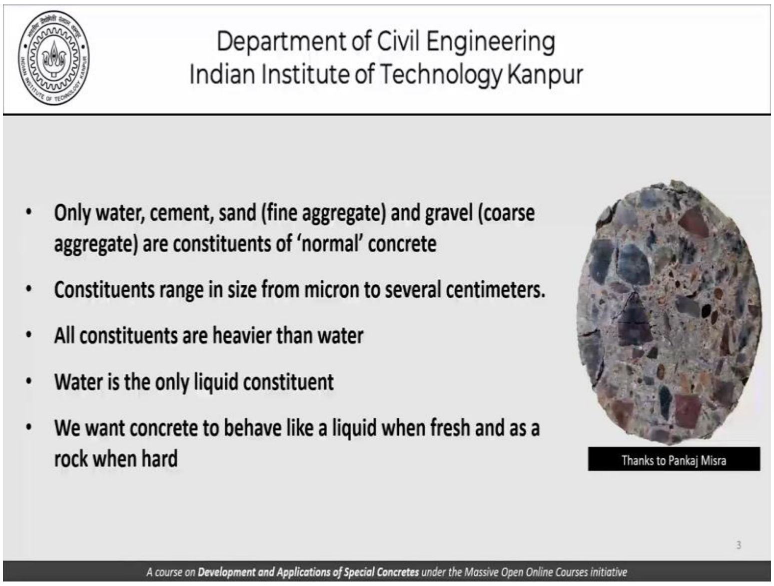
Development and Applications of Special Concretes
Dr. Sudhir Misra
Department of Civil Engineering
Indian Institute of Science – Kanpur

Lecture 07
Review of Normal Concretes Concrete Mix Proportion Analysis and Adjustment

Namaskar and welcome back again to our series of lectures on development and applications of special concretes. We will continue the discussion today with proportioning of concrete mixes and what we will do is the analysis and adjustments. Sometimes the proportions that we determine need to be adjusted. Also, the analysis that we do today, I hope will give you an insight into what concrete as a material is and what is the role of cement paste mortar and finally the coarse aggregates in the whole system.

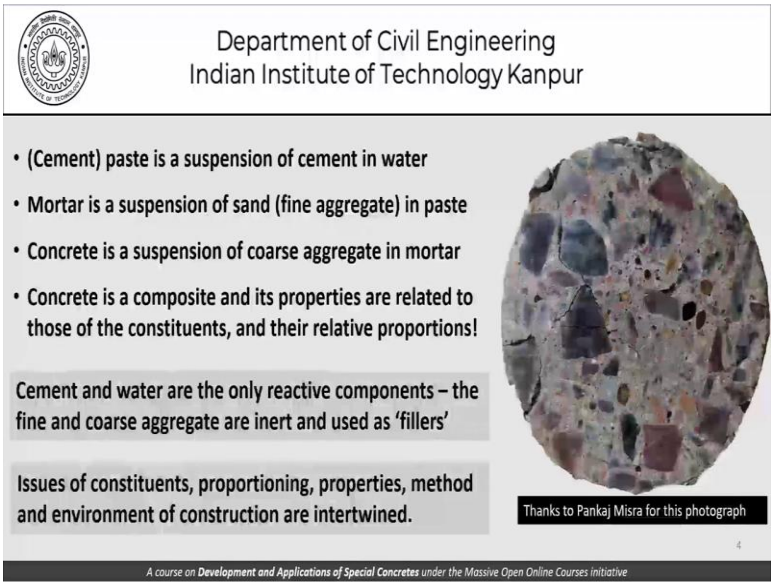
(Refer Slide Time: 00:55)



And, before we get started this slide and the next 2 are the customary slides that I am showing you all the time basically to orient you in the direction or in, the thought process that I have towards concrete. It tells you what I think some of it is fact some of it is a model that I have in my mind. The fact is only water, cement, sand and gravel are constituents of normal concrete which ranges from several microns to several centimetres.

They are all heavier than water, water is the only liquid constituent and as far as our desire is concerned, we want concrete to behave like a liquid when fresh and like a rock when it is hard.

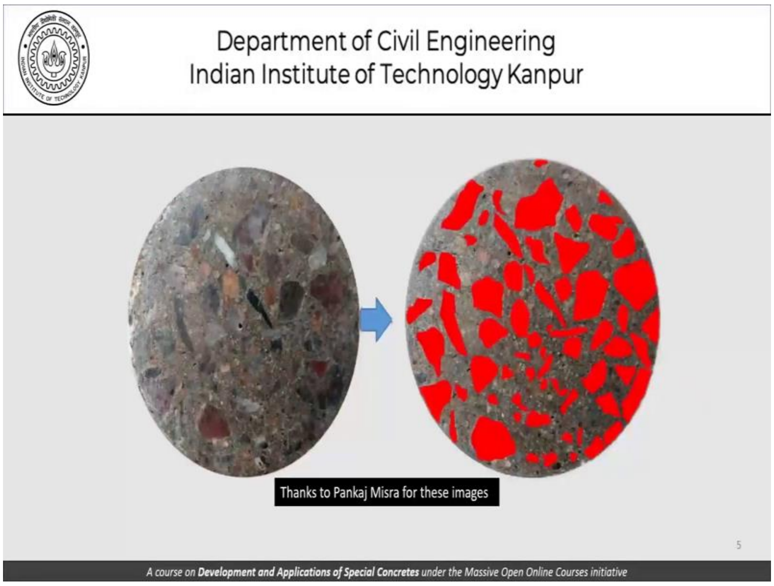
(Refer Slide Time: 01:38)



This tells you another fundamental model that I use paste being a suspension of cement in water, mortar being a suspension of sand and paste and concrete at the end of it being a suspension of coarse aggregate in mortar. I hope that the analysis that we will do today will help you understand this model which I have been trying to talk to you all the time. Cement and water are the only reactive components and fine aggregate and coarse aggregate are inert and used as fillers.

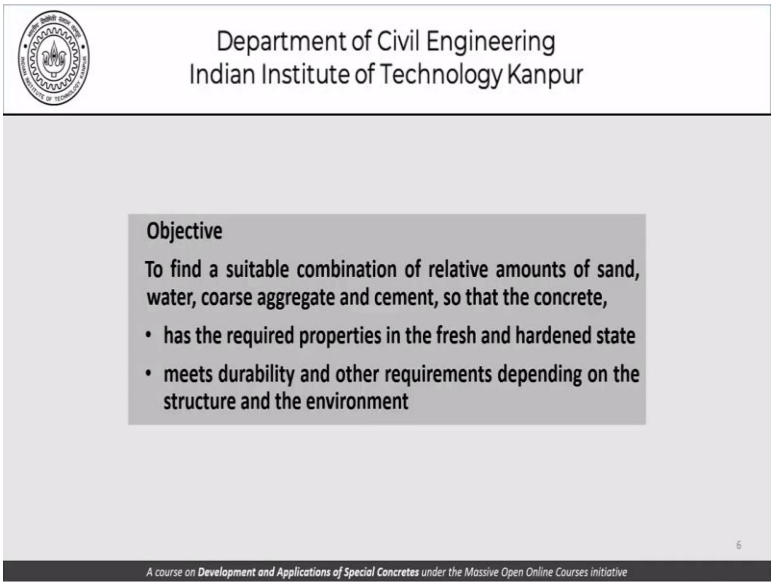
And, the issue of constituents proportioning properties and the method and environment of construction are all intertwined. So, what we are trying to do as far as this particular module is concerned, we are trying to review the properties of fundamental concrete that is normal concrete and we will move on to special concretes possibly the next lecture or maybe the lectures after next.

(Refer Slide Time: 02:36)



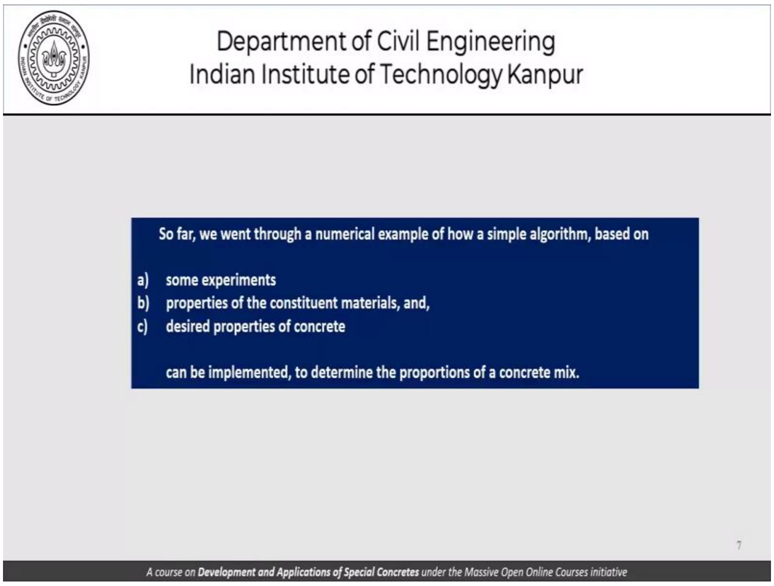
This is another picture which just shows you a real graphic picture or an image of aggregates being suspended in mortar i.e., the coarse aggregates being suspended in mortar.

(Refer Slide Time: 02:48)



Now, as far as proportioning is concerned you have seen this slide before. The objective of this exercise is to find a suitable combination of the relative amounts of sand, water, coarse aggregate and cement. So, that the concrete has the required properties in the fresh and hardened state and meets any other requirements that the client or the codes or a particular structure might have.

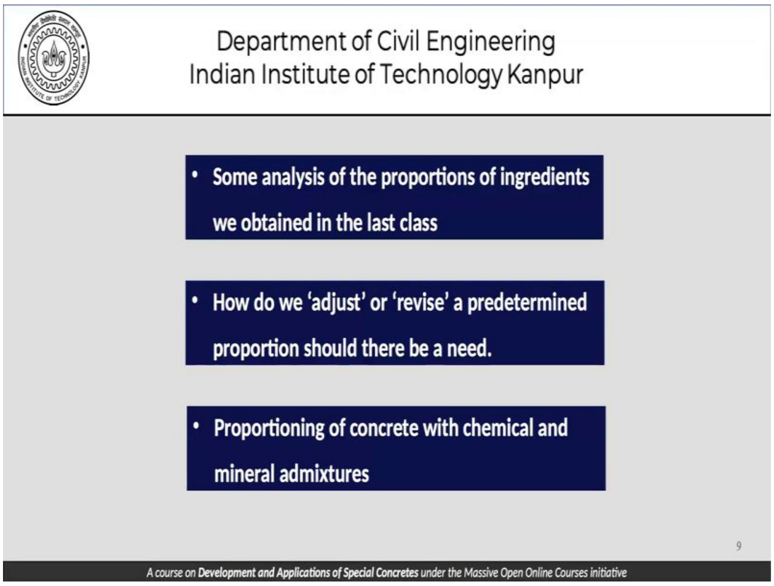
(Refer Slide Time: 03:10)



What we have done so far is that based on a simple algorithm and the principles that we have discussed. Some experiments, properties of constant materials and the desired properties of concrete, we have tried to do the determination of the proportions of a concrete mix and the exercise was largely volumetric. We went to the extent of saying that okay, we will have a 1000 litres pitcher or 1000 litres of fixed volume.

And, we will have cement water sand and coarse aggregate, the absolute volumes of all these filling up this 1000 litres. Of course, there was the air content that we have always taken to be a given as a granted or an input to the exercise.

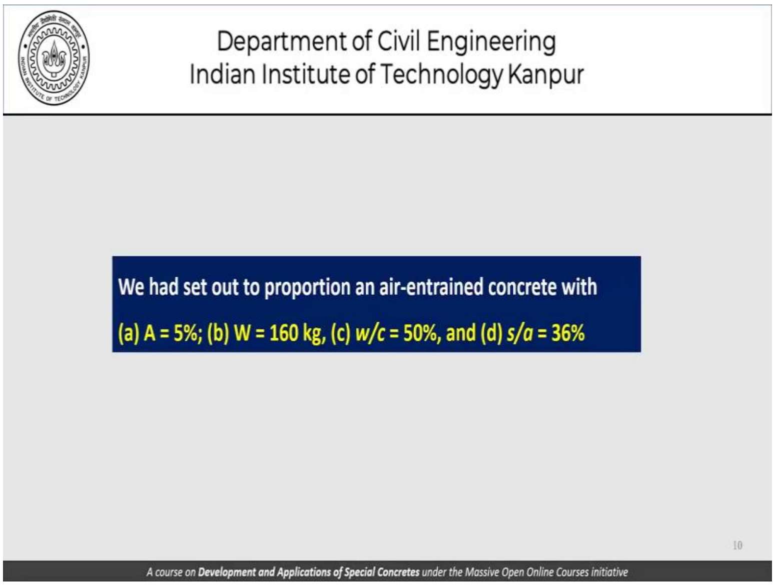
(Refer Slide Time: 04:04)



Having said that, what we will do today is we will do an analysis of the proportions of ingredients we obtained in the last class a small bit of that. Then, we go to adjust or revise the predetermined proportion such as the one that we got last time such that we will go to adjust or revise a predetermined proportion based on the principles should there be a need. And, we will try to do the proportioning of a concrete mix with chemical and mineral admixtures.

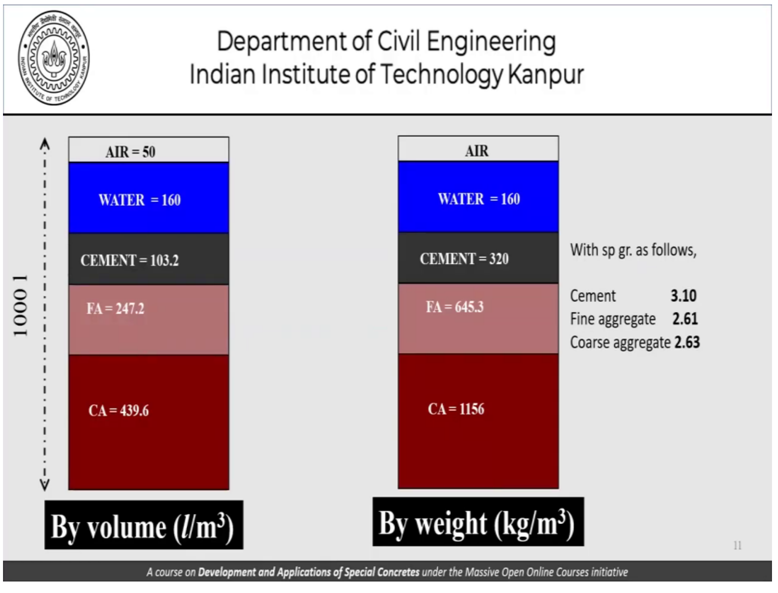
So, this is the 3-point agenda that we have as far as the discussion today is concerned. So, coming to the first bit which is the analysis of the proportions of ingredients we obtained in the last class.

(Refer Slide Time: 04:47)



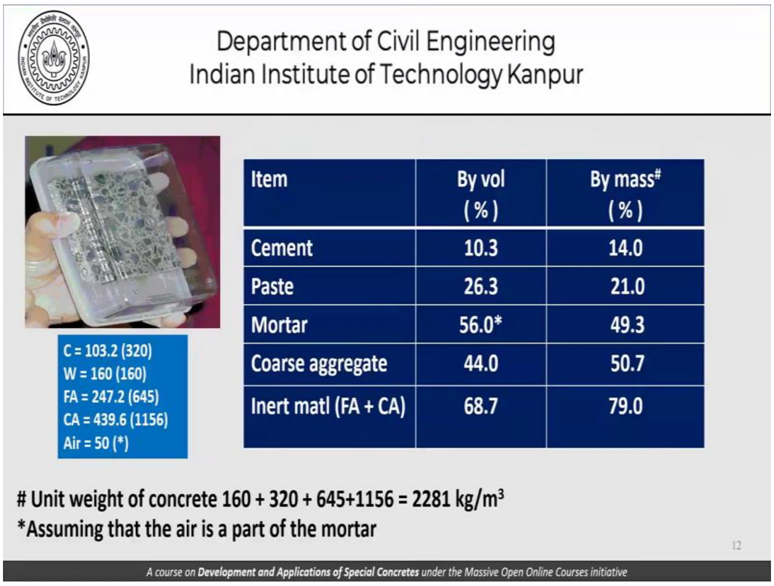
We had set out to proportion an air entrained concrete with the parameters 5% air, 160 kgs of unit water content, a water cement ratio of 50% and an s/a of 36% and with that we have determined these to be the proportions.

(Refer Slide Time: 05:04)



This is by volume and this is by weight of mass.

(Refer Slide Time: 05:16)



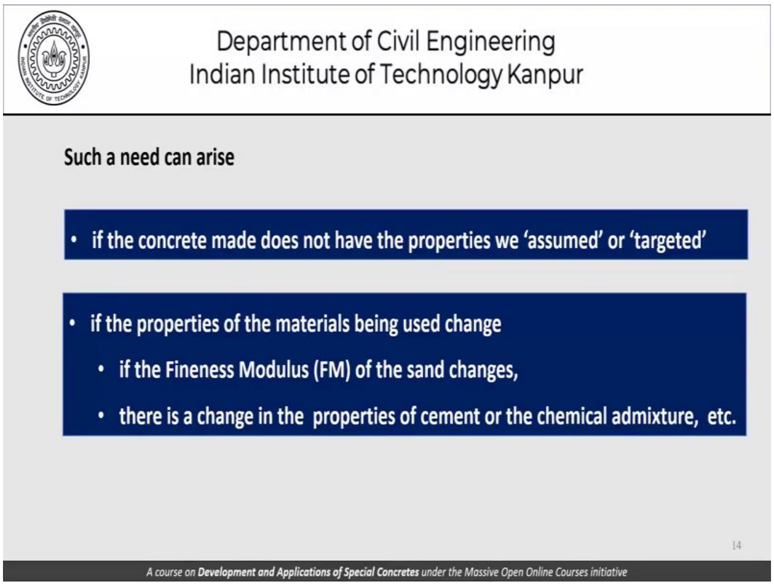
Now if we look at closely, we see that the cement is 103.2 litres, what is 160 Kgs fine aggregate, what is 247 Kgs coarse aggregate and what is 439.6 Kgs and these are the values in kgs per cubic meter. So, if we look at the relative volumes and the relative masses of these different constituents by way of percentage or in terms of percentages. We see that cement constitutes about 10% by volume and 14% by weight.

As far as paste is concerned i.e., cement + water that constitutes about 26.3, maybe in some cases it may be a little more 25% to 30% is what is paste by mass it is about 21, mortar is about 56%. It ranges in different concretes from about 50% to 60% by volume and about 50% by weight, coarse aggregates in this case turned out to be 44% by volume and about 50% by mass. Please notice that the inert material is more or less 2/3rd of the total volume and accounts for about 80% of the weight of concrete.

Also, cement is the most expensive material in the whole mix. So as far as, the expense is concerned cement is the most expensive of the materials and coarse aggregate possibly is the cheapest. So, the basic thought process that traditionally we have is that we should try to maximize the amount of coarse aggregate in the system and try to minimize the amount of cement from a strictly economic point of view.

But the economic point of view is something which will come later first of all we will stick to the technical aspects and that is what we are doing right now.

(Refer Slide Time: 07:09)



Let us move on to the second objective for the discussion today, how do we adjust or revise a predetermined concrete proportion should there be a need. When does such a need arise? The first case where the need can arise is, if the concrete does not have the properties, we assumed or targeted also it can happen that the material properties which we are using at a construction site. Change for example, the finest modulus of the sand may change there may be a change in the properties of cement or the chemical admixture and so on.

So, there are so many reasons because of which an adjustment in the mixed proportions can be required how do we go about doing that.

(Refer Slide Time: 07:55)

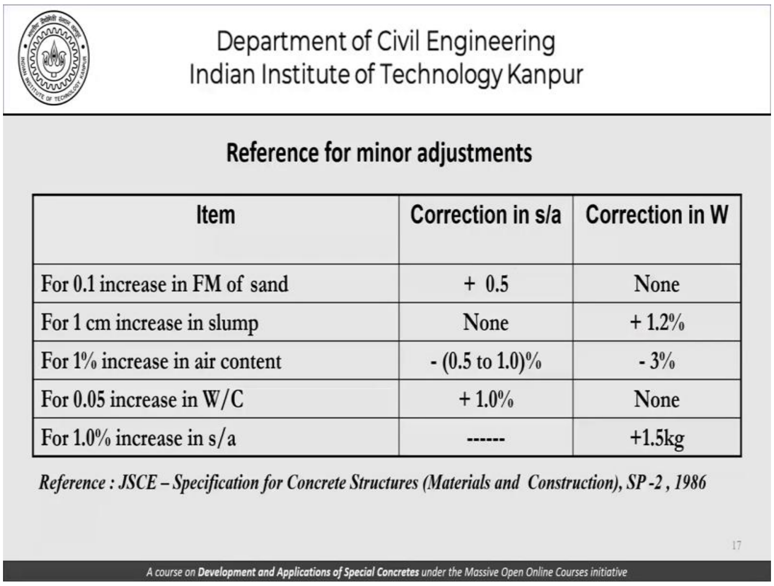
Now, in the present case we started with the idea that the slump of the concrete should be 8 centimetres and the air should be 5% by volume that was the basis for carrying on our proportioning exercise. Now, suppose it turns out that in actual case or in reality we get 7 centimetres of slump and 4% of air which is different from the slump that we targeted and the air that we targeted.

It could be that one of them matches the other does not match. So, it could be any combination. So, just for the sake of argument we are taking this situation, where the actual slump is lowered by one centimetre. And, so is the actual air content which is lower by 1%. Now, in order to adjust the air content what we really need to do is to use an air entraining admixture in fact for all AE concretes an air entraining admixture.

For all AE concretes an air entraining admixture is an integral part of the mix. Now, we have discussed this before that the admixture manufacturer would give you certain specifications and say that if you use a certain dosage of the set mixture you will get a certain amount of air entrained in the system. That may or may not be necessarily true and perhaps that could have happened in this case as well.

We fixed a dosage thought that it will be 5% but it turns out to be only 4%. So, for this adjustment what we need to do is to adjust the dosage of the air entraining admixture that we use. Apart from this, what else do we need to do?

(Refer Slide Time: 09:52)



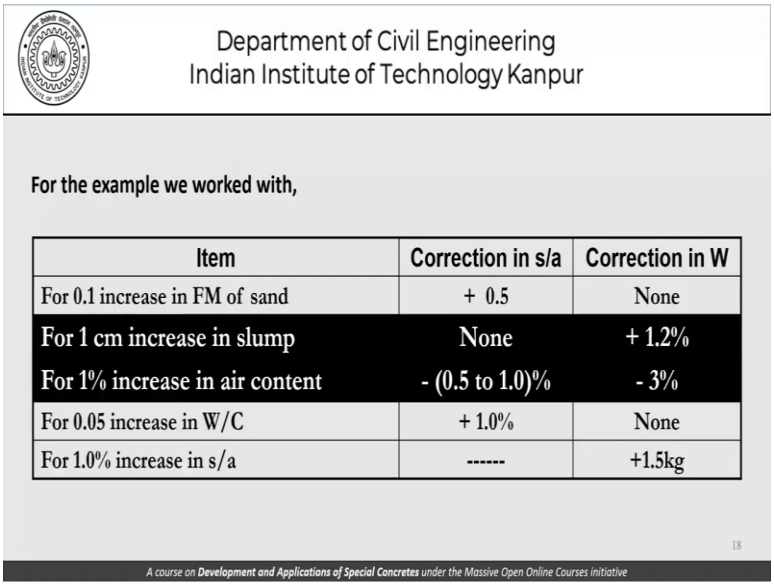
Item	Correction in s/a	Correction in W
For 0.1 increase in FM of sand	+ 0.5	None
For 1 cm increase in slump	None	+ 1.2%
For 1% increase in air content	- (0.5 to 1.0)%	- 3%
For 0.05 increase in W/C	+ 1.0%	None
For 1.0% increase in s/a	------	+1.5kg

Now, here is a reference table for minor adjustments in the mix. This has been taken from the JSCE specifications for concrete structures. And, it says that if the fineness modulus of sand changes by 0.1, you need to correct the s/a that you have by + 0.5. So, an increase here is a + here you do not need to adjust for water content. For each centimetre increase in slump, you do not need to correct for s/a but you need to add water to the extent of 1.2%.

So, increase slump increase the water in order to increase the air content or if you want to increase the air content for each percentage increase in the air content in the concrete mix you need to reduce the s/a by 0.5% to 1% and you need to reduce your water content by 3%. Recall that I had already discussed that if you increase your air content your workability increases. And, in order to compensate for that increased workability on account of increased air content you really need to reduce your water content and that is what is suggested here in terms of - 3% and so on.

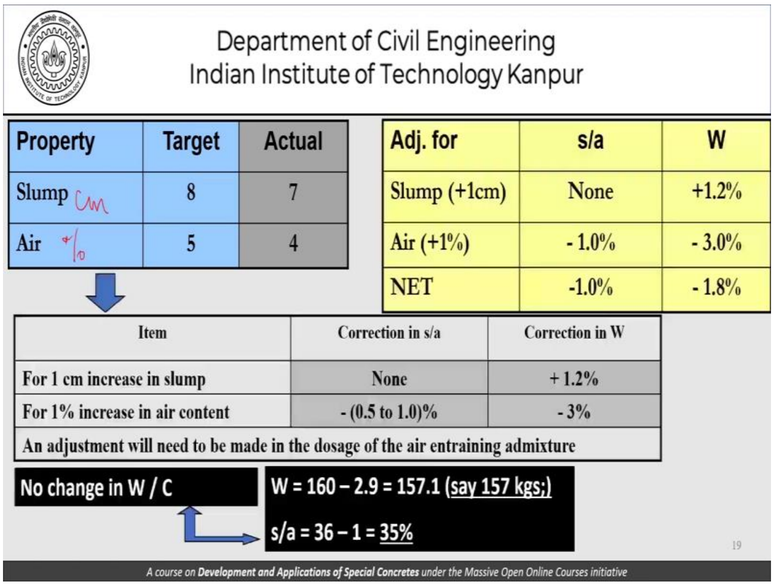
So, once you have this kind of a guideline or guidance available to you, we are ready to modify our mix.

(Refer Slide Time: 11:23)



So as far as we are concerned in our particular case, we want a change in the slump value and we want a change in the air content. So how do we go about doing it, we need to do the s/a correction here and we need to do the unit water content corrections here.

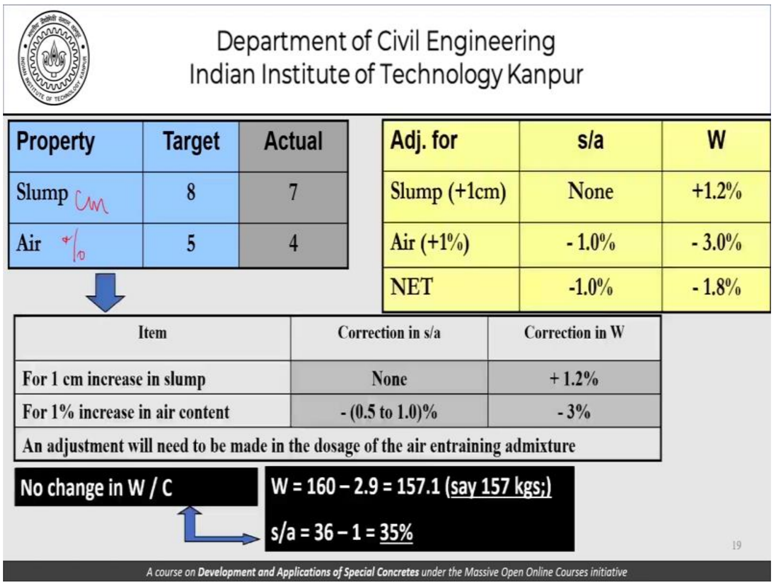
(Refer Slide Time: 11:44)



So, that is again a reiteration of what we wanted 8 and 5 and what we got 7 and 4. So, slump here is in centimetres and air is in percentage by volume. Now, if that happens from the previous table, we know that there is no adjustment here - 0.5 to 1 here. We need to go to + 1.2 here - 3 here. So as a result, if we take this information here none - 1 + 1.2 - 3, we do an algebraic operation and say that okay the net result is that we will reduce the s/a by 1% and we will reduce the water content by 1.8%.

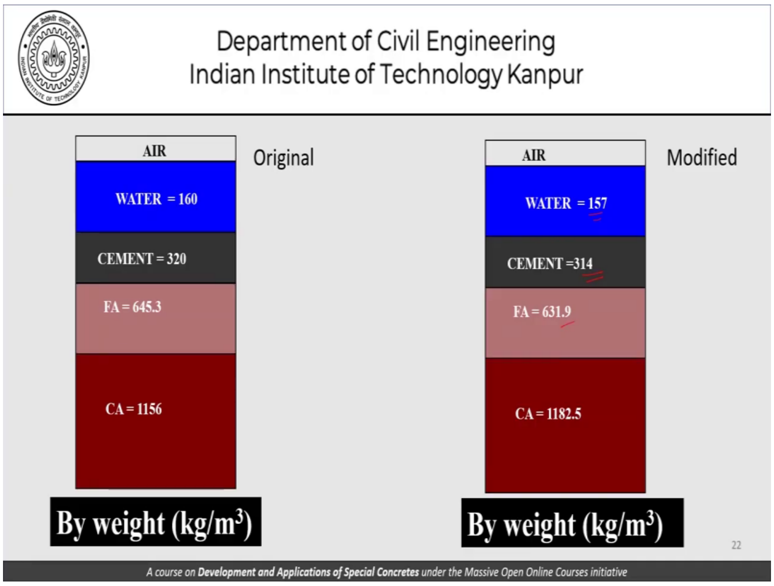
So, if we want to do that the water content becomes 160 is what we had, 2.9 which is 1.8% of that we get 157.1 let us say 157. Similarly, for s/a we have 36 - 1 which is 35. So, we do not want to change the water-cement ratio because that is something which should be governed by the strength considerations and that is not on the table right now. So, with these modified parameters we are ready to go.

(Refer Slide Time: 13:05)



The original mix was proportioned as an entrained concrete with these numbers and the mix has to be redesigned using this does not change because that is a given the water content has been changed from 160 to 157 like I showed you before we are not changing. This s/a is becoming 35 instead of 36. Of course, there have to be an adjustment in the dosage of the air entraining at mixture to increase the air content because we got 4% whereas we want actually 5%.

(Refer Slide Time: 13:50)

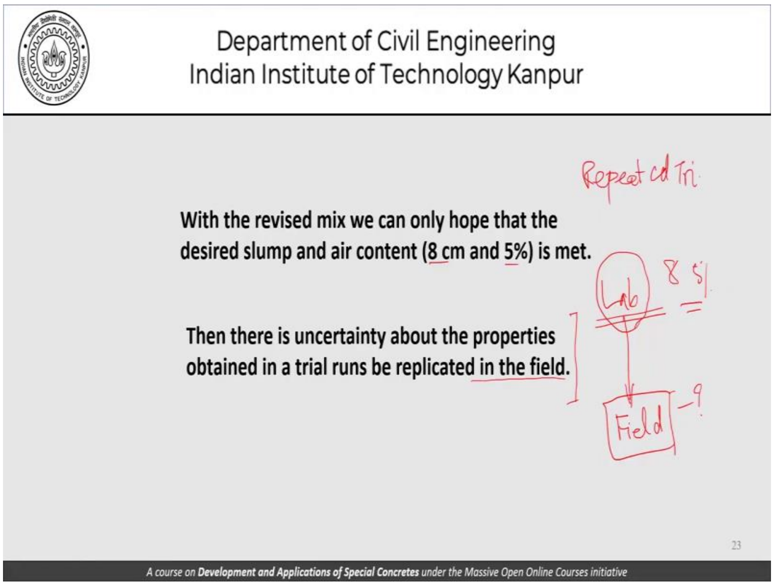


So having said that, if we do this exercise and I am not going through the details of the algebra this is what the modified mix would look like 157 kgs of water, 314 kgs of cement, water-cement ratio being 50% translating to 101.3 litres of cement, with this volume the inert material here that being proportioned using 0.35 instead of 0.36 you get 242 and 449.6 here. Use the specific gravity values to get the fine aggregate and coarse aggregate content in terms of kgs per cubic meter.

So that is your modified mix. If you want to summarize it this is what it looks like 160, 320, 645 and 1156 becomes 157, 314, 631 and 1182. So, as the water has gone down a little bit cement has gone down a little bit you reduce the s/a that has had its effect and as a result of that all this volume reduction has been consumed by the increase in the coarse aggregate. Of course, I am leaving it to you to construct a similar table by volume and then study how the things have changed.

There would be of course marginal changes and that is something which I am leaving to you as a small assignment.

(Refer Slide Time: 15:10)



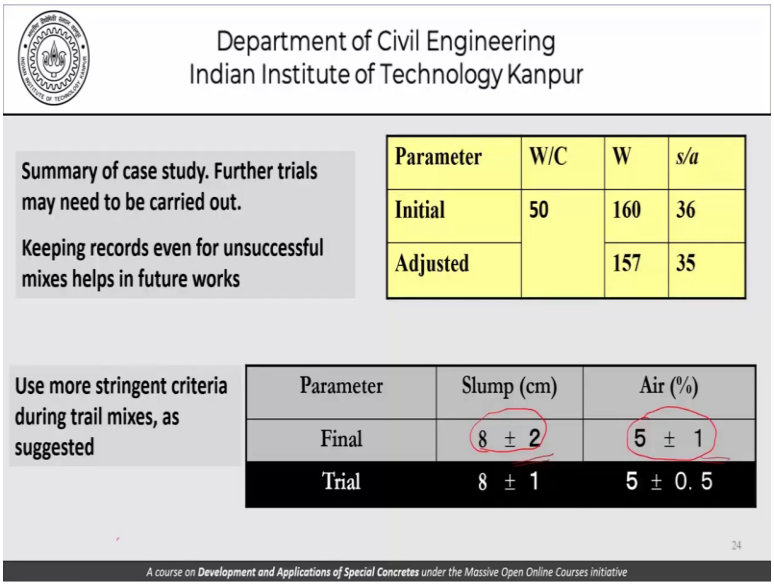
Now with the revised mix we can only hope that the desired slump and air content which is 8 centimetres and 5% is met, it may not happen and we may have to go back to the drawing board and carry out another iteration. Then there is uncertainty about the properties obtained in trial runs to be replicated in the field often times. As far as mixed design is concerned, proportioning of concrete mixes is concerned, this exercise is carried out in the lab to get a mixed proportion.

And, then that mix proportion is taken to the field. Now, the field conditions are quite different from that in the lab. For examples the mixers could be different, the power of the mixer could be different, the temperatures could be different and so on. Therefore, how do we ensure that what we have determined in the lab whether it is 8-centimetre slump or 5% air or whatever it is that is what we will get in the field also.

Very difficult question to answer concrete proportioning of concrete mixes is not a very well-developed science in that sense that okay if I use 160 kgs of water and 320 kgs of cement we will always get a certain strength. We use a certain amount of s/a will always get the slump? No. The properties of the material affect these properties like slump and air content or bleeding, setting time and so on and therefore at the end of it this exercise has to be repeated and it is only a trial-and-error procedure.

So now in that kind of an environment, how do we make sure that what we get in the lab is what we will get in the field.

(Refer Slide Time: 17:14)

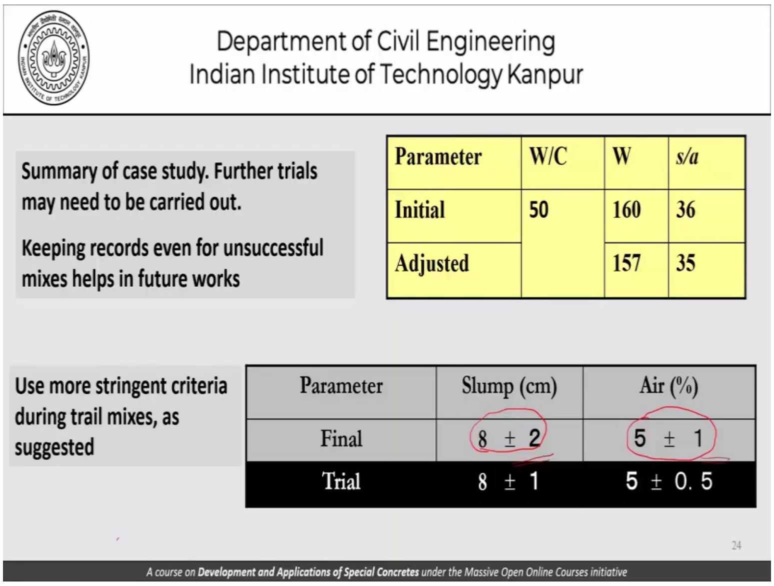


So, what we try to do in that case or for that contingency is that if the final requirement in terms of slump let us say is 8 + - 2 centimetres or for air it is 5 + - 1%. Because at the end of it people do write specifications also understand that there will be a certain amount of variation whether it is in slump or its air content or any such number and a certain tolerance is given.

Now we do not want to use all that tolerance when we do the trial in the lab. So, what we try to ensure that as far as the recommendation of proportions from the laboratory trials is concerned that matches or that needs a more stringent requirement. For example, we may insist that as far as the lab is concerned, we should be sure that the slump even though 6-to-10-centimetre kind of slump is acceptable to the client or acceptable at site as far as the lab is concerned the number should be between 6 should be between 7 and 9.

Similarly for air content we do not use the 1% here, we use let us say something like point 5% hoping that with this more stringent criterion being followed in the laboratory. The situation can be taken care of a little bit more robustly when it comes to the actual concrete being used at sites or in the field.

(Refer Slide Time: 18:50)



Having said all this now let us move on and try to understand yet another way of specifying a concrete mix. This method basically says that we will fix the coarse aggregate content. We want the coarse aggregate content to be some number. Of course, for this example, I have taken it to be 48% what this does is that it does away with our requirement for determining or working within s by a; we will see how?

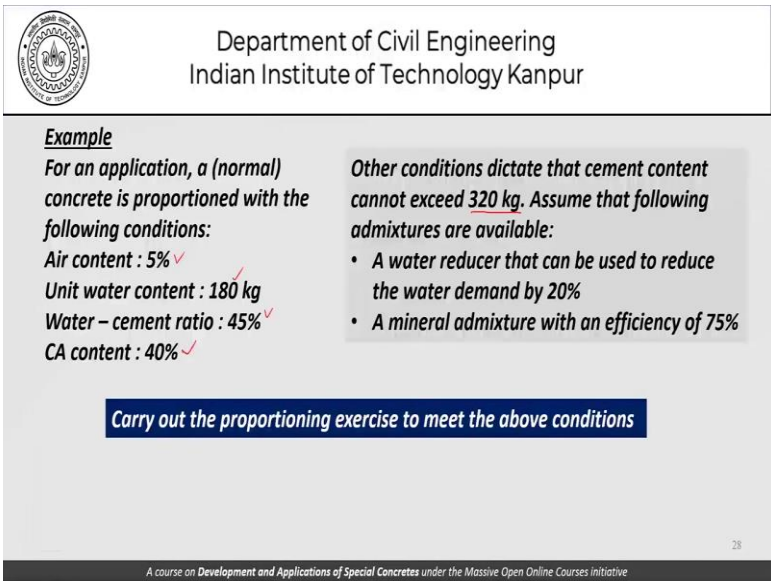
So, coarse aggregate is fixed meaning thereby that we are really talking of proportioning now only the mortar content which of course will include the air content and if this number was 48 this number will be so. If it is given that we want a concrete which has 5% air, unit water content of 175, a water-cement ratio of 50%. And, we fix this coarse aggregate content to be 48 then the proportioning is a one-minute exercise.

All that we need to do is we know the air content to be 50, we know the water content to be 175, the water-cement ratio being 50%, which is given here gives me the cement content of 350 which translates to 112.9, we already have fixed the coarse aggregate content to be 48% by volume and that is 480 litres and that translates to 1262.4 and therefore this volume of sand is automatically determined to be 182.1 which translates to 475.3 kgs per cubic meter.

So, this is a different approach where we try to fix the coarse aggregate volume and try to just play around with the volume of mortar. As you can see here, when I say 48 of coarse aggregate, I am trying to say 48% by volume. So therefore, this specification or this method of specifying the mix does not require any s by a. Because s/a was at the end of it only a parameter to tell you how much of sand is there in the entire inert volume.

In this case the coarse aggregate is directly specified and we can work out the fine aggregate from here.

(Refer Slide Time: 21:34)

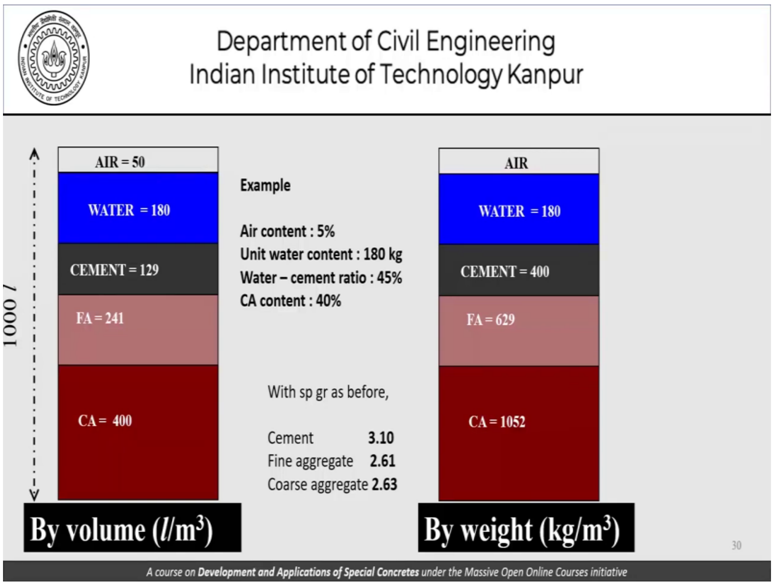


So, with this we move to the third part of the discussion that is proportioning of concrete with chemical and mineral admixtures. Now, this is something which is very interesting gives you a lot of options and tests your metal as a concrete engineer and we will see how? Let us say for an example a normal concrete is proportion with the following conditions 5% air, 180 kgs of water 45% water cement ratio.

And, the coarse aggregate content to be 40. So, I am not using the s/a route. I am using the coarse aggregate content route and I am specifying that to be 40%. We could very well go ahead and do the exercise of proportioning the mix. But the twist is other conditions dictate that the cement content cannot exceed 320 kgs. Assume that the following admixtures are available to you a water reducer that can be used to reduce the water demand by 20% and a mineral admixture with an efficiency of 75%.

We will talk a little bit more about these admixtures in the subsequent discussion. But I am sure, you will be able to follow the discussion as we go in this class because it is basically just a numerical example and it is going to be simple arithmetic that we will do. Now, we need to carry out the exercise of proportioning the concrete with these conditions. This is the base and these are additional constraints.

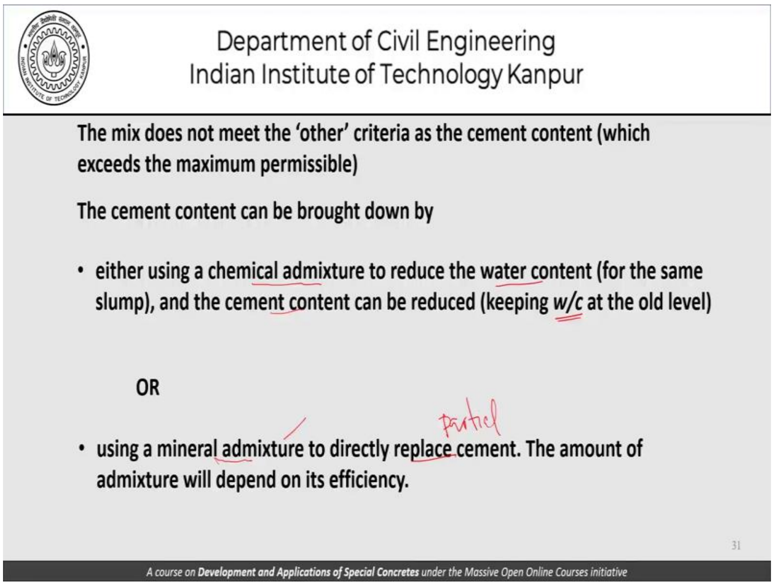
(Refer Slide Time: 23:16)



Now, obviously we start with carrying out the proportioning in a normal sense and if we do that 5% air, 180 kgs of water, 45% water-cement ratio, 40 coarse aggregate content, we get figures like this, this is by volume, this is by weight here we know 50 litres, 180 kgs i.e., 180 litres of water, 400 kgs of cement translating to 129 litres of cement and 40% here means 400 litres i.e., 1052 kgs and we have the fine aggregate to be 241 litres and 629 kgs.

The problem is that this cement content is greater than the 320 which is allowed. So, what do we do?

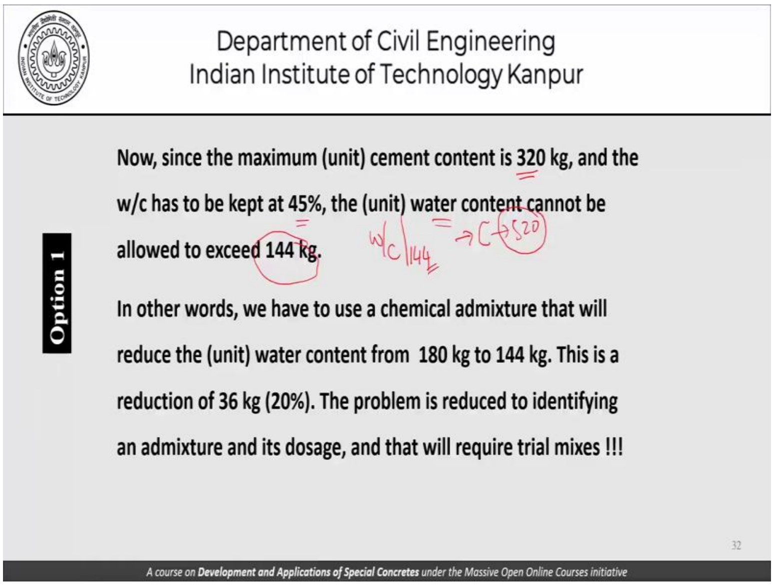
(Refer Slide Time: 24:07)



This mix does not meet the other criteria of cement content which exceeds the maximum permissible value. And this cement content can now be brought down using 2 options one is to use a chemical admixture such that the water content for the same slump can be reduced and the cement content will automatically come down because we are working with the water cement ratio there. And that has to be maintained at the old level because we are not trying to change the strength requirement.

Or we could use a mineral admixture to directly replace cement that is a partial replacement of cement using some kind of a mineral admixture and the amount of this admixture would depend on its efficiency. So, this is something which we need to explore and understand a little bit and these are the 2 routes that are available to us.

(Refer Slide Time: 25:07)



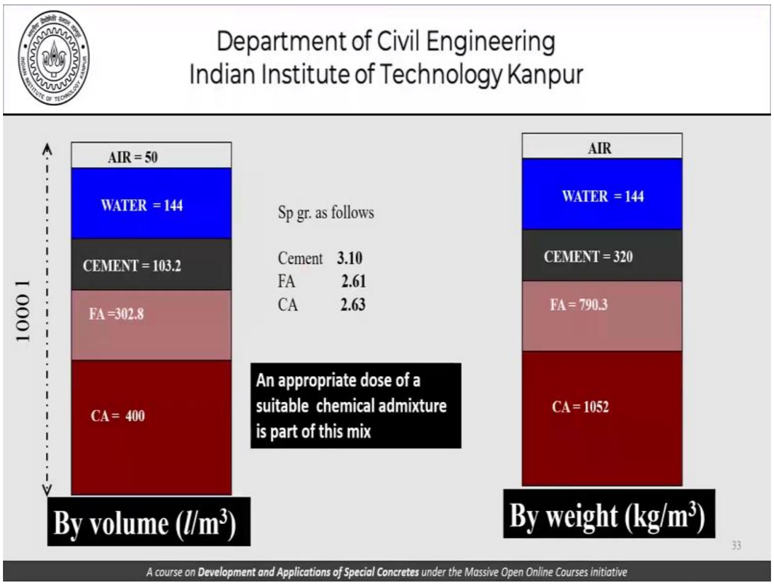
Let us examine the first route that is the chemical admixture route. What does it say that if the maximum cement content is 320 kgs? And the water cement ratio has to be kept at 45% then the maximum water content that you can have is only 144 kgs because water-cement ratio, if it is determined at 144 that will give you a cement which is 320 and that is the maximum that you can have. So, you cannot have water more than 144.

The problem in the previous discussion or the basic discussion was that the water content was much more than this 144 and therefore the cement content became much higher. Now, how do we go about doing it use the chemical admixture? The chemical admixture that will reduce the unit water content from 180 kgs to 144 kgs and this reduction of 36 kgs is about 20% and the problem is reduced to identifying an admixture in its dosage and that can be done through trial mixes.

So here again, once we have a high range water reducer or a super plasticizer or whatever it is that will also be prescribed as a dosage in terms of 1% or 0.5 % or 0.75 % by weight of cement. And, depending on this dosage we will get the extent of reduction in water content. So, we will need to do a little bit of search talk to some manufacturers read up their literature find out what kind of admixtures are available.

What is their power in terms of reducing the water demand for the same slump and come up with an admixture and a dosage which will give us a 20 reduction? And as far as the given information is concerned, it did say that yes, some kind of an admixture which will be helpful in achieving this is available. So, we more or less have the solution we will have to do some trial mixes and we are in business.

(Refer Slide Time: 27:22)



So, if we do that what we have is air is 50 litres, 144 kgs of water brings my cement content to 320 which now becomes 103.2 litres. We have this volume now to be adjusted. Now, this volume has to be adjusted but the fact is that, we are still keeping coarse aggregate to be 40%, this does not change which means that only the remaining volume will be absorbed all by the fine aggregate and this will translate to 790.

So, if you look at it from the previous discussion that is the basic mix, we will do a comparison shortly and you will know what has happened as far as the previous mix versus a mix which has a certain amount of chemical admixture dosed into it to reduce the water demand from 180 kgs to 144 kgs i.e., part of this mix. Now, if we look at it from the previous comparison i.e., what we had 180 kgs this is all by kgs per cubic meter, this is the cement 400 kgs which has been brought down to 320.

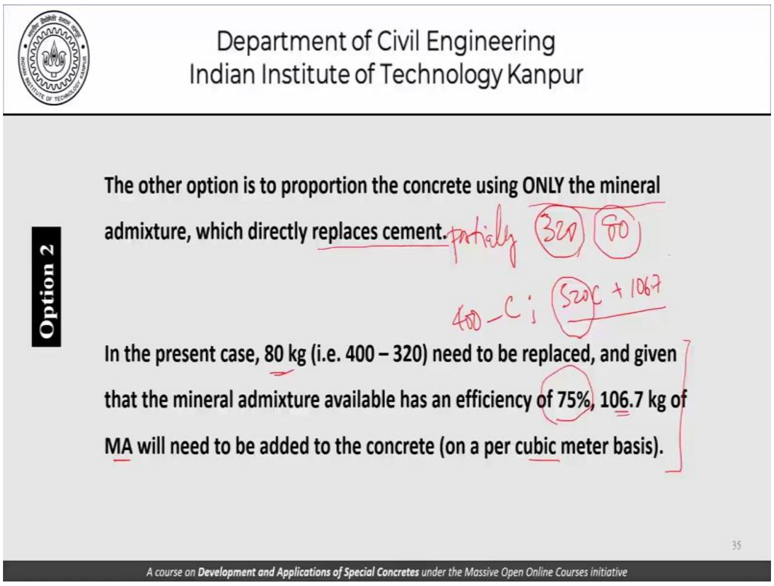
The 129 litres have brought down to or has come down to 103, 629 kgs of fine aggregate has increased to 790 kgs. So, you can see that the total increase there is substantial increase in the fine aggregate content and that can be expected because what is happening really is that all the reduction that is happening in the water volume. All the volume that is being reduced from the cement is being absorbed by the fine aggregate.

Because the coarse aggregate volume is not been changed and therefore there is a substantial increase in the amount of fine aggregate. But it also shows that the mortar content here is still 60% of the total volume. Of course, this is by mass so I cannot really be plotting it here be careful about that. But the mortar content in both cases is 60%. So effectively, the reduction in the paste content has all been replaced by sand in order to preserve the amount of mortar in the concrete mix.

So, this is the kind of thought process that you should have or you can have when we are trying to understand concrete in terms of that material that is concrete being a suspension of coarse aggregates in mortar. So, there is a certain amount of mortar, what we are talking here or what we have discussed here is the amount of mortar. What we have not discussed here is the quality of mortar the properties of mortar.

And, that is something which will take us into very specialized kind of discussions which will possibly do at a much later point in time in this course.

(Refer Slide Time: 30:46)

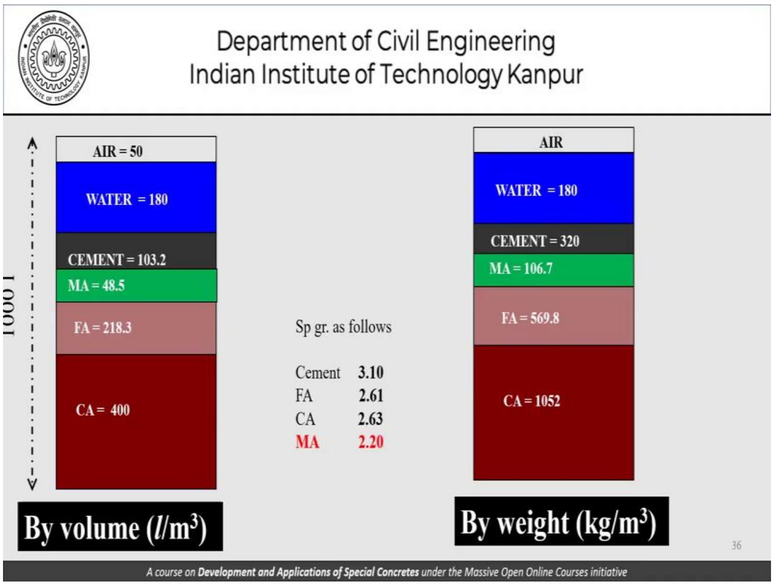


Now, let us move to the other option that we have and that is to use only the mineral admixture. We are not going to use the chemical admixture route; we are going to use the mineral admixture route and directly replace the cement partially. Of course, we only need to do it partially because 320 kgs is the cement which is still allowed and we are going to use that. So basically, what we need to do is to replace 80 kgs of cement.

Now, given the fact that the efficiency of the mineral admixture that we have is only 75%. So, we cannot replace it one to one, we will need to replace this 80 kgs by 106.7 kgs of the mineral admixture on a per cubic meter basis. So, once we understand this part that instead of 400 kgs of cement, we will use 320 kgs of cement + 106.7 kgs of mineral admixture. This will now meet our requirement that the cement content not exceed 320.

So, this is the other route that we are taking and let us move and see what happens to the proportioning.

(Refer Slide Time: 32:03)



So, what we are doing here is we are keeping the water content same air is of course 5%. So, water content is 180 litres, cement we have taken to be 320 kgs brings it to about 103.2 litres replacing this 80 kgs is 106.7 kgs and given the specific gravity of the mineral admixture to be 2.2 gives me, a volume of 48.5 litres. This 400 litres does not change so the fine aggregate becomes 218.3 litres which translates to 569.8 kgs.

So, this is the trick that we have done in proportioning this concrete mix with only the mineral admixture. Of course, there is another option that instead of going whole hog with the chemical admixture route or the mineral admixture route. We use a combination we bring down the water content not from 180 to 144 using the chemical admixture route. We bring it down to about 160 then we try to do a little bit of trick with the mineral admixture and still move forward.

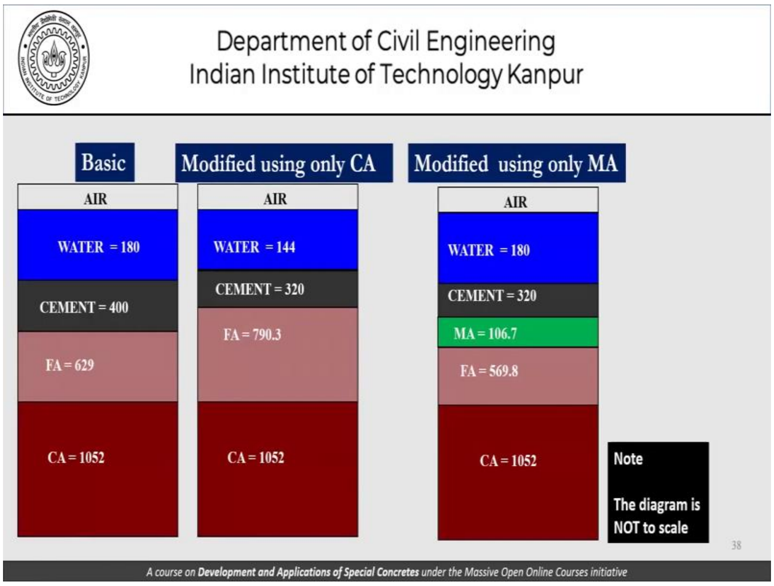
The issue that we have at hand which you must catch there is something which I am not telling you. I am still insisting that a concrete which had 180 kgs of water and 400 kgs of cement and whatever sand and coarse aggregate was there. Of course, coarse aggregate was 1052 whatever the sand was there in the beginning this had certain properties certain slump certain air content and so on and so forth. What I am insisting is that with this 180 kgs of water instead of 400 kgs of cement.

Even if we use 320 kgs of cement and 80 kgs or 106 kgs of mineral admixtures, we will still get the same workability that need not happen. And therefore, this discussion that we've had in terms of working only with the mineral admixture route or only with the chemical admixture route that is true with the chemical admixture discussion as well that a concrete which had 180 by 400 kind of a distribution and the rest of it being sand and coarse aggregate.

And, the other concrete that we had was 144 by 320. This will have the same workability now the amount of water has gone down, you have a lot more sand in the system, will this mortar have the same properties as this mortar? Now, that remains a slightly open question. Of course, there is some chemical admixture sitting here as well which will help you but that is why we need to do trial mixes.

We need to do trial batches to make the final adjustments. What we have done here is only a first run and the rest of it of course has to be done through laboratory trials.

(Refer Slide Time: 35:34)



Now, if we compare the option this is what we started with and that is what I was trying to explain to you in the previous slide 180, 400, 629, 1052 goes to 144, 320, 790, 1052 using only the chemical admixture route. And, then if we use the mineral admixture route this is the proportion that we have. Please note that this diagram is not to scale. So do not try to read this diagram from that point of view except that I have tried to show a slightly increased content of fine aggregate here reduced content of fine aggregate here reduce amount of water here and so on.

Now, in all these cases we have kept the coarse aggregate content to be 40% and the total water content has been kept to be 600 litres i.e., something which I have explained to you.

And of course, it is reiterated once again. And of course, the paste content is something which you need to bother about i.e., the other element. The difference is in the paste content, compared to one because in one the paste content is this + this, this is much lower.

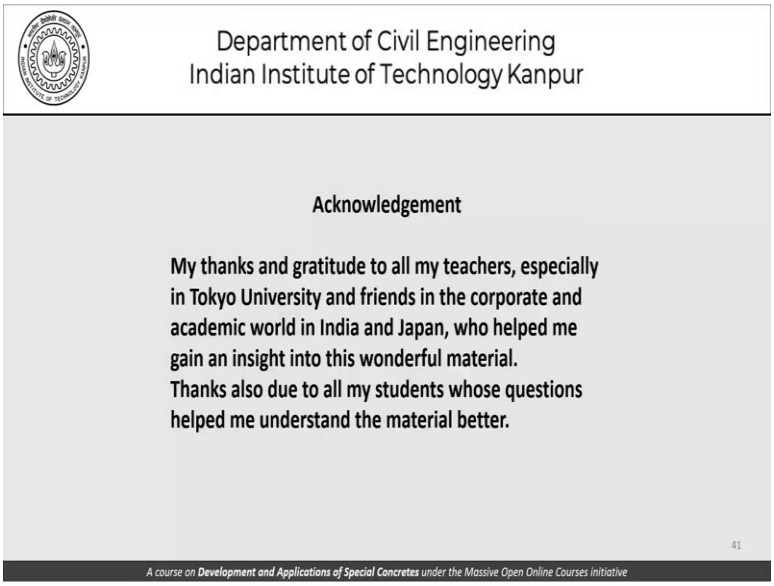
I am leaving it to you to work out the volumes, I am not showing you the volume or the volumetric comparisons. But when it comes to volumetric comparisons you will realize that the paste in the second concrete is much less compared to the first concrete. And, that is something which has to be studied further before we can finalize this mix. As far as the paste content is concerned, the obvious question or the second question that you will have or you should have is how will the mineral admixtures be counted?

Will they be counted towards the paste or not? My answer to that is yes. The mineral admixtures should be counted towards the paste not because the mineral admixtures behave like cement as far as hydration is concerned that is not the question here. The issue is that mineral admixtures typically have the same fineness as cement by and large it is comparable. And therefore, mineral admixtures + cement + water this is what constitutes your paste content.

And, to that extent perhaps your paste content in this mix here may be slightly more than the paste content in the original mix. Now, how it helps you or does not help you is a different story. Changes in paste content are being compensated by the change in the fine aggregate content here in order to keep the mortar content the same that is at 60% of the total volume i.e., 600 litres.

With this discussion that we have had today, I would think that you have some insight into the kind of logic or the model that I have been kind of presenting to you that the concrete is nothing but the suspension of coarse aggregates in mortar. And, mortar is nothing but a suspension of sand particles in paste and paste is nothing but a suspension of cement in water. So, that is the kind of backdrop in which or with which we close our discussion for today.

(Refer Slide Time: 39:16)



And, I am grateful to all my teachers and my students who have helped me understand this material so much better than I did when I started my career about 40 years ago. Thank you and I look forward to seeing you once again with further discussion on development and applications of special concretes.