Pavement Materials
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Lecture 44
Hot Recycled Mixtures (Part 3)

Hello friends. In the last class we were discussing about the mix design concepts of reclaimed asphalt pavement materials and we discussed about the use of blending chart and we completed our discussion on the use of viscosity blending chart. In case we are looking at the viscosity grading system, so, a viscosity blending chart can be used.

And then we looked at two cases. One was to determine the grade of the virgin binder to be used when the RAP percentage is fixed and we also know the grade of the target binder. And the second case was that we are trying to find that what will be the maximum percentage of RAP to be used when the grade of the virgin binder is fixed and also the target grade of the final mixture is also fixed.

So, today we will look at the PG grading system taking similar examples of these cases and then we will try to see that what are the steps when we talk about the PG grading system. So, as I mentioned in the PG grading system, we have three set of tests. We have high temperature PG corresponding to 2.2 KPa.

We have intermediate temperature PG corresponding to the value of $G^*\sin\delta$ of 5000 KPa. And then we have low temperature PG criteria's based on the value of creep stiffness and the value of m or the creep slope. So, we will try to look at the use of this blending chart in case of PG grading system again with examples.

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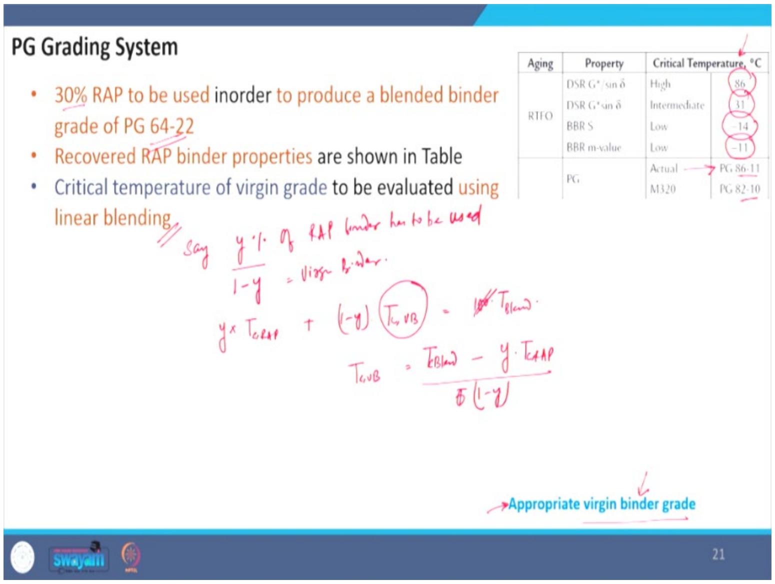

So, let us say that 30 percent RAP has to be used in order to produce a blended binder of grade PG 64-22. So, this is the target grade we are looking at and 30 percent RAP we are utilizing, which means I am trying to find out what should be the appropriate grade of the virgin binder for considering all these three criteria's. Recovered RAP binder properties are shown in this particular table.

So, we have taken the recovered binder, we have subjected it to testing and we know, we have discussed how to do the testing and this is what we have got. So, this is the critical temperature which means the true failed temperature corresponding to 2.2 KPa it is 86 degree Celsius, 31 G*sinδ value of S-14 and value of m-11.

So, the true grade becomes 86-11 whereas the actual grade becomes as per M320 it becomes 82-10. But as I mentioned we will use this particular temperature to do our calculations. So, before I show you the calculation let us try to understand the linear blending process here without using any charts, just by hand calculation. So, critical temperature of virgin grade, because this is what we are trying to determine, will be evaluated using linear blending. So, what do you mean by linear bending?

So, say that y percent of RAP binder when I say RAP binder or RAP I am just indicating the same thing here. So, a RAP binder has to be used. So, when it is y percent RAP which means 1-y is the virgin binder in the total mix. So, 1-y is the virgin binder. Let us say, linear blending says that $y \times T_{CRAP} + (1-y) \times T_{CVB}$ will give you finally $100 \times T_{Blend}$. So, this is the basic formula for blending.

So, in this particular case, we are trying to determine T_C for virgin binder. So, $T_{CVB} = T_{Blend}$. If I am considering this in fraction, so, this cannot be 100; this will be equal to 1. So, $\frac{T_{Blend-y \times T_{CRAP}}}{1-y}$. So, this will be the formula which will be using in this particular case where we are trying to determine the appropriate virgin binder grade, so, for all the three cases of critical temperatures.

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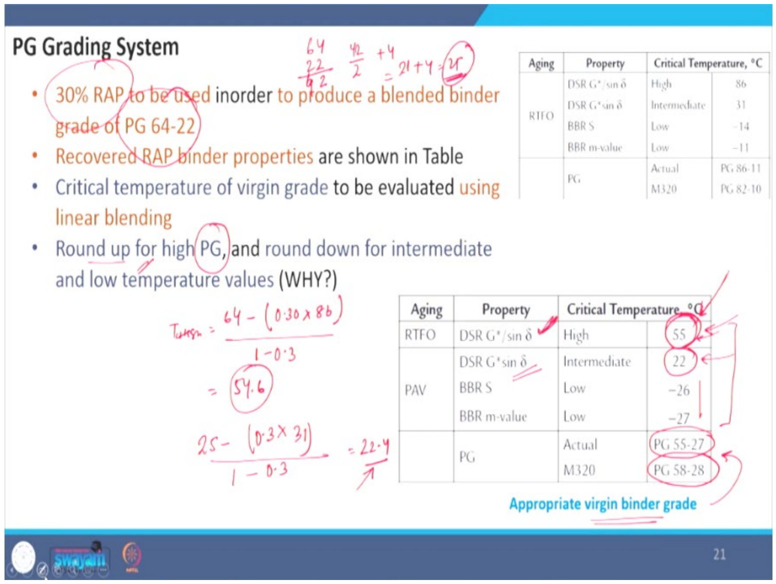

Now, here again, we will do some rounding off once we determine the value. We will discuss why the rounding off is done. But you have to remember that we have to round up when we talk about high PG and we have to round down for intermediate and low temperature values. Why? Because this will give us a more conservative approach, we will discuss why I am saying that the approach will be conservative.

Let us look at the example, these formulas which we have discussed. First we have calculated what will be the critical temperature for high PG. This table shows us the value which we have obtained using the linear blending which we have just discussed. So, this is for high PG. So, how they arrived at this 55?

We use the similar formula which I just wrote before sometime that for TC high of the virgin binder grade will be equal to how much. It will be equal to 64. This is the target grade -30 percent RAP to be used , $\frac{64-0.3\times 86}{1-0.3}$. If you do this calculation you get the value as 54.6. And as I said we have rounded up, which means 55. Why they have taken 55 here?

Because if we assure that the virgin binder grade which we are going to use satisfies the criteria of G*sinδ at 55, it will definitely satisfy at 54.6 degrees. If it satisfies at 55 degree. And that is why a rounding up is done. Similarly, you can calculate for G*sinδ using the same formula. If you calculate you get is, I am just showing you the example for intermediate it is 25. Why it is 25? Because, it is 64-22.

So, $\frac{42}{2}+4$.. This is our calculation which we have seen previously while discussing about PG grading system, so, 21+4, 25. So, the target grade is 25. So, $\frac{25-0.3\times31}{1-0.3}$. So, this gives us is 22.4. But they have taken as 22. Why they have taken as 22?

Because if the value of G*sinδ is less than 5000 KPa at 22, it will definitely be lower at a higher temperature of 22.4. So, the criteria gets satisfied. And similar discussion will go for the low temperature values. So, this is what they have obtained, which means that the binder grade which we are targeting, the critical grade should be PG 55-27 and the actual grade as per M320 should be, AASHTO M320 should be PG 58-28. So, this process tells us how to select the appropriate PG grade considering that the percentage of RAP binder is fixed and the target grade is fixed. So, this is the first example.

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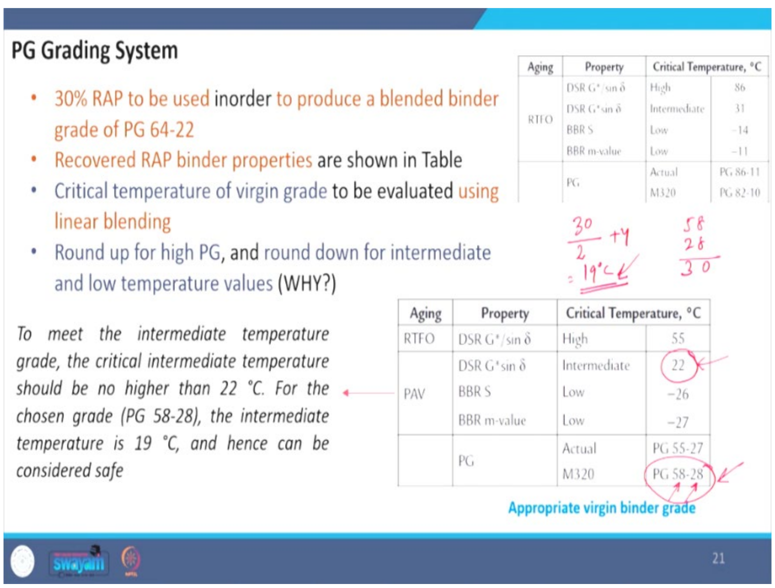

Before we discuss about the second case, there is a note here that to meet the intermediate temperature criteria, or the critical temperature should not be higher than 22 degree Celsius. So, this tells us that though you have got the final grade that is PG 58-28. But this shows only the high temperature and low temperature. It does not tell us about the intermediate temperature.

But you see if you do the calculation which is 58-28. So, this is $\frac{30}{2}+4$. So, this is 19 degree Celsius. So, as per the calculation, it tells that the critical temperature should not be higher than 22 degree Celsius. And if you take PG 58-28 it is 19 degree Celsius. So, this satisfies the criteria and we do not have to worry about the intermediate temperature here.

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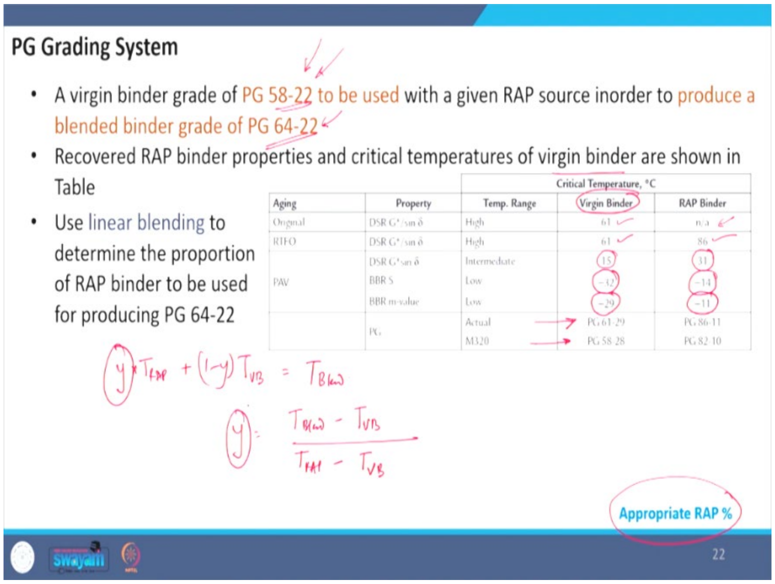

So, now let us move forward with the second case that I want to determine appropriate RAP percentage. Again with the example let us say that we have a virgin binder grade PG 58-22 to be used with a given RAP source in order to produce a blended binder of PG 64-22.

So, the target binder is fixed the virgin binder to be used is fixed and we have to determine what is the maximum percentage of RAP which I can use or what is the range of RAP percentage I can use considering all the three criteria's. The recovered RAP binder properties and the critical temperature of virgin binder, which means PG 58-22, are shown in the table.

So, this is the table and you see that we have the virgin binder which has a high PG of 61, for RAP binder we do not determine the original binder grade, so, not required, RTFO 61, RAP binder is 86, intermediate G*sinδ less than 5000 KPa, 15 degree Celsius in the virgin grade, 31 degrees for a RAP binder. The value of s corresponding to the BBR test is -32 for virgin binder minus 14 for RAP binder and this is -29 and -11. So, this is what is there, what is given. The actual binder grade and M320 is indicated here. So, this is what is given to us.

Now, let us talk about the steps. Again, we will use the linear blending formula to determine the proportion of RAP binder to be used for producing PG 64-22. Talking about the same formula which I just wrote in the previous slide, we wrote that $y \times T_{RAP} + (1 - y) \times T_{VB} = T_{Blend}$.

So, in this particular case we are trying to determine the value of y. So, $y = \frac{T_{Blend - T_{VB}}}{T_{RAP - T_{VB}}}$ So, this formula we will use to calculate the value of y for all the different cases.

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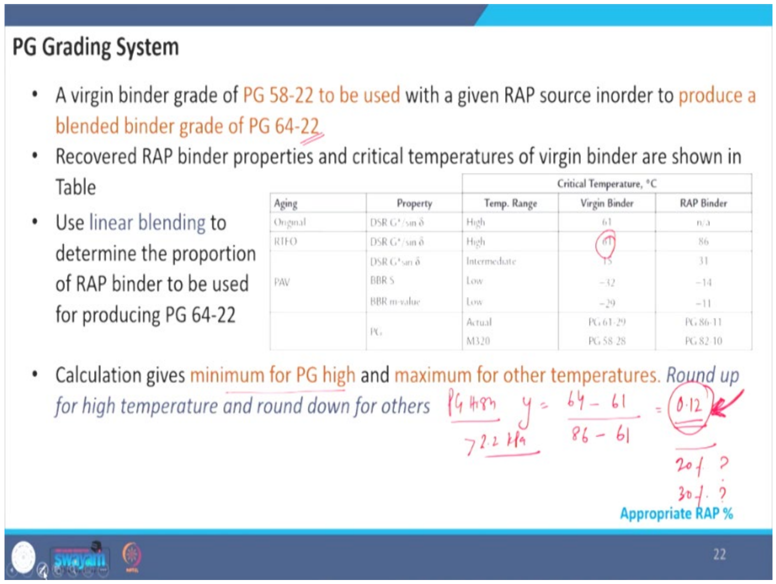

So, let us look at the calculation for each cases. Let us say that first we are looking at the value of PG high. So, when you do the calculation for PG high, y becomes equal to how much? $y = \frac{64-61}{86-61}$. This gives us 0.12, which means that at least 12 percent of RAP will be required such that the value of G/sinδ of the final blend is more than 2.2 KPa. Because you see the value of G*sinδ will be higher only when the stiffness is higher.

So, this is the minimum value which is desirable, which means that can we go up to 20 percent, can we go up to 30 percent. So, in order to ensure that this selected RAP percentage does not give us a PG grade to the next PG grade which means we are not landing at PG 70, we have to also find out the maximum value here. So, this is the minimum value. So, that is why it says calculation gives minimum for PG high. So, we have to find out the maximum value also. So, in order to find out the maximum value.

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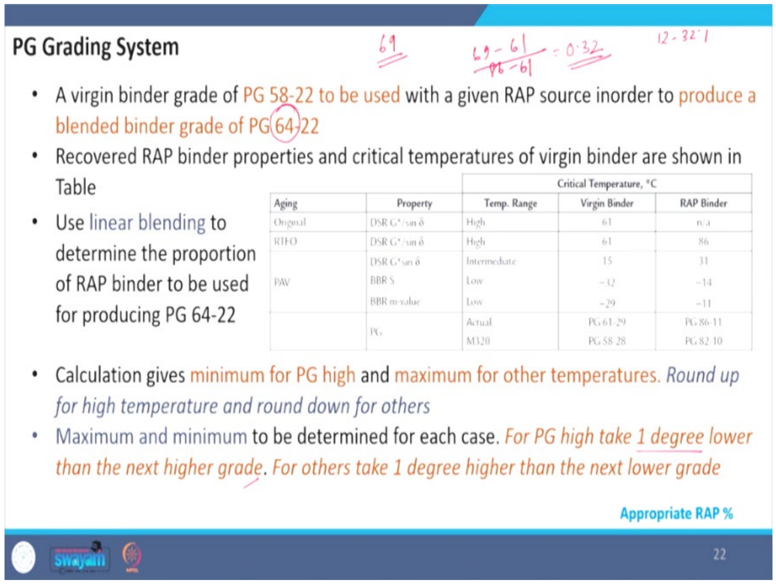

For finding out the maximum value, take one degree lower than the next higher grade. So, next higher grade is PG 70, so, I will ensure that it does not, it is not beyond 69. So, how do I do the calculation here? $\frac{69-61}{86-61}$. So, if you do this calculation you will get the value as 0.32. You will get the value as 0.32 which means that the RAP binder should not be more than 32 percent, so that it goes to PG 70. So, as per the high temperature PG, the range is 12 to 32 percent.

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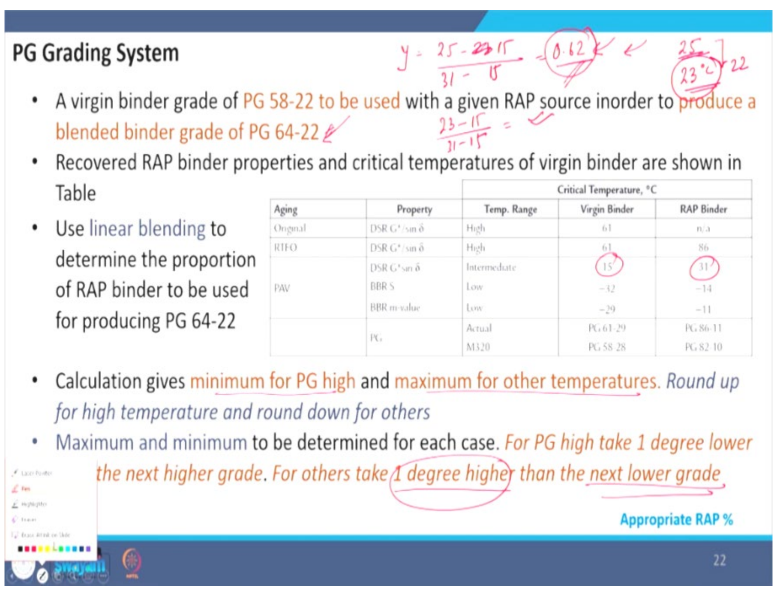

Talking about the intermediate temperature now, what we have to do? We will use the same formula. y is $y = \frac{25-15}{31-15}$. If you do the calculation, this is 0.62. This value is the maximum. Which means, in order to satisfy the criteria of G*sinδ less than 3000 KPa, the percentage of RAP should not be more than 62 percent.

Because if you go more than 62 percent, you will have a stiffer binder and which will not be sufficient to satisfy the criteria of our target grade. So, this is the maximum. And that is why it is written that calculation gives minimum for PG high and maximum for other temperatures. So, this is 0.62.

If the designer is interested to find out the minimum value corresponding to intermediate temperature also then similar to PG high, We will take one degree higher than the next lower grade. And for intermediate temperature, the grade changes by 3 degree Celsius. So, when it is 25 now, it should be how much? 23 degree Celsius.

Next lower grade is what? -3. So, it is 22. One degree higher than the next lower grade, so, 23. So, we will do the calculation is $\frac{23-15}{31-15}$ and if you do this calculation, you will get the percentage of, the minimum percentage corresponding to intermediate grade. But it is not very important for us to determine the minimum percentage corresponding to the intermediate grade here.

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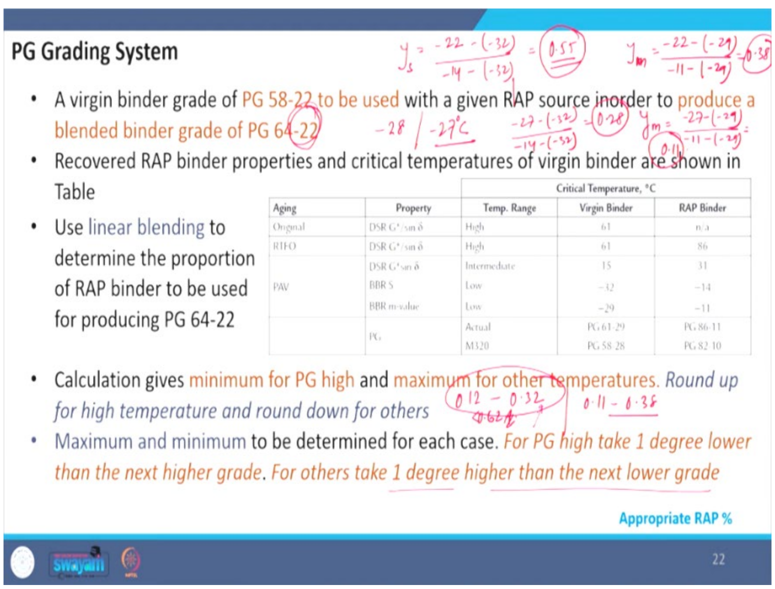

Now, coming to the last aspect that we also have to find corresponding to the low temperature. So, again, $y = \frac{-22-(-32)}{-14-(-32)}$. So, this gives us a value of 0.55.

So, similar to intermediate temperature, this is also the maximum value. So, this is the maximum value corresponding to the stiffness value. The value of S. Now, corresponding to m value it will be how much?

This is corresponding to s; corresponding to m it will be $y = \frac{-22-(-29)}{-11-(-29)}$. So, this is equal to 0.38. So, 38 percent maximum corresponding to m.

Here, the designer might be interested also to find out the minimum value, just to ensure that he is not using excessively soft binder corresponding to low temperature. So, Again follow the same thing. Take one degree higher than the next lower grade. So, the present grade is -22. So, the next grade is -28. So, I will take -27 degree Celsius for calculation.

So, corresponding to s value, it will be $\frac{-27-(-32)}{-14-(-32)}$. So, the minimum value corresponding to S is 0.28 and minimum value corresponding to m is $\frac{-27-(-29)}{-11-(-29)}$. So, this is equal to 0.11, 11 percent. So, which means that for lower temperature, a range between how much? 11 percent to 38 percent should be chosen.

So, just a recap, high temperature was 12 percent to 32 percent. Intermediate was, it should be less than 62 percent or 0.62 I am saying. In order to satisfy the low temperature grade it should be between 0.11 to 0.38. So, looking at all these three values, what we can finally conclude that we can take the final RAP between 12 to 32. So, if we take 12 to 32, it will satisfy all the criteria's. Which means up to maximum 32 percent is permissible in this particular example.

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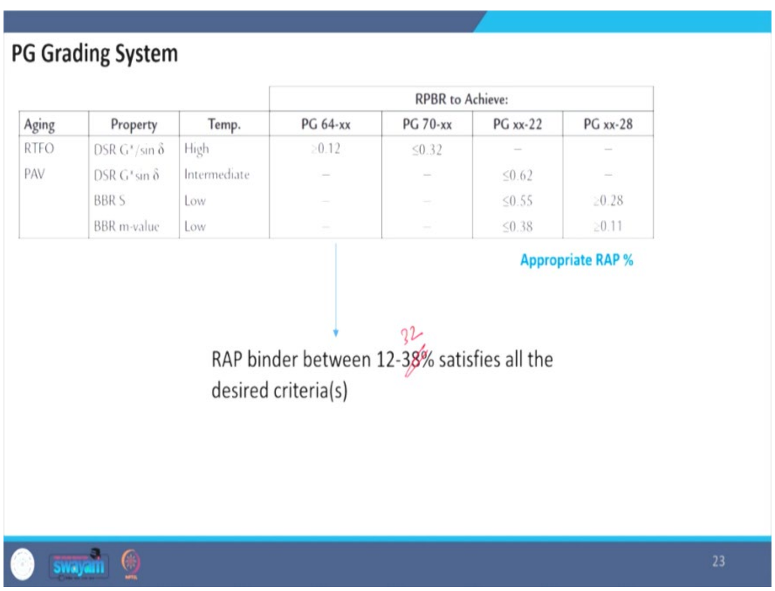

So, if we take the RAP binder between 12 to 32 percent, it satisfies all the desired criteria. So, I hope that this is again clear to you that how we do the calculation in case of PG grading system. A little more cumbersome than the viscosity grading system but very easy to understand.

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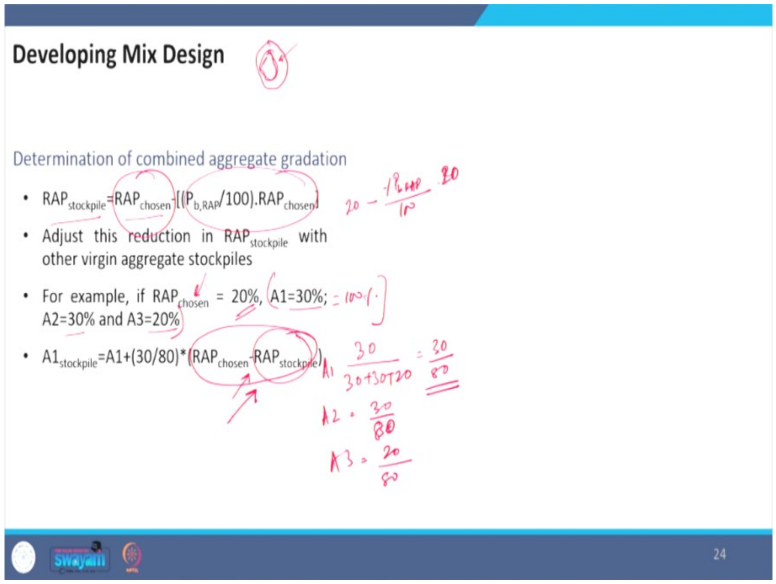

Now, the final steps of mix design that we have to determine the combined aggregate gradation. This is very simple. We have to remember that the RAP stockpile is not equal to the total RAP which is chosen. Because, in the RAP aggregate, we have the binder coated with it. So, we have to remove the binder in order to know the quantity in the stockpile.

So, the $RAP_{Stockpile} = RAP_{choosen} - P_{bRAP}$. So, this is very simple to understand. And once we have the RAP stockpile then we have to adjust the other virgin aggregate stockpile which have been determined corresponding to the chosen RAP value.

Now, this can be understood with an example. Let us say that the chosen RAP is 20 percent and the other stockpiles are taken as 30 percent, 30 percent and 20 percent. So, the summation is 100 percent. But this cannot be the exact stockpile because RAP chosen is not RAP stockpile.

So, we will determine first that what is the RAP stockpile here. So, $RAP_{Stockpile} = [RAP_{choosen} - (\frac{P_{bRAP}}{100} \times RAP_{choosen})]$, which is 20 percent. And we will adjust the other stockpile. So, how we adjust the other stockpile? By proportioning. So, this is the difference we are obtaining, $RAP_{Stockpile} - RAP_{choosen}$. This amount we have to adjust in other stockpiles. We are increasing the other stockpile by corresponding to the proportion of the remaining stockpiles.

So, just to avoid confusion, you look at these three values A1 A2 and A3. So, what is the proportion of A1 corresponding to A1 A2 and A3? It is $\frac{30}{30+30+20} = \frac{30}{80}$. So, this is the proportion of A1 corresponding to the virgin stockpile. So, similarly, the proportion of A2 is $\frac{30}{80}$ and the proportion of A3 is $\frac{20}{80}$. So, we will adjust this particular value in the other stockpile corresponding to their individual proportions.

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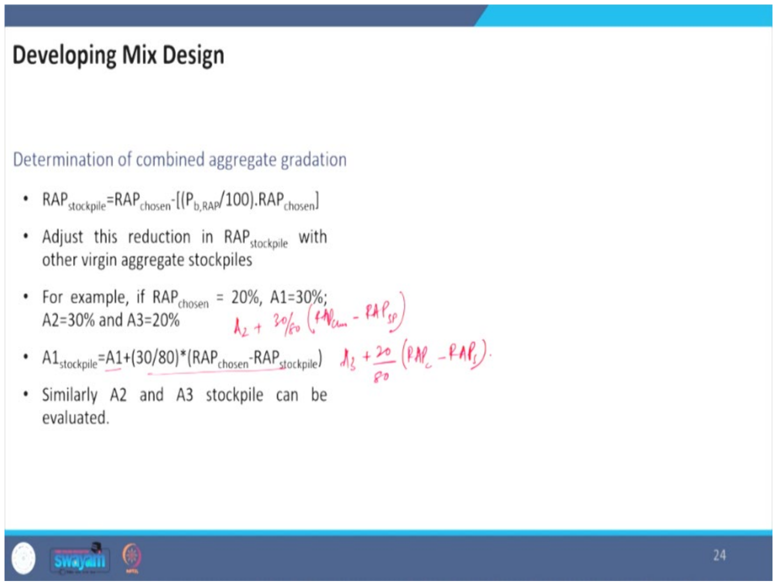

So, that is why A1 will increase by A1 of A1 chosen plus this particular value. Similarly, A2 will be $A_2 + \frac{30}{80}$. RAP chosen minus RAP stockpile and A3 will be $A_2 + \frac{20}{80} \times RAP_{choosen} - RAP_{Stockpile}$

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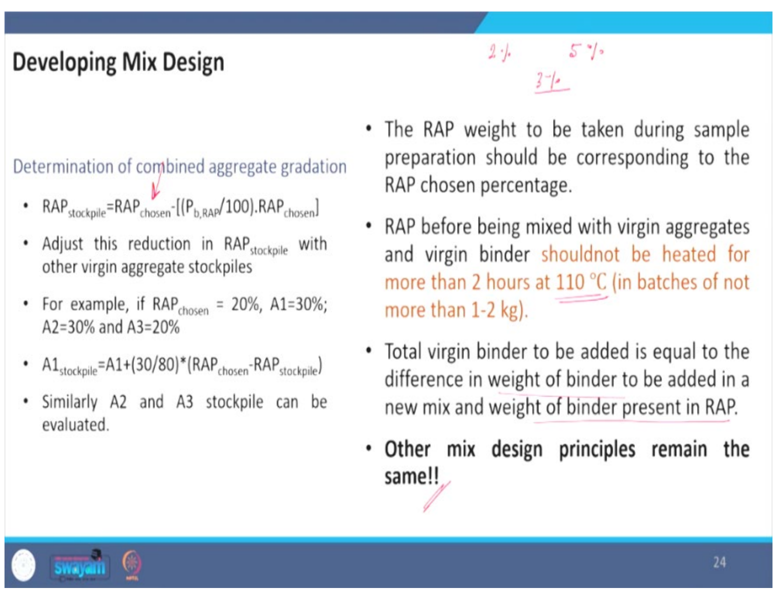

Alternatively, We can do the straightforward calculation, that when we are doing the gradation, we can at the initial stage use the stockpile value and then determine the value of A1 A2 and A3 instead of back calculating and adjusting the gradation.

Then during the laboratory mix design, we have to ensure that we are not heating the RAP beyond 110 degree Celsius for more than two hours because this can cause generation of flames and excessive aging of the RAP binder. And then total version binder to be added is equal to the difference in weight of the binder to be added in the new mix and weight of the binder present in RAP.

Well, this is very straight forward, we already know. For example, if the RAP binder is 2 percent is available and the optimum binder content is 5 percent then we only have to add 3 percent virgin bitumen to make the mix which is of course a very straight forward. Well, the other mixed design principles remains the same that we have discussed for hot mix asphalt that is preparation of mix, analyzing the volume matrix doing the performance testing and so on.

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So, with this we complete the mixed design concepts related to RAP. And some of the ending notes are, some of the pictures which I will show from typical, from a few site visits carried out in India. Now, you have to remember that though we are discussing about increasing the quantity of RAP but there are challenges, especially, related to the plant operation. Because RAP you cannot heat directly to elevated temperature.

So, for example, in a batch mix plant, we have heating drums where aggregates are exposed directly to the flames at very elevated temperatures and this is not permissible for RAP. So, there are adjustments which are done, sometimes, in the plant. Or if these adjustments cannot be done then we have to restrict the percentage of RAP to be used in the mix design.

So, some cautions have to be exercised before we can successfully implement higher dosage of RAP in the construction of bituminous mixes. So, this is one example where you see, what they have done. They have made an arrangement in the drum where the RAP comes somewhere in the middle portion of the drum and it is not directly exposed to the flames rather it moves only at the periphery of the drum. So, it is not direct exposure. And this system is applicable; they have made the system for only coarse RAP, the reason being the coarse RAP has lower binder content.

If they would have inserted even fine RAP here, this could lead to choking of the drum which is not desirable. And therefore only the coarse RAP is heated in this form. The fine RAP is basically taken in this conveyor belt and it is taken through the hot elevators and it is directly sent to the pug mill for mixing with the other materials.

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So, here you can see this is the cold RAP fine and this finally goes into the pug mill for mixing. This is an example of one typical plant.

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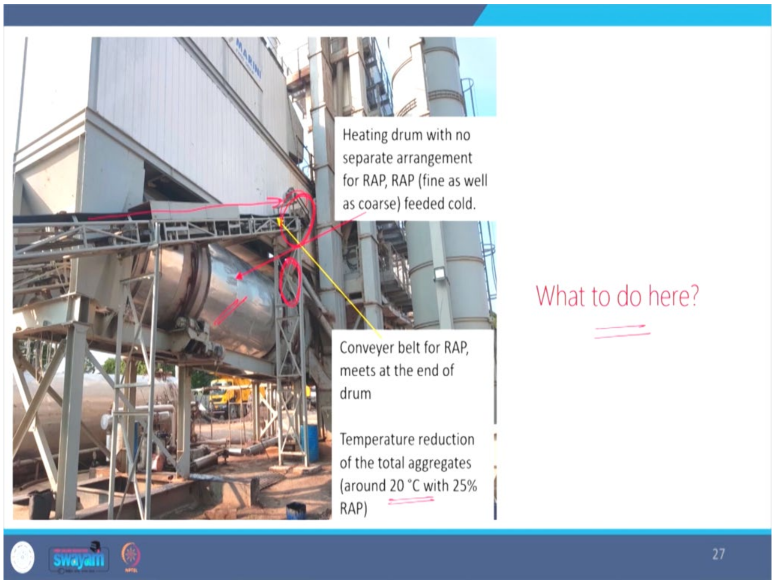

This is an example of another typical plant. Here basically, they had only one conveyor belt for coares as well as fine RAP and they were not subjected to any heating mechanism. So, this drum is used only by the virgin aggregates and this particular conveyor belt is used to transfer the coarse and the fine RAP mixed together which meets the other aggregates at the end of the heating drum. So, it was found that once this heated aggregate meets this cold RAP aggregates at the end of the heating drum, the temperature of the mix reduces by around 20 degree Celsius, considering that the RAP used was 25 percent.

So, the question is what to do here? Then we have to think of other mechanisms may be using rejuvenators, may be heating the aggregate, super heating the virgin aggregates using additives such as warm mix additives to prepare a proper mix having similar workability and so on. So, there are other aspects which need to be looked at in the mixing plant before exercising the use of a higher dosage of RAP.

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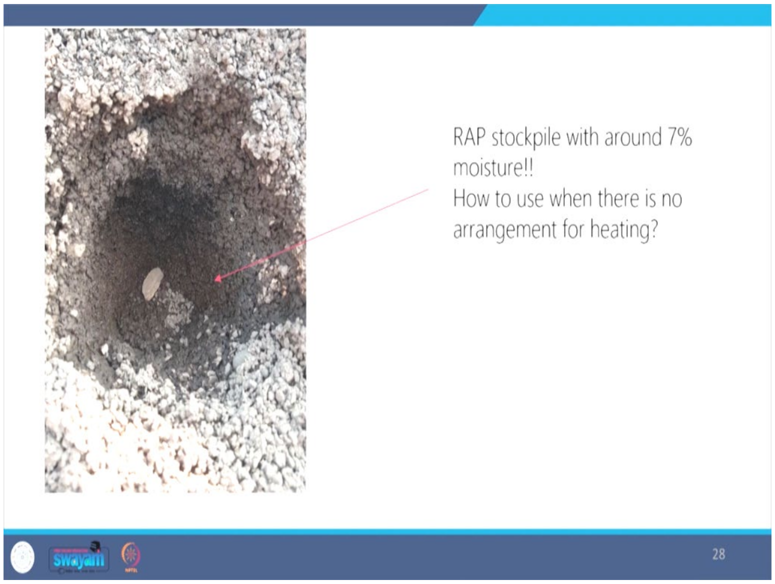

Another problem is stockpiling of RAP. Unlike aggregates, we cannot allow the RAP to be exposed to large amount of moisture. Because, moisture retainment is very huge in case of RAP. And we have to remember that RAP are not typically heated to higher temperature. So, moisture cannot be removed very easily as it can be removed from virgin aggregates and therefore RAP stockpile should be done using proper shades so that RAP is not exposed to a large moisture content. Otherwise this RAP will become non-usable.

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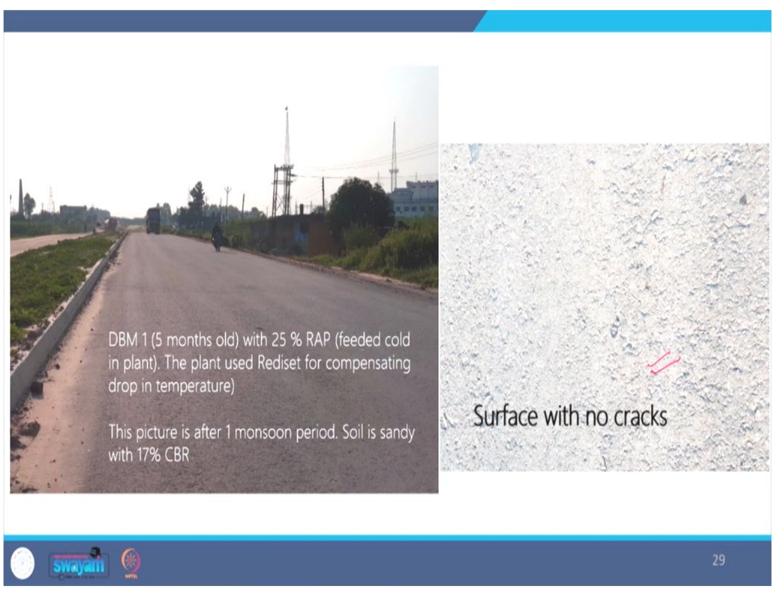

Well these are some pictures taken from one of the section where they constructed a DBM mix dense bituminous macadam, a binder course used in India with 25 percent RAP and this was feeded cold surprisingly. And they used ready set to have a uniform mixture and to have more college distance, so that the temperature drop could be minimized.

And this picture was taken after one monsoon period and I visited this site and we observed no distresses in the field. And you can see that this is a typical surface a picture which I took with no surface cracks. And we are waiting like how this particular section will perform in the future when it is further overlaid with a wearing course.

So, we end here discussing about the mix design of RAP. And we have covered various aspects related to the mixed design and I hope that this presentation was useful to you. And in the next presentation we will talk about the mixed design concepts for cold bituminous mixtures. Thank you.