Hydration, Porosity and Strength of Cementitious Materials

Prof. Sudhir Mishra and Prof. K. V. Harish
Department of Civil Engineering
Indian Institute of Technology, Kanpur

Lecture - 07
Aggregates

Hi, good morning to one and all. I am K. V. Harish Assistant Professor, Department of Civil Engineering IIT Kanpur. You are watching MOOCs lectures on hydration porosity and strength of cementitious material.

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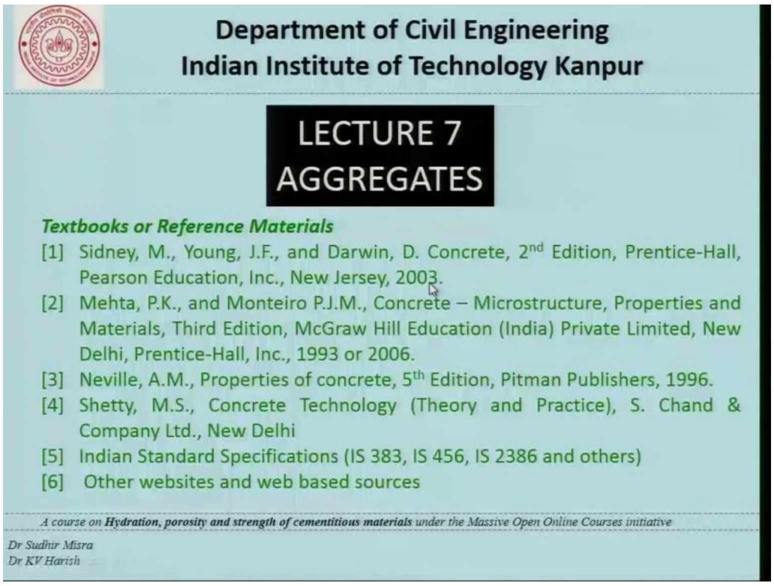

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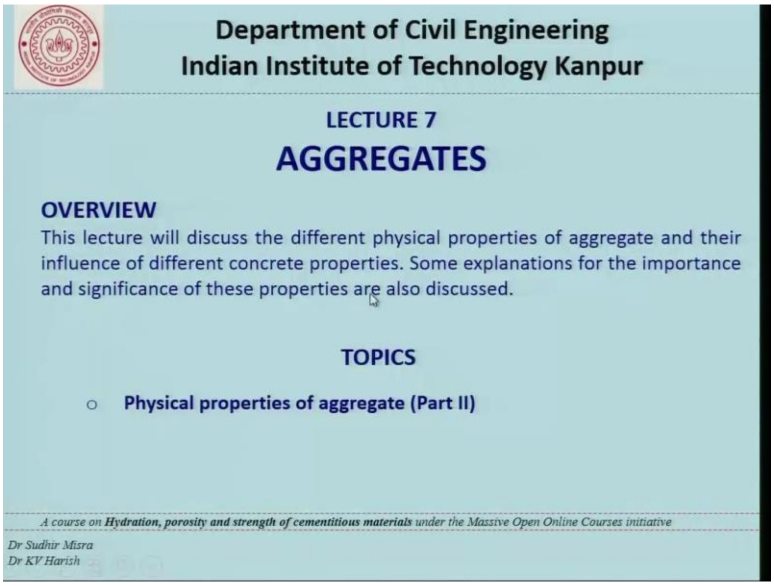

The text book and reference materials are shown. Today we will see the lectures 7 aggregates. Over view this lecture we will discuss the different physical properties of aggregate, and their influence on different concrete properties. Some explanations for the importance and significance of these properties are also discussed. So, the topic primarily is physical properties of aggregate part 2.

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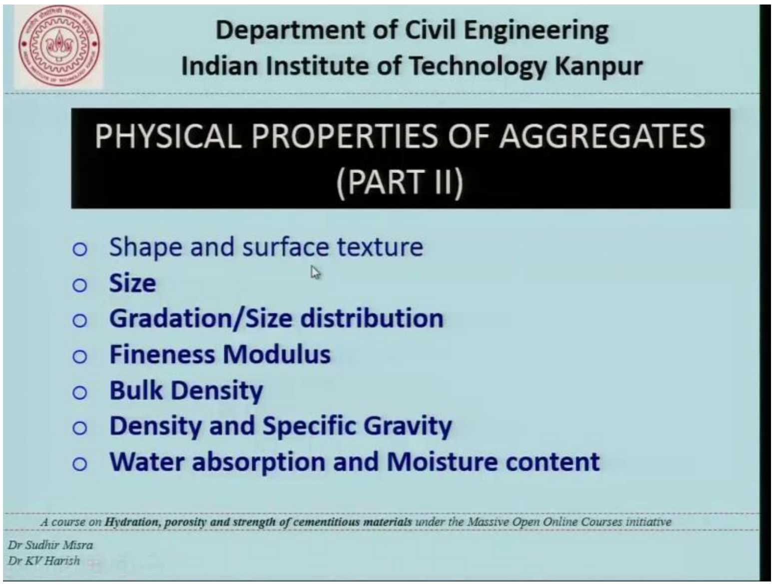

In the last lecture we have seen shape and surface texture and it is importance. And in this part we will see size gradation or size distribution, fineness modulus, bulk density,

density and specific gravity, water absorption and moisture content and the importance of all this physical property.

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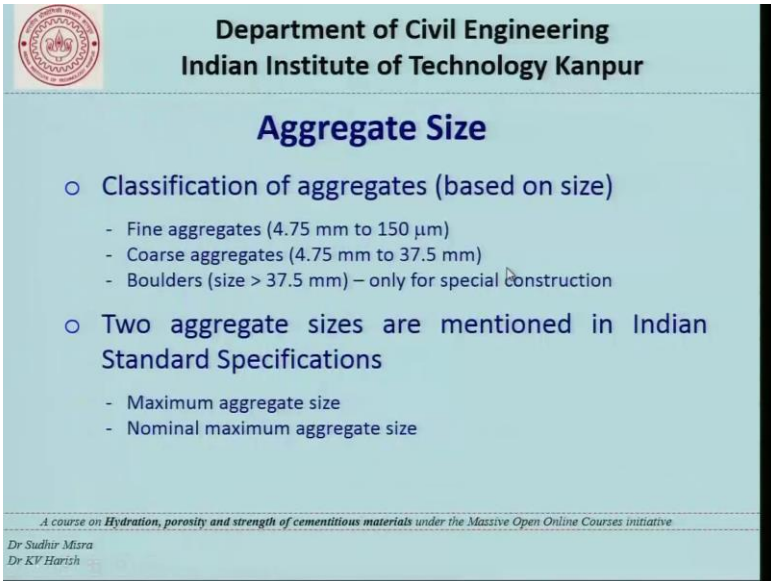

Size: aggregates or classified based on size as follows. Fine aggregates size range from 4.75 mm to 150 microns. Coarse aggregates size range from 4.75 mm to 37.5 mm. Boulders size greater than 37.5 mm and remember that boulders are used only for special construction. So, largely we have only two categories fine aggregates and coarse aggregates. Many often we use two aggregate sizes which are mentioned in Indian standard specifications. They are maximum aggregates size and nominal maximum aggregate size.

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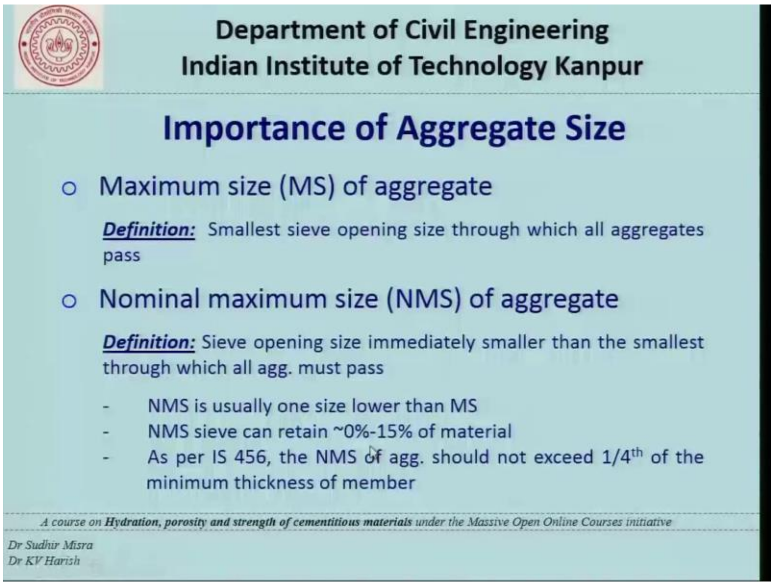

Maximum size in this lecture denoted as ms of aggregate is defined as the smallest sieve opening size through which all aggregates pass. Nominal maximum size in this lecture denoted as NMS is defined as the sieve opening size immediately smaller than the smallest through which all aggregates must pass. Essentially nominal maximum size of aggregate is usually one size below the maximum size. Nominal maximum size can retain approximately 0 to 15 percentage of material as per is 456, the nominal maximum size of aggregate should not exceed one-fourth of the minimum thickness of the member.

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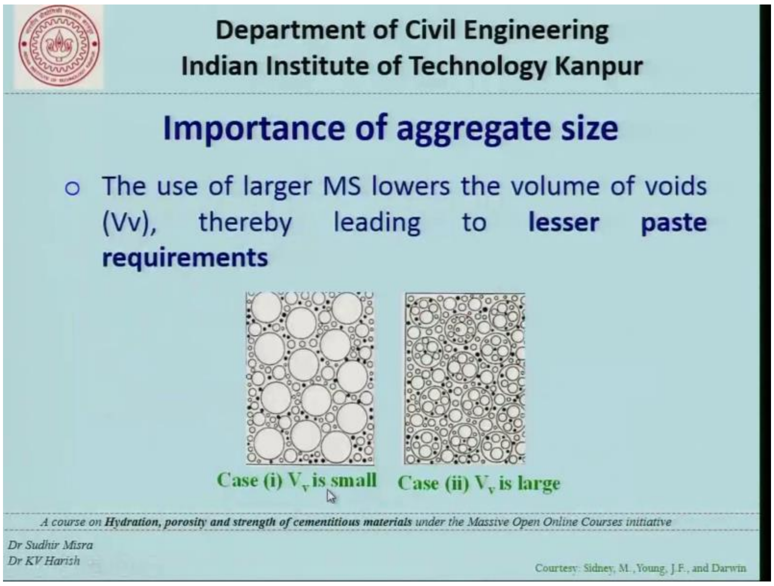

So, importance of aggregate size the use of larger maximum size lowers the volume of voids there by leading to lesser paste requirements. We need lesser paste requirements primarily from an economic stand point. So, in the slide you see two figures case one where Vv is small case two where Vv is large, and in a first figure you can see that you have coarse aggregates and fine aggregates. In the second figure you can see that the coarser aggregates are actually replaced by smaller fine aggregates.

Therefore, the maximum size of aggregate present the second case is much lower than the first case. So, this will result in larger volume of voids. And if the volume of voids is larger than the mixture will be uneconomical. And hence larger maximum size of aggregate is usually preferred.

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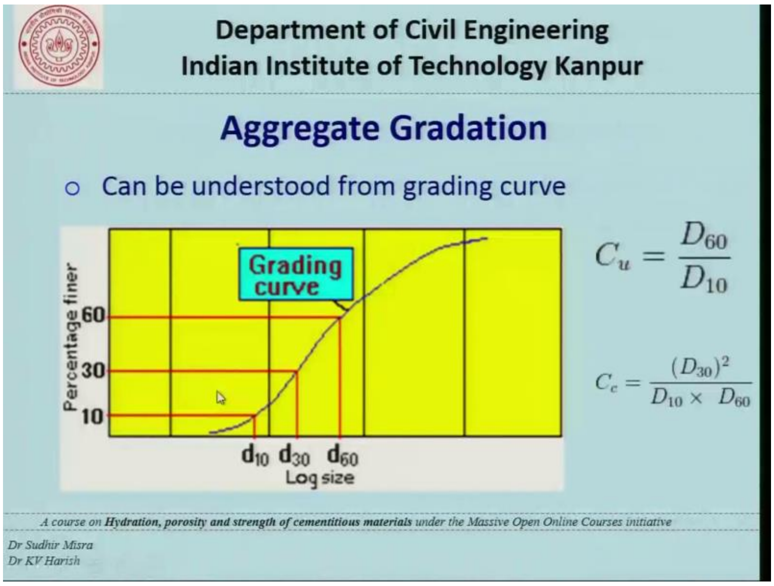

The second one is aggregate gradation the aggregate gradation can be understood from the gradation curve and the gradation curve is shown in the figure. In the x axis you take the sieve size or the aggregate size. In the y axis you take percentage finer or cumulative percentage passing. And what you see is that, in the right side you have a coefficient called cu which indicates coefficient of uniformity, which is equal to d 60 by d 10 and you have another coefficient called coefficient of curvature which is d 30 square divided by d 10 into d 60.

Now what is d 10 d 60 and d 30 d 10 d 30 and d 60 are the sizes corresponding to 10 percentages 30 percentage 60 percentage finer respectively. These are obtained by drawing the horizontal line from these values 10 30 and 60, and at which ever point these horizontal lines intersect ultra-vertical lines to get d 10 d 30 and d 60 values. So, you need these values to approximately indicate whether a particular gradation is coarser or finer.

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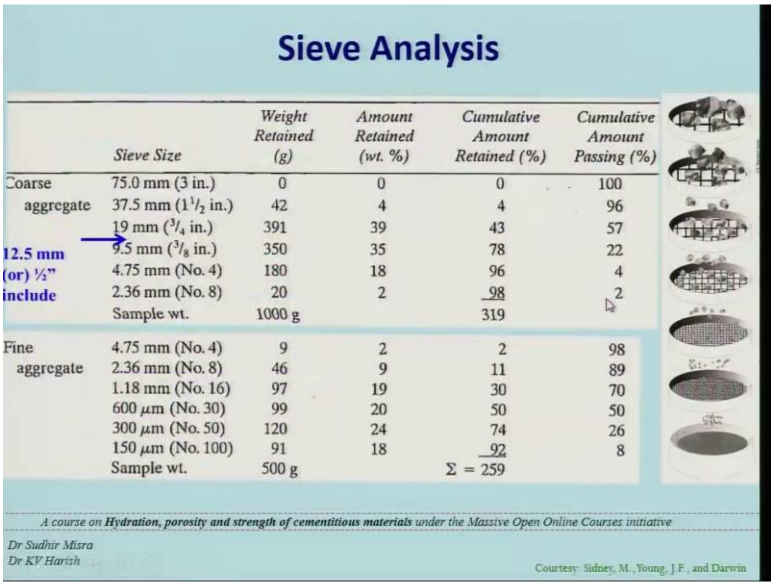

	Sieve Size	Weight Retained (g)	Amount Retained (wt. %)	Cumulative Amount Retained (%)	Cumulative Amount Passing (%)
Coarse aggregate	75.0 mm (3 in.)	0	0	0	100
	37.5 mm ($1^1/_2$ in.)	42	4	4	96
	19 mm ($^3/_4$ in.)	391	39	43	57
	9.5 mm ($^3/_8$ in.)	350	35	78	22
	4.75 mm (No. 4)	180	18	96	4
	2.36 mm (No. 8)	20	2	98	2
	Sample wt.	1000 g		319	
Fine aggregate	4.75 mm (No. 4)	9	2	2	98
	2.36 mm (No. 8)	46	9	11	89
	1.18 mm (No. 16)	97	19	30	70
	600 μm (No. 30)	99	20	50	50
	300 μm (No. 50)	120	24	74	26
	150 μm (No. 100)	91	18	92	8
	Sample wt.	500 g		Σ = 259	

Now, how do you get this gradation curve? The gradation curve is done by using the test call sieve analysis. So, an example of sieve analysis is shown where in different sizes for coarse aggregate and difference sizes for fine aggregate sieve are chosen. So, as you can see for coarse aggregate the sieve size ranges from 75 mm to about 2.36 mm. Remember that the actual size ranges only 37.5 mm to 4.75 and some additional sieves are also stack likewise for fine aggregates the sieve size ranges from 4.75 until 150 microns.

Now in this example an approximate sample weight of thousand grams is taken for the coarse aggregate and finer dam by taken for the fine aggregate. And the sieves or stat one below the other and you see that the bigger sieves are stat on the top and finer sieves are stat at the bottom. And these materials coarse aggregate and fine aggregates are saved in sieves and the percentage passing through each of the sieve is calculator.

So, in this table what you see is that the weight retained in each of the sieve is recorded and this is expressed in grams. And the amount retained in percentage is recorded. And cumulative amount retained which is nothing, but for the first one 0 0, for the second one it is 4 which came from 0 plus 4 for the third one, it is 43 which came from 0 plus 4 plus

39 and likewise the cumulative amount retained on the each of the sieve is measure. And then cumulative amount passing is calculated by subtracting these values from 100. So, in the first case 100 minus 0 is 100. The second case 100 minus 4 is 96 in the third case 100 minus 43 is 50. And likewise the cumulative amount passing is cumulated for each sieve and this value and the sieve size are plotted and you get this curve and you get this grading curve finally, likewise coarse aggregates and fine aggregates are separately calculated and the gradation curves are formed.

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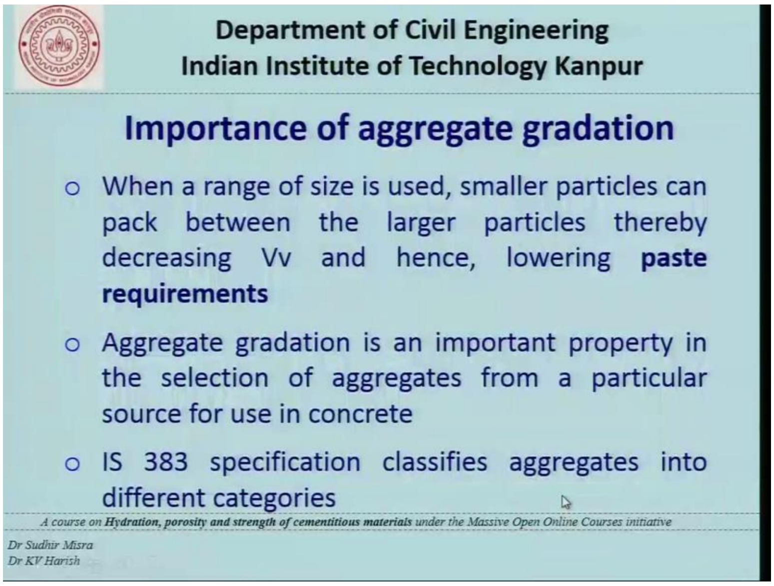

Now, some important information about aggregate gradation when a range of size is used smaller particles can have packed between the larger particles, thereby decreasing Vv which is volume of voids and hence lowering paste requirements. Aggregate gradation is an important property in the selection of aggregates from particular source for use in concrete IS 383 specification classifies aggregates into different categories.

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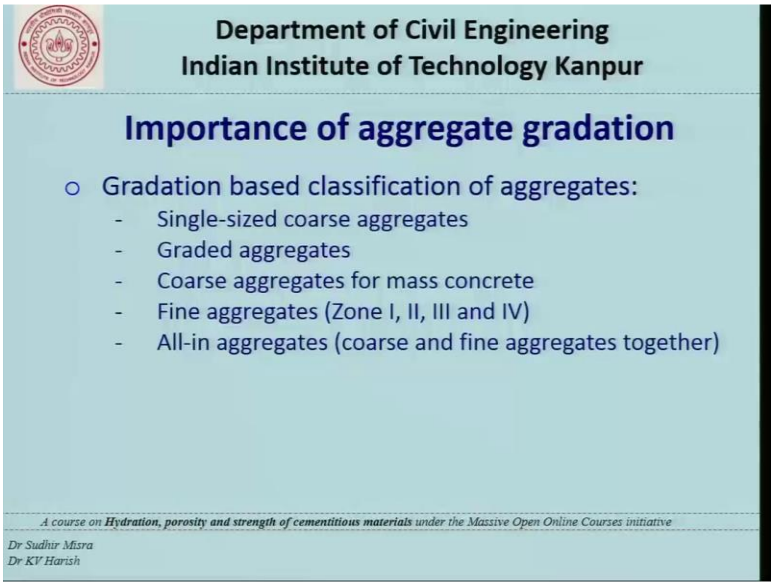

So, the gradation based classifications that we have are as follows. Single sized coarse aggregates, graded aggregates, coarse aggregates for s mass concrete. Fine aggregates and again fine aggregate is divided by into zone I, zone II, zone III and zone IV. Zone I refers to the coarser gradation. Zone IV refers to the finer gradation. The fifth one is all in aggregates where the coarse and fine aggregates are club together. We will see the specifications given for each classification of aggregates.

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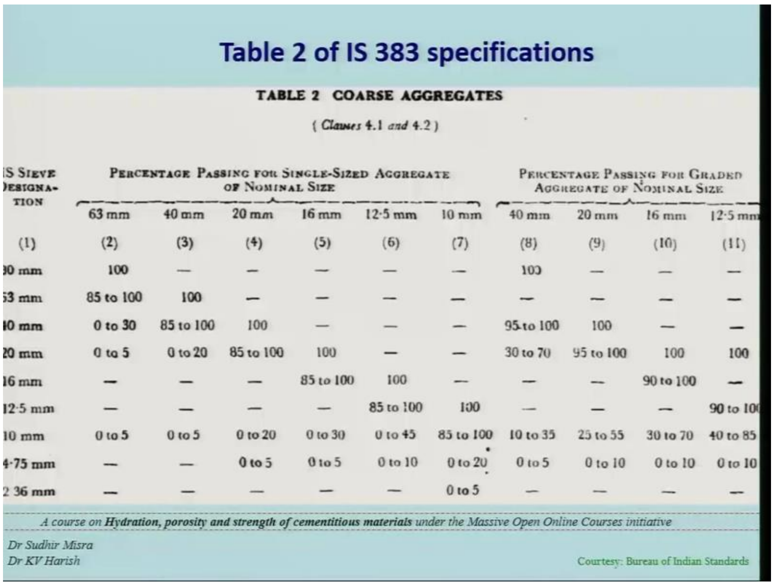

TABLE 2 COARSE AGGREGATES

(Clauses 4.1 and 4.2)

IS Sieve Designation	Percentage Passing for Single-Sized Aggregate of Nominal Size						Percentage Passing for Graded Aggregate of Nominal Size			
	63 mm	40 mm	20 mm	16 mm	12·5 mm	10 mm	40 mm	20 mm	16 mm	12·5 mm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
30 mm	100	—	—	—	—	—	100	—	—	—
53 mm	85 to 100	100	—	—	—	—	—	—	—	—
40 mm	0 to 30	85 to 100	100	—	—	—	95 to 100	100	—	—
20 mm	0 to 5	0 to 20	85 to 100	100	—	—	30 to 70	95 to 100	100	100
16 mm	—	—	—	85 to 100	100	—	—	—	90 to 100	—
12·5 mm	—	—	—	—	85 to 100	100	—	—	—	90 to 100
10 mm	0 to 5	0 to 5	0 to 20	0 to 30	0 to 45	85 to 100	10 to 35	25 to 55	30 to 70	40 to 85
4·75 mm	—	—	0 to 5	0 to 5	0 to 10	0 to 20	0 to 5	0 to 10	0 to 10	0 to 10
2 36 mm	—	—	—	—	—	0 to 5	—	—	—	—

So, in this table which is taken from IS 383 you can see single sized aggregate and you can also see graded aggregates. And you can see that again you have sub divisions based on the nominal size. For example, in the case of single sized aggregate you have nominal size starting from 63 mm to about 10 mm. Likewise for graded aggregates you have nominal size starting from 40 mm to about 12.5 mm. Likewise in the left you see that the same sizes are mentioned right from 8 mm to say 4.75 or 2.36 mm and remember that this is a coarse aggregate gradation. So, what you can understand is that the single sized aggregate gradation and graded aggregate gradation are different in the sense that the number of same sizes in which the aggregates are retained or lower in the case of single sized compare to the graded.

So, in case of single size you typically see only 2 same sizes or one sieve size that is dominate. So, if you take the 63 mm nominal size the dominating sieve size is 40 mm where as if you take a graded aggregate there were 2 sieve sizes, that dominate here in this case for a nominal size of 40 mm 20 mm sieve also dominates at the same time 10 mm sieve also dominates and likewise for others.

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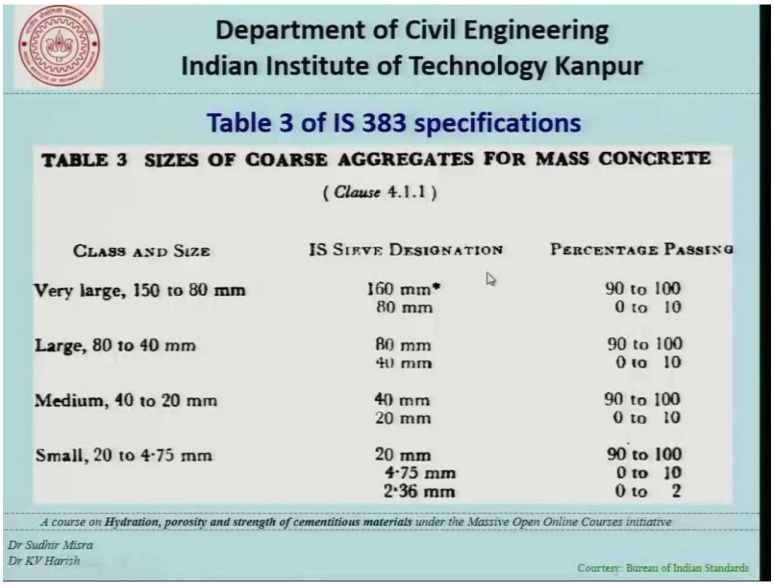

Class and Size	IS Sieve Designation	Percentage Passing
Very large, 150 to 80 mm	160 mm*	90 to 100
	80 mm	0 to 10
Large, 80 to 40 mm	80 mm	90 to 100
	40 mm	0 to 10
Medium, 40 to 20 mm	40 mm	90 to 100
	20 mm	0 to 10
Small, 20 to 4·75 mm	20 mm	90 to 100
	4·75 mm	0 to 10
	2·36 mm	0 to 2

So, in the third category, we have this coarse aggregate gradation for mass concrete, where you can see that the classes and sizes are separately listed and in the top you see 150 to 80 mm size of stones 80 to 40 40 to 20 and 20 to 4.75. And remember that this is mass concrete where the volume of concrete is very high and hence larger size stones is preferred from economic stand point remember that use of larger maximum size of aggregate is preferred from economy stand point, the highest sieve designation for this is one 60 mm or 8 mm likewise for 80 to 40 it is 80 and 40 40 to 20 it is 40 and 20 20 to 4.75 it is 24.75 and 2.36.

The percentage passing or provided in this column, this will give some approximate idea about what is the maximum size and gradations that are used for mass concrete applications.

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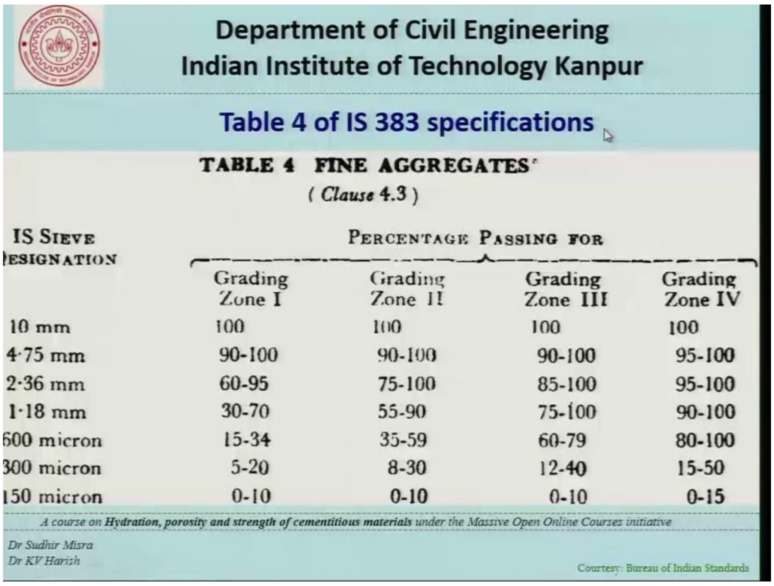

TABLE 4 FINE AGGREGATES

(*Clause* 4.3)

IS Sieve Designation	Percentage Passing for			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10 mm	100	100	100	100
4·75 mm	90-100	90-100	90-100	95-100
2·36 mm	60-95	75-100	85-100	95-100
1·18 mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0-10	0-10	0-10	0-15

In the fourth category we have fine aggregates which are divide into zone I, zone II, zone III and zone IV. As already mentioned zone I as coarser grading compare to zone IV. And the IS sieve designations from 10 mm to 150 microns are provided in the left side. So, you can see that the zone I, zone II, zone III and zone IV are available, and if any of the sources of aggregates does not pass through this grading then that particular aggregate is rejected.

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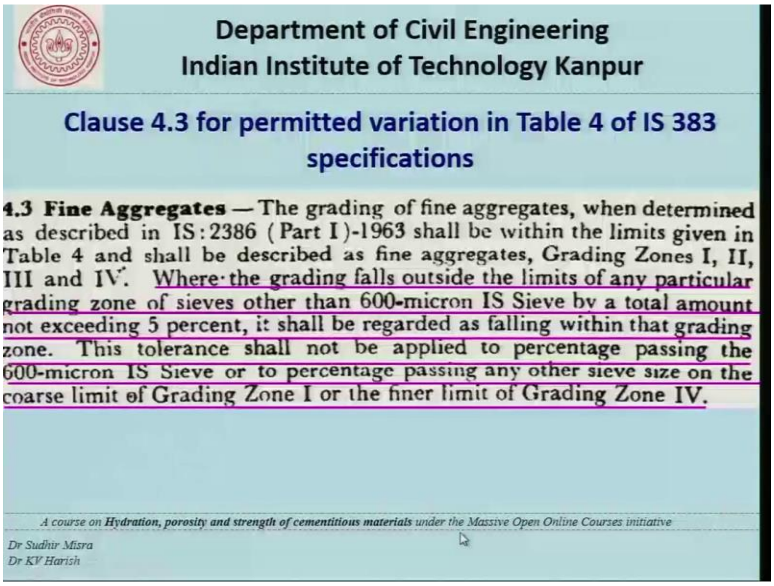

Some important things in table 4 of IS 383 specifications where the grading falls outside the limit of any particular grading zone of sieves other than 600 microns, by a total amount not exceeding 5 percentages it shall be regarded as falling within that grading zone. This tolerance shall not be applied to percentage passing the 600 micron IS sieve or to percentage passing any other sieve size on the coarse limit of grading zone I or the fine limit of grading zone II. So, what is this indicates for example, if we have a aggregate from other sources, and if it has a gradation similar to the one that is shown in table 4, like for example, you have zone I, zone II, zone III and zone IV and assume that you have a aggregate that as a grading very quick close, but that is not meet the particular gradation, then the first thing that we have to see is how much is the deviation from the specified grading.

So, if the deviation is 5 percentage then it is permitted, but it is permitted with some conditions. So, what is shown in this figure is the pink color one, where this 600 micron is highlighted. And also some grading above the 600 micron for zone I, and some grading below the 600 micron for zone IV. The tolerance limit of 5 percentage is accepted for all the other grading except these grading which means if you have an aggregate which as a gradation where the 600 micron passing is say 14 percentage and here the limit given is 15 to 34. So, in that case that aggregate has to be rejected, even though the value of 14 is very close to 15.

Why because, the core as clearly stated that 5 percentage variability is accepted except for this particular horizontal row and this particular column. So, for all other things the variability of 5 percentage is accepted that is the meaning of this slide.

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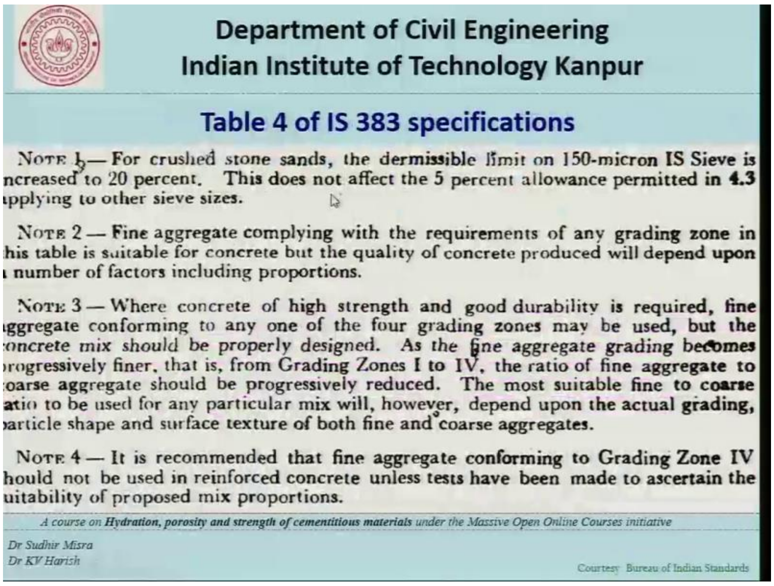

In addition to this there are also different notes that are given. So, I am just allowing you to go through these notes which are pretty much self-explanatory.

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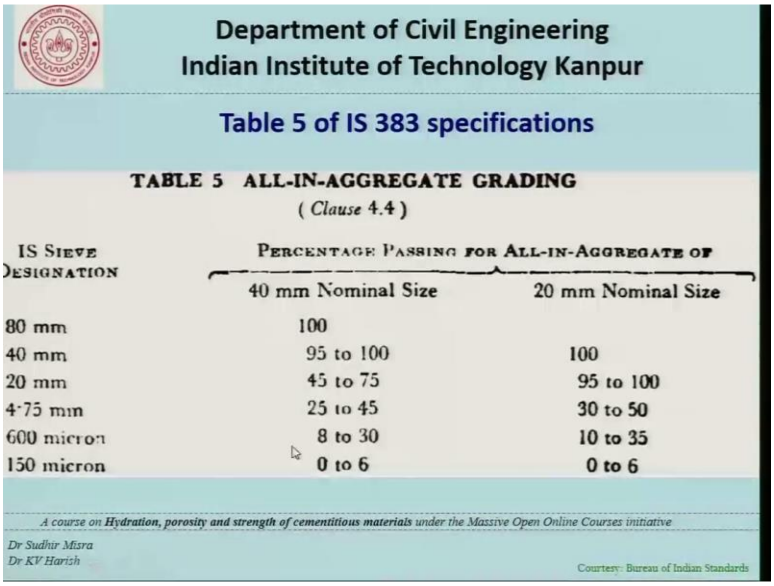

IS Sieve Designation	Percentage Passing for All-in-Aggregate of	
	40 mm Nominal Size	20 mm Nominal Size
80 mm	100	
40 mm	95 to 100	100
20 mm	45 to 75	95 to 100
4·75 mm	25 to 45	30 to 50
600 micron	8 to 30	10 to 35
150 micron	0 to 6	0 to 6

Now, you have the fifth grading which is taken from table 5 of IS 383 specifications all in one grading where the coarse aggregates and fine aggregates are combined. In that case we have again 2 different nominal sizes one is 40 mm and 20 mm which can be used and the highest sieve designation here ranges from 80 to 115 micron remember 80 is the top limit for coarse aggregate and 150 is the bottom limit for fine aggregate. And you have two gradations and one has to make sure that we have a source which contains both coarse and fine aggregates then this gradation has to be very strictly followed.

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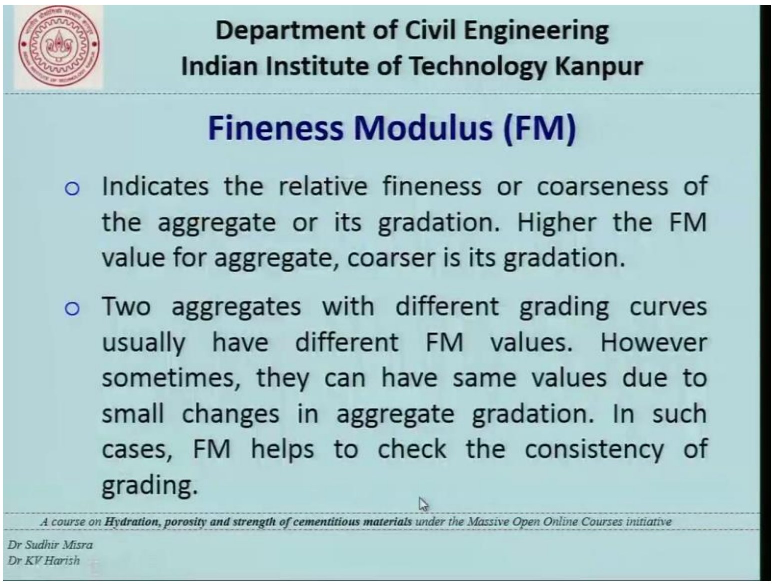

The next property is fineness modulus in this lecture it is indicator has FM fineness modulus indicates the relative fineness or coarseness of the aggregate or it is gradation. Higher the FM value for aggregate coarser is it is gradation two aggregates with different grading curves usually have different fineness modulus values; however, sometimes they can have same values due to small changes in aggregate gradation. In such cases fineness modulus helps to check the consistency of aggregate grading.

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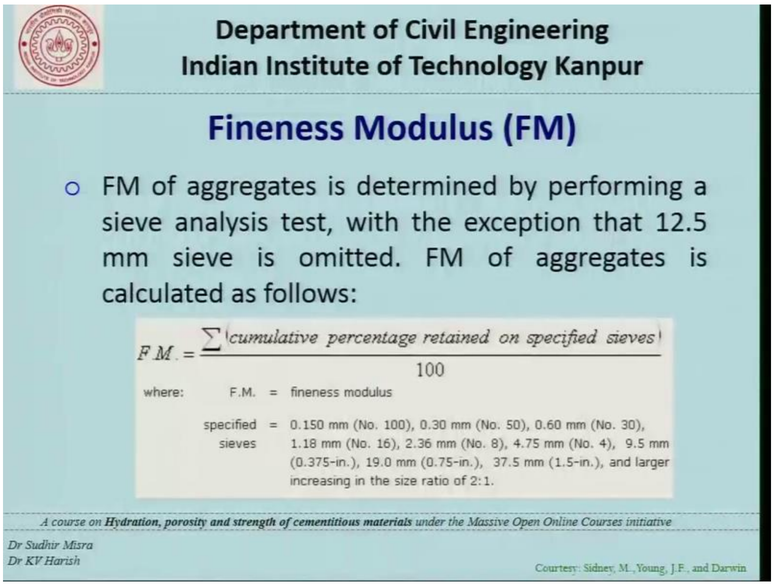

Fineness modulus of aggregates is determined by performing a sieve analysis test with the exception that 12.5 mm sieve is omitted. Fineness modulus of aggregates is calculated by using the following formula. Fineness modulus equal to summation of cumulative percentage retained on specified sieves divided by 100. And the specified word is very important because only certain sieve source specified.

So, here you find the list of specified sieves which ranges from 150 microns or 0.150 mm to about 37.5 mm, but remember that this is only until coarse aggregate maximum size. It can also if you have particle sizes greater than 37.5, then you have to include the source larger than that also, and when I say larger it should be in the size ratio of 2 is to 1.

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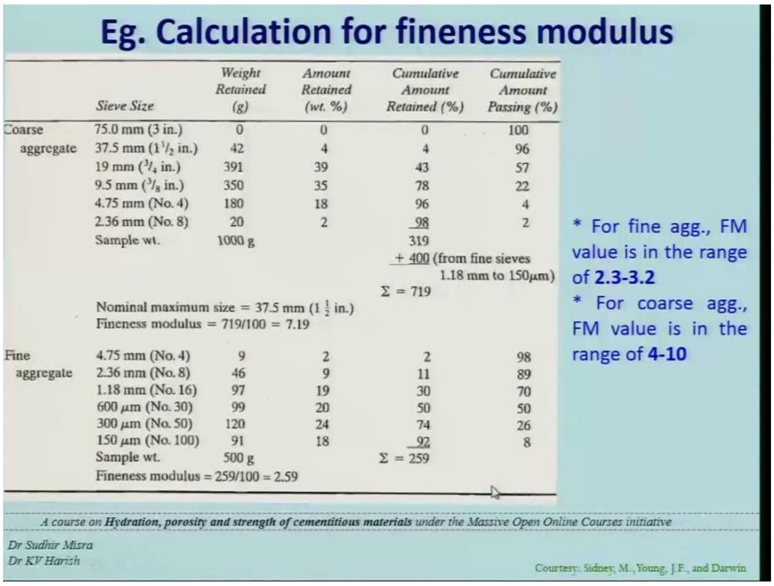

	Sieve Size	Weight Retained (g)	Amount Retained (wt. %)	Cumulative Amount Retained (%)	Cumulative Amount Passing (%)
Coarse aggregate	75.0 mm (3 in.)	0	0	0	100
	37.5 mm (1 1/2 in.)	42	4	4	96
	19 mm (3/4 in.)	391	39	43	57
	9.5 mm (3/8 in.)	350	35	78	22
	4.75 mm (No. 4)	180	18	96	4
	2.36 mm (No. 8)	20	2	98	2
	Sample wt.	1000 g		319	
				+ 400 (from fine sieves 1.18 mm to 150μm)	
				Σ = 719	
	Nominal maximum size = 37.5 mm (1 1/2 in.)				
	Fineness modulus = 719/100 = 7.19				
Fine aggregate	4.75 mm (No. 4)	9	2	2	98
	2.36 mm (No. 8)	46	9	11	89
	1.18 mm (No. 16)	97	19	30	70
	600 μm (No. 30)	99	20	50	50
	300 μm (No. 50)	120	24	74	26
	150 μm (No. 100)	91	18	92	8
	Sample wt.	500 g		Σ = 259	
	Fineness modulus = 259/100 = 2.59				

An example for the calculation of fineness modulus is shown. As you can see that in this example we are taking thousand grams of coarse aggregate and 500 grams of fine aggregates separately. So, a coarse aggregate is we have from 75 mm to 2.36 mm. Fine aggregate we have from 4.75 mm to 150 micron. And the weight retained is calculated by using the sieve analysis. And then you calculate the amount retained by having this as 100 percent. And then you determine the cumulative amount retained in percentage.

So, here 0 directly 0 comes from here. 0 plus 4 you get 4, 0 plus 4 plus 39 you get 43, 0 plus 4 plus 39 plus 30 5 you get 78 and so on. You calculate the cumulative amount retained for each of the sieve and in this example it is calculated until 2.36 and the summation comes to 3.19, but remember that we should also use the cumulative amount retained in all others sieves until 150 microns. So, here in this example they are added only until 2.36.

So, we have to also include 1.18 600 micron 300 micron and 150 and it is obvious that in all these the cumulative retained is 100 and hence 100 into 4 is 400. So, the summation comes to 400 plus 300 and 19 which is 719. Remember that in sieve analysis for plotting the grading curve, we use cumulative amount passing. And in the case of fineness modulus we use cumulative amount retained. The same procedure is followed for fine aggregates also and here you find that the cumulative amount retained or calculated. And all other sieves that are larger than 4.75 the cumulative amount of retained is 0 and hence it can be omitted in that particular case alone.

So, the summation here comes to 259 and as per the formula for fineness modulus 700 and 19 divided by 100 which is 7.19 will be the fineness modulus for coarse aggregate. And 259 divided by 100 is 2.59 which will be the fineness modulus for fine aggregate.

So, from the values of fineness modulus one can find out whether a particular aggregate is fine aggregate of coarse aggregate. For fine aggregate fineness modulus is usually in the range of 2.32 to 3.2 for coarse aggregate the fineness modulus value is in the range of 4 to 10.

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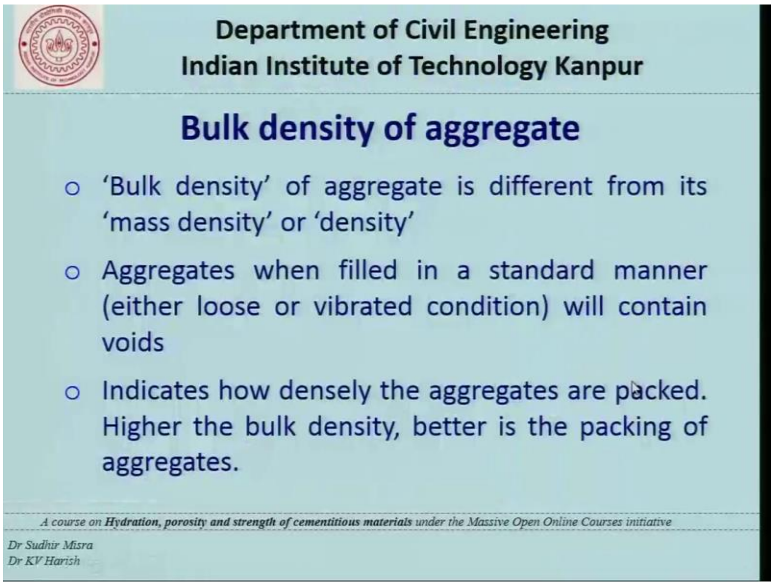

The next step is bulk density of aggregate bulk density of aggregate is different from it is mass density or density aggregates when filled in a standard manner, either loose or vibrated condition will contain voids bulk density of aggregates indicates how density the aggregates are packed higher the bulk density better is the packing of aggregates.

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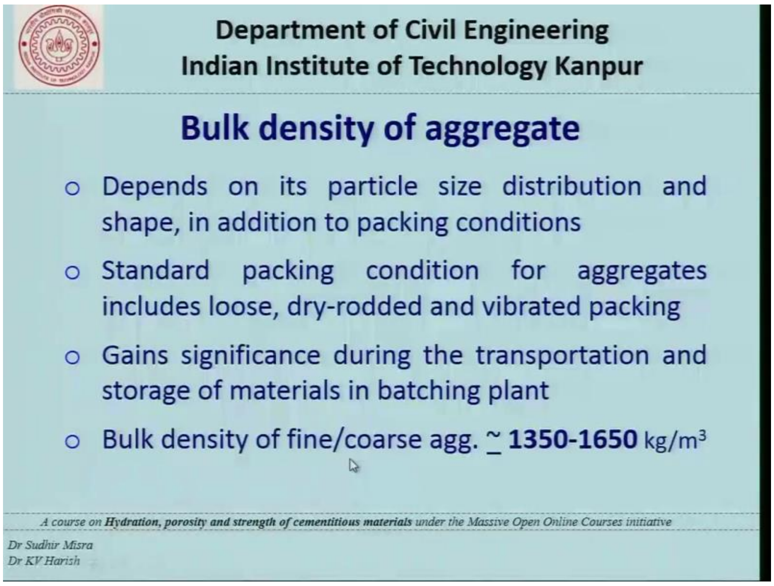

Bulk density of aggregate depends on it is particles size distribution shape in addition to packing conditions. Standard packing conditions for aggregates include loose packing, dry rodded packing and vibrated packing; bulk density of aggregate gains significance during the transportation and storage of materials in batching plant. And usually the bulk density values for fine or coarse aggregate is in the range of 1350 to 1650 kg per meter cube.

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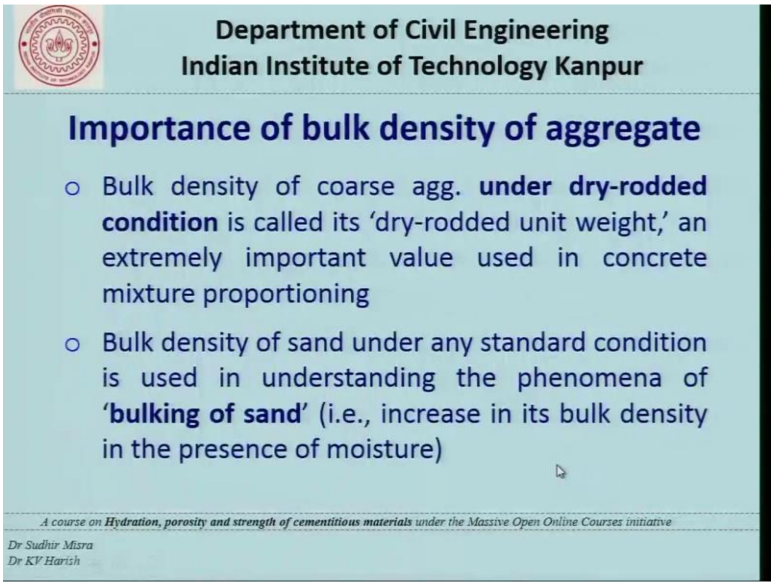

What is the importance of bulk density? Bulk density of coarse aggregate under the dry rodded condition is called it is dry rodded unit weight. It is an extremely important value that we used in concrete mixture proportioning. Bulk density of sand under any standard condition is used in understanding the phenomena of bulking of sand. Bulking of sand is very famous and it is defined as an increase in it is bulk density in the presence of moisture bulking of sand is not very significant factor in concrete for the simple reason that for the amount of water that we add the bulking of sand does not take place for bulking to take place significant moisture or water content is required.

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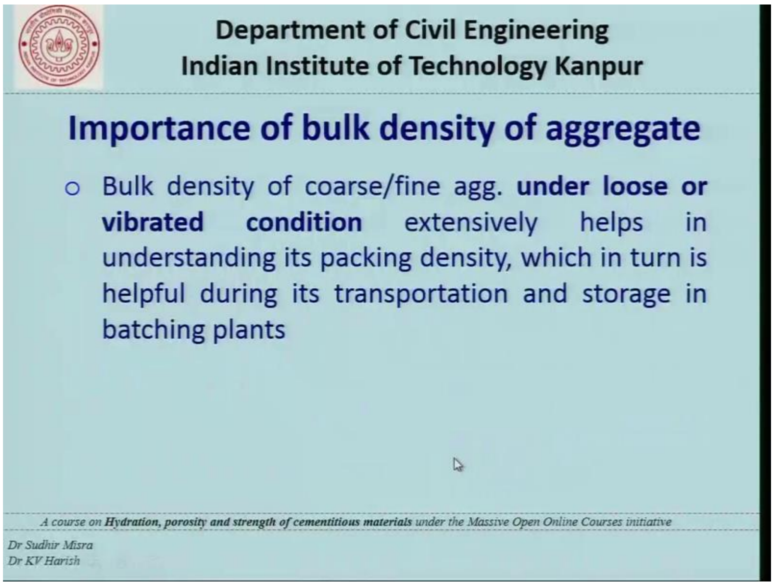

The third importance is that bulk density of coarse of aggregates under in loose or vibrated condition extensively helps in understanding it is packing density which in turn is helpful during it is transportation and storage in batching plants.

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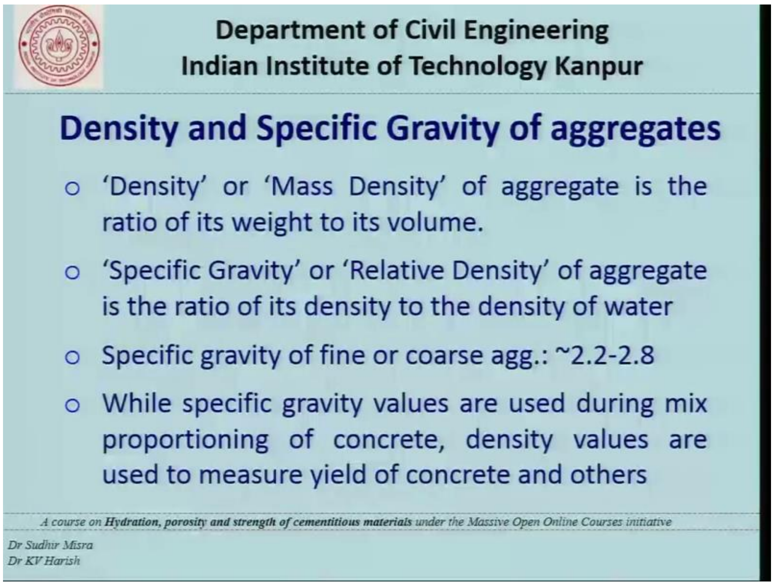

The next is important property is density and specific gravity of aggregates. Density also referred as mass density, is a ratio of it is weight to it is volume. Specific gravity or relative density of aggregate is a ratio of it is density to the density of water. Specific gravity of fine or coarse aggregate is usually in the range of 2.2 to 2.8. While specific gravity values are used during mix proportioning of concrete density values are used to measure yield of concrete and others.

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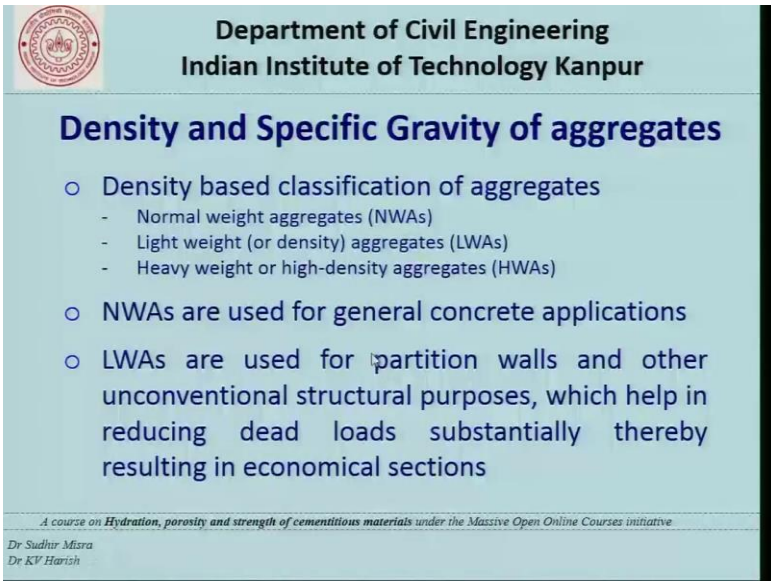

Aggregates may be classified based on density as normal weight aggregates or normal density aggregates indicated as NWA, light weight or light density aggregates indicated as LWA, heavy weight or high density aggregates indicated as HWA. Normal weight aggregates are used for general concrete applications, light weight aggregates are used for partition walls and other unconventional structural purposes which help in reducing dead loads substantially thereby resulting in economical sections.

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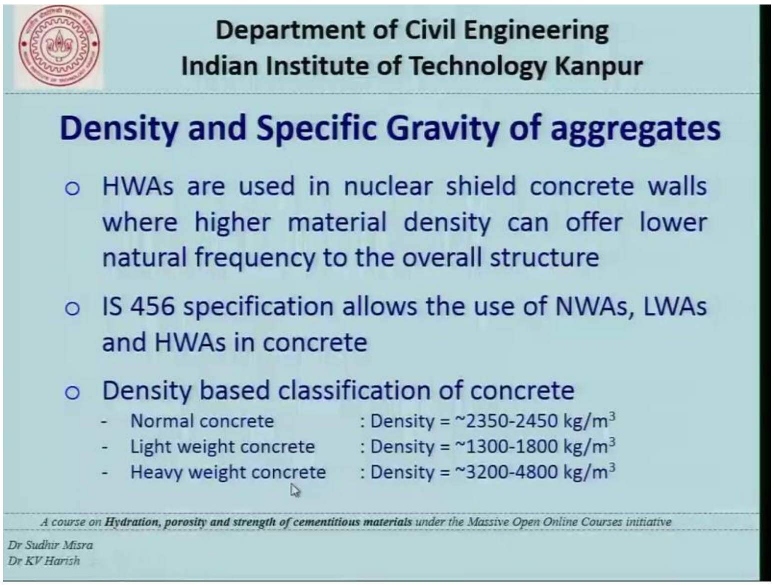

Heavy weight aggregates are used in nuclear shield concrete walls, where higher material density can offer lower natural frequency to the overall structure IS 456 specifications allowing the use of normal weight aggregates light weight aggregates and heavy weight aggregates in concrete. The density based classifications for concrete are as follows; normal concrete density ranges from 2350 to 2450 kg per meter cube or light weight concrete density varies from 1300 to 1800 heavy weight concrete density ranges from 3200 to 4800 kg per meter cube.

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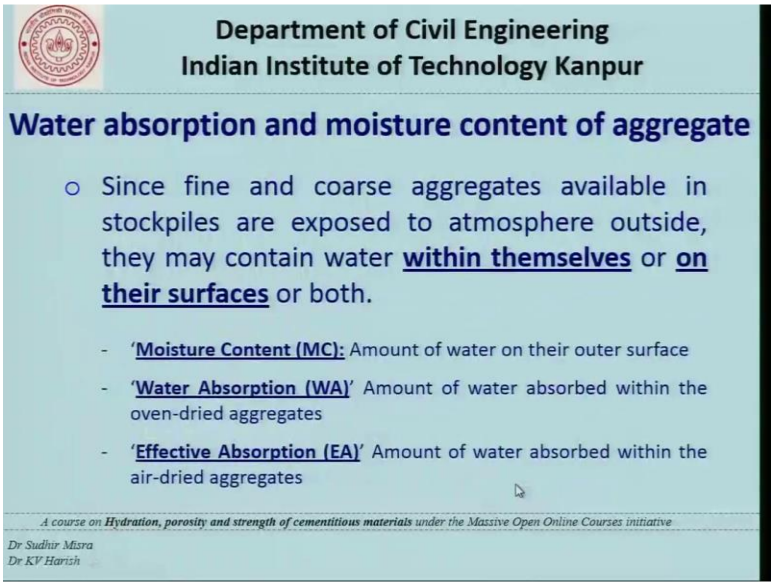

The next important property is water absorption and moisture content of aggregate, since fine and coarse aggregates available in stockpiles are exposed to atmosphere outside, they may contain water within themselves or on their surfaces or both. So, the amount of water that is present on their outer surface is called as moisture content. The amount of water that is the absorbed with in the oven dried aggregates is called as water absorption. The amount of water absorbed within the air dried aggregate is called as effective absorption.

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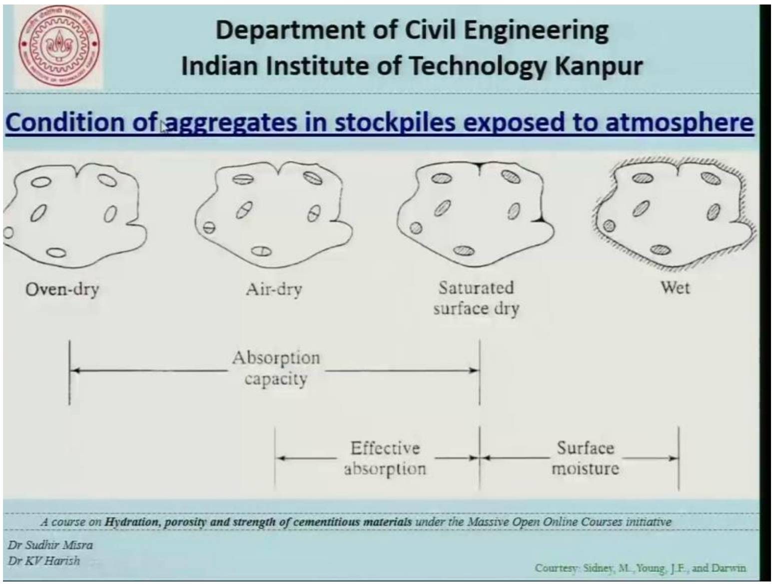

There are four conditions that are possible one is oven dry condition the other one is as air dry condition the other one as saturated surfaced dry condition the other one is wet condition. Oven dry condition aggregates are usually not possible in the open atmosphere as there will be always some amount of moisture, water absorption capacity is defined as the weight of the surface dried aggregate and oven dried aggregate. The surface moisture is defined as weight of the weight aggregate and the saturated surface aggregate. And effective absorption is defined as the percentage weight of the surface dry aggregate and the air dry aggregates.

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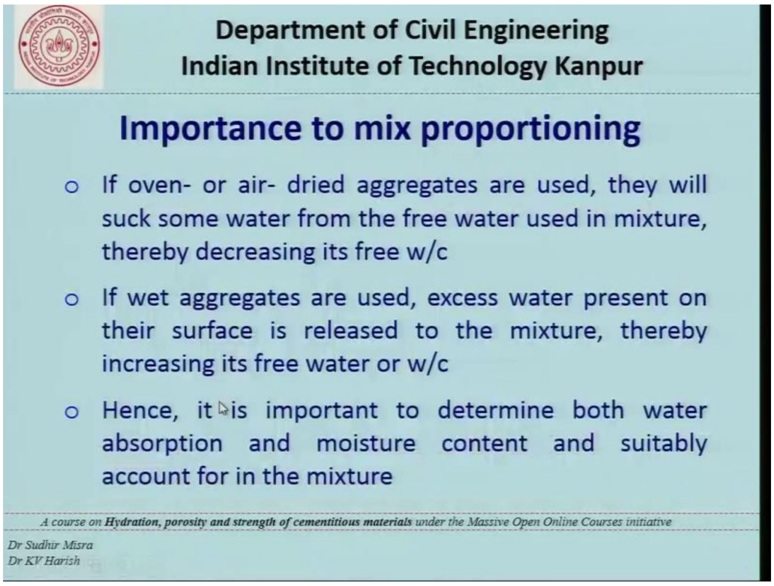

So, these water absorption and moisture content values importance for mixture proportioning if oven or air dried aggregates are used they will suck some water from the free water used in mixture. Thereby decreasing it is free water cement ratio. If wet aggregates were used excess water present in their surfaces is released to the mixture, thereby increasing it is free water or water to cement ratio. Hence it is important to determine both water absorption and moisture content and suitably account for in the mixture.

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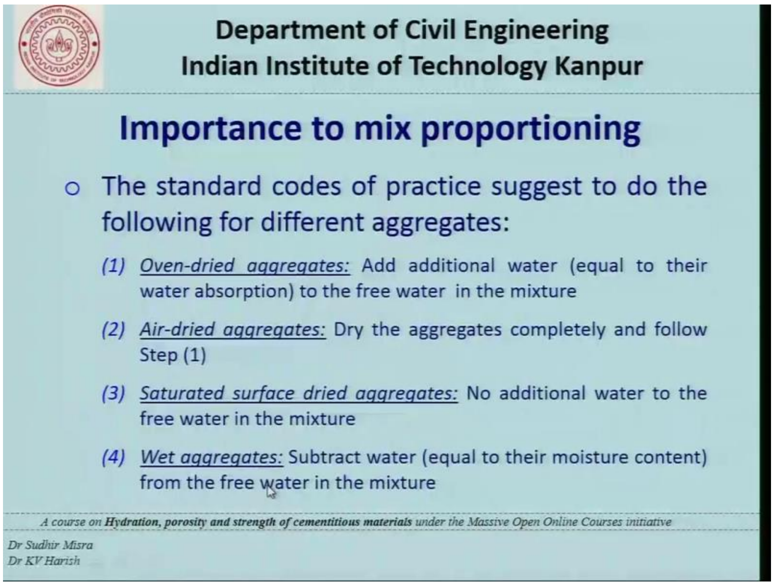

The standard codes of practice suggest to do the following for different aggregates. If you have the over dried aggregate, then add additional water that is equal to their water absorption to the free water in the mixture. If you have a air dried aggregate dry the aggregates completely and follow step one.

In the case of saturated surface dried aggregates no additional water to the free water in the mixture is required for wet aggregates subtract water equal to their moisture content from the free water in the mixture.

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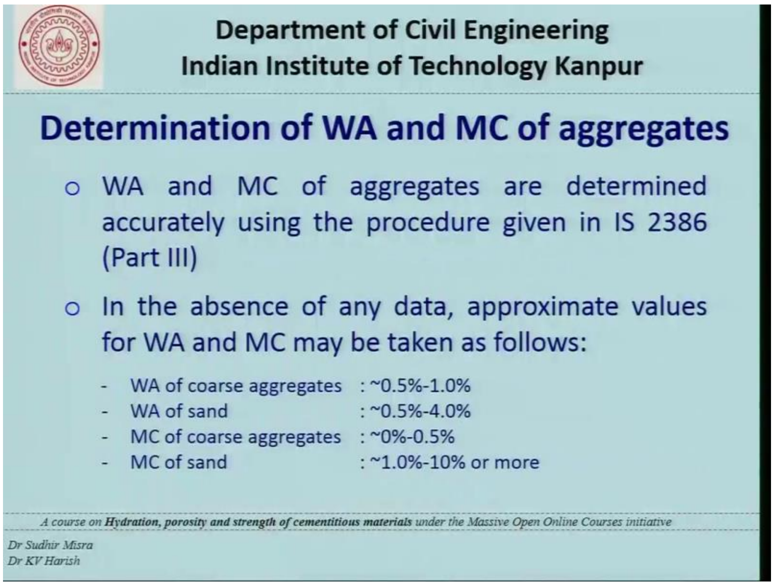

Determination of water absorption and moisture content of aggregates; water absorption and moisture content of aggregates are determined accurately using the procedure given in IS 2386 part 3. In the absence of any data approximate values for water absorption and moisture content can be taken as follows. Water absorption for coarse aggregate can be taken in the range of 0.5 percent to 1 percent. Water absorption of sand can be taken in the range of 0.5 percent to 4 percent moisture content of coarse aggregate can be taken in the range of 0 percent to 0 0.5 percent.

And moisture content of sand can be taken in the range of 1 percent to 10 percent or more with this we come to an end for this lecture.

Thank you.