Advanced Concrete Technology
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Lecture – 05(B)
Cement Classification – Part 2

Good morning everybody, in the last class we were talking about the classification system of cements.

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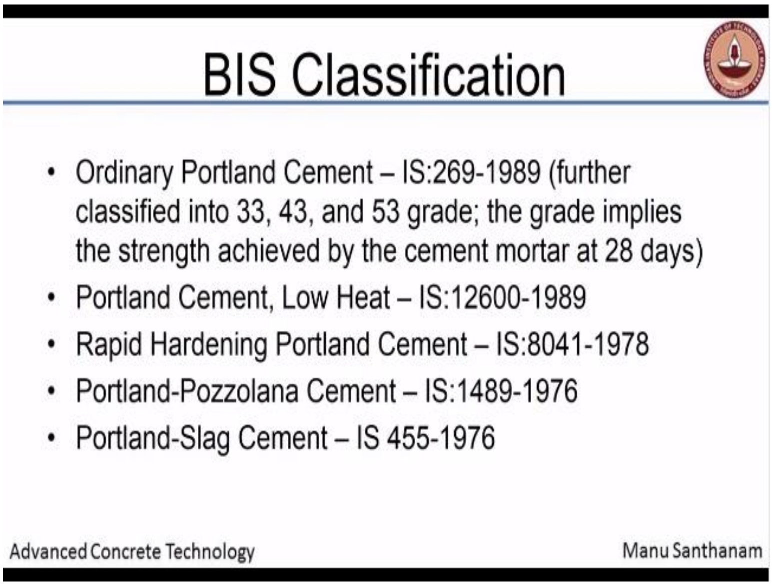

We talked about ASTM classifications, according to which we have 5 different types of cement along with the blended cements that include fly ash and slag or even natural pozzolans and slag. Then we started talking a bit about BIS classifications and we saw that ordinary Portland cement in BIS is classified in IS:269 according to the grade of the cement itself that refers to the strength attained by the cement mortar at 28 days.

What sort of specimens are used? you have done this test before, what sort of specimens are used for determination of cement strength or cement mortar strength? Cube specimens which are measuring 7.07 cm, essentially the cross sectional area comes to 50 square centimeters, okay, 50 square centimeters is the cross sectional area and these are standard IS cubes which are prepared for doing the test.

Now one thing I must tell you that in the future the Indian standards will be getting more in line with the ISO. ISO is basically the International Standards Organization and generally the

ISO gets its inputs from all over the world but obviously there is a Europe heavy representation in the ISO, because of which lot of the ISO standards will be in line with European standards.

So European standards or EN, Euro Norms, we will talk about the cement classification according to that later. Euro Norms has a slightly different way of determining the cement strength. In IS codes the cement strength is determined from a cement mortar which is prepared with a certain water to cement ratio and this water to cement ratio is determined from what? from the normal consistency of the cement, from the normal consistency.

So what happens now is two cements, which are both trying to classify themselves as 53 grade may actually end up having different normal consistencies, right, what is normal consistency? what is the definition of normal consistency? what is the physical meaning of normal consistency?

Essentially it is the minimal water required to wet all the cement particles, and provide a uniform paste, get a uniform paste. So that in some ways actually it is a good thing that we base are water requirement on the normal consistency, but now the problem is in the EN norms, in the Euro Norm tests for determination of cement strength you have a fixed water to cement ratio.

So in the past what happened was 2 cements which want to be classified as 53 grade both could have actually different water contents to prepare the same mix, to prepare the same mortar mix, but now with the Euro Norm all cements will have to be tested with the same water to cement ratio. Now there are benefits, there are disadvantages to this approach. What are the benefits? What are the benefits of adopting a constant water to cement ratio approach?

There has been normal consistency test wont conducted properly. Okay you are talking about if people commit errors in the normal consistency, that is a different aspect altogether but what about the constant water to cement ratio, what is that equivalent to, I mean we assume that the strength of a concrete depends primarily on the water to cement ratio, so if you are testing 2 cements at exactly the same water to cement ratio, then you are obviously paying respect to that in it right.

You say that strength is basically dependent on water to cement ratio, I am going to have constant water/cement ratio across the different cements that I am testing. So that lend some credibility to the result. Unfortunately given the way that our cements have been produced over the past few years and the fact that there are vast differences between different brands of cement.

That leads to different normal consistencies with the cement. What are the typical normal consistency value that you determine in the laboratory? About 30%, yeah, about close to 30% +/- 1 or 2. Now even if there is a difference of let us say 2 units like one cement is at 28% consistency, the other has a 30% consistency and if you adopt a constant water to cement ratio, according to EN you should adopt a 0.5 water to cement ratio.

So 0.5 means you have 0.22 water/cement ratio above the normal consistency in the case of the first cement, the second cement you have 0.2 above, that means you have different amounts of excess water present in the system and that may lead to completely different characteristics with respect to strength.

So there are pluses and minuses of doing things one way or the other, the aspect that we need to worry about generally is that in concretes since we know that the strength depends particularly on the water to cement ratio, of course it depends on many other factors, but primarily on the water to cement ratio, it is a good thing to do the cement test also at a constant water to cement ratio.

So the Euro codes or the Euro Norms have a constant water to cement ratio test and that will be reflected in the ISO and probably in the future be adopted by the Indian standards also. Right now there is a large amount of testing going on by the cement companies to locate what might be the possible pluses and minuses of adopting this approach.

Now of course based on that your cement classifications also may change, right. Cement classifications also may change based on adoption of 0.5 water/cement ratio, because then you are not going to be getting the strengths of 43 and 53 any longer. You may get actually lower strengths. So in truth when you compare Indian 53 grade cements with the European cements it actually corresponds only to the 43 grade European cements because of this difference in the testing stand.

I will talk about European classifications in just a minute but essentially, there is going to be a difference in the cement grading depending upon the country in which you do the test. So it is a very complicated world, cement testing, because of which adopting one cement to another country standards may sometimes be very difficult.

That is why people are trying to come together and bring all the standards under single umbrella that is the ISO, International Standards Organization. Now whether those will be helping our cement producers or not we do not know, it is a long way off because it is yet to be adopted, it will take some time before that actually happens.

Now of course the other cements that are present as per the BIS classification are similar to what is there in other standards you have the Portland cement low heat, you have the rapid hardening Portland cement, Portland-pozzolana cement and Portland-slag cement. If you look at Portland-pozzolana cement standard, in the past the pozzolanic material that was used in PPC was calcined clay.

Okay they allowed clay to be calcined, what happens when you calcine the clay or burn the clay? Not CO_2, clay does not have carbonates, clay has aluminosilicates which are basically present in layers and some clays have water between the layers. So then you heat up to a certain temperature the water in between the layers gets removed and the layers get activated.

This is exactly what happens inside the cement kiln also, the temperature at which that happens is nearly 7-900 degrees Celsius. At that level you produce calcined clay and in the past the PPC used to allow up to 25% replacement of cement clinker by calcined clay to produce PPC. Now what happened was the lack of strict control norms on the quality of the clay let to all kinds of things we put inside the cement.

Because of which the confidence of people in PPC ran out, so IS then started clamming down heavily on the requirements of the PPC and people were no longer able to suitably produce PPC with calcined clay. Then of course the whole awareness with fly ash started in India and people started producing PPC with fly ash, and today almost all PPC in India probably all not almost all, all PPC in India is produced with fly ash as a pozzolanic material.

And fly ash can be permitted up to about 35% of the cement clinker, but in most cements I would say fly ash content is between 25 and 30%. Okay you permit about 25-30% of fly ash to be used as the replacement of cement clinker. Now Portland slag cement again is similar to what we saw earlier with the ASTM type 1S. So here we have 25-70% slag permitted as the replacement for the cement clinker.

Now again please when I say slag it means only one slag, and that is ground granulated blast furnace slag or GGBFS. There are several types of slags available depending upon the industry that you talk about, but what we are concerned with in terms of cementitious reactivity is only obtained from ground granulated blast furnace slag and this is what is permitted by the IS codes up to 25-70% replacement.

Again you permit larger levels of replacement because slag has cementitious properties, slag is actually a hydraulic cement. It can set and harden on its own with water but that takes a long time so we need some activation and this activation is provided by the cement which is added along with the slag so combination of cement and slag work very well.

Now let us move on to the European classification because these are now getting adopted in several countries. In fact, several other countries, which had in the past adopted the ASTM norms, have started shifting towards the EN, because of the kind of flexibilities and kind of combination that it actually gives you. To the civil engineer the Euro Norms can be a lot confusing because there are all kinds of permutations and combinations that are possible.

And I will try to pass on some of that confusion to you, okay. So you have 5 different types of cements, CEM I to CEM V.

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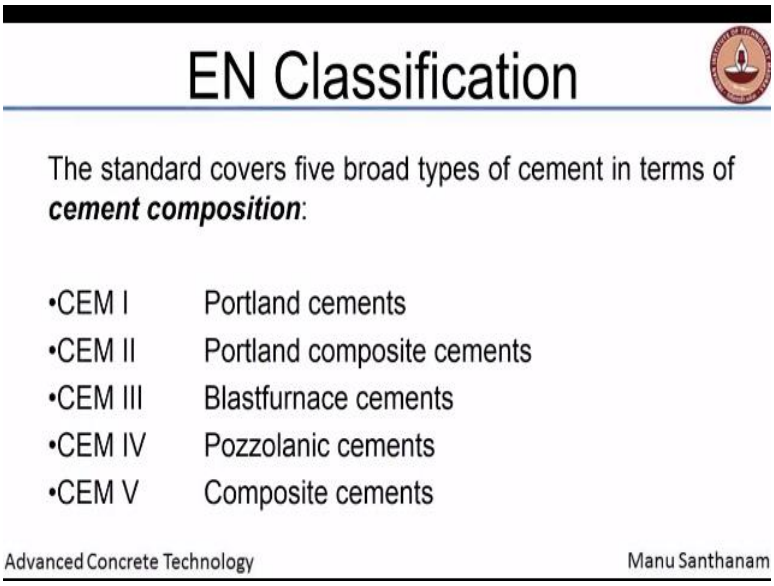

CEM I is basically your Portland cement or ordinary Portland cement as we call it. CEM II is the Portland composite cement that means we are allowed some level of replacement of the cement by certain mineral additives. CEM III is blast furnace cements. So here you have a category entirely for blast furnace slag replaced cements, and depending upon how much you replace you further classify the CEM III into A, B and C.

I will talk about that in a minute. CEM IV is pozzolanic cements, that means there are specific replacements of cement by pozzolanic materials and CEM V is composite cements. Now CEM II and CEM V, the difference essentially is CEM II has lesser amount of the mineral additives, CEM V has larger amount of mineral additives, that is why one is called Portland composite cement and the other simply called composite cement so that is the difference.

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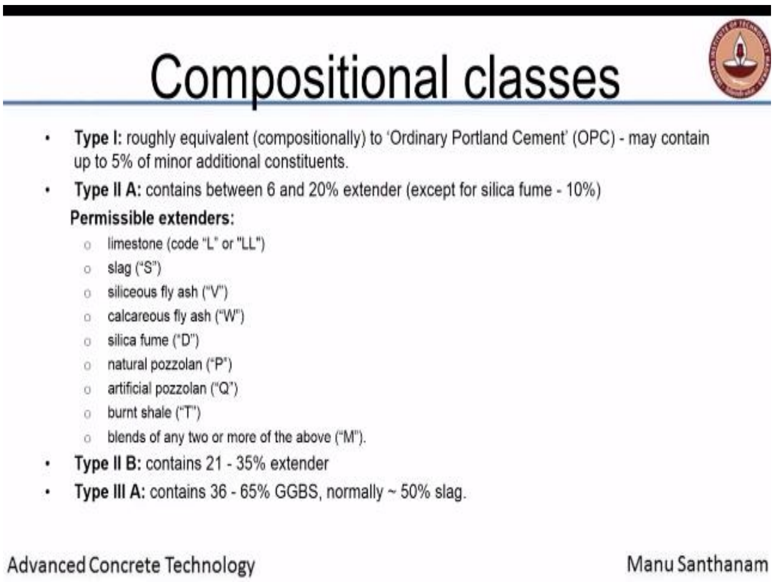

So there are compositional classes given under each cement. So type I or CEM I is roughly equivalent to ordinary Portland cement like we have in the Indian standards OPC and may contain up to 5% of minor additional constituents. In IS codes we call that performance improvers as I told you before we commonly add limestone or fly ash as performance improvers, up to 5% can be added.

That is the same in CEM I also, okay. Type IIA, type II is further classified into A and B. Type IIA contains between 6 and 20% of the mineral additives, except when you are using silica fume. So please remember silica fume is also a very highly reactive pozzolanic material, it has got large amount of reactive silica and it is very fine because of which it produces pozzolanicity very fast.

But the problem is when you are using a very fine material as a cement replacement what do you expect will happen to the cement? Basically the water demand will be significantly higher. So to avoid issues with the cement itself what we do is we allow only about 10% replacement of cement by silica. In all the other cases, all the other mineral additives I will show you the table in just a minute.

The other mineral additives can be added between 6 and 20%, and they call it extenders. Now extender is the common term adapted for either supplementary cementing materials or fillers, you can even add fillers, to that extent. For example, some fillers like quartz powder, or limestone powder and so on can be added up to 20% in this case. So possible extenders here are listed.

You have limestone, if you have limestone, it is given the name as type II A-L, if you have slag it is called type II A-S, and if you have natural pozzolan it is called type II A-P, just indicating what is the possible replacement that is present in the cement. So you can see all kinds of combinations are possible because you have this final category of the blends of any 2 or more of the above.

So you can actually have more than 2 also. You can have a multi blend cement produced under the Portland composite cement standard. So it gives a lot of flexibility depending upon what you want in a particular situation. Of course, it might also give lot of headaches to the cement manufactures to make sure that they are segregating and packaging the bags and cement properly to ensure that this goes to the right job.

Otherwise it can lead to a lot of confusion. Type II B is when you have greater amount of extender 21 to 35%, the extenders being the same as what is listed here, all the permissible extenders you can use up to 21-35%. Type III is what contains more than 35%, but it is only with replacement of blast furnace slag, because type 3 or CEM III are blast furnace cements so type III or CEM III cements will contain only slag as a replacement material and the content of replacement will be more than 35%.

So 36-65% is type III A, the normal thing is 50% slag, even in Indian standards like I showed in the previous slide here although we allow 25-70% slag replacement the typical is about 50%. With fly ash and PPC 25-30% is typical and in slag cements 50% is the typical number that you choose for the slag content.

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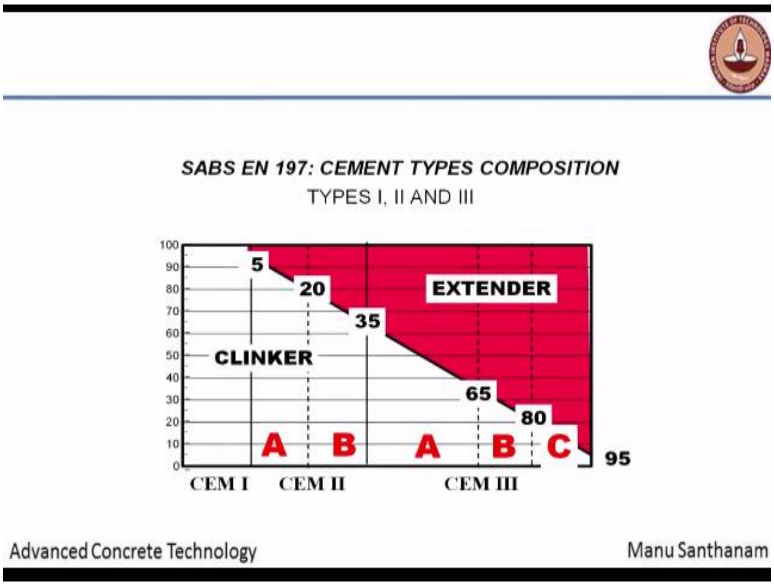

So let us look at the type of cements and extenders, now of course this is not directly from the Euro Norms. The Euro Norm is EN 197 so this is actually the adopted version of the Euro Norms for the South African standards, SABS is the South African standards, of course this was in the past now it is I think called SANS if I am not mistaken, it is called SANS, South African National Standards.

So what South Africa did like many other countries and soon Singapore is to follow suit that they adopted the Euro Norms in-Toto. That means they just adapted that to their own specifications and they have been using the Euro Norms to define the cement composition types. So if you look at this the CEM I, CEM II and CEM III, can be seen with the kind of additives that you have.

So if you have clinker on one side and the extender on the other side, if the content of the extender is less than 5 % then it is called CEM I, if it is between 6 and 35% it is called CEM II and 36 to even 95% is CEM III, so here CEM III you have type A which is containing up to 65% of slag, type B up to 80% and type C up to 95%, that means there are only 5% clinker there, you have only 5% clinker.

So that in India we sometimes use that as a super sulphated cement, that is a special cement which is not produced anymore, but it used to be based on essentially 80% slag, 5% clinker and 10-15% what? What do we need for super sulphated? obviously we need gypsum, so that was super sulphated cement, but essentially it was a slag cement which had very high contents of slag, 80-85%. So types I, II and III can be look at based on these extender compositions.

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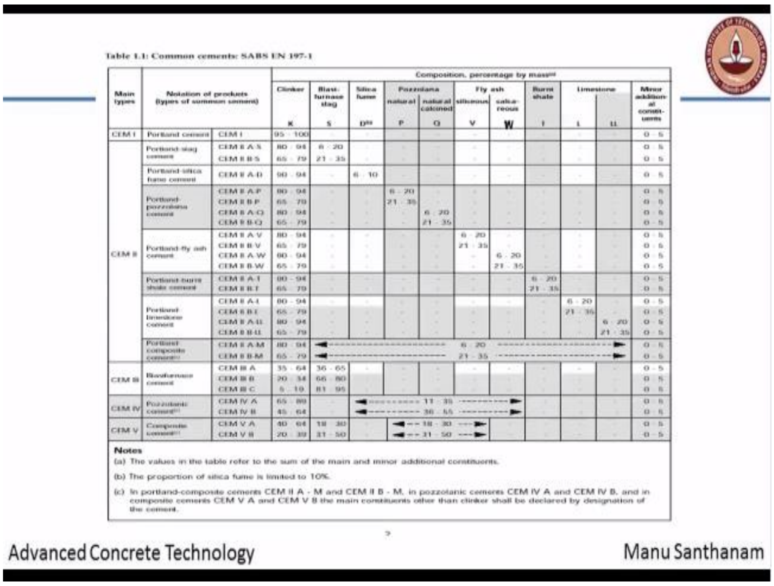
Table 1.1: Common cements: SABS EN 197-1

Main types	Notation of products (types of common cement)		Clinker K	Blast-furnace slag S	Silica fume D[b]	Pozzolana natural P	Pozzolana natural calcined Q	Fly ash siliceous V	Fly ash calcareous W	Burnt shale T	Limestone L	Limestone LL	Minor additional constituents
CEM I	Portland cement	CEM I	95 - 100	-	-	-	-	-	-	-	-	-	0 - 5
CEM II	Portland-slag cement	CEM II A-S	80 - 94	6 - 20	-	-	-	-	-	-	-	-	0 - 5
		CEM II B-S	65 - 79	21 - 35	-	-	-	-	-	-	-	-	0 - 5
	Portland-silica fume cement	CEM II A-D	90 - 94	-	6 - 10	-	-	-	-	-	-	-	0 - 5
	Portland-pozzolana cement	CEM II A-P	80 - 94	-	-	6 - 20	-	-	-	-	-	-	0 - 5
		CEM II B-P	65 - 79	-	-	21 - 35	-	-	-	-	-	-	0 - 5
		CEM II A-Q	80 - 94	-	-	-	6 - 20	-	-	-	-	-	0 - 5
		CEM II B-Q	65 - 79	-	-	-	21 - 35	-	-	-	-	-	0 - 5
	Portland-fly ash cement	CEM II A-V	80 - 94	-	-	-	-	6 - 20	-	-	-	-	0 - 5
		CEM II B-V	65 - 79	-	-	-	-	21 - 35	-	-	-	-	0 - 5
		CEM II A-W	80 - 94	-	-	-	-	-	6 - 20	-	-	-	0 - 5
		CEM II B-W	65 - 79	-	-	-	-	-	21 - 35	-	-	-	0 - 5
	Portland-burnt shale cement	CEM II A-T	80 - 94	-	-	-	-	-	-	6 - 20	-	-	0 - 5
		CEM II B-T	65 - 79	-	-	-	-	-	-	21 - 35	-	-	0 - 5
	Portland limestone cement	CEM II A-L	80 - 94	-	-	-	-	-	-	-	6 - 20	-	0 - 5
		CEM II B-L	65 - 79	-	-	-	-	-	-	-	21 - 35	-	0 - 5
		CEM II A-LL	80 - 94	-	-	-	-	-	-	-	-	6 - 20	0 - 5
		CEM II B-LL	65 - 79	-	-	-	-	-	-	-	-	21 - 35	0 - 5
	Portland composite cement[c]	CEM II A-M	80 - 94	◄---- 6 - 20 ----►									0 - 5
		CEM II B-M	65 - 79	◄---- 21 - 35 ----►									0 - 5
CEM III	Blastfurnace cement	CEM III A	35 - 64	36 - 65	-	-	-	-	-	-	-	-	0 - 5
		CEM III B	20 - 34	66 - 80	-	-	-	-	-	-	-	-	0 - 5
		CEM III C	5 - 19	81 - 95	-	-	-	-	-	-	-	-	0 - 5
CEM IV	Pozzolanic cement[c]	CEM IV A	65 - 89	-	◄---- 11 - 35 ----►					-	-	-	0 - 5
		CEM IV B	45 - 64	-	◄---- 36 - 55 ----►					-	-	-	0 - 5
CEM V	Composite cement[c]	CEM V A	40 - 64	18 - 30	-	◄-- 18 - 30 --►			-	-	-	-	0 - 5
		CEM V B	20 - 39	31 - 50	-	◄-- 31 - 50 --►			-	-	-	-	0 - 5

Notes

(a) The values in the table refer to the sum of the main and minor additional constituents.

(b) The proportion of silica fume is limited to 10%.

(c) In portland-composite cements CEM II A - M and CEM II B - M, in pozzolanic cements CEM IV A and CEM IV B, and in composite cements CEM V A and CEM V B the main constituents other than clinker shall be declared by designation of the cement.

So for the other type that is type IV and V, you need to then refer to this table. Now this table can be very confusing to the average engineer so you really need to understand this table well to interpret what your cement type is actually. So if you look at this on the top it presents the composition in terms of percentage by mass.

And it gives you clinker, blast furnace slag, silica fume, natural pozzolans or natural calcined pozzolans which will include what natural calcine applying calcined clay, natural calcine means calcined clay. Then you have siliceous fly ash or type F fly ash, calcareous fly ash or type C fly ash, you can also use burnt shale, which is a good pozzolanic material, you have limestone.

And you have again I think LL probably refers to Portland limestone cement which has higher degrees of replacement. You can see that this classification can confuse everybody so and then of course you have minor additional constituents, which are 0-5% in all the cases. So if you look at CEM I obviously you have 95-100% clinker, up to 5% is natural constituents, additional constituents, that is 5% of performance improver.

Now all this is cement minus gypsum, please remember that there is always gypsum that you need to add in the cement to control the setting and hardening process. Without gypsum you cannot have a cement. So in all these cases there will be gypsum added but these are only the cement minus the gypsum. Then you have Portland slag cement, Portland silica flume cement, Portland pozzolan cement, fly ash cement, burnt shale cement, limestone cement and composite cement.

Now the idea about composite cement here means that you can have a mixture of one or more of the mineral additives that are listed here, but then if it is type II A, that means the amount of the mineral additives together should be between 6 and 20%, if it is type II B, it can be 21-35%, so the idea is now you already have a chance of producing a cement that is ternary blended.

If you look at durability, one of the components that leads to very high durability in cementitious materials is the use of blends, multi blended components of cement. The idea is that it gives you a particle packing between the cement constituents which leads to efficient filling up for the pore spaces and that can only be possible with multiple blended cements.

So you already have a chance of producing cement which has a combination of cement, fly ash and silica fume or cement, slag and silica fume. So they can start filling up pore spaces which are very small and you will see later when you talk about high performance concrete that the best way to get very high durability and strength in concrete at fairly controlled cement contents is to ensure that you have ternary blended systems inside.

So here there is a possibility of even producing a cement of that type. Type III or CEM III is blast furnace cement which has III A, B and C depending upon the extent of replacement of cement by slag. Then you have pozzolanic cement again there is no slag there. In the pozzolanic cement you are not allowed any slag obviously because slag is not a pozzolan, it is a hydraulic cement on it is own.

So here you are allowed these pozzolans, you see what are allowed, silica fume, you are allowed natural pozzolan, natural calcined pozzolan, type F fly ash and type C fly ash. You are not allowed burnt shale, you are not allowed limestone, because all those are going to be more acting as fillers, when you have limestone it is more of a filler. Fly ash is okay because it has got sufficient pozzolanicity.

So we do not consider it separate from a pozzolan, we consider it to be pozzolanic and cementitious. Then finally you have type V composite cement A and B where you can see the quantities of the extenders allowed are slightly higher but again these are with respect to only certain types of fillers. You have either the natural or calcine pozzolans or you have siliceous fly ash.

It is a little bit of a tricky category, this type V composite cement is a slightly tricky category because it allows you larger levels of replacement, but you can have slag in combination typically with either a natural pozzolan, natural calcined pozzolan or siliceous pozzolan. So composite cement CEM V = clinker + slag + either of P, Q or V.

You have a combination of slag as a replacement material with either natural pozzolan, natural calcined pozzolan or type F fly ash. Now if you look carefully in the Indian standards also there is a new standard for composite cements. I am sorry I do not have the number right now with me, but if you look up the Indian standards you will also find, you have a standard for composite cements where they allow you to have a ternary blended system with cement, type F fly ash and slag.

That is the composite cement standard as per the Indian specifications and you will probably be able to see it if you browse through the Indian standards, it is a recently released standards, it is not yet been floated in the market, although there are several companies that are ready to manufacture it. Now why would you produce a blend of fly ash and slag as a cement replacement?

And here this will allow up to 40 to I think even 50% replacement of the cement, just look up the standard to get the clear idea about this, it will allow upto 40-50% replacement of the cement clinker with combination of fly ash and slag, okay. Why do you think we want to use fly ash and slag together? In what environments we want to use this kind of a material? I am sure you know a little bit about fly ash and slag.

What do they contribute to? Long term strength gain, yes, but more than that they contribute to the resistance to sulphate attack in some cases they contribute to long term durability, especially in certain environments, certain types of sulphates and primarily in the chloride environment you will get very good durability with slag fly ash combination, of course you can get very good durability with just slag also.

But for chloride induced corrosion slag fly ash combinations can also give you excellent durability. Now again the idea is that you can produce now a composite and tailor-make it to suit the needs for a given situation. The only problem is these kinds of blends are highly susceptible to carbonation. We will talk later about carbonation in the durability chapter.

But these blends are highly susceptible to carbonation because of which there are several companies that are still vary of putting it out into the market, okay, so the standard is ready, cements are already, people are already geared up to prepare these cements, but not yet been commercially utilized. So as if the previous table was not detailed enough the Euro Norms also tells you to classify in strength classes.

They have different strength requirements once again like India 33, 43 and 53. Here they have 32.5, 42.5 and 52.5.

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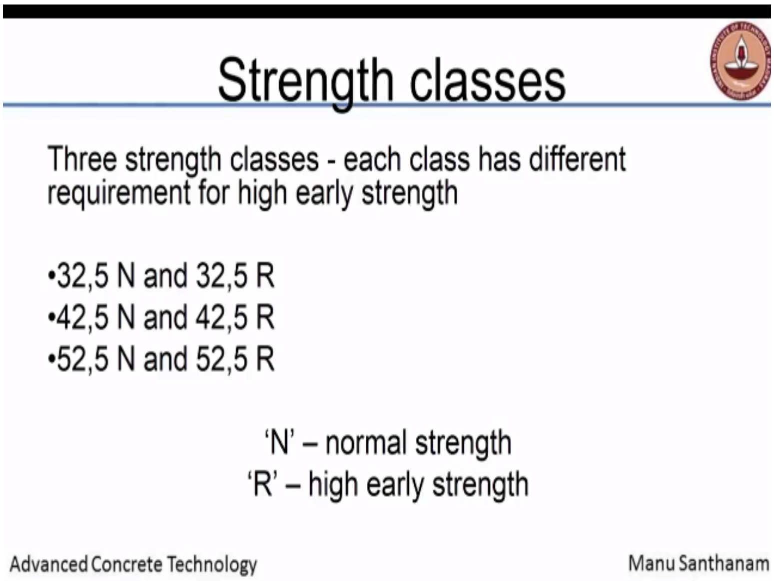

And they further have 2 subdivisions of the strength classes one is called N or normal strength, and R or high early strength, so obviously the requirements for these cements will be different in terms of whether they are normal strength or high early strength. So let us look at how these requirements are.

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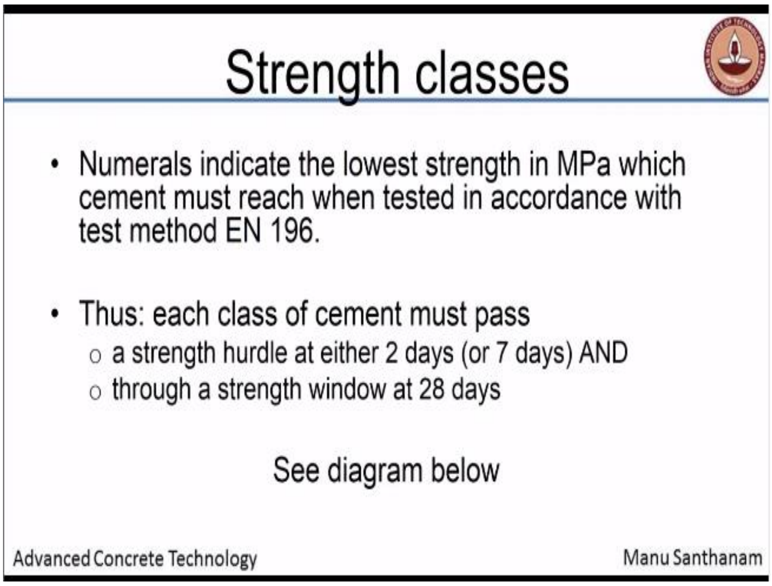

So numerals which are 32.5, 42.5 and 52.5 indicate the lowest strength in megapascals which cement must reach when tested in accordance with the test method EN 196, it is the lowest strength. It is not the characteristic strength, it is the lowest strength, in IS we call it the characteristic strength. Each class of cement must pass a strength hurdle of either 2 days or 7 days that is the early strength hurdle is 2 or 7 days.

And then there should be a window of strengths that you get from the cement blend at 28 days. So I will show you the diagram here which talks about this.

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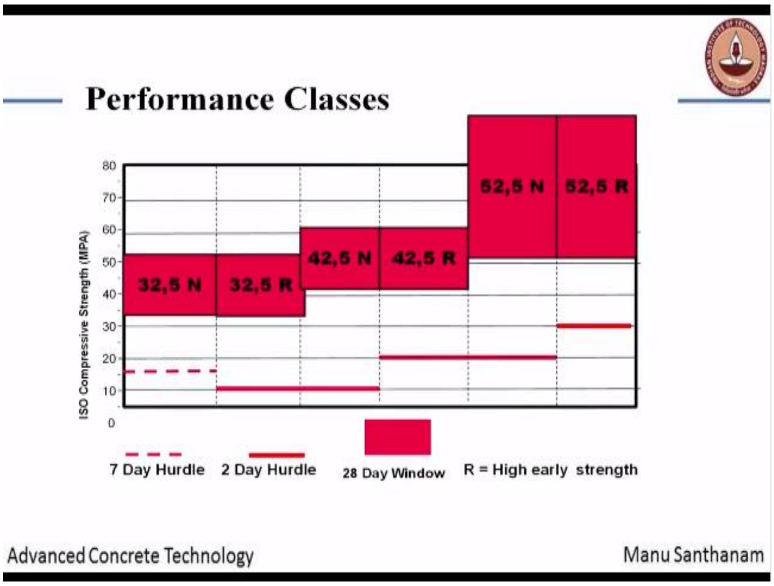

For example, with 32.5 N, okay, you have a 7-day hurdle to cross that is 16 megapascals at 7 days, but at 28 days you should have a strength between 32.5 and 52.5. At the same time when you have a rapid hardening cement of the same type 32.5 R it does not have a 7-day hurdle any more, it has a 2-day strength limitation, it has a 2-day limitation of 10 megapascals.

So it needs to cross 10 megapascals at 2 days and then it should also satisfy the 28-day regulation of 32.5 to 52.5, that range. Now one interesting part here is obviously that they have given an upper limit to what your cement can actually have. Now here in the 42.5 N, the 7-day hurdle is only in the case of 32.5 N. In 42.5 and 52.5 you only have a 2-day strength requirement.

When you have 42.5 N, the 2-day strength should be at least 10 megapascals and with R the 2-day strength should be at least 20 megapascals. Similarly, with 52.5 N, the 2-day strength must be at least 20 and the 52.5 R the 2-day strength must be at least 30 megapascals. The 7-day hurdle is given in terms of the dotted line. The 2-day hurdle is the solid line. So you can see that.

In some cases, you have the 7-day hurdle, in some cases you have the 2-day hurdle, and look at the strength requirement here, for 42.5, it is 42.5 up to 62.5. For 52.5 cement the minimum is 52.5, the maximum is all the way up to 92.5. So you have a very wide range of performances possible for a 52.5 grade cement and indeed when you actually take European cement that is 52.5 you will see that it has a very high fineness.

The fineness is typically close to the order of 400 square meters per kilogram, very high fineness. What is the fineness of typical Indian cements? about 300 square meters per kilogram, specific gravity is not all that different, both cements will have 3.15 or near about 3.15 as the specific gravity, but the fineness of the cement which is produced in Europe is typically much greater than what we produce in India.

Because again they have to meet this extremely high strength requirement with the 0.5 water/cement ratio, mind you, they need to meet this requirement with the 0.5 water/cement ratio, whereas the equivalent test that is conducted in India may actually end up having a water/cement ratio of 0.4 or 0.42 or something like that depending upon the consistency being 28-30% like that, okay.

So there is a vast difference in the strength attained by the Indian cement and what is possible by the European cements. So if you have to align your codes with ISO then the cement company should start rethinking the process by which they produce their cement and probably look at grading of the cement carefully once again.

So these are the strength classes or strength performance classes and in terms of a table the same data which is presented here in the graph is presented in the form of a table so there is nothing specific about this.

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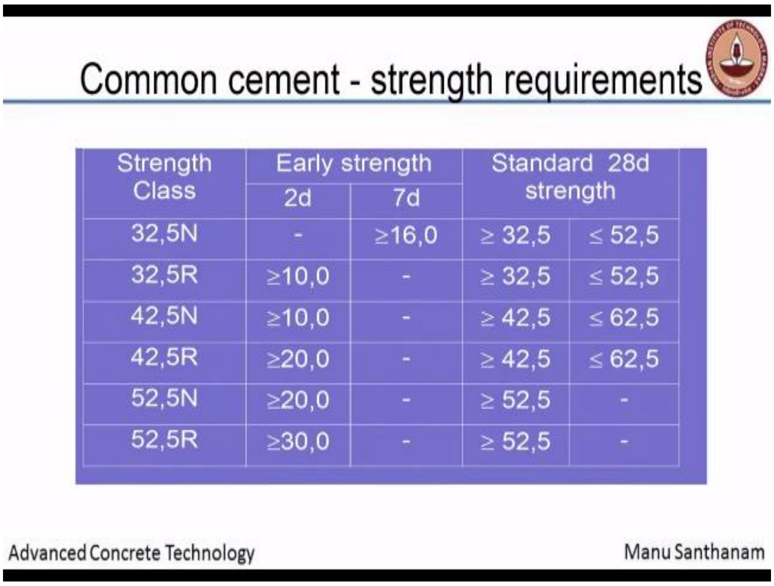

Strength Class	Early strength		Standard 28d strength	
	2d	7d		
32,5N	-	≥16,0	≥ 32,5	≤ 52,5
32,5R	≥10,0	-	≥ 32,5	≤ 52,5
42,5N	≥10,0	-	≥ 42,5	≤ 62,5
42,5R	≥20,0	-	≥ 42,5	≤ 62,5
52,5N	≥20,0	-	≥ 52,5	-
52,5R	≥30,0	-	≥ 52,5	-

In fact, actually if you look at the 28-day strength you do not seem to have any higher limits prescribed for the 52.5, although technically cement companies will not produce anything stronger than 90 megapascals because then they start grinding too fine or changing the C_3S content so much that it becomes unviable. Your cement becomes very uneconomical to produce at that level.

So just to give you examples of different strength, different types of Euro cements, you can have type I cements.

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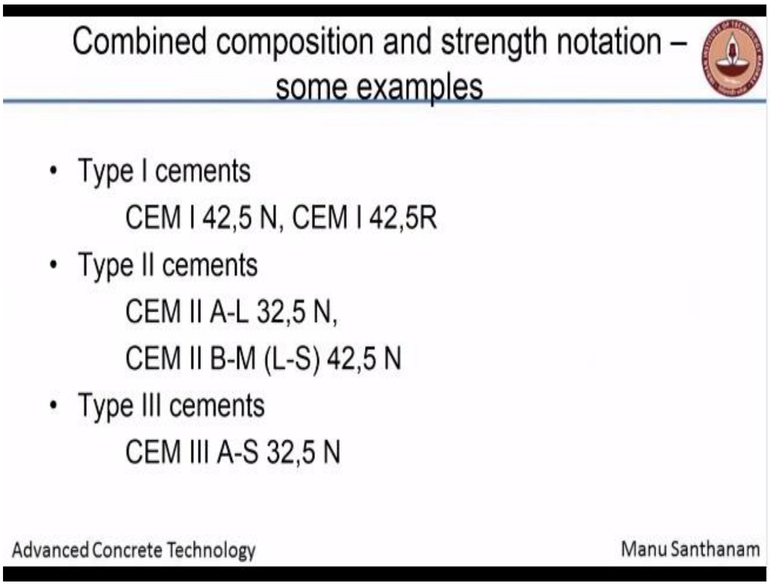

Type I 42.5 N or CEM I 42.5 R, here it is quite straight forward, that means you have only up to 5% of extenders in your system, and N means you have certain requirements of the strength at 2 and 28 days. Similarly, R also has specific requirements at 2 and 28 days. Now here comes the confusion, when you come to CEM II A-L.

A means what? 6-20% replacement and L means the replacement material is limestone. Again here we have the strength class 32.5 N, N means you have certain requirement for the 7-day strength and the 28-day strength for 32.5 class alone.

Now please remember that not in all composite cements you cannot have all strength classes, right, because with certain cements for example the fly ash based cements you cannot hope for a strength class of 52.5. Now here look at this one, type II B-M (L-S) that is probably as complicated as it can get right, what is type II B? 21-35%, M means it is a mixture, L-S means it has got limestone and slag.

Now how much of limestone and how much of slag they have not specified, could be anything as long as the total component is about 21-35%, and then again type III cements you have type III A-S 32.5 and that is fairly easy to understand.

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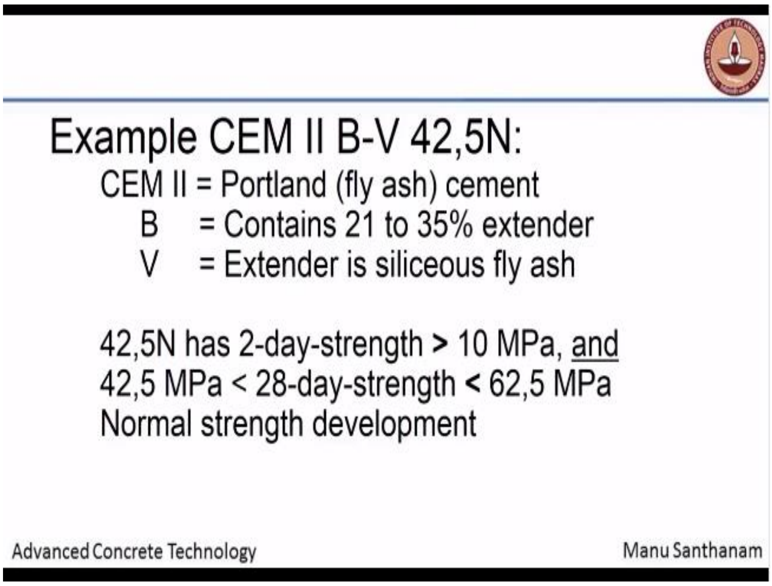

Again another example is given here CEM II B-V 42.5 N. So again it has got strength requirements, it has got compositional requirements and so on and so forth. Now in EN standards there is no performance based specification like in the ASTM standards. Now there ASTM is taken a step forward and given a very challenging scenario to the cement producers that they can actually come up with cement that match performance requirements.

And that is a very interesting move because now it permits all kinds of combinations, but then again you need to have the backup data to show that those combinations will actually lead to that performance being achieved in concrete and that is a very challenging thing to do.

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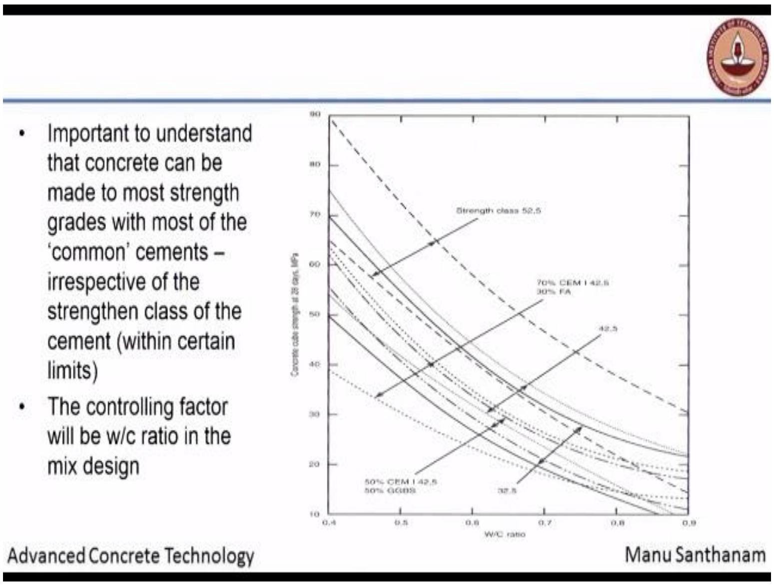

Again this is simply explaining the whole thing once again there is no big difference here, the same aspects that I was explaining earlier the same things have been listed once again. Now of course what you need to know is, when you design concrete with these cements the water to cement ratio for a given strength in the concrete will obviously depend upon the type of cement because we are shooting for a 28-day design strength.

So the curves that you have for strength versus water to cement ratio will vary depending upon the type of cement that you have. I think that is quite obvious, based on the type of cement that you have, for a given water to cement ratio you can get any range of strengths depending upon different types of cements that you use in the system. So all this is assuming that you have the same concrete mix design.

You have the same mix design for a particular cement content, for a particular water cement ratio you will get this definite strength for a given cement. So now in IS we have been using this strength to water-cement ratio relationship and that again shows you the distinction between 33, 43 and 53 grade cements. So what we need to do is understand locally what are the implications of choosing a particular cement and what would be the relationship between the strength and the water to cement ratio.

Now this is a good guideline that most mix design guidelines would give, that for a given strength this should be the water cement ratio but then it is up to us to really fix that because in a given area based on the type of experience you have with the particular locally available cements, aggregates and so on you can actually determine more meaningful relationships on your own.

Especially when you are a concrete producer it is all the more beneficial for you have your own strength to water/cement ratio relationship so that you do not go grossly wrong while using the curves suggested by the codes and guidelines. If you look at IS codes or actually not codes, IS guidelines for mix design that is 10262 there you can actually see such curves being specified but these are only recommendations.

Those guidelines are meant for a person who does not have any idea about mixed design to get started but then if you are a concrete producer, you have been producing concrete over a long period of time then obviously you can produce your own curves to ensure that you have a clear understanding of your mixed design, okay again these are some curves that have been fitted for 33, 43 and 53 grade cements or 32.5, 42.5 and 52.5.

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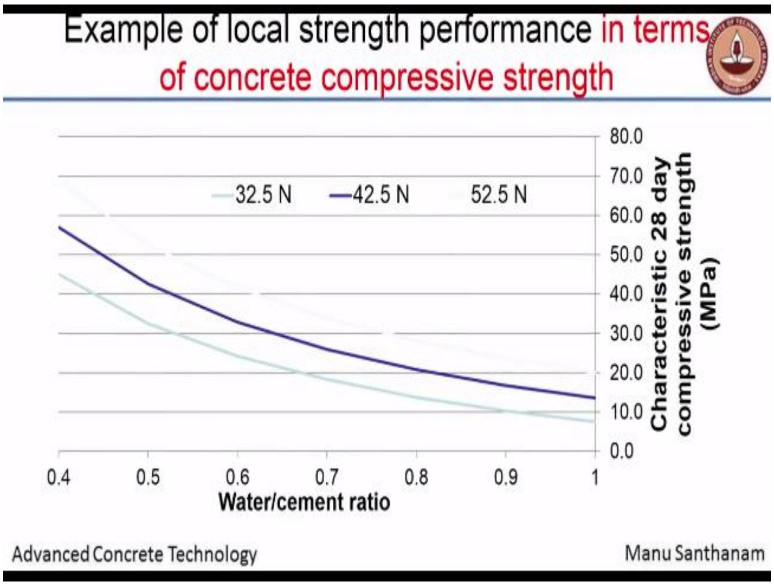

In terms of concrete compressive strength, characteristic concrete compressive strength and water/cement ratio. So similar curves need to be determined every time that you do a mixed design with a new cement, so the IS guideline helps you get started at a given point. So if you choose a certain water/cement ratio, let us say you have a requirement of 45 megapascals in your concrete and you choose a water/cement ratio of 0.4.

Your trial mix design ends up giving you a concrete strength of let us say 42, that means you are definitely lacking. So you do another mix design with a trial mix in which you reduce the water/cement ratio to 0.38, so all this essentially is by trial and error. There is no other way around concrete mix design than doing multiple numbers of trials. Now interestingly you see a lot of research nowadays being published where they talk about artificial neural network for concrete mix design.

Now if you ask me it is all bogus because no two materials can ever be the same. Aggregate you get in one location will be very different from aggregate you get in different location. The same cement I already told you that story that when you get the clinker from different sources and produce the same brand of cement sometimes there are variations in performance, there is no way that you can actually model this ever because of the extremely high variabilities in your system.

You can have a good idea about where you would be in terms of water/cement ratio, but there is no exact answer you will get without actually testing the concrete, which is why in concrete most of the learning that has been obtained is by experimentation and observation only then you can actually learn a lot about concrete mix design, just a small note about what are the test that we typically do.

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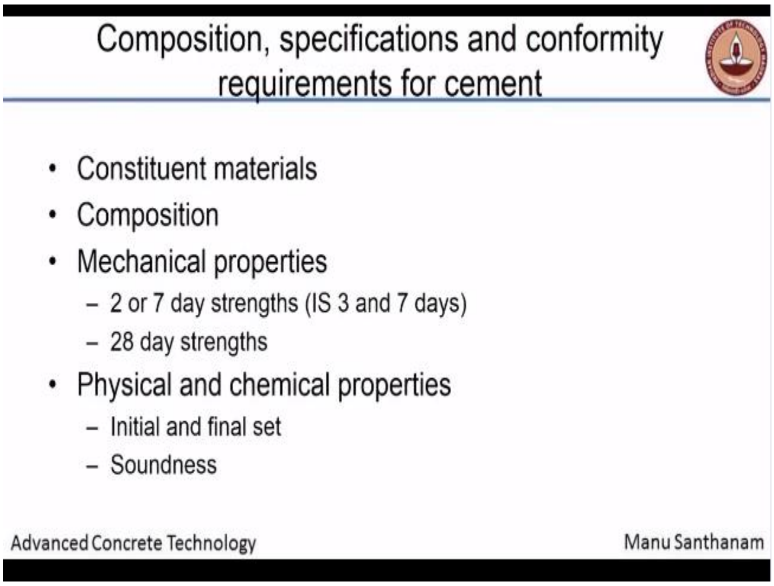

Of course there are requirements for the constituent materials, and the composition, there are requirements for the mechanical properties of the cement, as per the Euro Norms it is 2 or 7 days, in the Indian standards it is 3 and 7 days. You have requirements for 3-day strength and 7-day strength and one thing that is common in all standards is the 28-day strength. You have the 28-day requirement.

Then you have physical and chemical properties that you need to test. One is obviously the initial and final setting time of the cement. You all know why that is important because initial set gives you an indication of what? How much time the concrete it takes to lose it is mouldability that means it gives you the amount of time you can work with the concrete.

Time to transport, to place, finish, compact and so on. So all those things should be done within the initial set and what does final set indicate, some form has been attained by the concrete which will not go away even if you remove the formwork that is redundant, not the load bearing formwork but the redundant formwork on the sides that means you maintain the form of the concrete beyond the final set.

What are the typical value of cement initial setting time? That is specification for minimum setting time that is 30 minutes. Minimum setting time should be 30 minutes as per the IS codes, but that does not mean cement sets in 30 minutes. Most cements are designed to set between 2-3 hours or sometimes 1-2 hours depends on the type that you are producing.

So between 1 and 3 hours most cements will have initial set, but final set will be generally 1-2 hours more than that, 1 or 2 hours more than the cement initial setting time will be the final setting time. Now this is not the general rule. Final setting time as per the Indian standard should be less than 10 hours yeah, 600 minutes, 10 hours, but you can produce cements which can vastly vary in the setting times also.

Now when you have superplasticizer in your system obviously all these numbers will go for a toss, you do not really have a clear understanding of what should be your setting time, so these tests are done only on the cement and at the value determined by the normal consistency. Right and then of course we test the soundness. We already talked about why cements become unsound primarily because of the presence of free lime and free magnesia in the system.

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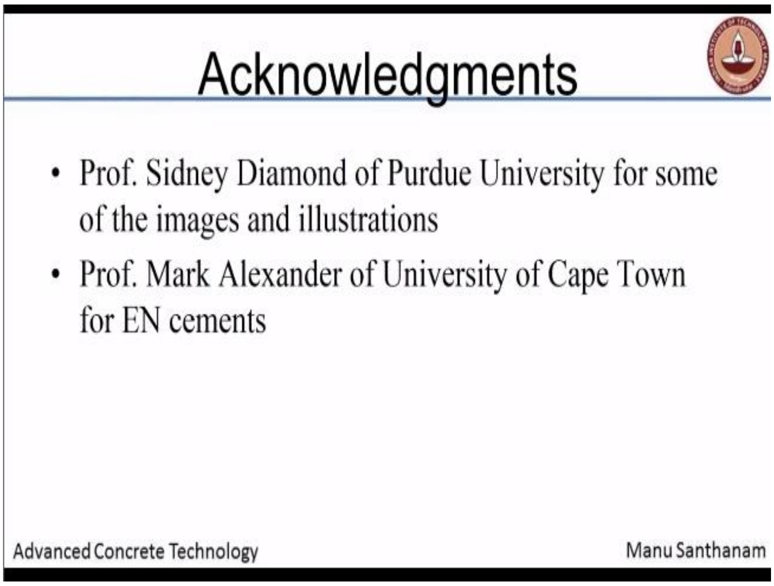

So I would like to acknowledge, Prof. Sidney Diamond of Purdue University and of course, Prof. Mark Alexander from University of Cape Town for the inputs to prepare these lectures. Thank you, there is a lot of further reading you can do there are some websites that are recommended.

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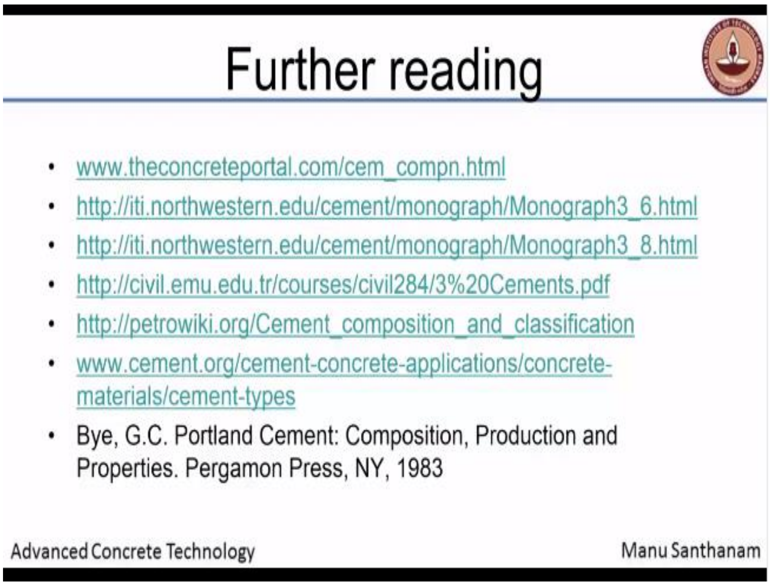

And there are also some books that will produce very good information about the composition of cement because it is a subject that has been looked at extensively around the world, there are standards obviously which are dictating the type cement required in the particular location, but there is a lot of information that you can actually gain by looking at some of these sources again, thank you.