Hydration, Porosity and Strength of Cementitious Materials
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Lecture – 09
Concrete Mix Proportioning Strategies

Hi, good morning to one and all. I am K. V. Harish, Assistant Professor Department of Civil Engineering, IIT Kanpur. You are watching MOOCS lecture course on Hydration Porosity and Strength of Cementitious Material.

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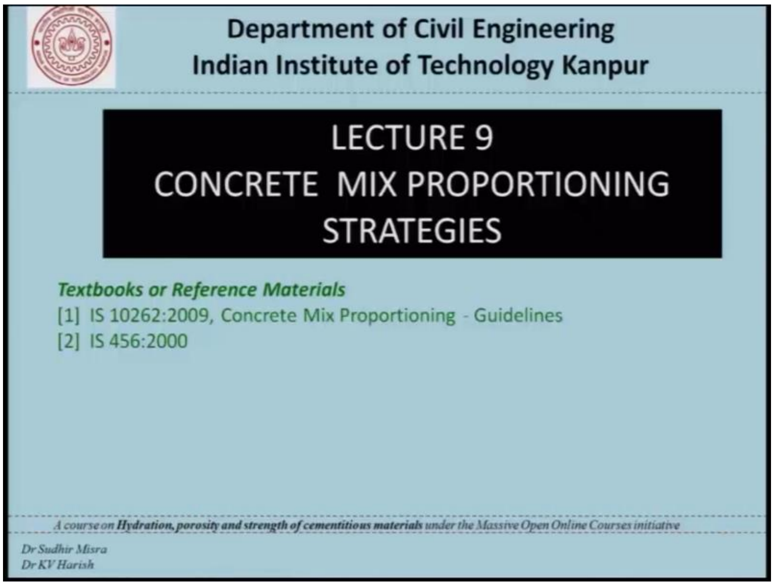

Today we will see lecture 9, concrete mix proportioning strategies. The text book or reference materials are shown primarily the concrete mixer proportioning is from Indian standards 10262, and some mix design strategies are stated in is 456.

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Overview today we will deal with two topics: Indian standard method of concrete mixture proportioning and mix design strategies.

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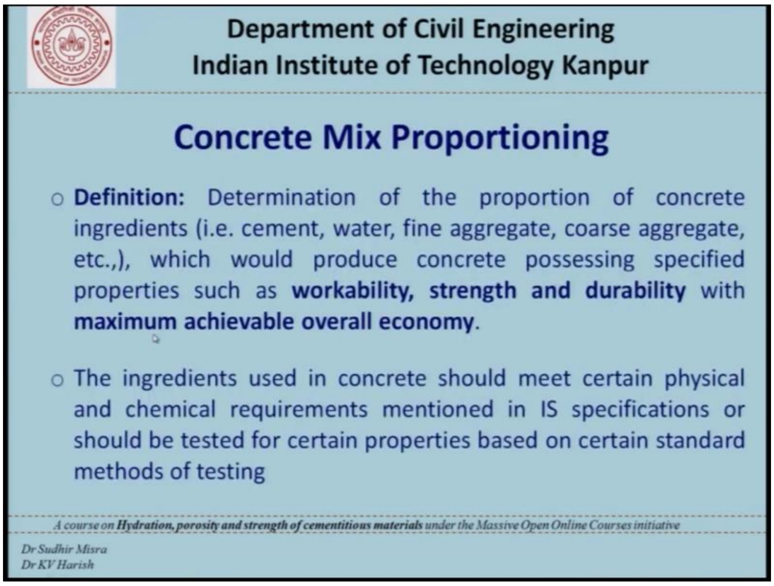

So, concrete mixture proportioning. The definition of concrete mixer proportioning from is as follows. Determination of the proportion of concrete ingredients that is cement water fine aggregate coarse aggregate etcetera which would produce concrete possessing specific properties such as workability strength and durability with maximum achievable economy. The ingredients used in concrete should meet certain physical and chemical requirements mentioned in the codes and should be tested for certain properties based on certain standard methods of testing.

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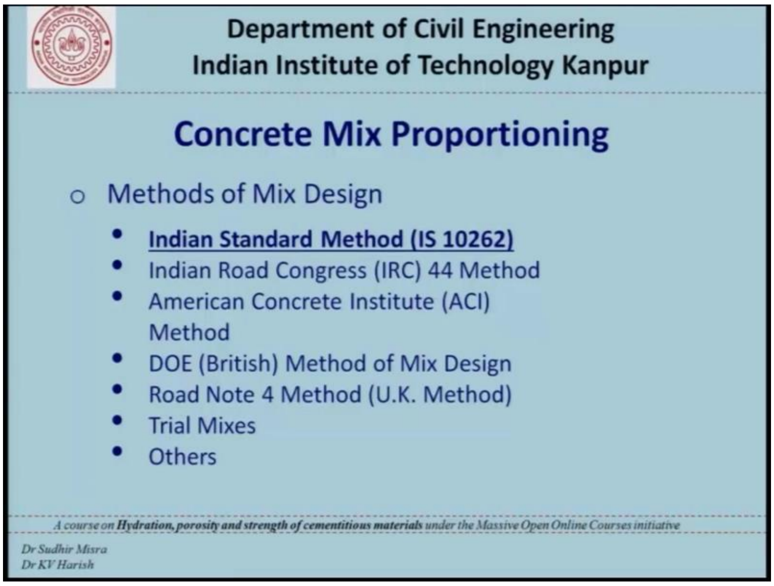

Concrete mixture proportioning can be done by several methods some of them are listed here. Indian standard method which is given in IS 10262 Indian road congress IRC 44 method American concrete institute DOE or British method of mix design road note 4 or UK method sometimes through trial mixtures and several other methods.

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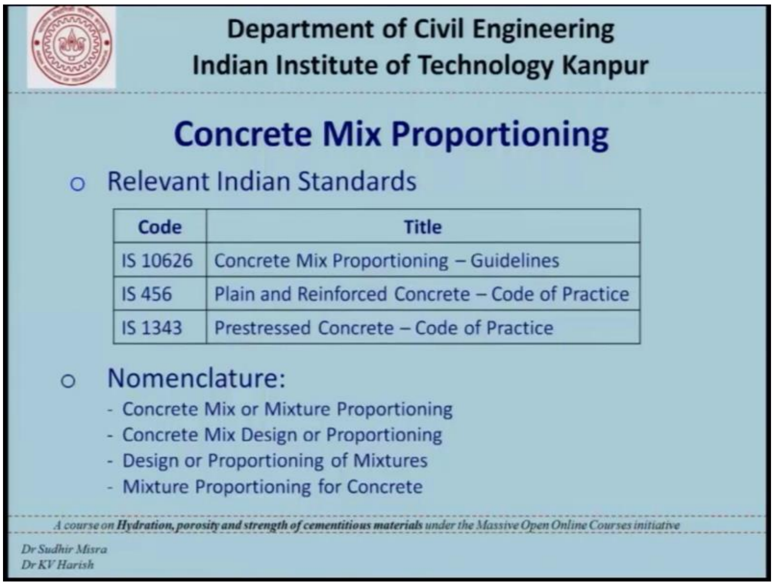

Now, the relevant Indian standards for concrete mixture proportioning are as follows. IS 10626 nearly for the guidelines in concrete mixture proportioning. IS 456 for specific guidelines related to plain and reinforced concrete IS 1343 for specific guidelines related to pre stressed concrete.

Sometimes different nomenclatures are used to indicate concrete mix proportioning. Some of them are as follows. Concrete mix proportioning can also be called as concrete mixture proportioning, concrete mic mix design, concrete mix proportioning design of mixtures or proportioning of mixtures or mixture proportioning for concrete. So, all these things refer to the same name concrete mix proportioning.

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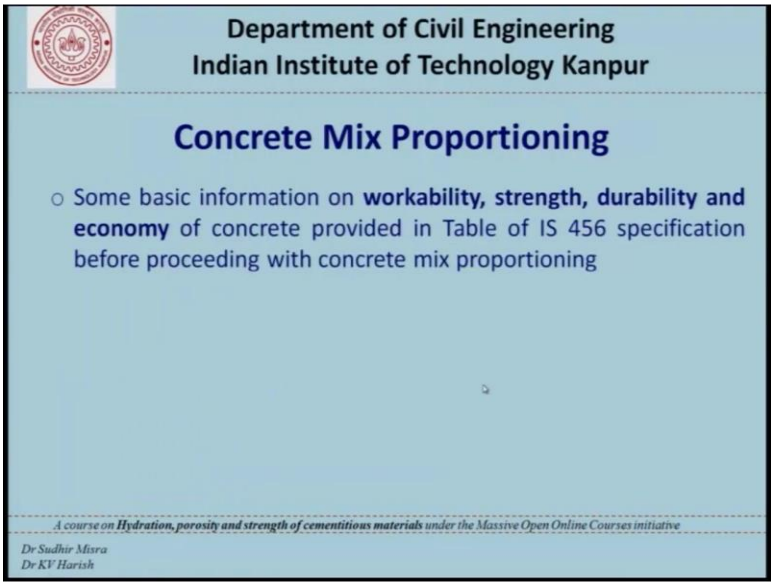

Some basic information on workability strength and durability in addition to economy for concrete is provided in some tables in IS 456 specifications before proceeding with concrete mix proportioning.

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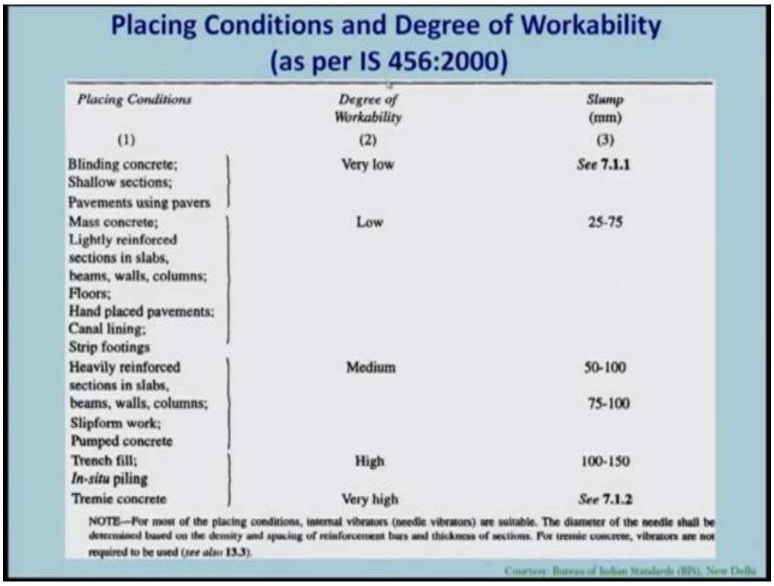

Placing Conditions and Degree of Workability (as per IS 456:2000)

Placing Conditions (1)	*Degree of Workability* (2)	*Slump* (mm) (3)
Blinding concrete; Shallow sections; Pavements using pavers	Very low	*See* **7.1.1**
Mass concrete; Lightly reinforced sections in slabs, beams, walls, columns; Floors; Hand placed pavements; Canal lining; Strip footings	Low	25-75
Heavily reinforced sections in slabs, beams, walls, columns;	Medium	50-100
Slipform work; Pumped concrete		75-100
Trench fill; *In-situ* piling	High	100-150
Tremie concrete	Very high	*See* **7.1.2**

NOTE—For most of the placing conditions, internal vibrators (needle vibrators) are suitable. The diameter of the needle shall be determined based on the density and spacing of reinforcement bars and thickness of sections. For tremie concrete, vibrators are not required to be used (*see also* **13.3**).

Courtesy: Bureau of Indian Standards (BIS), New Delhi

So, the table for workability from IS 456 is as follows. Here we have 3 columns the first column indicates what is the placement condition for concrete. The second column indicates the degree of workability desire for that particular placement condition. And the third one indicates the workability measured in terms of slump. The unit is mm now if you take the placing condition there are totally 4 different groups of placing condition provided. In the first group you have blinding concrete usually blinding concrete indicates a small layer of concrete that is poured before you place any reinforcement. The second one within the first group is shallow sections then payments using pavers.

So, for all these placements condition the degree of workability required is described as very low. In the second group you have mass concrete lightly reinforced sections in slabs, beams, walls, columns, floors, hand placed pavements, canal lining strip footings. For all these things the degree of workability is low. And a appropriate slump value is 25 to 75 mm in the third group we have heavily reinforced sections in slabs, beams, walls, columns, slip form pumped concrete etcetera.

And the description for workability is medium and the corresponding slump value is either 50 to 100 mm or 75 to 100 mm in the 4th group we have trench fill in situ piling tremie concrete and for that the degree of workability could be either high or very high and the corresponding slump values in mm or 100 to 150 mm. And remember that some extreme cases like for very low degree of workability or very high degree of workability separate instructions are given in clause 7.1.1 or 7.1.2 which can be read at a later stage.

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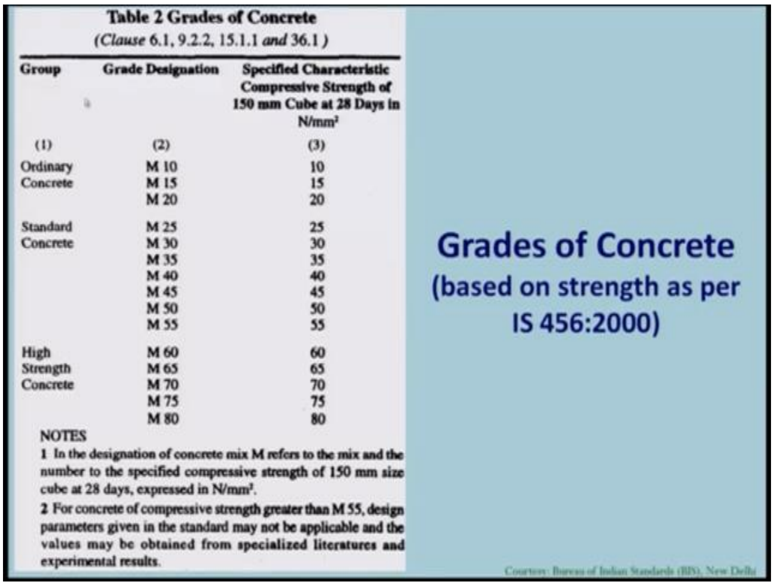

Table 2 Grades of Concrete
(*Clause* 6.1, 9.2.2, 15.1.1 *and* 36.1)

Group	Grade Designation	Specified Characteristic Compressive Strength of 150 mm Cube at 28 Days in N/mm²
(1)	(2)	(3)
Ordinary Concrete	M 10	10
	M 15	15
	M 20	20
Standard Concrete	M 25	25
	M 30	30
	M 35	35
	M 40	40
	M 45	45
	M 50	50
	M 55	55
High Strength Concrete	M 60	60
	M 65	65
	M 70	70
	M 75	75
	M 80	80

NOTES
1 In the designation of concrete mix M refers to the mix and the number to the specified compressive strength of 150 mm size cube at 28 days, expressed in N/mm².
2 For concrete of compressive strength greater than M 55, design parameters given in the standard may not be applicable and the values may be obtained from specialized literatures and experimental results.

Now, the second important table which gives more information about strength of concrete from IS 456 is shown here again here you have 3 columns one is the group of concrete that is designated the second one is a grade of concrete the third one is the specific compressive strength that we can expect from a 150 mm cube tested at 28 days and the strength here is measured in Newton per mm square in the first group we have ordinary concrete referring to M 10 M 15 or M 20. Remember that here 15 and 20 refers to 10 Newton per mm square, 15 Newton's per mm square and 20 Newton per mm square respectively. Likewise, you have standard concrete where the grade is designated as M 25 and it goes until M 55 and likewise the compressive strength here ranges from 25 Newton per mm square to 55 Newton per mm square.

We also have high strength concrete designated between M 60 to M 80 and the strength ranging from 60 to 80 Newton per mm square remember that this is characteristic compressive strength of 150 mm cube at 28 days.

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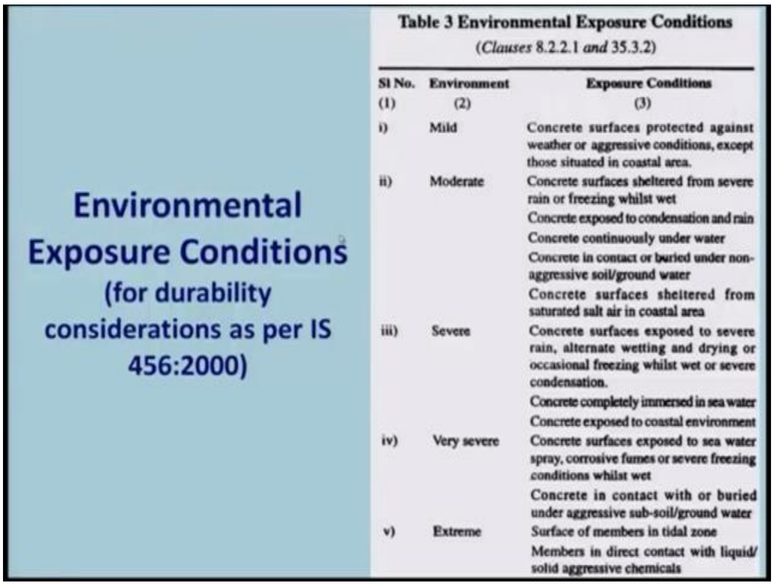

Table 3 Environmental Exposure Conditions
(*Clauses* 8.2.2.1 *and* 35.3.2)

Sl No. (1)	Environment (2)	Exposure Conditions (3)
i)	Mild	Concrete surfaces protected against weather or aggressive conditions, except those situated in coastal area.
ii)	Moderate	Concrete surfaces sheltered from severe rain or freezing whilst wet
		Concrete exposed to condensation and rain
		Concrete continuously under water
		Concrete in contact or buried under non-aggressive soil/ground water
		Concrete surfaces sheltered from saturated salt air in coastal area
iii)	Severe	Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation.
		Concrete completely immersed in sea water
		Concrete exposed to coastal environment
iv)	Very severe	Concrete surfaces exposed to sea water spray, corrosive fumes or severe freezing conditions whilst wet
		Concrete in contact with or buried under aggressive sub-soil/ground water
v)	Extreme	Surface of members in tidal zone
		Members in direct contact with liquid/ solid aggressive chemicals

The third table that we have in IS 456 is for durability considerations here you have 5 different environmental conditions mild moderate severe very severe and extreme and each of the exposure conditions are explained in detail. So, if you take mild condition the exposure condition is as follows concrete surfaces protected against whether or aggressive conditions except those situated in coastal areas.

Similarly, for moderate you have about 5 exposure conditions. Concrete surfaces sheltered from severe rain or freezing whilst wet concrete exposed to condensation and rain concrete continuously under water concrete in contact or buried under non aggressive soil or groundwater concrete surfaces sheltered from saturated salt air in coastal areas. So, like this you also have explanations for severe very severe and extreme. So, before using any concrete, we should be very clear about what is the environmental exposure condition. And this is very important because some tables will include all these exposure conditions and assign different values and we will see that in the next slide.

So, in this slide you will see the minimum cement content maximum free water cement ratio and minimum grade of concrete that is specified from economy perspective and this table is also from IS 456.

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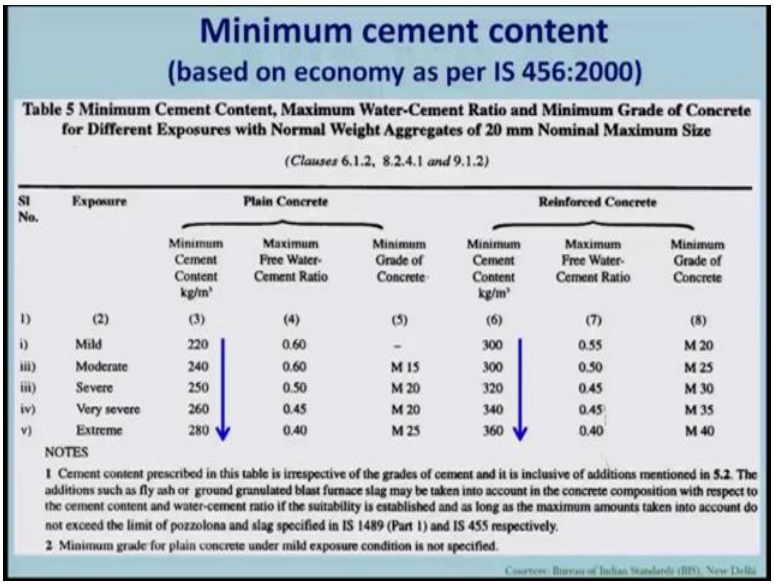

Minimum cement content

(based on economy as per IS 456:2000)

Table 5 Minimum Cement Content, Maximum Water-Cement Ratio and Minimum Grade of Concrete for Different Exposures with Normal Weight Aggregates of 20 mm Nominal Maximum Size

(*Clauses* 6.1.2, 8.2.4.1 *and* 9.1.2)

Sl No.	Exposure	Plain Concrete			Reinforced Concrete		
		Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete	Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete
1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Mild	220	0.60	–	300	0.55	M 20
iii)	Moderate	240	0.60	M 15	300	0.50	M 25
iii)	Severe	250	0.50	M 20	320	0.45	M 30
iv)	Very severe	260	0.45	M 20	340	0.45	M 35
v)	Extreme	280	0.40	M 25	360	0.40	M 40

NOTES

1 Cement content prescribed in this table is irrespective of the grades of cement and it is inclusive of additions mentioned in **5.2**. The additions such as fly ash or ground granulated blast furnace slag may be taken into account in the concrete composition with respect to the cement content and water-cement ratio if the suitability is established and as long as the maximum amounts taken into account do not exceed the limit of pozzolona and slag specified in IS 1489 (Part 1) and IS 455 respectively.

2 Minimum grade for plain concrete under mild exposure condition is not specified.

So, in the left what you have is we have the different exposure conditions mild moderate severe very severe extreme. And again you have 2 broad classifications, one is whether you have reinforcements in concrete or not the first one is plain concrete, where you do not have reinforcement in second one you have reinforced concrete, and within plain concrete again you have three classifications. One is minimum cement content that you have to use second one is maximum free water cement ratio, the third one is minimum grade of concrete. Likewise, reinforced concrete also you have same classifications.

At this point of time let us see only the minimum cement content because minimum cement content is the important factor from economy stand point. We will again revisit this table at the later stage. So, what you find is that under minimum cement content for mild exposure 220 is provided, moderate 240 and likewise for extreme it is 280. So, you see that the minimum cement content is increasing if the conditions are extreme. And likewise the same is true for reinforced concrete also, where the values are changing from 300 to 360.

You will also notice that the minimum cement content that is used for reinforced concrete all these values from 300 to 360 for how much higher than the plains concrete values ranging from 220 to 280 for that particular exposure condition. As I mentioned we will revisit this table at a later stage.

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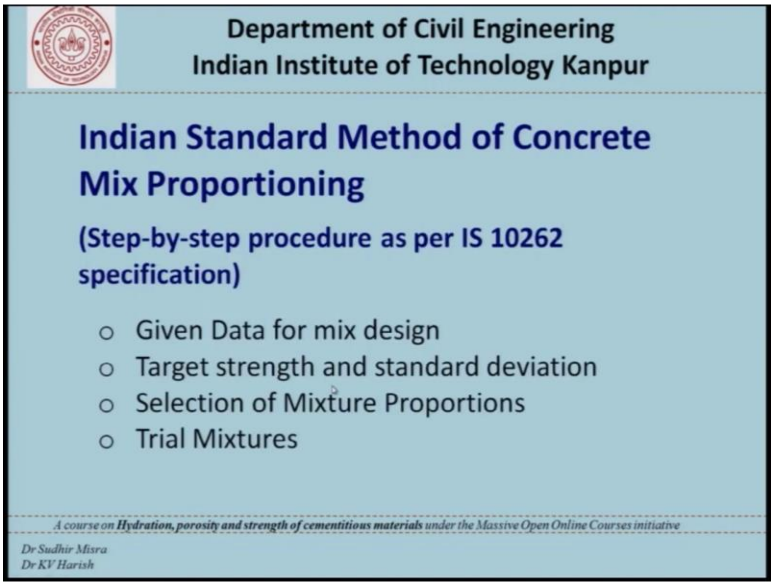

Now, coming on to Indian standard method of concrete mix proportioning: the step by step procedure is provided, the first step is we have to see what are the datas that we have at the initial stage even before doing the mix design. The second one is we should target at a specified strength and we should also understand what is the standard deviation for that particular concrete that we are designing. Third one is selection of mixture proportions and finally, doing trial mixtures to find out whether they obtained mixer proportion provides the desired strength and other properties.

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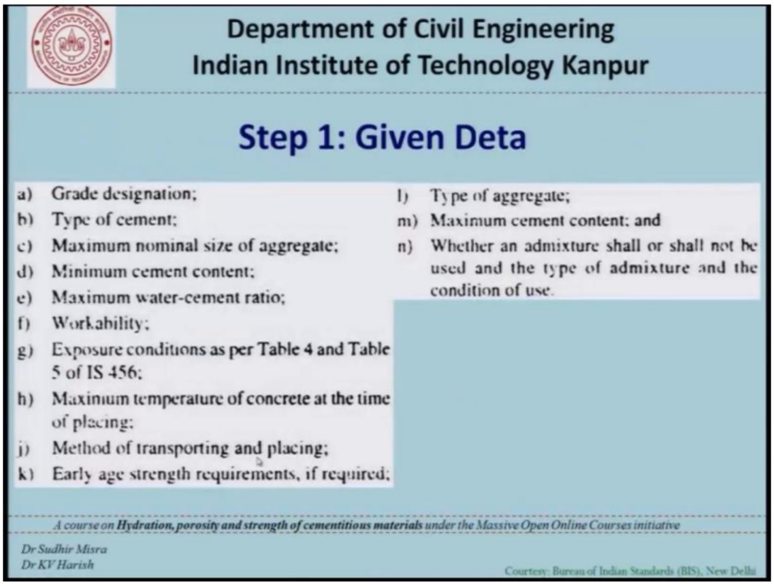

Now, step one data such as great designation type of cement, maximum nominal size of aggregate, minimum cement content, maximum water to cement ratio, workability for that application, exposure conditions as if we saw in the previous tables, maximum temperature of concrete at the time of placement method of transporting and placing early age strength requirements type of aggregate maximum cement content and whether an admixture shallow or shall not be used and also the type of admixture and condition of use all these things have to be known even before doing concrete mixture proportioning.

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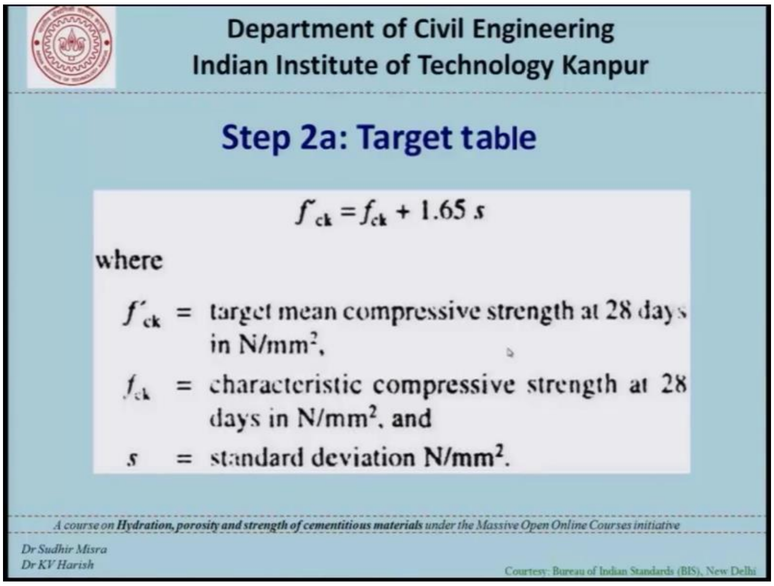

Now, the second step is broken down into few more parts in the first part if we target at a particular compressive strength. So, f c k bar is equal to f c k plus 1.65 times s. F c k bar is the target mean compressive strength at 28 days a Newton per mm square, f c k is the characteristic compressive strength at 28 days in Newton per mm square and s is the standard deviation.

Now there is a factor 1.65 refers to a constant indicating a confidence level of 95 percentage in many cases we can also take 99 percentage accordingly this coefficient will change. Largely for concrete we use a confidence level of 95 percentage and the constant referring to the 95 percentage confidence level is 1.65.

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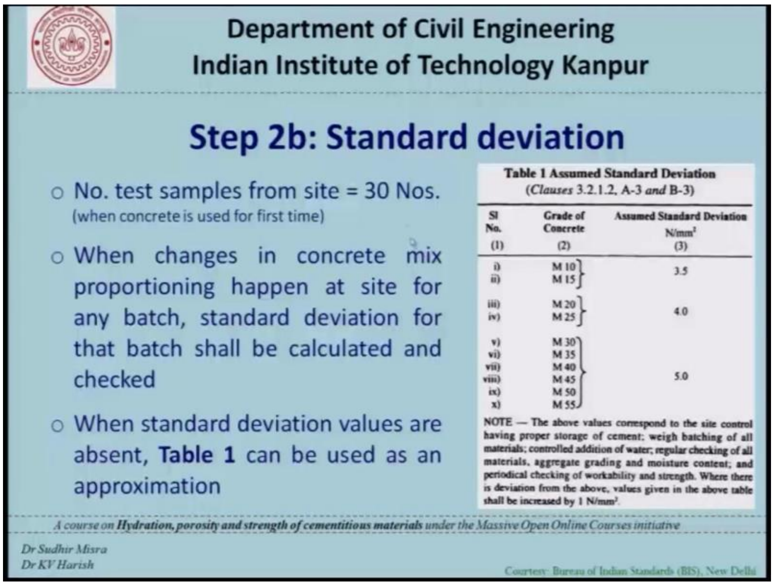

Now, we have to determine s which is the standard deviation. So, we go to the next part within step 2. Number of test samples from the site should be approximately 35 numbers. And this is with a condition that the concrete is used for the first time. When changes in concrete mixture proportioning happening at site for any batch the standard deviation for the batch shall be calculated and checked. When standard deviation values are not available then one can use the table one of the code IS 456, but you may have to remember that at a later stage if possible actual standard deviation should be calculated by testing the desired number of samples.

Now, in the table what is shown as the grade of concrete like M 10 M 15 M 20 M 25 35 until M 55. And for the 3 groups the standard deviation can be assumed as 3.5 4 and 5. And remember that this table can be used only if you do not have the standard deviation values or it is not possible to determine standard deviation values.

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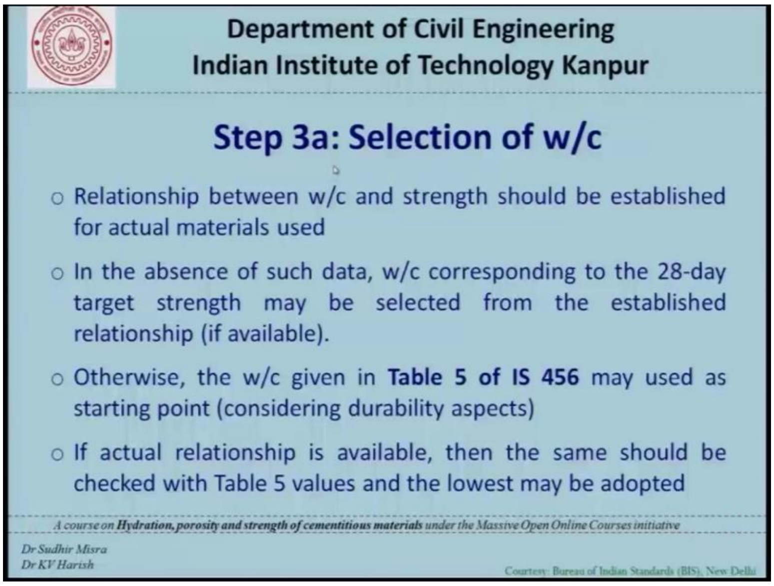

The third step is again divided into several parts. Part one part a is selection of water to cement ratio. The relationship between water to cement ratio and strength should be established for the actual materials that are being used. In the absence of such data water to cement ratio corresponding to the 28 day target strength may be selected from the established relationship if available. If it is not available, then the water to cement ratio given and table 5 of IS 456 may be used as the starting point. And this is based on durability consideration.

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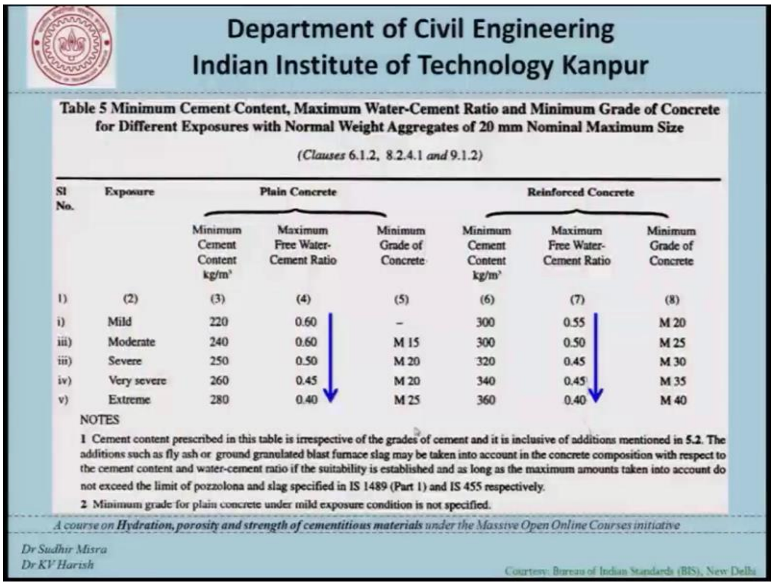

Table 5 Minimum Cement Content, Maximum Water-Cement Ratio and Minimum Grade of Concrete for Different Exposures with Normal Weight Aggregates of 20 mm Nominal Maximum Size

(*Clauses* 6.1.2, 8.2.4.1 *and* 9.1.2)

Sl No.	Exposure	Plain Concrete			Reinforced Concrete		
		Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete	Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete
1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Mild	220	0.60	–	300	0.55	M 20
iii)	Moderate	240	0.60	M 15	300	0.50	M 25
iii)	Severe	250	0.50	M 20	320	0.45	M 30
iv)	Very severe	260	0.45	M 20	340	0.45	M 35
v)	Extreme	280	0.40	M 25	360	0.40	M 40

NOTES

1 Cement content prescribed in this table is irrespective of the grades of cement and it is inclusive of additions mentioned in **5.2**. The additions such as fly ash or ground granulated blast furnace slag may be taken into account in the concrete composition with respect to the cement content and water-cement ratio if the suitability is established and as long as the maximum amounts taken into account do not exceed the limit of pozzolona and slag specified in IS 1489 (Part 1) and IS 455 respectively.

2 Minimum grade for plain concrete under mild exposure condition is not specified.

If actual relationship is available then the same shall be checked with the values provided in table 5 and the lowest may be adopted. So, we are revisiting table 5 of IS 456. So, what you find here is there is a maximum free water cement ratio that is mentioned for different exposure conditions ranging from 0.6 to 0.4 for plain concrete or 0.55 to 0.4 for reinforced concrete.

So, if we do not have actual information, then as a starting point. We can choose these values, but remember that actual relationship have to be established between water cement ratio and strength and later on it has to be checked with these values before proceeding further.

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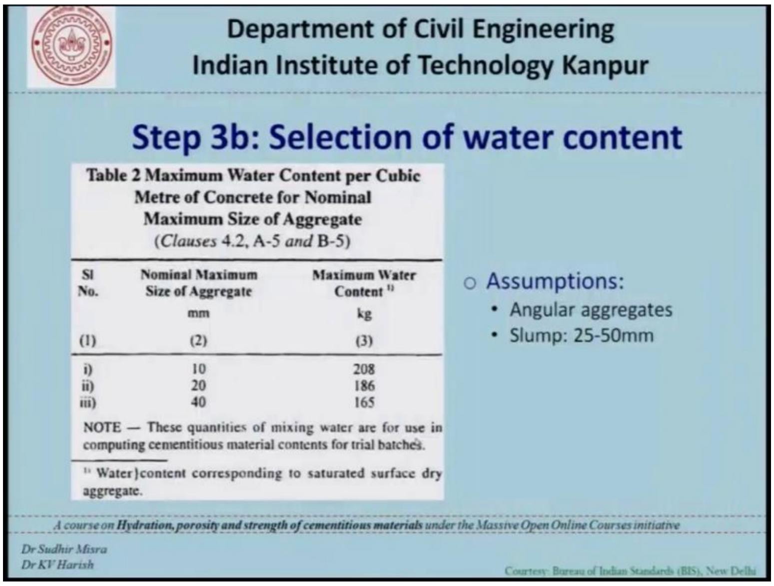

In the second part we have selection of water content and this is primarily chosen from table 2 of IS 10262. And in this table what you find is the nominal maximum size of aggregate is provided 10, 20 and 40, and for the nominal maximum size of aggregate suitable maximum water content is also provided. So, in this case for 10 mm nominal maximum size 208 kg of water should be used. And for 20 mm nominal maximum size 186 kg should be used and likewise for 40 mm 165 should be used.

Remember that the maximum water content here is expressed in kg which is also equal to liters, same values in liters because the specific gravity of water is 1. And this table is primarily for angular aggregates and for mixture that has slump between 25 to 50 mm.

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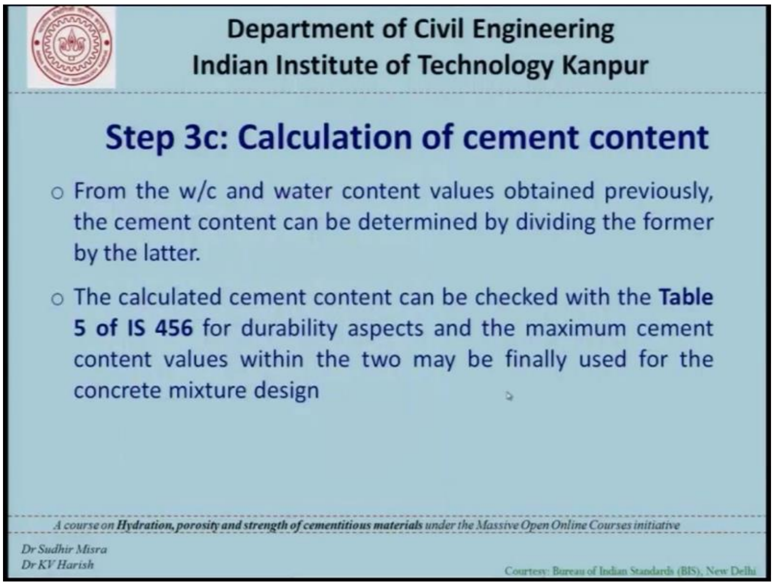

In the third part of step 3, we have calculation of cement content. Since we know the water to cement ratio and the water content, the cement content can be determined by dividing one from the other. The calculated cement content can be checked with the table 5 of IS 456 again for durability aspects, and the maximum cement content values within the two maybe finally, used for the concrete mixture design.

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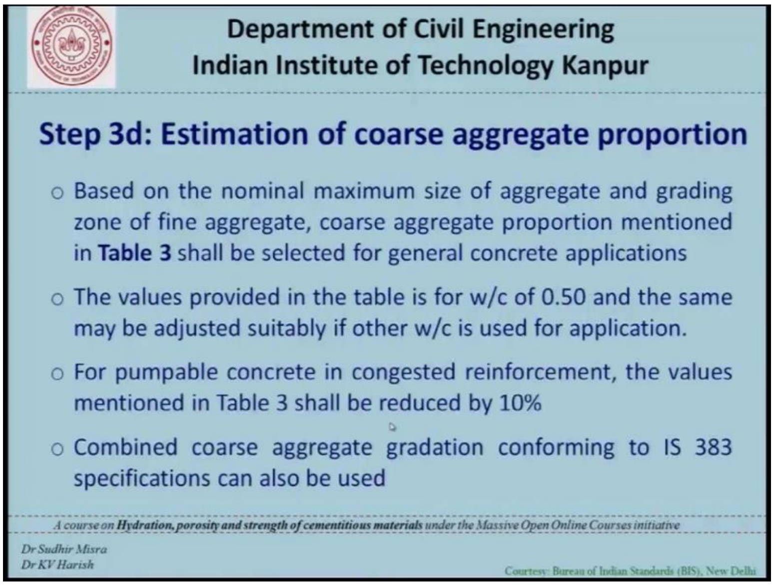

In the fourth part of step 3 we have estimation of coarse aggregate proportion. Based on the nominal maximum size of aggregate and grading zone of fine aggregate coarse aggregate proportion mentioned in table 3 shall be selected for general concrete applications. The values provided in the table is for water to cement ratio of 0.5 and the same may be adjusted suitably of other water cement ratio is used for application. For a special case where we need pump able concretes, especially in areas where we have congested reinforcement, the values mentioned in table 3 shall be reduced by 10 percent.

Similarly, IS 383 specification providing the use of combined coarse aggregate gradation and if we prefer to use such gradations then it shall be checked with the specifications of IS 383.

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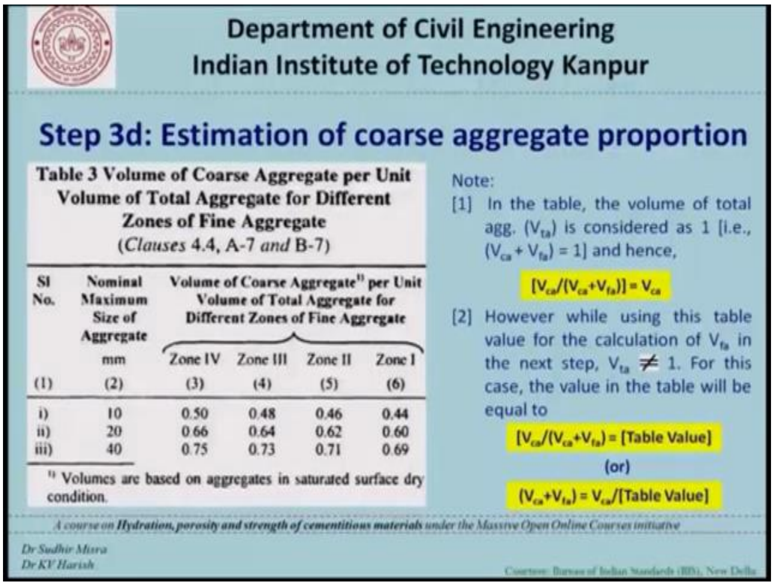

And the table that we use in this step is from table 3 of IS 10262. And what you find here is the nominal maximum size of aggregate ratio and in this column 10 20 and 40.

For which we have to choose the volume of coarse aggregate per unit volume of total aggregate for the different zones of san specified. So, as we have already discussed in previous lectures we have zone I, zone II, zone III and zone IV for fine aggregates. And the volume of coarse aggregates per unit volume of total aggregate is chosen from this table. So, you may note the following while using this table. The volume of total aggregate is considered as one in this stable that is if V ca is the volume of coarse aggregate and V fa is the volume of fine aggregate V ca plus V fa is equal to 1, and hence V ca divided by V ca plus V fa is equal to V ca what is this this is actually the table values that are provided here nothing, but volume of coarse aggregate per unit volume of total aggregate.

So, that value will be equal to V ca again because the denominator is one now the second note is; however, while using this table value for the calculation of V fa in the next step V ta is not equal to one very important. So, in the next step when we are calculating fine aggregate proportion we have to make sure that V ta is not equal to one for this case the value in the table will be equal to V ca divided by V ca plus V fa is equal to table value. Or in other words V ca plus V fa is equal to V ca divided by table value this one we have to substitute in the next step to get the fine aggregate proportion.

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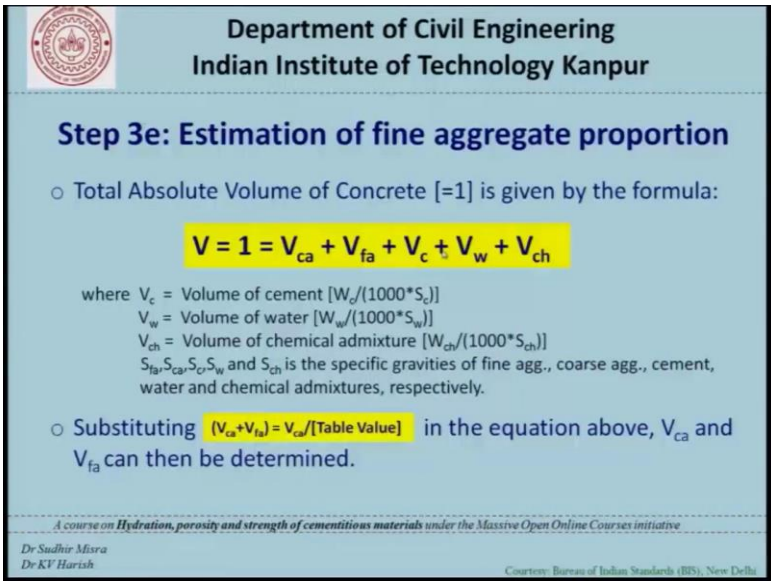

In the fifth part of step 3 estimation of fine aggregate proportion, the formula that is used is V equal to V ca plus V fa plus V c plus V w plus V ch.

Where here ca represents coarse aggregate fa represents fine aggregate c represents cement w present water and ch represents chemical admixtures if they are used in concrete. And this volume is called as total absolute volume of concrete and it is usually taken as one now. V c V w V ch can be determined if we know the weight of cement water and chemical admixture that are used and if we know the specific gravity of cement water and chemical admixture. So, if you know all the specific gravity and the weights we can find out the volume of cement water and chemical admixture remember that we do not have the volume of V ca plus V fa and for this we have to substitute the values that we got in the previous table. So, substituting V ca plus V fa equal to V ca by table value in this equation about V ca and V fa can be determined weight percentage.

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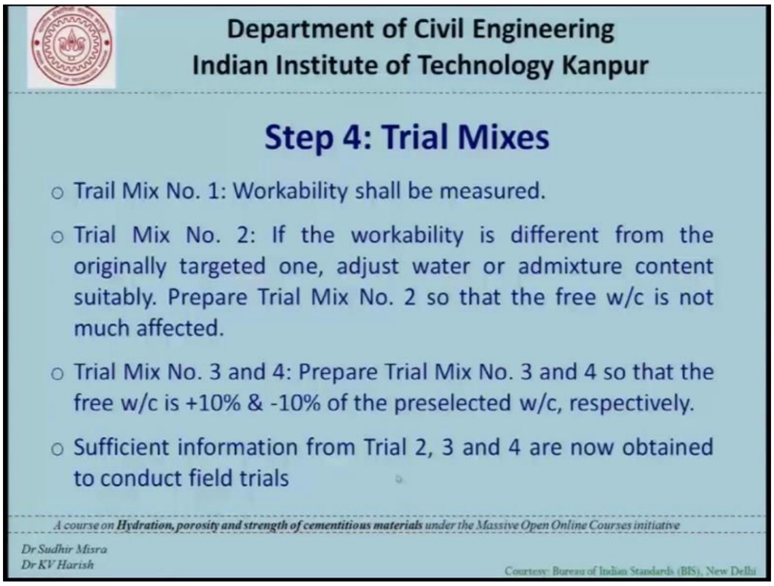

Finally, step 4 once, we arrive at the different volume proportions we have to do trial mixtures. So, what Indian standard suggest is, we have to do trial mixture one and check whether the workability that we targeted or we assume have been obtained. Trial mixture number 2 if the workability is different from the originally targeted one adjust water or admixture content suitably. Prepare trial mixture number 2, so that the free water to cement ratio is not much affected. Trail mix number 3 and 4 prepare trail mix number 3 and 4. So, that the free water to cement ratio is plus 10 percentages and minus 10 percentage of the preselected water to cement ratios is respectively. Sufficient information from trial 2 3 and 4 are now obtain to conduct field trials.

So, this is approximately the procedure for the mixture proportioning of concrete. Now we go to the next topic which is concrete mix design strategies. Concrete we will go through a brief introduction before getting into the strategies.

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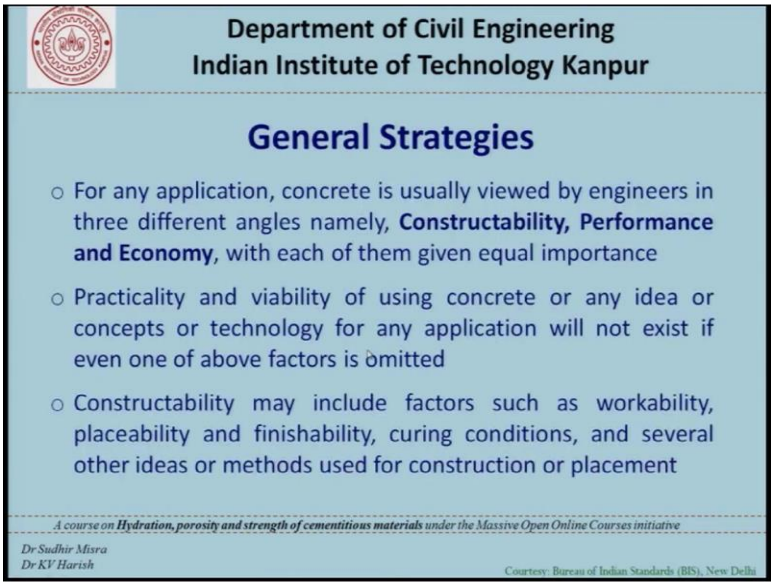

For any application, concrete is usually viewed by engineers in three different angles namely: constructability, performance and economy. Remember that each one of them is given equal importance. Practicality and viability of using concrete or any idea or concept or technology for any application will not exist if even one of the above factor is omitted. Constructability may include factors such as workability place ability and finish ability curing conditions and several other ideas are methods used for construction or placement.

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Performance includes primarily the property or properties that are required for that application. Performance may include workability strength toughness modulus of elasticity permeability and remember that permeability will come as a durability factor or the any other methods in addition to the combination of the above property.

So, in some cases we may expect only one property in some cases we expect combination of properties. Economy includes primarily cost benefit is obtained either by using a particular concrete or composite or a method and comparison with the conventional ones. So, both material and method plays an extremely important role in deciding the economic aspects.

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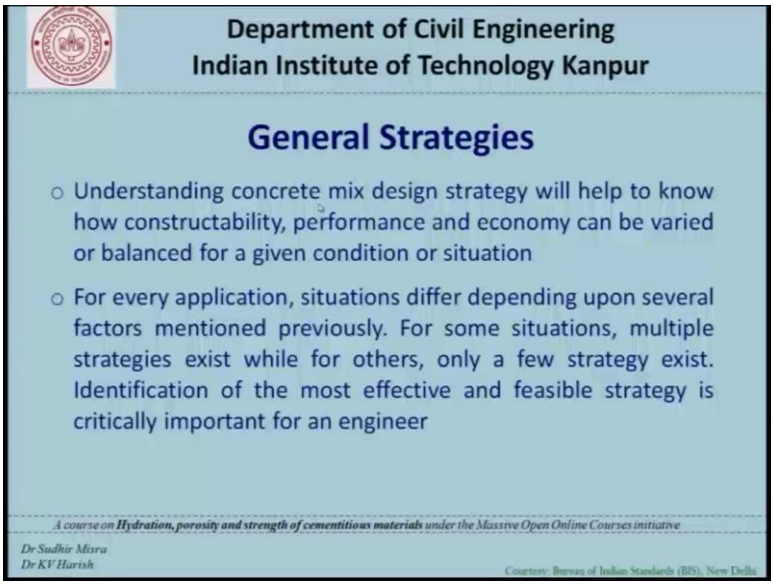

Understanding concrete mix design strategy will help to know how constructability performance and economy can be varied or balance for a given condition or situation. For every application situations differ depending upon several factors mentioned previously. For some situations multiple strategies exist while for others only a few strategies exist. Identification of the most effective unfeasible strategy is critically important for an engineer.

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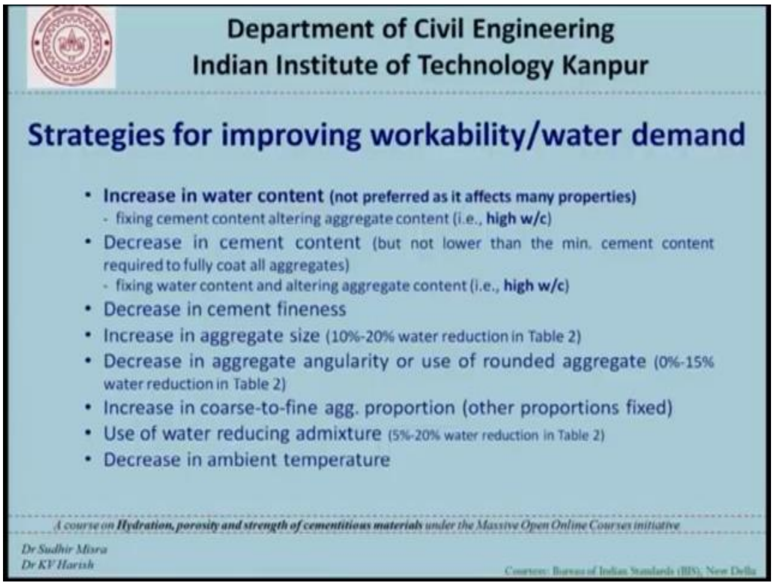

Now, some of the strategies that we use for improving workability or water demand are as follows. Now for improving workability we can either increase the water content, we can decrease the cement content we can decrease the cement fineness we can increase the aggregate size, we can decrease the aggregate angularity or use rounded aggregates, increase the coarse to find aggregate proportion we can use water reducing admixture and if possible we can reduce the ambient temperature. So, you have so many strategies to improve workability of which some are practicable some are not practicable, because these strategies may affect other properties like strength and durability.

So, in the case of increasing the water content this is usually not preferred as it affects many properties primarily strength and durability. So, what is usually done is fixing of the cement content by altering the aggregate content. So, this will usually result in high water to cement ratio this is usually not preferred, the second one decrease in cement content can be done, but not lower than the minimum cement content required to fully coat all aggregates. So, one has to be very careful because a minimum cement content is required.

So, that it can coat the surfaces of the aggregate, and make sure that the mechanical interlocking to in decrease and cement content, we have to make sure that we cannot a lower the cement beyond or below the minimum that is specified. This is usually done by fixing water content and altering aggregate content thereby we can get high water to cement fineness. Decrease the 4th one where we can increase the aggregate size and this will result in 10 percentages to 20 percentage water reduction and this is mentioned in table 2.

In the fifth one because of the use of rounded aggregates one can get a water reduction of 0 to 15 percentage. And this is also mentioned in table 2. Likewise, you have all other strategies and the when you use a water reducing admixture you can result up to 5 percentages to 20 percentage water detection which is also mentioned in table 2.

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Now, the next one is some of the strategies that we use for improving strength. So, the commonly use strategies or decrease in water content this is usually preferred provided it is economical and does not affect other properties. Fixing cement content by altering the aggregate content and this will result in low water to cement ratio. Increase in cement content. So, here higher the cement content that can be increased it should be higher than the minimum the amount of cement content that you use should be higher than the minimum content required to fully coat all aggregates. This is similar to what we have seen in the previous case. And this is achieved by fixing water content and altering the aggregate content and this will result in low water to cement ratio.

The third one is decrease in aggregate size the 4th one is use of angular cubical aggregates the fifth one is use of water reducing admixtures.

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The following provides the strategies for improving permeability or durability first one is decrease in water content. This is usually preferred provided the mixture is economical and workable, this can be done by fixing cement content and altering the aggregate content which will result in low water to cement ratio. Increase in cement content and this is preferred provided the mixture is economical and workable. This is done by fixing water content and altering the aggregate content.

And this will also result in low water to cement ratio. The third one is use of supplementary cementing materials or mineral admixtures and you also have other strategies.

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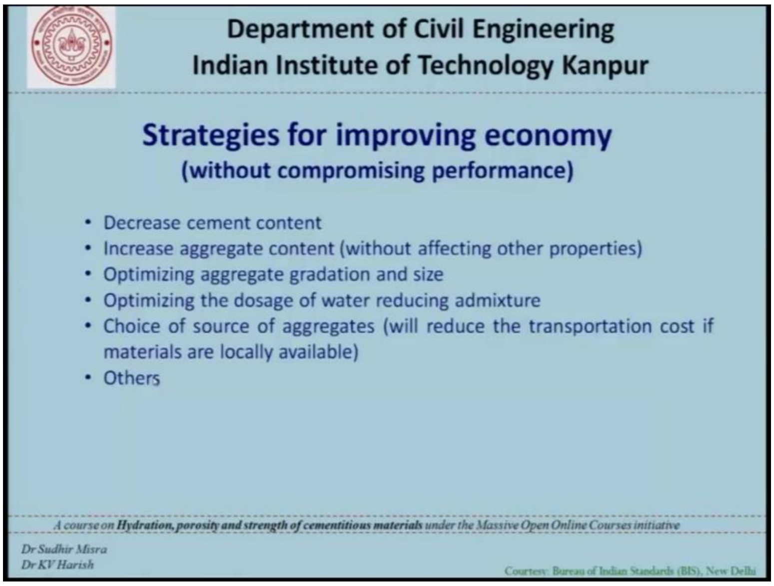

Strategies for improving economy and remember this is without compromising other properties or other performance. So, decreasing cement content, increase aggregate content. Remember this is without affecting other properties optimizing aggregate gradation and size, optimizing the dosage of water reducing admixture choice of source of aggregates this will primarily reduce the transportation cost if the materials are locally available you can also use other strategies to achieve economy.

With this we come to an end for this lecture.

Thank you.