Admixtures And Special Concretes

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Lecture -54

Special concretes - High strength concrete - Particle packing models

Modified Andreassen Model:

So, this MR model is based on modified and recent model. If you look at this previous gradation that I talked about, this model is not that much different from the same model described by Fuller.

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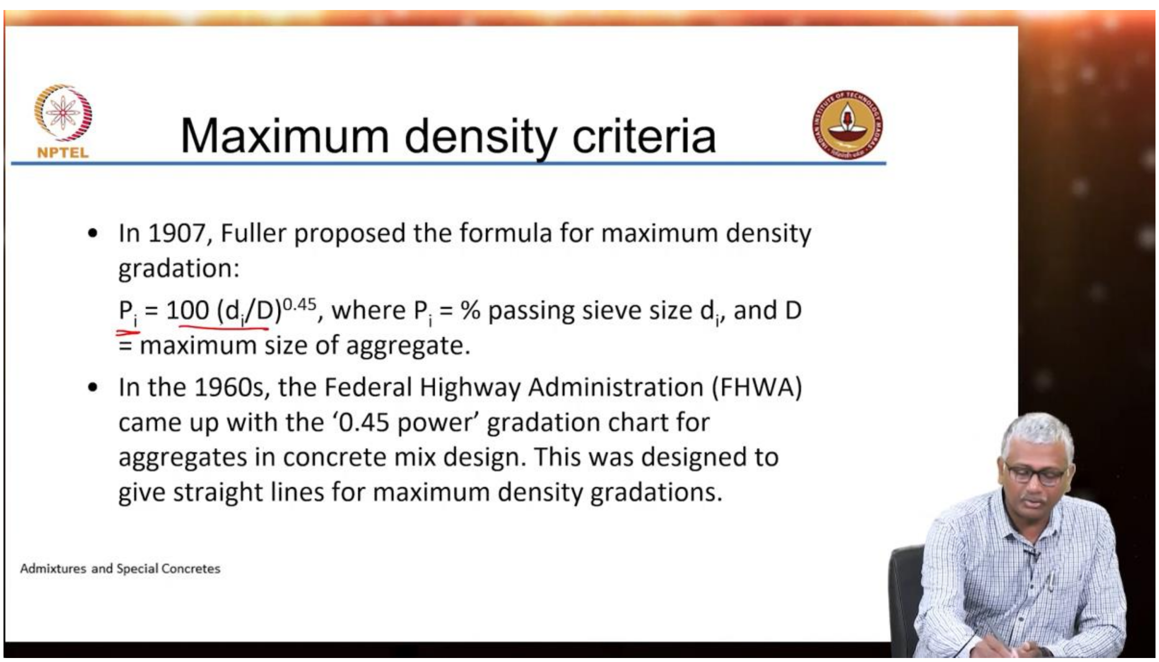

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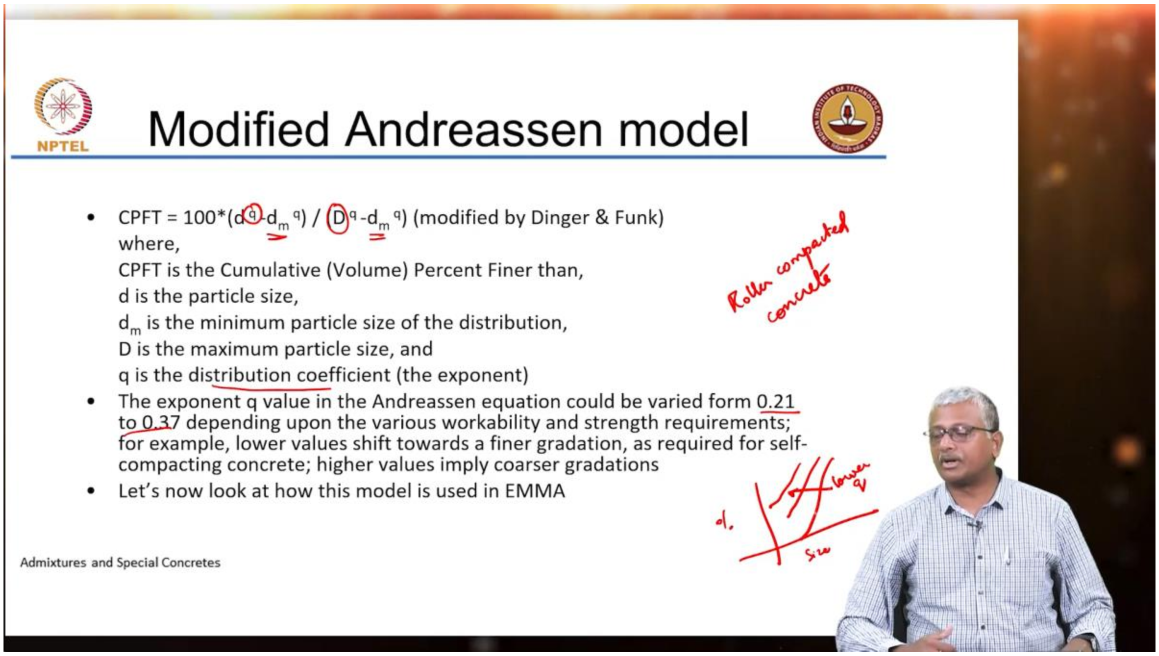

What it does is, it gives you an exponent q which is not 0.45 and it also in the numerator and denominator subtracts the minimum size of the particles d minimum. This D is the maximum diameter or maximum particle size, d_m is the minimum particle size and d is the specific particle size for which you are calculating the percentage that is finer than that size. So, this is how you will arrive at a cumulative percentage finer than or a particle gradation which is required to produce the ideal gradation curve.

Ideal implies the curve that gets you best packing in the system. Now this model was not developed for concrete, it was developed for optimizing the combination of powders in powder metallurgy. They optimize the particle grain size in such a way that when they do the compaction of these powders, they are able to then produce ceramics of very high density of very minimal voids content. So, ceramics also follow the same rules as concrete, minimum voids maximum strength.

So, if you can pack the powders in such a way that they get you the best gradation, minimal voids then you can get a system that performs the best in ceramics. So, this model is basically adopted from metallurgy- powder metallurgy and the same approach can be used for concrete design. Only problem is how do you choose this exponent Q, the exponent or distribution coefficient Q, how should you choose it? It turns out that when you are in the higher range of Q around, so Q varies between 0.21 and 0.37.

When you are closer to this 0.37 range you are dealing with a mixture that has very coarse particles. You do not have much fine materials like your particles contributed by your mineral additives like silica fume or ultrafine slag or something like that. So, when you are at that high range you are designing concrete mixes that adopt very little of your cementitious materials such as what kind of concrete mixes will have less cement? What examples would be having less cement? What type of concrete would be designed with very less cement? Go on, I need a quicker answer than this. High-strength concrete? No.

Which one? Slow setting does not have to do with less cement. Low strength concrete but low strength is a very generic term. What application? Footings require low-strength concrete? You are talking about lean concrete. Lean concrete we are not even bothered with going with particle packing. These are not concrete that we are interested in following such complicated designs.

We can as well do some simple design. Pavements how do we do that? How do we produce pavements with low cement content? You can produce pavements with high cement contents also because pavements require 40 MPa strength. But you can still do it with low cement contents by choosing roller compaction. Roller-compacted concrete is where we minimize the cement content. Roller-compacted concrete is where we use harsh mixes which cannot be worked with regular vibrators and that is why you need rollers to compact this concrete.

And this is ideal for dams. In dams, we need roller compaction. We do not need roller compaction for buildings. We cannot do roller compaction in buildings. Wherever you have plain concrete you can do roller compaction.

So, in such instances when you have much lesser cementitious materials coarser gradations are followed and you can choose a higher value of the exponent. But when you have fine materials like self-compacting concrete where lot of fines are used in form fly ash or slag or silica fume and so on then you are shifting towards the lower end of Q. So if you look at the particle gradation curve you typically have the S-shaped curve. When you go from a higher Q to a lower Q all you are doing is shifting the curve to that side. That means when you go to a lower Q you have a wider range of particle sizes from very small to large.

Whereas when you go for a lower Q you have more steep gradations implying that your particles are more and more uniform. What is uniformly graded and what is well graded? Exactly. So when you go for a uniformly graded material you have a limited particle range or particle size range. When you have a well-graded material, you have a much wider particle range. So, that is what the distribution coefficient Q means for a system which is very highly well graded you are simply stretching your particle distribution between very large size ranges and high values of Q means you have a small particle size range.

So, this is what you need to be aware of when you do the mix design using this modified Andreassen model.

EMMA Software:

Step 1- Input material PSD:

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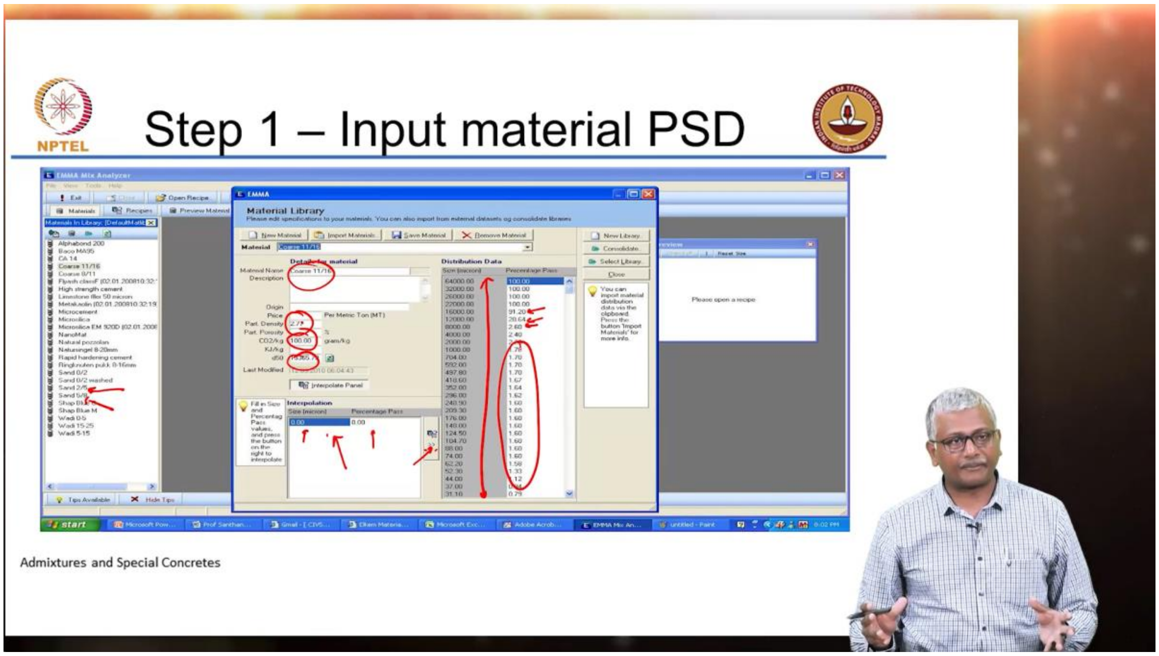

So, this is the picture from the software EMMA. From Emma software, you can create material libraries in that software with different kinds of materials and define the properties of these materials. For instance, here this is the coarse aggregate 11 to 16 mm of course that is a European definition in India we do not define coarse aggregates by this particular nomenclature we have 20 mm, 10 mm and so on. In Europe, they have well-defined size ranges between which the particle sizes lie in sand as well as coarse aggregate.

So coarse aggregate 11 to 16 mm they have particle density given here. Interestingly, in this software now you can also put in the CO_2 impact per kilogram of this aggregate. The advantage there is you can when you do a result in mix design you can then calculate the net CO_2 impact also. It then talks also about a D_{50} of the system that means percentage finer than- 50% finer than value. Now how do you obtain that you obviously have to do sieve analysis.

You feed in the results of a sieve analysis here, size microns and percentage passing and when you click this button it basically distributes that entire size range over the maximum and minimum particle sizes that you have chosen here. Now of course this is a 11 to 16 mm coarse aggregate so it is only going to have these particle sizes. It may have a little bit less than 11 but at least 90% will be more than 11 mm and at least 90% will be less than 16 mm that is how we define these particle sizes. At least 90% should be either more or less than the upper limit or lower limit. So here you have particle sizes primarily in the 16 to 8 mm range.

But what this is doing, what this interpolation panel is doing is converting the values that you enter into a distribution across different sizes. Now all these are random values obviously that does not mean that all these materials are actually present in your system. So what you will be entering is % finer than 16 mm, % finer than the intermediate whatever fraction you may have 12 mm let us say % finer than 11 mm and whatever passes through 11 mm is retained in the pan when you do sieve analysis. But here what it is simply doing is distributing that pan into several smaller sizes. So, this does not really mean anything.

You can similarly create particle libraries for other types of particles like sand. Now in Europe, they have sand 5 to 8 mm, 2 to 5 mm, 0 to 2 mm, 3 different ranges of sand sizes are given in Europe, and then you can again put in all these values for the same. So any new material that you want to put in you can create the library by putting the sieve analysis in this interpolation panel clicking this button that will sort of distribute that across a range of particle sizes. Same thing with cement or with fly ash you can do the same thing. You enter the particle density, you enter the CO_2 impact if you know that of course and then you can do the particle size distribution.

How do you determine particle size distribution of cement or other fine mineral additives? Sedimentation will not be accurate, you want to choose a much more accurate methodology and as we discussed earlier it is by laser diffraction. We use the method of laser diffraction to get the particle ranges for very fine particle sizes. And using those particle sizes given by laser diffraction you can do the same. You can put that into this interpolation panel to describe the particle sizes and then when you click this button it takes you to the distribution data there. So all it is doing is creating a material library.

Once you create a material library you need to actually make a recipe.

Step 2- Preliminary recipe

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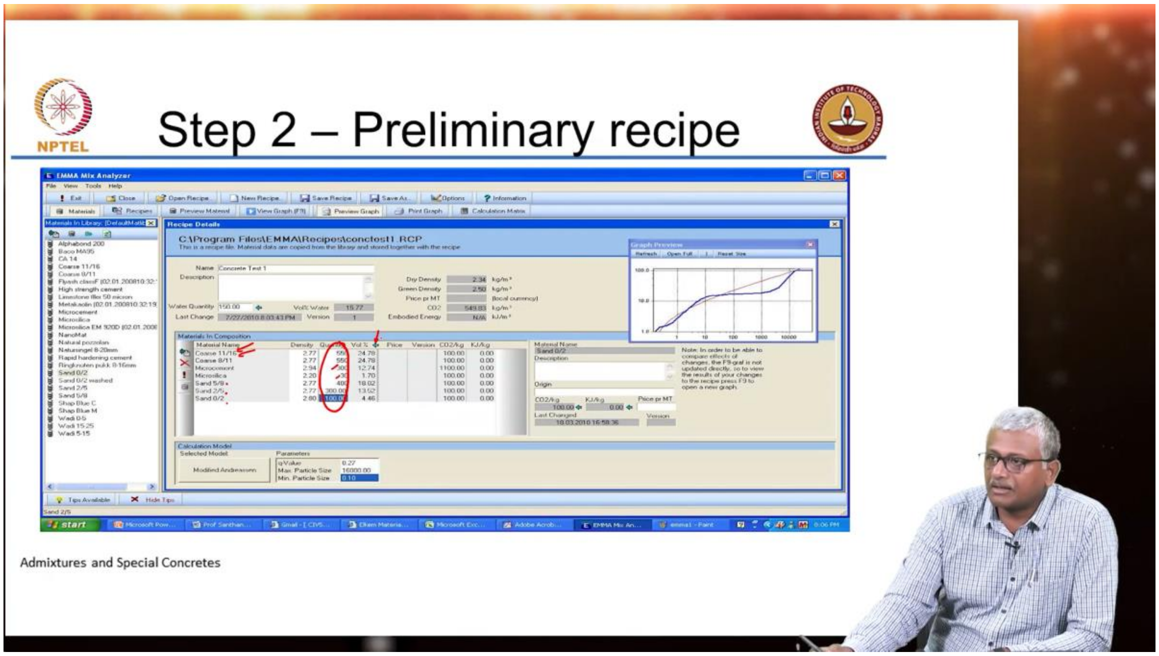

A recipe simply means that for your concrete mix design, you choose certain amount of fine aggregate, certain amount of coarse aggregate, cement and so on. So for instance in this example coarse aggregates 11 to 16, 8 to 11, sand 5 to 8, 2 to 5, 0 to 2, they have all been selected for a certain quantity in kilograms per cubic meter. Now obviously you cannot shoot in the dark, you need to have some estimate. Let us say you are designing an M50 concrete or M60 concrete, you know that you will need a certain level of cementitious material component inside the system.

You need to have a certain water-to-cement ratio in your system and so on. So some initial estimates you need to have for your design, some initial thought process of how do I want to go about with this design. That does not mean that you have actually done any trials yet. The job of particle packing is to simply help you cut down the number of trials to get to the right level of workability and strength. So here for instance, 300 kilograms of cement and 30 kilograms of micro silica have been put into this recipe and you have all other different types of aggregate present.

Now when you click this arrow button here, what it does is it converts these quantities that you have put in into the volumetric percentages of these materials. It converts that quantity into a volumetric percentage and that is what is indicated in this column here.

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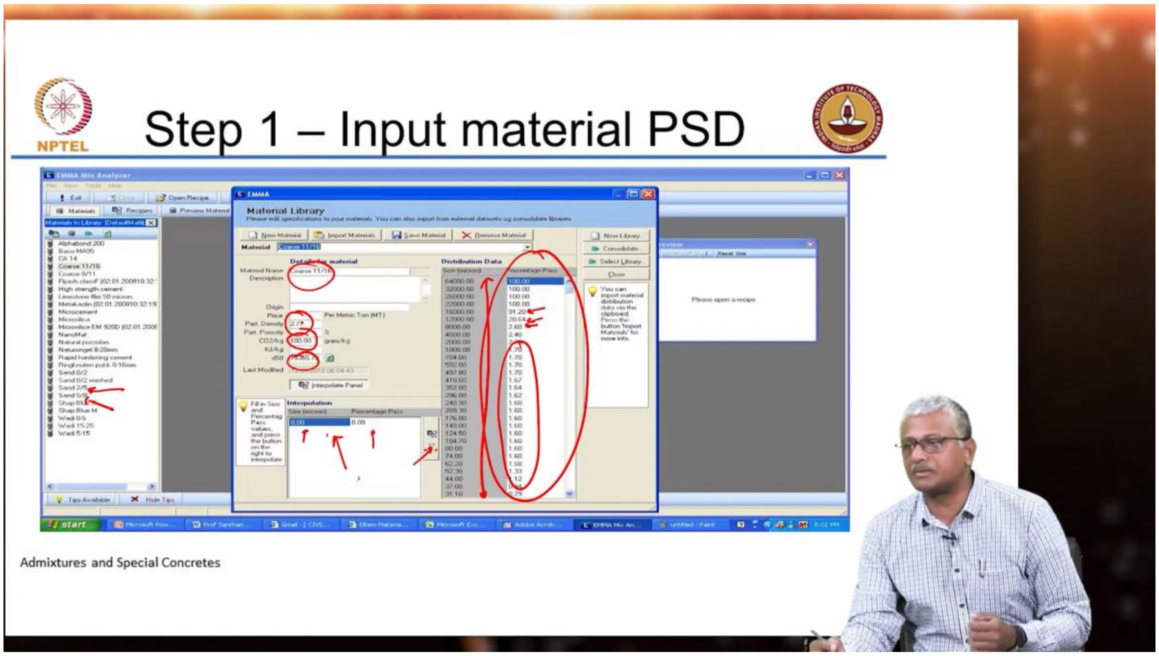

The distribution data that is generated here, the percentage passing data, it is the volumetric distribution data, not the mass distribution that you do with sieve analysis. In sieve analysis we do not determine volume of material passing, we determine mass of material passing. But this is converting that into volumetric particle size distribution.

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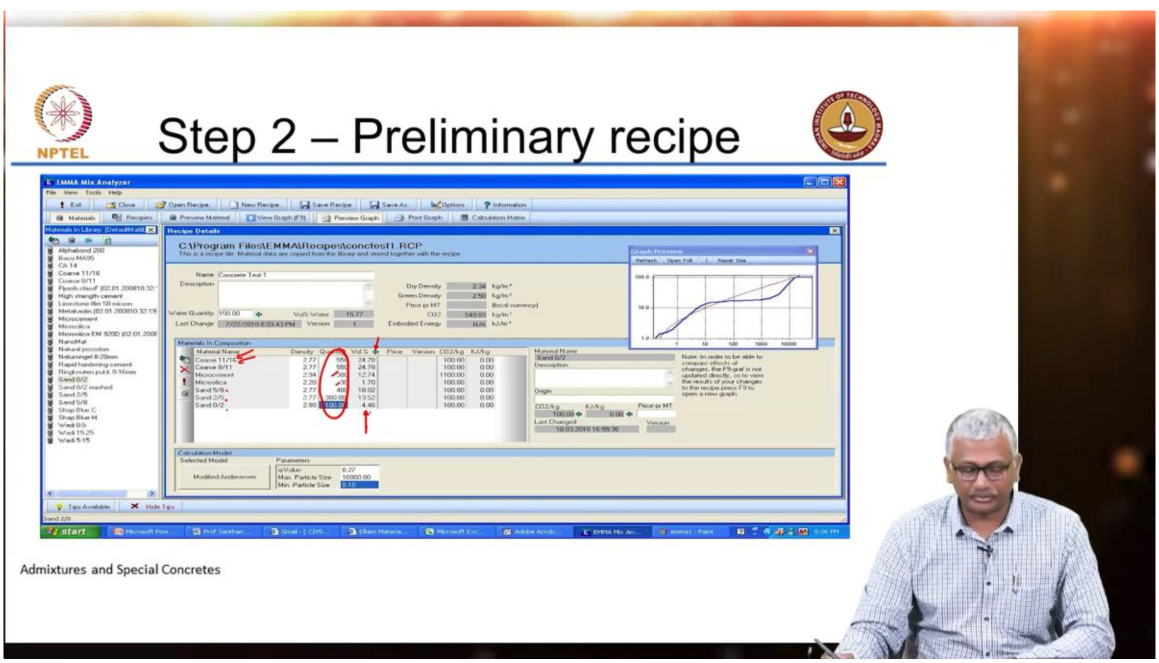

So that is what this step also does is converts the material masses into volumes or volume fractions.

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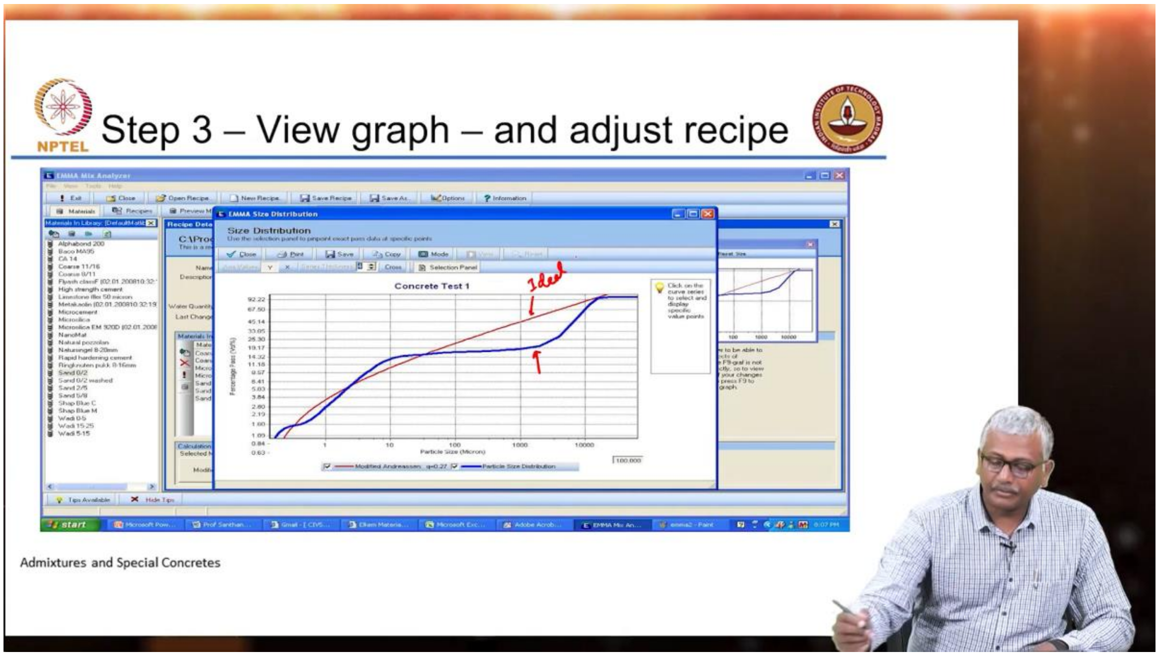

So that is what this step also does is converts the material masses into volumes or volume fractions. Now for this combination of materials that you have input into the system, the system gives you now the combined particle gradation. This blue curve is the combined particle gradation based on the particles that, the quantity of particles that you have input into the system. The red curve is the ideal gradation and ideal gradation as prescribed by the modified Andreessen model. But in that equation, you have this maximum size, minimum size, and this distribution coefficient Q.

So all those have to be also specified.

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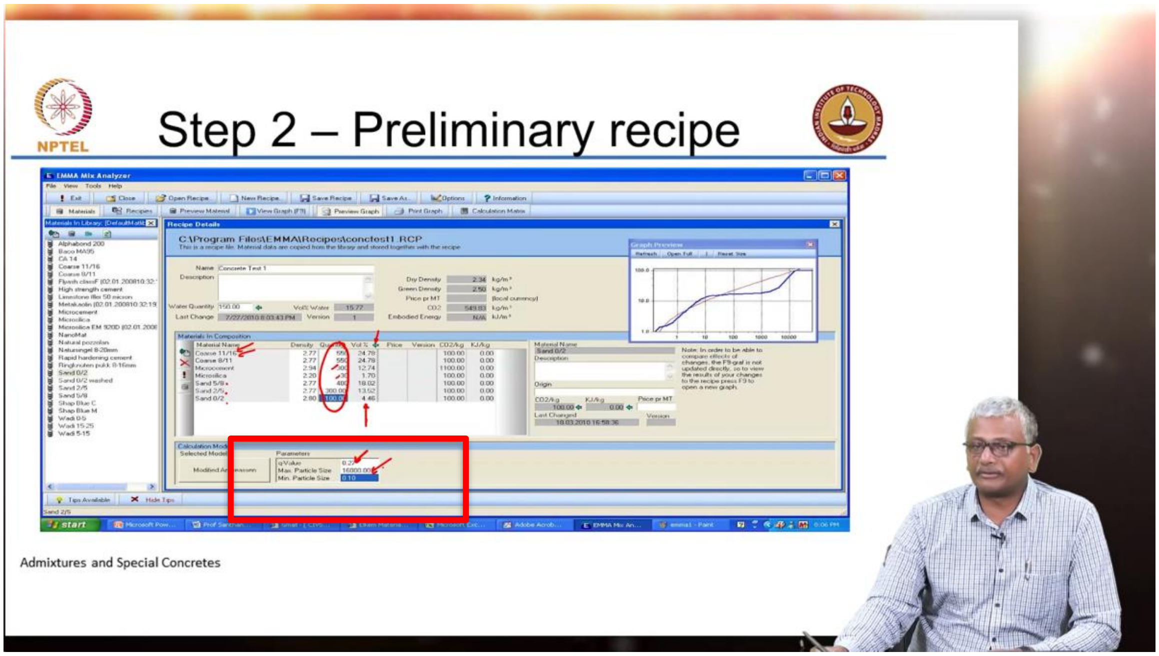

So here Q value has been taken as 0.27. For most concretes you can be in that range 0.27 unless you have very fine materials like an SCC where you want to decrease that to about 0.22 or 0.23. Maximum particle size is 16 mm that is defined by the maximum size of coarse aggregate that you have in your system. And minimum particle size because you are using micro silica in this case, if you look at the particle gradation that is been provided in the software for micro silica, it has 0.1 micron as the minimum particle size. So based on this Q value, this maximum particle size and this minimum particle size, you apply this equation to get you the ideal gradation curve.

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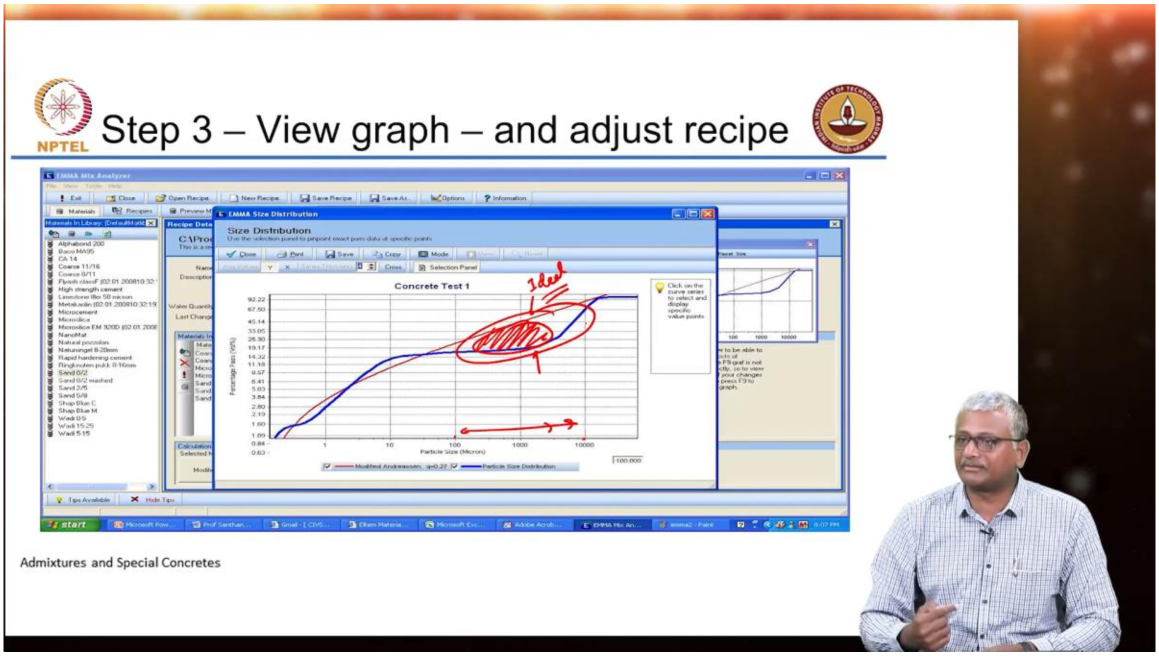

You can get the ideal gradation. What does this tell you now? Our initial supposition was that if you have an ideal packing, a packing as close to ideal as possible, you will get maximum strength. That was the initial idea. So to follow that idea what we need to do is, see where our packing is not as good as the ideal. Now here the range is obvious. We know that in this range (Marked area in the slide) my combined particle gradation is lower than the ideal gradation.

What does it mean? I need to increase particles in that size range and what are the size range? 100 to 10,000 micron. So or mostly 100 to 5000 micron. Mostly it is this range here. And what is going to contribute to that? 100 micron to 5000 microns. What particles will contribute? 5000 micron, 5 millimeter.

Fine aggregate, come on. 100 to 5000 microns basically your sand size. So this means that you need to choose your mineral mix or material mix in such a way that you increase the sand a little bit. So now what you do?

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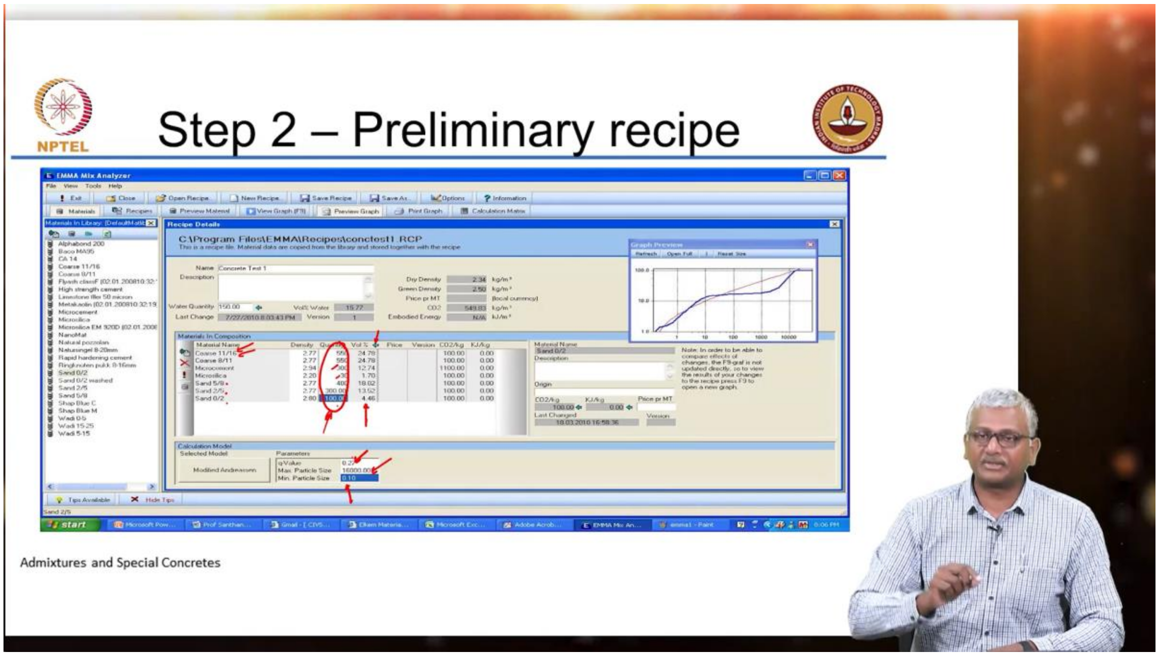

You go back here and just play around with the numbers with slightly higher sand content.

Put in slightly higher sand content. The idea is to get this curve as close to the ideal as possible.

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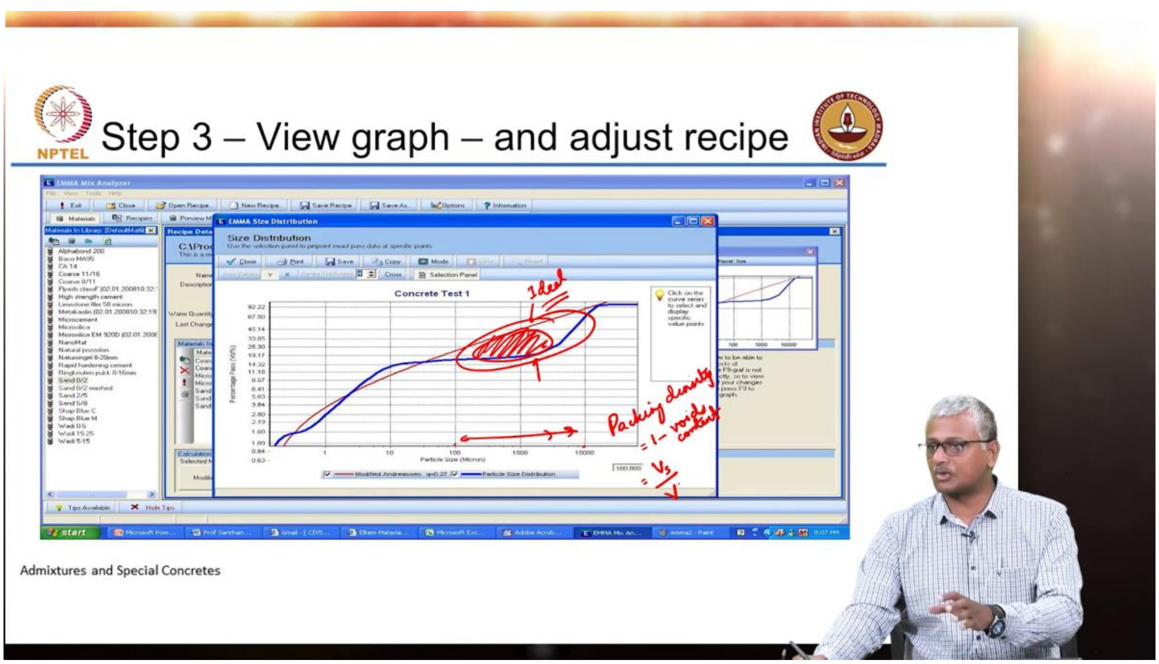

Now that is only in theory. It is not yet practiced. In theory, we know that we are going to minimize voids when we reach the ideal gradation. Now in practice what you need to do is once you arrive at a curve that gives almost an equal ideal gradation to you, you then work out the actual concrete mix design in the laboratory, determine the workability and the strength and see whether it matches with your expectation.

That is the concept of application of particle packing in your concrete mix design. Now we have been talking about one factor which is called the packing density. Packing density, what does it mean? What does packing density mean? Now I have a combination of particles with different specific gravities. I am going to fill up a volume with that set of particles. The combination that gives me the maximum packing density gives me the minimal voids.

So packing density is nothing but 1 minus voids content. That is what packing density is. So how will I calculate this? It is nothing but volume of the solids by total volume.

$$Packing\ density = 1 - void\ content = {V_s}/{V}$$

Volume of solids by total volume because voids content or porosity in the system. Voids content, Of course, the soil definition of voids content is volume of voids by volume of solids. That is not what we are using here. Voids content here is the same as porosity, void fraction which is volume of voids divided by total volume. So your packing density is volume of solids divided by total volume.