Pavement Materials

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Lecture 42

Hot Recycled Mixtures (Part 1)

Hello friends. If you remember in the last class, we have discussed about the mix design steps related to MARSHALL and SUPERPAVE MIX DESIGN.

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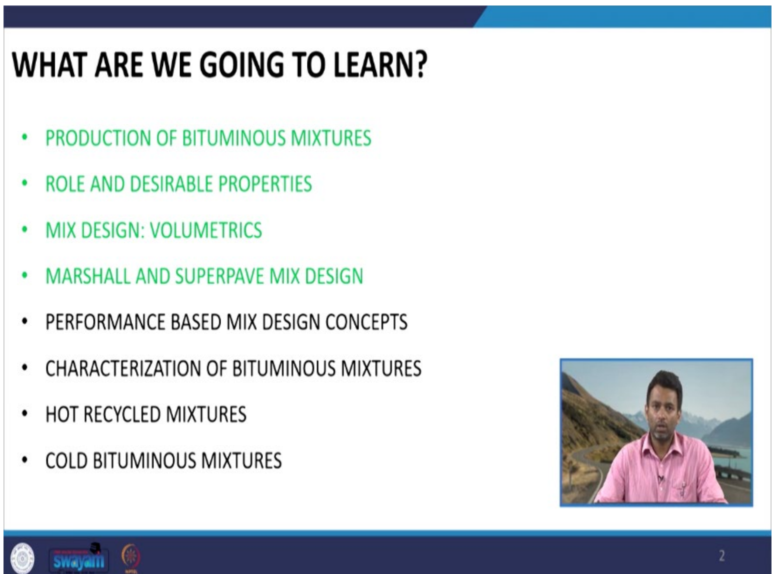

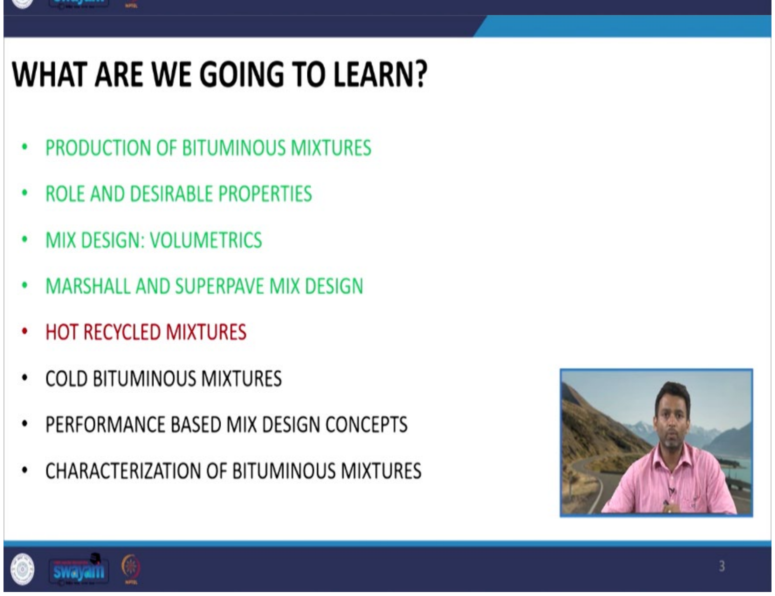

And we are supposed to start discussing about performance based mixed design concepts from today's class.

However, it just appeared to me that it is better to first discuss about hot recycled mixtures and cold bituminous mixtures before starting performance based mix design concepts and further the characterization of bituminous mixtures. So, I think the performance based mix design concepts will also include the concepts related to performance based mix design of recycled mixtures as well.

So, it will be more rational to first discuss about hot recycled mixtures and then we will shift our discussion towards performance based mix design concepts. So, I have just altered the content in this particular way that today we will discuss hot recycled mixtures followed by cold bituminous mixtures. And then we will talk about performance based mix design concept and this will be followed by our final discussion on characterization of bituminous mixtures under this particular module.

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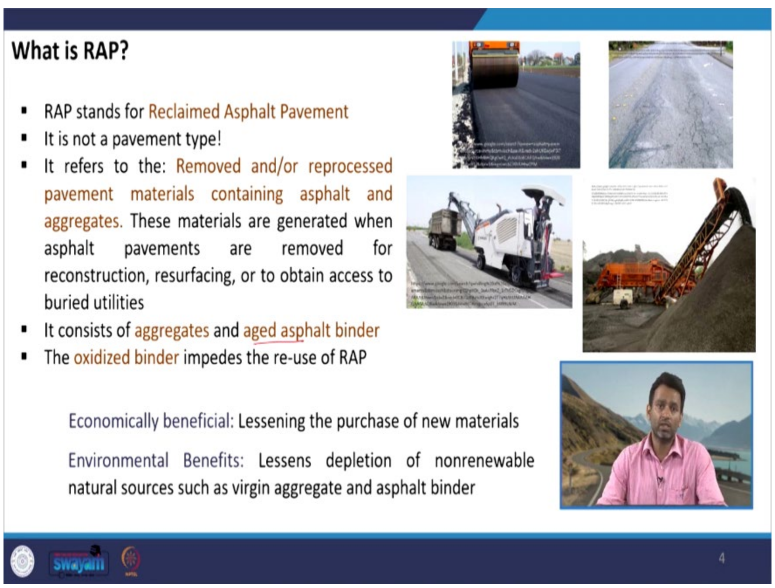

So, when I say hot recycle mixtures, I am basically talking about something which is popularly termed as RAP. So, RAP stands for reclaimed asphalt pavement. And what do we mean by reclaimed asphalt pavement it is not basically a pavement type as the name might indicate, it says reclaimed asphalt pavement but actually it is not a type of pavement rather it refers to removed or and reprocessed pavement materials containing asphalt and aggregates.

So, these materials they are generated when the existing asphalt pavements which are in service, they are removed, maybe for reconstruction or resurfacing or to obtain access to buried utilities. So, when we construct a pavement, it appears to be a smooth surface a new surface without any distresses.

Over a period of time when traffic starts moving over it when the pavement is subjected to load and environmental conditions, we start observing distresses on the pavement and the time period will arrive when the existing surface will no longer be in functional condition, then most of the times we have to remove the existing surface and lay a new bituminous mixture layer over it.

So, the removal can be done using different types of machineries, we have scrappers which will just scrap the existing material and then it will be dumped into the truck and it will be further taken to the plant for stockpiling. We can also break the pavement directly using probably a bulldozer and then further these broken chunks will be subjected to crushing and then it will be finally stockpiled in the mixing plant.

So, this stockpile material which you are seeing it refers to the reclaimed asphalt pavement which we also called as RAP, just to make you comfortable, I have just some sample of RAP with me. Now, I want to show it to differentiate how the rap differs in appearance from the conventional granular materials or the aggregates about which we have been discussing in our presentations.

So, with me, I have some aggregates if you are able to see it, you will see that these are virgin aggregates and it is not coated with any form of binder, this is in its natural form. And then we have some materials which will appear somewhat dark brown to blackish color to you depending on the edge of the pavement depending on the source of the material.

So, this is basically a reclaimed asphalt pavement material. Here we have aggregates in my hand I have aggregates which are coated with binder and this binder has been edge during its service life and therefore, the color has turned from the conventional black color of the bitumen to something which appears to be more of dark brown color, or you can say faded black color.

So, the material which I just showed you the RAP it consists of aggregates and aged asphalt binder. Now, the question here is that if we already have a material and we are talking about sustainable construction, we are talking about environmental friendly construction, then what is the problem in reusing the same material again and again in the pavement. The problem is that the oxidized binder, the binder which has undergone short term and long term aging present in the existing pavement, it will be very stiff in nature and because of this higher stiffness of this oxidized binder.

If we try to use it again and again, this higher stiffness can lead to distresses such as fatigue cracking. And that is why the presence of this oxidized binder it impedes the reuse of rap and this is a more challenging aspect to handle that we are trying to reuse rap again in the pavement. However, reusing the RAP in the pavement is of course, economically beneficial.

Because if we are reusing the same material again for new construction, we are reducing the need of acquiring new materials. And this new materials also includes virgin aggregates as well as asphalt binder, which are a nonrenewable energy resources. Also, it is environmental friendly because as I said, it reduces the use of non-renewable natural resources like Virgin aggregates and asphalt binder.

So, definitely when we think of RAP, it is reuse is beneficial as it gives us benefit in terms of cost as well as environmental friendly solution for construction of pavement. However, as I said, there are challenges related to it and the primary challenge is the presence of the oxidized binders. So, high percentage of replacement in new construction can be very challenging and researchers are continuously trying to seek answers to this challenging question on how to maximize the use of RAP for the construction of bituminous pavement.

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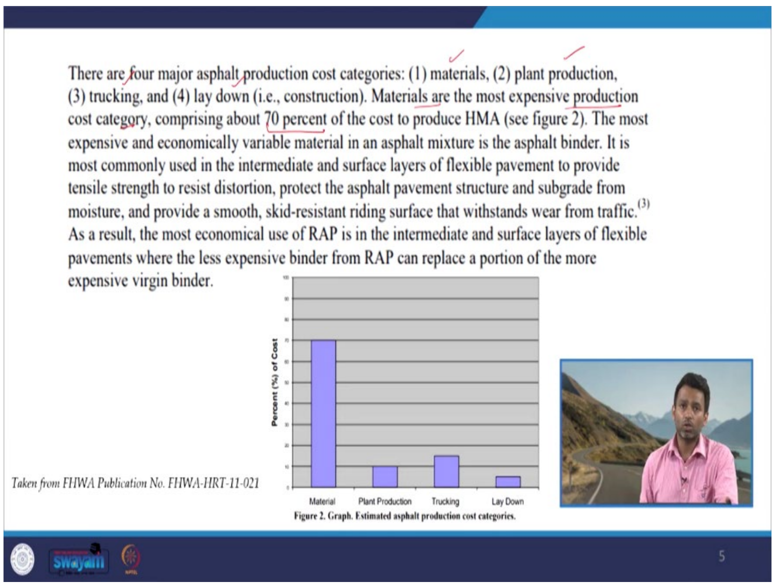

This note has been directly taken from one of the Federal Highway Administration publications which states that there are four major production cost categories this slide is basically to tell us about the importance of replacing the virgin materials with the rap material.

So, if you see the cost of production of bituminous mixture, this cost includes material cost, production costs, planned production cost, transportation cost, which is trucking cost and then lay down cost that is the construction cost. Now, if you try to compare all these cost categories, we see that materials are basically the most expensive production cost category, which comprises of almost 70 percent of the cost to produce the hot mix asphalt and in this particular hot mix asphalt, the presence of bitumen, which is an economically variable material and is also a very important component of the bituminous mix.

Now, if we try to use RAP again, this will reduce the need of this expensive material that is bitumen. On the other hand, it also reduces the need of acquiring virgin aggregates, thus making the cost of construction less and thus making the construction and environmental friendly.

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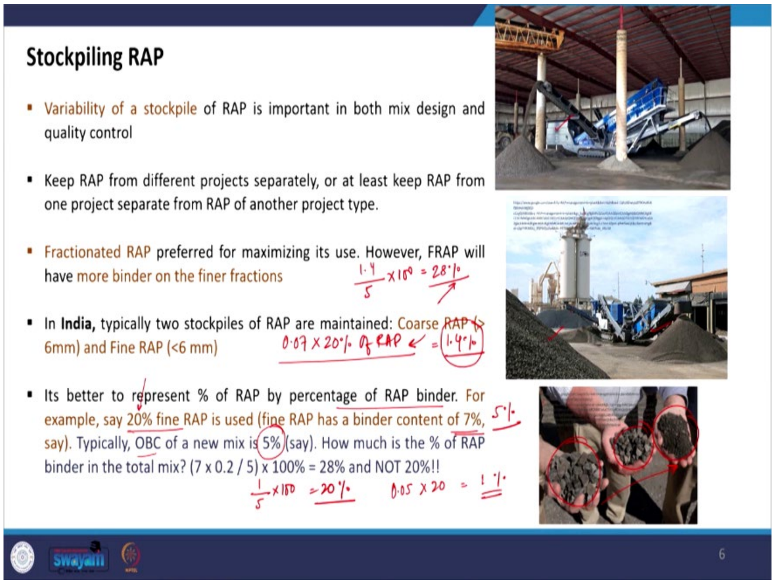

Now before we talk about how to reuse RAP, we talk about the mix design concepts and how it is different from the conventional mix design concepts of the HMA it is important to understand few aspects related to handling of RAP. So first, we talk about the stockpiling of RAP, that how the RAP is stockpile. Once it is acquired from the existing pavement it can be either in the form of crushed material, it can be either in the form of big chunks, which will be further subjected to crashing. So, crashing is an important step after we acquired the RAP from the existing pavement.

So, once we have acquired the RAP material in the crush form, there will be variability of stockpile depending on from where we are taking it from how many sources we are targeting to take the RAP because for a given hot mix plant its, it will not be very feasible to make multiple stockpiles of RAP from different sources as it will acquire a large space.

Therefore, the variability which is associated with the stockpile of RAP is important and this will finally lead to variation in the mix design as well as in quality control. So, it is generally suggested that we have to keep RAP from different projects separately. So, if we are trying to acquire RAP from five different projects, they ideally should be stored separately.

But if that is not feasible probably due to the space constraint or management constraint, then at least RAP from one type of pavement should be separated from another type of pavement when I mean type of payment. For example, if I am acquiring a RAP from let us say a parking lot, and I am acquiring a RAP from a high speed or the National highway let us say.

So, these both the materials are designed for different purpose which means the gradation will be different, the type of binder may be different, the purpose of design might be different, so, the volumetric might be different. So, therefore, if we try to mix them together, this will lead to large variability in the final properties of the RAP in that particular stockpile.

So, what we can do if we have three different RAP from national highways, they can be kept together considering or assuming that the variability in the production will not be very different, because all the three facilities are high speed facilities meant for movement of trucks, but as I said RAP from a project for example, a parking lot definitely kept separately to the RAP which we acquire from national highways or state highways.

Now, once we are crushing the procured RAP material, it is better to fractionated them. And it is suggested that more number of fraction we make when I say fractionating RAP, I mean I am separating different sizes maybe I have 26.5 to 19 mm kept separately 19 mm to let us say 4.75 mm kept separately and then 4.75 mm to further lower sizes kept separately.

So, we can create more number of fractions, which is preferable to maximize its use. However, we have to remember that when we fractionate the RAP, the binder goes more towards the final material or the finer fractions, because of higher specific surface area.

The finer materials will have more bitumen in comparison to the coarser fraction. So, this has to be taken into consideration when we are reutilizing the RAP for mix design and we have to do the calculations accordingly. For example, what we have seen typically in India that in most of the plants when they keep two different stockpiles usually one is a core stockpile of RAP which is 6.3 mm plus and then we have fine stockpile of RAP which is 6.3 mm minus.

So, usually on an average it is found that course RAP has a residual binder content of about 2 to 3 percent and while the fine RAP can have a residual binder content of about 6 percent. Considering that the optimum bitumen content is somewhere around 5 to 5.5 percent, which is typically used for the production of wearing course or binder course we use in India.

This tells us about the crushing operation, then we have the stockpiling of RAP and this is how the final RAP looks like and you see once you go towards the final fraction the color becomes more darker indicating that you have more residual binder in the final fractions in comparison to the coarser fractions this I already mentioned that in India typically two stockpiles of RAP are maintained.

I also told you about the typical percentages of residual binder we have observed in the, Coarse and find fractions of RAP from different projects. Now, one important point when we talk about the mix design or in general about the concepts related to recycled asphalt pavement is that when we say that we are trying to reutilize 10 percent RAP or 20 percent RAP we should ideally mean that it is the percentage of RAP binder and not the RAP in total.

For example, let us say in a project we want to use 20 percent Fine RAP. So, what do you mean by 20 percent Fine RAP? This is something which we have to discuss. So, in a project we want to reutilize the RAP, which means I am using 80 percent virgin material and 20 percent Fine RAP and let us say after doing a laboratory analysis we found that the Fine RAP has a binder content of 7 percent.

So, when I say 7 percent which means it is 0.07×20 percent of RAP. So, this is the percentage of total binder we will have in the new mix that is with 80 percent virgin material and 20 percent RAP. So, out of the RAP this is the percentage of binder we will get. So, this is how much 1.4 percent, let us say that in the typical mix design which we do for the Bituminous Coarse.

The optimum binder content is somewhere around 5 percent, that is the optimum binder content of the total mix. So, then how much is the percentage of RAP binder in the total mix. So, the RAP binder is 1.4 percent, if you take 1.4 and you try to see its proportion in the total binder which is 5 percent $\times100$, this gives us a value of 28 percent which means, we have used 20 percent Fine RAP, but the RAP binder in the total mix is 28 percent.

And this is what we should indicate is the amount of RAP we are using. So, typically, the amount of RAP should be represented in terms of percentage of residual bitumen rather than the actual percentage of RAP we are using in the mix, because it is a binder which will play a critical role in influencing the mix design related to the production of RAP.

So, typically it is seen that if you know the residual binder is almost similar to the optimum binder content which we use in the RAP then the percentage of RAP bulk will be also equal to the percentage of RAP binder, let us take the same example that I want to use 20 percent RAP. And in this particular RAP, which I am using the binder content is let us say 5 percent.

So, which means that the binder coming from, RAP is equal to 0.05×20 percent. So, this is equal to 1 percent and now, let us say the optimum binder content of the new mix typically is 5 percent. So, what is the contribution of RAP binder in the total mix it is $\frac{1}{5} \times 100$ = 20 percent.

So, 20 percent RAP we have used 20 percent is the RAP binders so there is no problem. However, if the binder content is too low or too high in comparison to the total percentage of RAP, then the actual RAP binder percentage should be calculated and should be used as the actual RAP percentage in the mix.

In this presentation how we will go that will try to ask questions related to RAP and we will try to answer them because ultimately we know how the mix design is done which we have already discussed. So, we just need to see the difference of the mix design of a conventional HMA in comparison to the mix design when we are using RAP in the mixture.

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Which Properties of RAP do I need to Determine?

Depends on the % of RAP to be used

For all levels of RAP:

- Binder Content:
  - Ignition oven (AASHTO 308);
  - Solvent extraction (AASHTO T 164)
- Gradation: Aggregates after extraction procedure is subjected to sieve size analysis (AASHTO T 30)

- Use solvent extraction method if properties of RAP binder is to be found
- Ignition oven may cause degradation for some aggregate types (due to high temperature)

For higher RAP% (>25%):

- Physical properties of RAP binder

- Bulk specific gravity of RAP aggregates ($G_{sb,RAP}$) is required as input in the mix design
- Determination is not straight forward. RAP aggregates are quoted with bitumen
- In a mix using 25% RAP, an error of 0.04 in SG can effect VMA of mix by 0.5%

$$VMA = \left[1 - \left(\frac{G_{mb}}{G_{sb}}\right)(1 - p_b)\right] \times 100$$

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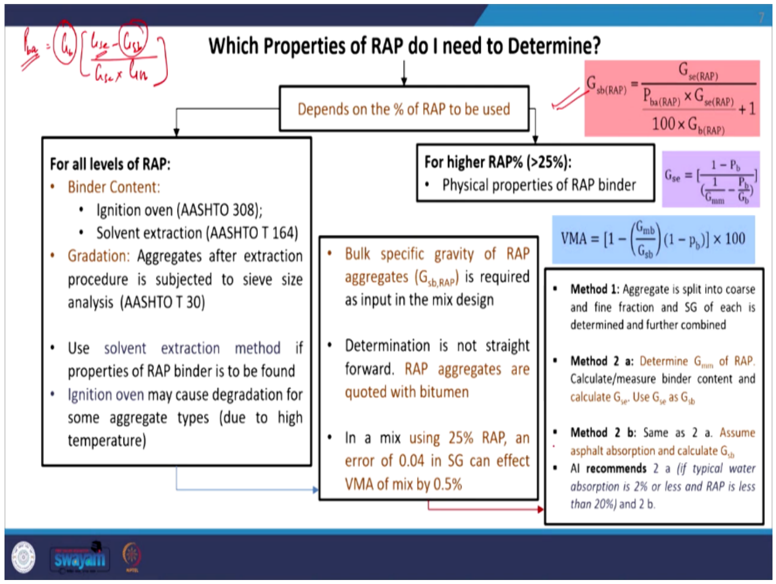
$$G_{sb(RAP)} = \frac{G_{se(RAP)}}{\frac{P_{ba(RAP)} \times G_{se(RAP)}}{100 \times G_{b(RAP)}} + 1}$$

$$G_{se} = \left[\frac{1 - P_b}{\left(\frac{1}{G_{mm}} - \frac{P_b}{G_b}\right)}\right]$$

$$VMA = \left[1 - \left(\frac{G_{mb}}{G_{sb}}\right)(1 - p_b)\right] \times 100$$

- **Method 1:** Aggregate is split into coarse and fine fraction and SG of each is determined and further combined
- **Method 2 a:** Determine G_{mm} of RAP. Calculate/measure binder content and calculate G_{se}. Use G_{se} as G_{sb}
- **Method 2 b:** Same as 2 a. Assume asphalt absorption and calculate G_{sb}
- AI **recommends** 2 a *(if typical water absorption is 2% or less and RAP is less than 20%)* and 2 b.



So, which properties of RAP do I need to determine? Well, this depends on the percentage of RAP I am intending to use in the final project or the in the final mix, irrespective of any percentage we use these properties we have to determine irrespective of any percentage ranging from more than 0 to let us say even 100 percent RAP you are targeting.

So, these properties you have to determine which are these properties, one is the Binder content. So, mandatorily we have to find the amount of binder present in the RAP source. There are various methods I am not going to discuss about the procedures of determining the binder content or extracting the bitumen from the RAP, but I have listed the CODEL provision and they can be referred.

So, the binder content can be determined by different methods, the two more prominent methods or popular methods are the ignition oven method whose guidelines are given in AASHTO 308. And then we have solvent extraction method for which we have to follow AASHTO T 164. In the ignition oven method, one of the problem is that actually in the ignition oven method, we heat the RAP to very high temperature.

So, we are trying to burn the binder from the surface of the aggregates. So, that when we take the difference in mass before and after we will get the percentage of RAP binder. But it has been found that in some of the aggregate sources, the ignition oven may also degrade some of the aggregate types because of the very high temperature we are using. And this method is also not suitable.

In case we are also interested to determine the properties of the RAP binder because here everything the binder is burned. So, it is not no longer available to us to determine the properties. So, this method cannot be used when we are trying to determine the property of the RAP binder as well.

The other method is the solvent extraction method in which we basically submerge the RAP sample in a solvent which has the capability of dissolving the bitumen and then using a centrifuge extractor. We can remove the dissolved bitumen in the solvent separately and then the aggregates are separated and then we can easily do the calculation to determine the percentage of binder in the RAP material.

So, binder content we have to determine irrespective of any RAP percentage we are using, we also have to determine the gradation of the aggregates because in the mix design by now, we already know that in the mix design gradation plays an important role. So, gradation we have to determine after extracting the bitumen.

So, we will first separate the bitumen using a extraction method it can be an ignition oven extraction method, it can be a solvent extraction method and then when we get the residual aggregates the remaining aggregates we will just subject it to sieve analysis. And then we will determine the gradation of the RAP source or the RAP aggregates.

And I just forgot to mention that the advantage of solvent extraction is that after extracting the bitumen from the RAP the solvent is further removed, because now bitumen is mixed with the solvent. So, solvent is further removed and the binder which will get can be subjected to further testing.

So, using this method we can also determine the properties of the residual RAP binder for all levels of RAP these are the properties which mandatorily should be determined, while for higher percentage of RAP when I say higher percent, I mean, more than when I am intending to use more than 25 percent of RAP in the bituminous mixtures.

We also have to determine the physical properties of the RAP binder. This means that if we are using less than 25 percent of RAP, we only need to extract or only need to separate the binder from the aggregate surface. Determine the binder content and determine the aggregate gradation and then further some of the properties of RAP.

But, when we are using higher percentage that is more than 25 percent. In addition to these activities, we also have to determine the physical properties of the RAP binder and later, we will discuss that this is important to use the blending charts and I just do not want to confuse you right now, we will discuss what blending charts are in further slides.

Now, we know that what properties we have to determine coming to all levels of RAP again after you get the gradation you have to determine some of the properties of aggregates so that we can use it in the mix design. If you remember, mix design once we have the aggregates of the RAP we will require its bulk specific gravity, which is directly used as an input in the mix design.

For example, in VMA calculation, if you remember the formula, we have a Gsb as one of the parameter and Gsb of the mix is basically a harmonic mean of the Gsb of different fractions. So, you have fractions of virgin aggregates, you have fractions of RAP aggregates and therefore Gsb of RAP aggregate is required to determine the Gsb of the entire mix or the new mix, which I am going to make.

So, bulk specific gravity of RAP aggregate is required as an input in the mix design. But the determination of bulk specific gravity of RAP aggregate is not as straightforward as we have discussed about virgin aggregate. So, this aspect also needs to be analyzed critically before we can complete the mix design process.

So, why it is not very straightforward, because in the RAP aggregates are coated with bitumen. So, it becomes challenging that how do we determine the bulk specific gravity of the RAP aggregates and, why it is important why it is important to determine? Because as I said that bulk specific gravity of aggregate is directly related to the volumetric properties such as VMA.

So, if you have a mix with 25 percent RAP, so, this is an observation which has been made, we can also prove this using some examples and calculations. So, in a mix with 25 percent RAP an error of 0.04 in the specific gravity can affect the VMA of the mix by 0.5 percent. I can give you an example just to explain the importance of specific gravity or some error which we make in the determination of specific gravity.

Let us say that we have any bituminous mixture and let us say that the actual specific gravity bulk specific gravity of the aggregate is 2.65. And by mistake we did some error and the error was very small, let us say of the order of 0.04 only and by mistake we found that the specific gravities or we measured the specific gravity is 2.61.

Now the question is this small error, how important is it with respect to the volumetric parameters? For example, let us talk about VMA. So, let us assume few things let us assume that the mix is prepared with 5 percent binder content in the mix and let us say that the bulk specific gravity of the mix is 2.4. So, this we have fixed.

Now we know the formula of VMA is what $(1 - \frac{G_{mb}}{G_{sb}}) \times (1 - P_b) \times 100$. If you remember, so I am just plugging the first the actual value here $\frac{2.4}{2.65} \times (1 - 0.05) \times 100$. This is the actual value which we should get. And this if you do the calculation you get as 13.96 percent.

But let us see that by mistake we did that small error and what it resulted what it will result in? So, VMA now becomes (1 - 2.4) this is 2.61 now, (1 -0.05) ×100. If you do this calculation, you get the value is 12.6 percent. So, you see, just as 0.04 of error in the determination of specific gravity has resulted in reduction of VMA by about 1.36 percent.

Now, this 1.36 percent is very significant for us why, let us say that for a nominal, given nominal maximum aggregate size, our codal specification said that the minimum VMA required is 13 percent. So, we did the mix design we are doing the calculation according to the actual value the VMA is 13.96 percent which satisfies the minimum VMA criteria.

But, our mistake of 0.04 in the determination of specific gravity has given a wrong value of 12.6 percent by looking at which we will reject the mixed design which should not have been done. So, this tells us or gives us some idea about the importance of specific gravity and this is what is written here that when we are using 25 percent RAP or more this error of 0.04 can affect the VMA by about 0.5 percent, which can be significant in terms of volumetric.

Now, the question is how do I determine when I say it is not very straightforward, then how do I determine the specific gravity of the RAP aggregates. So, there are three methods that have been outlined in MS 2. The method one is very straightforward, but is not usually used.

The method is that once you have removed. Let us say you have used the ignition oven method you have removed the binder from the aggregate surface, you take that residual aggregate and you split it into coarse and fine fraction this we know that how to determine the specific gravity we will separate into coarse and find fraction and further we will determine the individual's specific gravity.

And then we will combine the specific gravity depending on the proportion but this method is not typically used for the determination of specific gravity. Then we talk about method 2a, the method 2 a, says that first you determine the GMM that is the theoretical maximum specific gravity of RAP.

So, RAP is a bituminous mixture for which we can easily determine the Gmm value. So, you determine the Gmm of the mixture of RAP using the GMM and once we know the binder content, we can easily calculate Gse if you remember the calculation of Gse is shown here. So, Gse is a function of the amount of binder and the theoretical maximum specific gravity.

Here the value of Gb for RAP is typically assumed as 1.04. Considering that this is an oxidized binder, and it will be a little stiffer than the virgin binder, which typically has a specific gravity of around 1.02. So, you determine Gse using this particular formula, and use Gse as Gsb.

So, this is again something very interesting to note here. So, they are suggesting use Gse as Gsb. But we all know that Gse is greater than Gsb both are aggregate properties, both are specific gravity of aggregates, but the consideration of volume is different in both the cases and Gse is higher than Gsb.

But as suggested in MS 2 if the amount of RAP in the final mix, which you are going to use is less than 20 percent then using Gse as Gsb will not cause very large error in the bulk mixture, because in the mixture, it is only 20 percent RAP 80 percent are virgin materials. So, if you have done small assumption of taking Gse as Gsb for that 20 or lesser amount of RAP, which you are going to use, then this error will not cause a significant error in the volumetric calculation of the bulk mixture.

But if the amount of RAP is more than 20 percent, because once you keep on increasing the RAP percentage this error will keep on accumulating and the error of the bulk mixture will become large. So, if the RAP is more than 20 percent and if the absorption of the aggregate is also more than 2 percent. Then they suggest to use method 2b and what is done in method 2b. here we will follow the steps of method 2a that is determination of Gmm. And then calculate of Gse and further, we will go one step further and we will assume some bitumen absorption for that particular source of RAP.

So, looking at the historical mix design, which have been done in that location, the engineer will be aware about the typical water absorption of the aggregate which they obtain or they have used previously in the mix design.

So, looking at the previous records, we can assume some value of the bitumen absorption for that particular source of RAP and this bitumen absorption along with the value of Gse can be used to calculate Gsb and this also we know, we have seen that the formula for absorbed bitumen is Gb into Gse minus Gsb divided by Gse into Gsb. So, this formula we have already derived.

So, you assume PBA based on the previous records, you know Gse from the previous measurement and calculation, Gsb we are going to determine Gb I am assuming is 1.04. So, using this formula, finally, which can be converted to this form, we can calculate the value of Gsb of RAP. So, this method, this is the method 2b to be used when the RAP binder is more than 20 percent in the mix.

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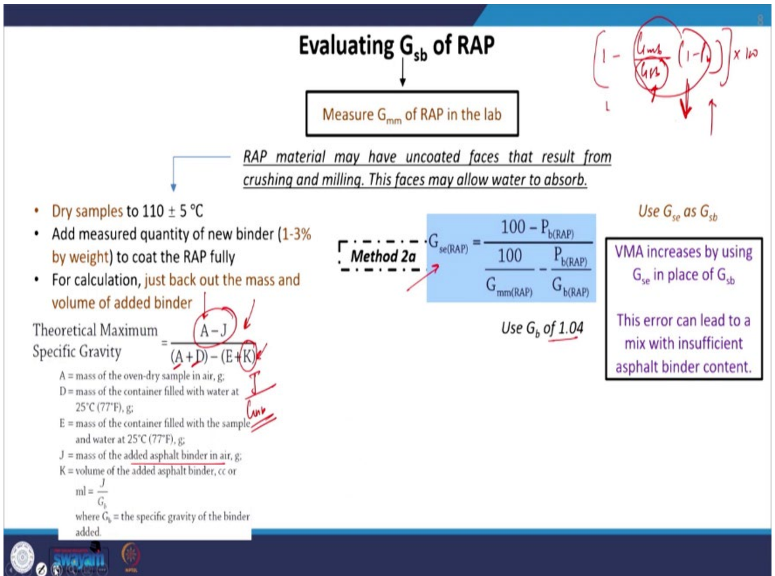
Evaluating G_{sb} of RAP

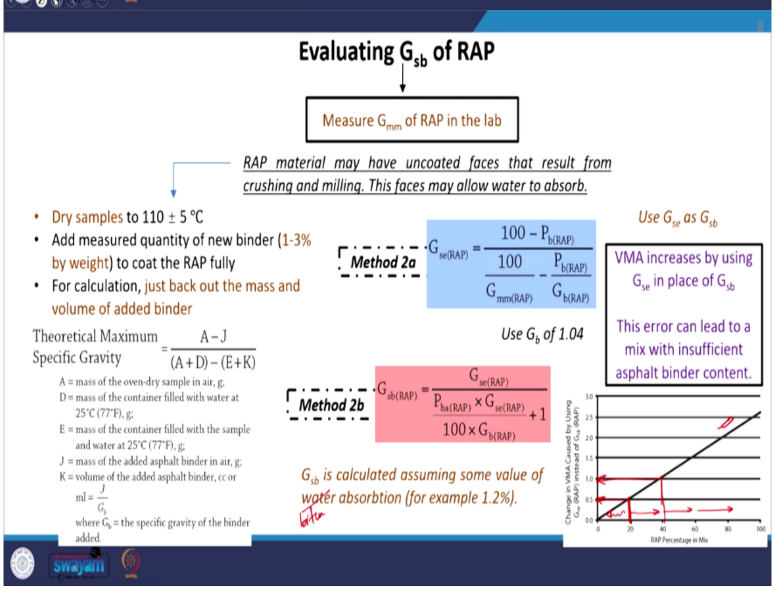
Measure G_{mm} of RAP in the lab

RAP material may have uncoated faces that result from crushing and milling. This faces may allow water to absorb.

- Dry samples to 110 ± 5 °C
- Add measured quantity of new binder (1-3% by weight) to coat the RAP fully
- For calculation, just back out the mass and volume of added binder

$$\text{Theoretical Maximum Specific Gravity} = \frac{A - J}{(A + D) - (E + K)}$$





Now, when I said in method 2a, that you have to determine the Gmm of the RAP and using the Gmm and percentage, residual bitumen, we can calculate the Gse of RAP. The determination of Gmm of RAP is also not very, very straightforward, like the conventional method which we use for hot mix asphalt, well, the method remains the same, but some additional steps needs to be performed.

So, if you try to imagine a RAP source and you try to imagine how RAP is acquired from the field, you will understand that RAP material may have some uncoated faces. And how this uncoated faces results it results from the crushing and milling operation. So, probably if the aggregate is crushed from this phase, then this material is removed.

So, this only you get this part as coated and this will be exposed phase of the RAP aggregate. And this phase may, allow water to absorb when because when you try to do Gmm in the RAP, you have to submerge the sample in water. So, when you are submerging the sample in water, this face may absorb some water and the measured value or the calculated value will have some error.

So, in order to avoid that, what we can do? We can add some measured quantity of virgin binder or new binder to the existing RAP sample. So, you get the RAP sample and you recoated with some new virgin binder taking approximately 1 to 3 percent of the weight and this is actually done only to coat the exposed faces. So, this use of 1 to 3 percent of additional new binder will assure that the entire surface of the RAP is coated with bitumen.

So, once you obtain the RAP material, you dry the material at a temperature of around 110 plus minus 5 degrees Celsius, add measured quantity of new binder and then perform the Gmm test as per specification which we have already discussed that is using a pycnometer or rice specific gravity method. And we will use the same calculation procedure, but in the calculation.

We have to remove this additional the weight and volume of the additional binder which we have added because we are interested in the Gmm of RAP and not in the Gmm of the new mix which has been made by adding this new binder. So, the theoretical maximum specific gravity can be calculated as follows. In this formula, if you remove this J and if you remove this K, the formula is similar to what we have discussed previously.

But you will see that we are now this is (A –J). So, what is J here? J is the mass of added as per binder in the air. So, (A –J) will give you the $\frac{\text{mass of the RAP aggregates in the air}}{A+D-(E+K)}$, where (A is the mass of oven dry sample in air+D is the mass of container filled with water at 25 degrees Celsius- (E+K). So, this K is subtracted and K must be the volume. So, this is equal to J by specific gravity of the new binder which we have added.

So, using this formula and I hope that since we have discussed specific gravity in detail very easily you will be able to understand that a how this formula has come up. So, using this formula the theoretical maximum specific gravity of the RAP can be determined. So, once you determine that calculate Gse and in Gse calculation as I said Gb will be taken as 1.04 use Gse as Gsb.

So, but you have to remember that substituting Gse as Gsb we are basically artificially increasing the value of VMA. Why is it so? Let me write down the formula again $(1-\frac{G_{mb}}{G_{sb}})\times(1-P_b)\times 100$. So, when you use Gse, you are basically increasing this value once you increase this value, this entire value will come down when this value reduces 1 minus this value increases.

So, basically, using a higher value of a specific gravity in place of bulk specific gravity will basically artificially increase the value of VMA and large increase is not desirable. So, you will see that when you use about 20 percent RAP, this error is only about 0.5 percent, but beyond 20 percent as you keep on increasing the percentage of RAP the error keep on increasing the change in VMA keep on increasing.

So, for example, for 40 percent RAP the change is almost about 1 percent which can be very, very significant. So, that is why it is suggested that method 2a can be used only when the RAP is lower than 20 percent. So, that we do not incur higher error in the volumetric calculation if we have higher percentage of RAP than method 2b has to be used.

So Gsb is calculated by assuming some value of bitumen absorption for now, this bitumen and using that we can calculate the value of Gsb.

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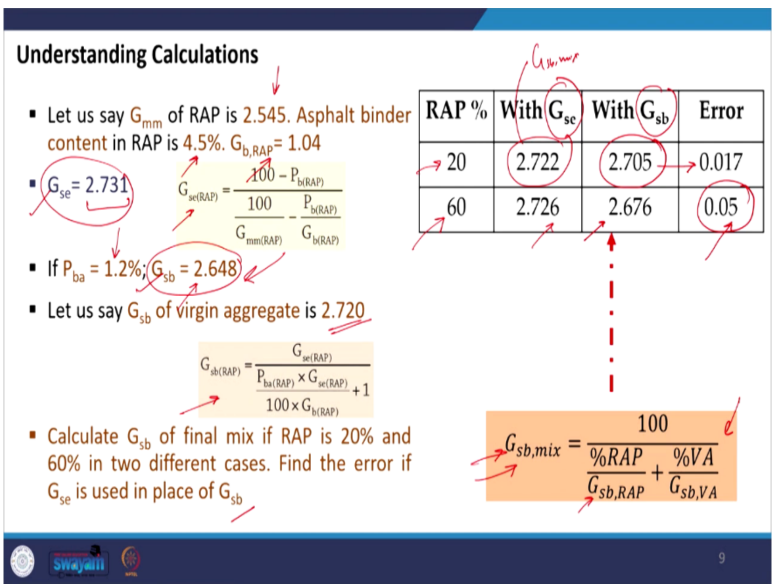

So, before we conclude let us just try to take an example and then try to see what we have discussed how the calculation is done. So, this is just an example let us say that the Gmm of RAP is measured as per the procedure we discussed and it came out to be 2.545. And then we have used some extraction method and Asphalt binder content in the RAP was found to be 4.5 percent and the specific gravity of RAP is taken as 1.04.

Then, using these values, I can calculate Gse of the RAP, if you put this just putting these plug these values in the given formula, you will get that the Gse is 2.731. Now, if you take that the percentage of absorbed bitumen is about 1.2 percent and we use this particular formula, you will get that Gsb is 2.648. So, here you are getting 2.648 and using Gse you are getting 2.731.

So, now, let us say that we are going to make a mix with different percentage of RAP samples and the virgin aggregate which we are using to produce the new mix has a specific gravity of 2.720. So, let us calculate the Gsb of the final mix, if RAP is 20 percent in the first case, which means 20 percent RAP and 80 percent virgin aggregate and 60 percent. In the second case, which means 60 percent RAP and 40 percent virgin aggregate, and we will also try to see this calculation both by using Gse and by using Gsb in place of Gsb, and then we will try to see how much error basically comes in.

So, how you will determine the Gsb of the mixture? It will be by taking the harmonic mean which is $\frac{100}{\frac{\%RAP}{Gsb_{RAP}}+\frac{\%VA}{Gsb_{VA}}}$. So, this is something which we already know. So, I have just done this calculation and this is the table which I generated that when I am using 20 percent RAP.

And if I use Gse in place of Gsb of RAP, the value of the specific gravity of the mix is 2.722. So, this is Gsb of mix. When I am using the Gsb which is 2.648 of the RAP in place of Gsb of RAP and calculate the Gsb of the mix I get as 2.705. This is when the RAP percentage is 20 percent. So, the error which is incurred is only 0.017.

On the other hand, if I am using 60 percent RAP, the error, which are incurred is about 0.05. And we have discussed previously that an error of 0.04 can cause error in the calculation of VMA, which can be very critical in the mix design process. So, we will stop here today and we will continue are discussing about the further concepts related to the mix design of RAP in the next presentation. Thank you.