Pavement Materials
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Lecture 46
Performance based mix design concepts

Hello everyone. In the last class, we have discussed about the mix design of cold bituminous mixtures. Today, we will start discussing about performance based mixed design concepts. So, we are not going to discuss in detail about the available guidelines. Basically, there are no guidelines specifically, but the steps which are followed by different state agencies.

Rather, we will discuss about the idea behind the performance based mix design and the steps which are the procedures which have been more popular in this direction of carrying out a performance based mix design of bituminous mixture.

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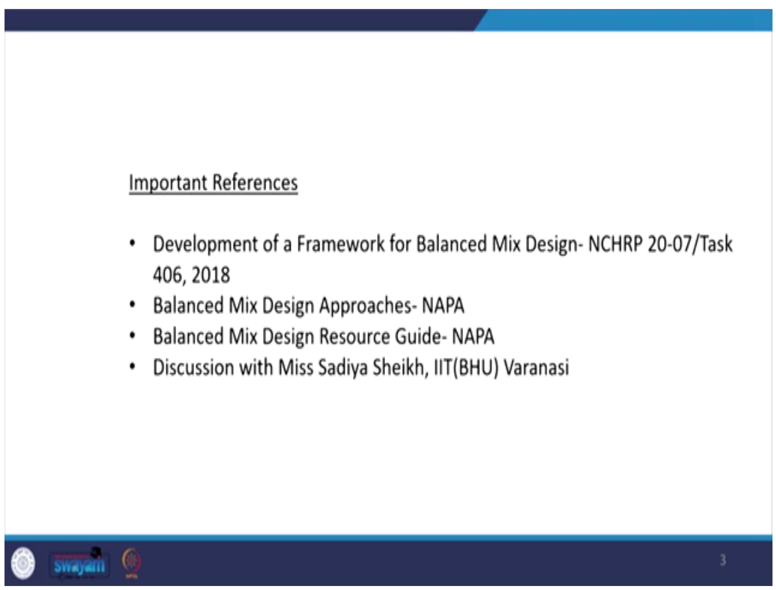

Some of the important references using which I have prepared this particular presentation. It includes the NCHRP report on development of a framework for balanced mix design. I have also used e-reference from the website of NAPA, on balanced mix design approaches and also one of the document published by Napa on balanced mix design resource guide.

I would also like to thank Miss Sadiya Sheikh who is a research scholar at IIT, BHU because she is also working in the area of developing a balanced mix design or performance based mix design. In one of these sponsored projects by NHAI with discussion with her many of my concepts, were also cleared and using which I was able to complete this particular presentation.

So, before we start discussing about the available approaches on performance based mix design or what we call as balanced mix design, let us try to understand why this, why the need has arise to go for performance based mix design. What is the need by now we all understand that the present mix design concepts, which are available, they are mostly based on volume metrics of bituminous mixes.

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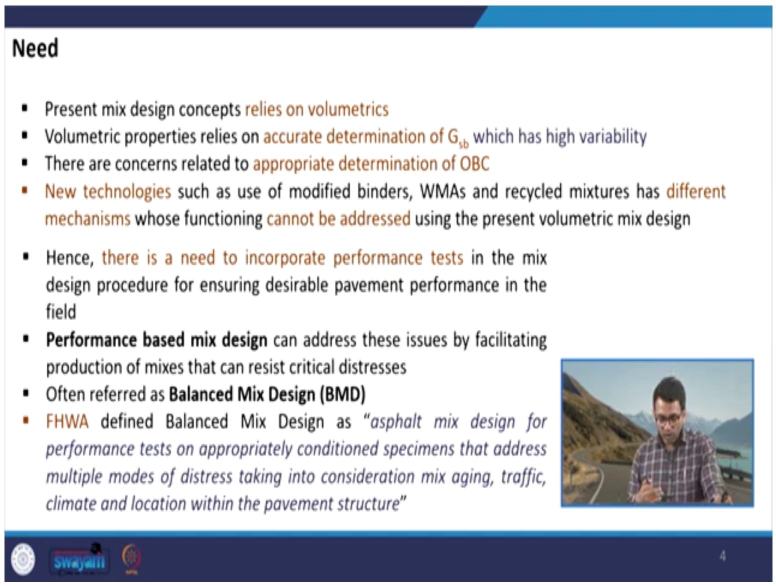

For example, typically, we use air void as the primary criteria, we determine the optimum mineral content at 4 percent air voids and then we check whether at this binder content, other parameters like VMA like voids filled with bitumen, the stability of the mix or the flow in the mix are they within the specified ranges and then we confirm this particular binder content as the optimum binder content.

If you recall the concepts and volume metrics which we have discussed, you will agree that the volumetric properties at large it depends on the accurate determination of the bulk specific gravity of the aggregates. And this is something which I have iterated many times during our discussion on volumetrics that accurate determination of specific gravity is very critical for the successful implementation of volumetric based mixed design.

So, the accurate determination of Gsb is very important. However, unfortunately, in the laboratory, the determination of Gsb is subjected to very high variability, specially for fine aggregates. And this also we have discussed that the reason is that, getting a appropriate saturated surface dry condition is very, very difficult and is has high variability.

Because of this reasons, there can be concerns related to appropriate determination of the optimum binder content. So, we are performing all our calculations based on the determined G somebody. If there is an error in the Gsb, the volumetric calculations can be wrong, if the volumetric calculations are wrong, the optimum binary content which we have determined may not be appropriate.

On the other hand, other than this particular aspect of variability in Gsb, the other issues are related to the use of new technologies and new materials in pavement construction. These days very commonly, we use various new materials, various additives for production of materials using which a bituminous mixture is produced.

For example, we have polymer modified binders. We have additives to produce warm mix asphalt, we are commonly using recycled mixtures of a construction of pavement and all these technologies, all these new mixtures which are prepared, they work on different mechanisms, which means the performance of these mixtures may not be directly related specifically to the volumetrics in the mixtures, which we are assuming for conventional hot mix asphalt and the functioning of these materials cannot be directly addressed, only by looking at the volumetric mix design.

And therefore, there is a need to incorporate performance tests in the mix design procedure just to ensure that once we produce the mix in the laboratory, this mix is going to give us desirable payment performance in the field. When I say performance test, I am basically indicating about the various distresses which are going to occur and the test which are carried out in the laboratory to address or to see the sensitivity of the mix to these particular distresses. So, performance based mix design can address these issues by facilitating production of mixes that can resist these critical distresses.

Now, before we start doing the mix design or any agency start doing the performance based mix design for a particular project for a particular location, they have to identify these critical distresses, maybe for a tropical region a low temperature cracking is not very important to us, but for a very northern climate in US, low temperature cracking will be the primary mode of failure of the flexible pavements. So, that becomes a critical distress for them.

So, for a given project for a given location for a given region, we have to identify these critical distresses and the performance based mix design should be oriented around these distresses which are anticipated in the field for that particular project. Well, the performance based mix design is also referred to as balanced mixed design. So, this is just the use of terminology.

Federal Highway Administration if we try to define what is a balanced or performance based mix design, they have defined balanced mix design as asphalt mix design for performance tests on appropriately conditioned specimen that addresses multiple modes of distresses taking into consideration various parameters such as mix aging, traffic, climate, location, within the payment structure, etc. These parameters should be considered while defining the approach of the balanced mix design.

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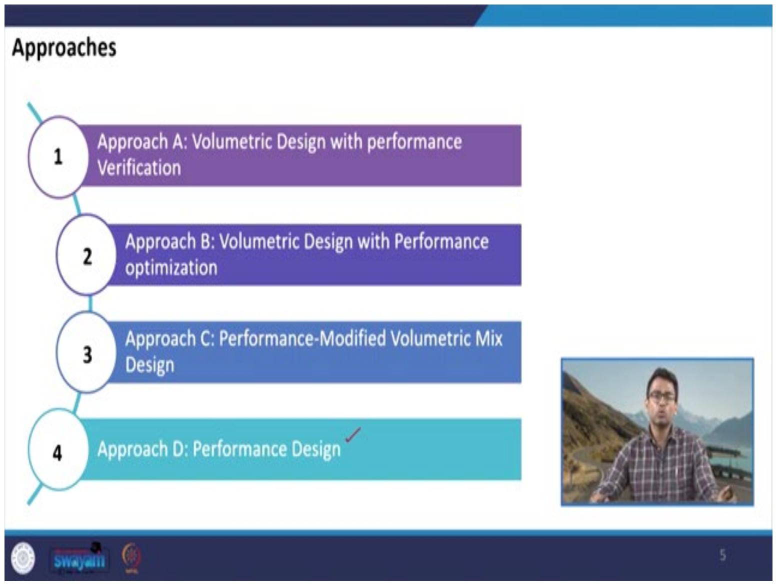

Now, let us talk about the available approaches. Firstly, as I mentioned, there are no standard specifications available on balance mix design. So, this is an area of research currently and state agencies in different countries, they are working towards developing their own performance based mix design, so that the mix which is produced can actually perform in the field, but few approaches have been identified, which tells us about the different steps involved in the balanced mix design process.

So, there are four different approaches currently, which has been identified. These include volumetric design, with performance verification, so, this is approach 1, one of the very conventional approaches or conservative approaches, approach B is volumetric design with performance optimization, we will be discussing about the steps, but just to add few comments here, approach B is almost similar to approach a with some minor change. So, both are conservative designs.

We have approach C which is performance modified volumetric mix design, here we have a little more flexibility to change different attributes of the mix, so that we can produce a mix having some desirable performance. So, this is approach C, we will be discussing about the steps.

And then we have approach D which is performance design, which has the highest level of flexibility to vary the volume metrics within the mixture, just to ensure that the mix which is produced satisfies the given performance criteria, which can be in terms of resistance to permanent deformation resistance to cracking resistance to moisture damage or whatever critical distress has been identified.

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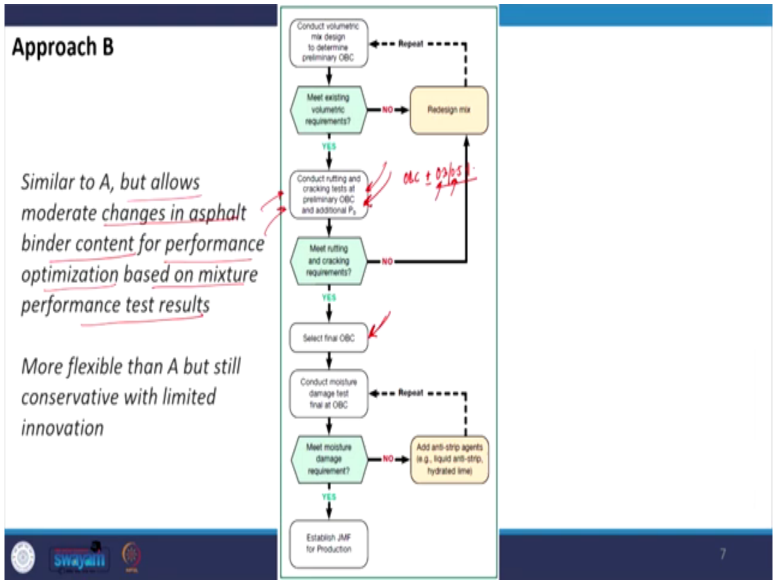

So, let us discuss about the steps involved in each of these approaches. So, we are first discussing about approach A, let us go through the steps. So, the first step is conduct volumetric mix design to determine OBC. So, this is similar to what we have been discussing in the mix design of bituminous mixtures, we will make the mixtures and based on the volumetric properties, it can be a 4 percent air void criteria we will determine the optimum binder content.

So, meet existing volumetric requirements we have to ensure that at the optimum binder content, the other volumetric criteria's like VMA like VFB or, filler to binder ratio et cetera is satisfied. If it is not satisfied, this design approach does not allow us to go forward we have to redesign the mix.

So, here is a constraint that without satisfying the volumetric requirements, we cannot move to the next step. Once it is satisfied, we will conduct performance test this can include rutting and cracking test considering that permanent deformation or rutting and fatigue cracking are the primary mode of failures.

So, add the optimum binder content. We will perform these tests a rutting test. A appropriately selected test method and an appropriately selected for the cracking test method at the optimum binder content. And then we will check does it meet the rutting and cracking requirements?

Now the question is what are these rutting and cracking requirements? We will discuss about them that how are these rutting and cracking requirements identified? Let us say the agency has already identified the requirement corresponding to the test, which are being used for assessing the rutting and fatigue characteristics.

So, does it meet the reading and credit requirements? If it does not, then again, we redesigned the mix. And again we redesigned the mix probably we are changing the aggregate gradation, we are changing the binder type, we are varying the filler proportion and again we have to start from step one that is starting with the volumetric mix design.

If it does satisfy, then we have almost progressed a little further and then we will conduct the moisture check, moisture resistance, check on the mixture prepared at that particular optimum mineral content, it can be a tensile strength ratio test or it can be any other test identified by the agency. So, we will see does it meet the moisture damage requirement, if it does not meet, which means that the aggregates and binder are not compatible?

Probably we will have to add some anti stripping agents. So, if we are adding anti stripping agents, we also should ensure that the addition of these is not changing the volumetrics of the mixture, otherwise, the main criteria of this particular approach will not be satisfied. So, we will add anti stripping agent and we will repeat the motion sensitivity test assuming that the volumetric properties are not changed or the performance attributes that is rutting resistance and fatigue resistance are not changed. So, if it satisfies the moisture damage criteria, then we finalize our mix for production.

So, this is the first step as I mentioned it requires full compliance with the existing volumetric requirements and additional performance requirements and it is the most conservative approach and but the innovation potential is less because we are doing many experiments, various steps here in this particular approach and this is one of the commonly followed approach by various US state highway agencies.

Then we have approach B. As I mentioned, approach B is almost similar to approach A, the only difference is in this particular step. Once the volumetric criteria is satisfied and we are doing performance testing, we can do the performance testing at OBC plus minus 0.3 to 0.5 percent.

So, we prepare additional samples not only at OBC but, we do not prepare samples only at OBC but add additional binder content and we will check the rutting and fatigue criteria, when I say that I am adding 0.3 to 0.5 percent, I have to ensure that this edition is not violating the volumetric criteria's, it is not violating for example, the minimum VMA criteria it is not violating the range of VFB criteria.

So, do I am changing the binder content by a little amount 0.3 or 2 $\pm$0.5 percent, But I have to ensure that the volumetric criteria is not violated, then we select the OBC here so, OBC is not selected primarily based on the volumetrics. It is selected based on volumetrics as well as performance test. So, both criteria are satisfied and then the volumetric final optimum binder content is selected.

The other steps remains the same, that we have to do a moisture test. If it does not satisfy, we will add anti stripping agents if it does satisfy, we will finalize the job mix formula. As I have said it is similar to A but it allows moderate changes in asphalt binder content for performance optimization based on mixture performance test results, and this is the step where the difference exists, it is a little more flexible than A because it allows some changes in the optimum binder content, but it is still conservative with very little innovation in this particular approach.

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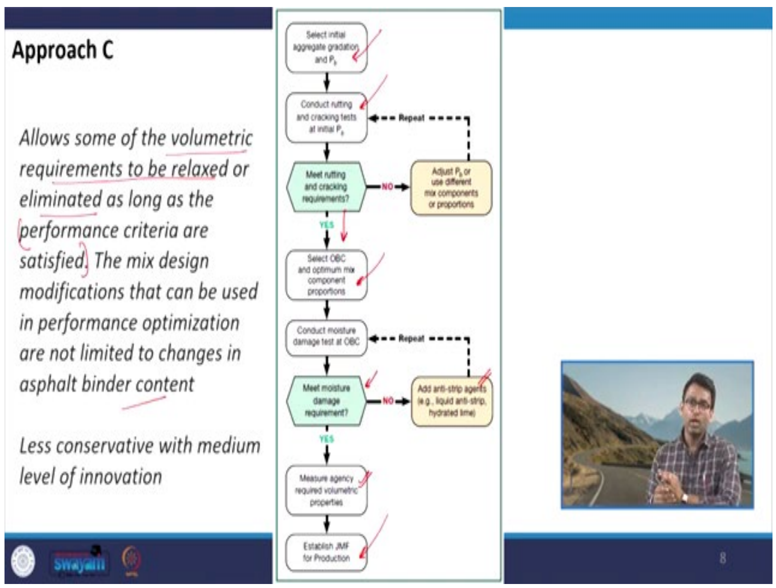

Well the approach C which is performance modified approach here what we do let us see the steps you select the aggregate gradation and binder content and then you conduct a performance test which means that we are not restricting ourselves to the volumetric criteria here, we are selecting an gradation and a binder content we are making samples and we are subjecting the mix to rutting and fatigue test or whatever performance test we will see does it meet the performance criteria.

If it does not meet the performance criteria, we will make changes in the aggregate gradation, we will make changes in the amount of binder content which is used and so on. And we will keep doing this iteration until the performance criteria is satisfied. If it does satisfy the criteria, then we will select the optimum binder content and optimum mix proportions.

Now, here after this step what we do we will conduct a moisture sensitivity test if it we will see does it satisfy the minimum value of moisture resistance if it does not the step remains the same that we are adding some anti stripping agents to meet the minimum criteria of the moisture sensitivity test result, if it does satisfy, then finally here we also check if the agency has specified that they need some volumetric properties.

So, here also modification can be made, but if the agency requires that the volumetric property should be assured it should be satisfied in this particular step and then only we will finalize the job mix formula. As we have discussed, it allows some volumetric requirements to be relaxed or maybe eliminated as long as performance criteria is satisfied.

So, the mixed design modifications can be used in performance optimization and not limited to changes in asphalt binder content. So, of course, as we are discussing, we understand that this approach is not very-very conservative and it is giving us more flexibility and it has certain level of innovation in it.

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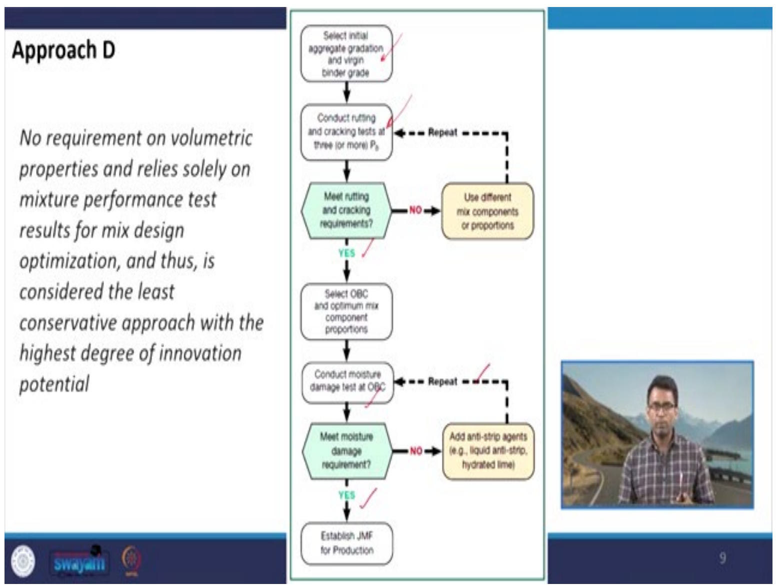

The final approach is the most flexible approach and here we will discuss that in no steps, there is any requirement for the volumetric requirements to be met. So, we will select the initial gradation and the binder grade, we will conduct performance test at different binder contents.

If it does satisfies the performance requirement, we will select the optimum binder content using the performance test results, we will conduct the moisture sensitivity test. If it does satisfy the moisture sensitivity results, we will finalize the job mix formula. So, you see here know where we are talking about the volumetric requirements and therefore, this approach is more flexible and as highest degree of innovation potential.

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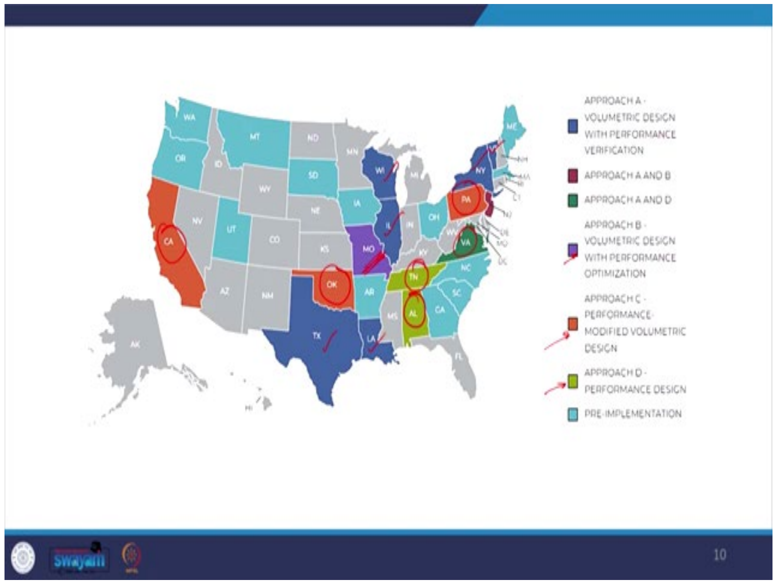

Though in India we are yet to adopt a performance based mix design approach in US, several dot's have a tried to implement the performance based mixed design approach many agencies have used different approaches, from approach A B C and D. So, this map it shows that which state has tried which type of approach.

So, you will see that mostly approach A and B has been adopted by various state agencies and very few agencies for example, you see approach D only very few agencies have basically, tried this particular approach which is more flexible and it has a very high degree of flexibility and innovation associated.

You see if you talk about performance C, then again we have few state agencies here. And if you talk about approach B which is on performance optimization, only one highway agency has tried this whereas approach A and B and approach A and D, A and D has been used again by one and approach A and B has been used by various other agencies which is marked here.

Well, this just tells us that how we are progressing with time and in the coming time probably, if we have a proper specification with us, most of the highway agencies are going to adopt it and probably in the coming time in India. So, we are going to adopt a similar procedure for carrying out the balance mix design.

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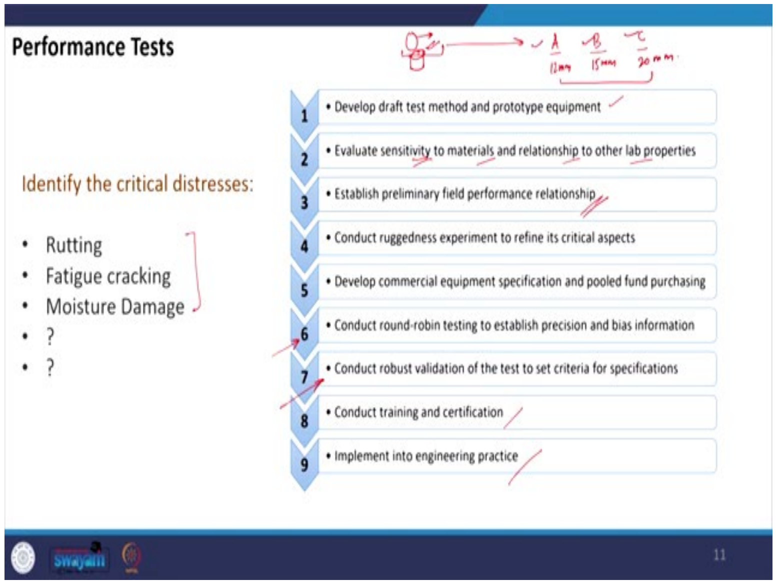

Talking about various factors which influence the balanced mix design, one of the most prominent I would say is the selection of the performance test. So, the NCHRP report has already identified that what are the steps that are required to select any performance test suppose, we are trying to identify a test method which will tell us about the rutting resistance of the mixture.

So, the question is which test method you will use, presently existing there are various test methods which are conventionally used probably as a part of Superpave mix design or in various research works, but, if you want to use it as a specification, which test method are we going to use, so, let us say that tomorrow we want to develop a new method.

So, what should be the steps that must be involved in selecting that particular test method. So, these are the steps I will quickly go through them just to have an understanding that we will we need to develop first draft test method and prototype equipment.

So, let us say we have some idea in mind that this test method is appropriate for quantifying the rutting resistance or let us say fatigue resistance. So, we develop or we manufacture the particular equipment. But in that equipment, we have to ensure that the when we carry out a test, the results are not subjected to high degree of variability and are not subjected to changes because of change in different parameters.

So, we have to evaluate the sensitivity of the equipment of the test method to materials and relationship to other lab properties. So, we have to see that how the test result is changing, let us say we are talking about wheel rut depth. So, if it is a rutting machine, wheel rutting machine, we have to see that the run depth is sensitive to which all parameters during the test, maybe the temperature at which we are doing the test, maybe the volumetric properties of the mixture may be the type of bitumen we are using or maybe the load which we are giving to carry out during the Windward tester and so, on. So, you have to identify by doing a detailed research on the equipment that how sensitive the equipment is.

Then we have to establish now this is one of the most important step that you have to establish the field performance relationship. Ultimately the idea is the machine which we develop or the machine which we are using is being used to measure the resistance to a distress and this distress should be well correlated to the occurrence of distress in the field.

Let us say I will give an example let us say we have pavements like A B and C, I am talking I am giving this example in terms of rut depth and these are placed in similar environmental condition and similar traffic condition because if you vary these conditions again the results can change. So, let us say the all the conditions remain same. And we found that the mix which is laid in Section A shows a run depth of 12 mm after say 2 years or 3 years of in service period, this shows 15 mm, this shows probably 20 mm. So that, is just an example.

So therefore, the test which I am doing in the lab, or the machine, which I am using in the lab, to do the test using the Mix as A B and C should give me similar relative value of rut depth, and then only the results which I am seeing in the lab could be correlated to the observations in the field.

So, for any equipment, this is a very important aspect to be considered that the results using the equipment should be able to tell us or should be able to predict the occurrence of distress in the field. Then the other steps it includes that you have to refine the critical aspect of the machine considering various other parameters in step 2 and 3, then you have to commercialize the equipment develop the specification generate funding for purchase of this equipment.

Then, this step 6 is also very important just to ensure repeatability just to gain more confidence on the use of this particular equipment. A round robin test can be done taking into consideration different labs in the country similar samples could be sent and these samples could be subjected to testing in different labs and then the results should be compared to see that what is the difference in the result which we get. So, a round robin test can be conducted.

Then we have to go for validation check which means we have to take a field data. We have to take lab data and we have to see whether the results are in line with each other. Then we have to further go for training and certification, this is about how to use the equipment, what are the parameters, how to use the data which is being generated and so on.

And finally, it has to be implemented in practice. So, this 9 steps it is a huge task to be done before we decide which equipment to be used to quantify a particular distress. So, any performance test we decide, it will depend on the location or the region where you are doing the project and it will also depend on the occurrence of the critical distresses. For example, the three critical distresses which has been identified even in the Napa report includes rutting, fatigue cracking and moisture damage.

Though the NCHRP report also talks about other forms of damage for example, in fatigue cracking, we can have top down cracking we have bottom up cracking, we also have thermal cracking and low temp or low temperature cracking and so on. So, these distresses have to be identified and for each distress, we have to select an appropriate test method.

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Mixture Property	Laboratory Test	Test Standard	Test Parameter(s)	Criteria Available
Thermal Cracking	Disk-Shaped Compact Tension Test*	ASTM D7313-13	Fracture Energy	Yes
	Indirect Tensile Creep & Strength Test	AASHTO T 322-07	Creep Compliance & Tensile Strength	Yes
	Semi-Circular Bend (SCB) Test*	AASHTO TP 105-13	Fracture Energy	Yes
	Thermal Stress Restrained Specimen Test	BS EN12697-4	Fracture Temperature & Fracture Strength	No
Reflection Cracking	Disk-Shaped Compact Tension Test*	ASTM D7313-13	Fracture Energy	No
	Texas Overlay Test*	TxDOT Tex-248-F NJDOT B-10	Cycles to Failure & Fracture Properties	Yes
	Illinois Flexibility Index Test	AASHTO TP 124-16	Flexibility Index	Yes
Bottom-Up Fatigue Cracking	Direct Tension Cyclic Fatigue Test	AASHTO TP 107-14	Damage Characteristic Curve & Fatigue Model	No
	Flexural Bending Beam Fatigue Test*	AASHTO T 321 ASTM D7460	Cycles to Failure Fatigue Equation	No
	IDT Fracture Energy Test	N/A	Fracture Energy	No
	Illinois Flexibility Index Test	AASHTO TP 124-16	Flexibility Index	Yes
	SCB at Intermediate Temperature*	LaDOTD TR 330-14 ASTM D8044-16	Strain Energy Release Rate	Yes
	Texas Overlay Test*	TxDOT Tex-248-F	Cycles to Failure Fracture Properties	Yes
Top-Down Fatigue Cracking	Direct Tension Test	N/A	Fracture Parameters	No
	IDT Energy Ratio Test*	N/A	Dissipated Creep Strain Energy & Energy Ratio	No
	Illinois Flexibility Index Test	AASHTO TP 124-16	Flexibility Index	Yes
Rutting	Asphalt Pavement Analyzer	AASHTO T 340	Rut Depth	Yes
	Flow Number	AASHTO T 378	Flow Number	Yes
	Hamburg Wheel Tracking Test	AASHTO T 324	Rut Depth	Yes
	Superpave Shear Tester	AASHTO T 320-07	Permanent Shear Strain	No
	Incremental Repeated Load Permanent Deformation	AASHTO TP 116-15	Minimum Strain Rate	Yes
Moisture Susceptibility	Hamburg Wheel Tracking Test	AASHTO T 324	Rut Depth & Stripping Inflection Point	Yes
	IDT Strength Test	AASHTO T 283	Tensile Strength Ratio & Wet IDT Strength	Yes
	Moisture Induced Stress Tester	ASTM D7870	Changes in G_{mb} & Visual Observations of Stripping	No

Note: * Tests selected at the Cracking Test Workshop in NCHRP Project 09-57 (Zhou et al., 2016)

In the existing literature you see, we have huge number of test methods which have been tried already in various researches already by various agencies. So, the question is, which test should we used? Well, this has to be decided by the corresponding highway agency based on the experience with that particular equipment based on the correlation with the field and lab data and based on the availability and the easiness with which the equipment can be operated.

So, you can see for thermal cracking, we have these many tests that are available, they have their standardized using an AASHTO or ASTM specification. For reflection cracking, we have for bottom up cracking, for top down cracking, rutting, we have a number of tests Matias acceptability, we have a number of tests. If you see here, there are criteria’s available in many of the test methods and in many of the other test methods, we presently do not have any specification criteria.

So, we have to develop these criteria and we also have to select the appropriate test method, either from the existing test procedures, which are already there, or probably we have to develop a completely new test method for quantification of any particular distress.

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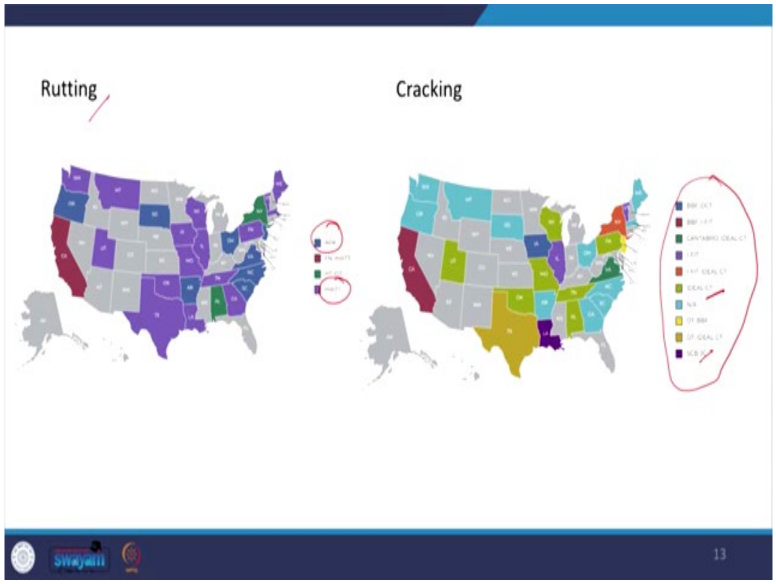

Well, this is again a map taken from the reports just to show you that for example, rutting for example, if you talk about Hamburg wheel rut tester, so all the state agency marked in purple, they are presently using Hamburg wheel rut tester. All the agencies marked in the blue color, they are using an asphalt pavement analyzer for quantification of rutting in the mix design process.

So, you see in the same country, different states are adopting different test for quantification of similar type of distresses. So, again, some specifications should be developed, so that some universal tests can be used and the results can be compared from state to state.

Similarly, in the cracking, we have too many tests available here, you can see for example, ideal cities being used by states which are marked in green color here. Some of the agencies they use for example, let us say Scb test, the one in purple, which is marked here, the semicircular, beam test is being used, and so on. It depends on which highway agencies adopting which test method and then corresponding specifications are going to change.

Some of the examples of establishing like once we decide which equipment we have to use, then we have to establish limiting criteria. For example, if you are using a Hamburg, wheel rut tester, then what are the parameters, the temperature, so, you have to fix the temperature at which you are going to do the test you have to fix whether you are going to look at the number of load cycles to achieve a particular depth or are you looking at the right depth after a particular number of cycles.

So, these parameters of the test method has to be fixed and then you have to generate criteria for example, if you say it after 8000 cycles, I will compare the rut depth in the bituminous mixture. So, you have to now establish that what is acceptable; after 8000 cycles greater than 10 mm rut depth is that acceptable for the mix? After 8000 cycles, less than 5 mm rut depth is that acceptable to the mix or what is the actual criteria?

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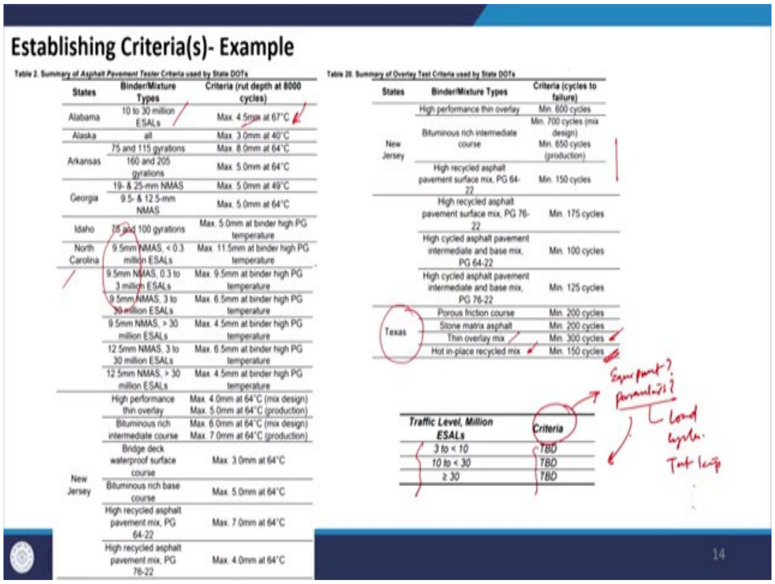

So, this is for example, a data taken from different states in the US that uses asphalt pavement tester for quantification of rutting and you see for example, in Alabama, we have for 10 to 30 million standard axial, this is the criteria that at 67 degrees Celsius, the maximum rut depth which is permissible after 8000 cycle is 4.5 mm.

For example, if you see North Carolina, then the rut depth itself is a function of the nominal maximum aggregate size. Let us see for 9.5 mm, you see 9.5 mm they have multiple criteria for less than 0.3 MSA loading between 0.3 to 3 MSA from 3 to 30 MSA and also for more than 30 MSA. So, depending on the traffic level, they have decided what should be the limiting rut depth after 8000 cycles at the PG high temperature. So, again, these specifications depends on the highway agency with the validation which they have already carried out.

So, similarly, some specifications or criteria are required. Again this is an example, which shows how the overlay test criteria is used for quantification of cracking in different states for example, you see in Texas they will look first at the cycles to failure and then they have said that for a hot in place we cycle mix at least 150 cycles should be taken by the sample before failure.

Similarly, for thin overlay mix the minimum cycles is 300 and so, on. So, again this criteria needs to be set up and the criteria can be put in this particular format that for different levels of traffic what is the criteria and this criteria should also clearly mentioned that what is the equipment we are using what are the parameters in the equipment to be used these parameters may include loading, cycles, test temperature and so on. So, all the things should be fixed and then this criteria should be established.

Since, we are also doing a project in India which is on ballast mix design. So, here is an idea put forward by us and this idea came up after discussing with different colleagues here in India and also reading the available literature's and also after discussion with the research team.

So, this is an idea which I am just going to present here, which tells us that how do we select the rutting criteria let us say, if I want to produce a mix, which will have high resistance to rating, so, how to develop the criteria.

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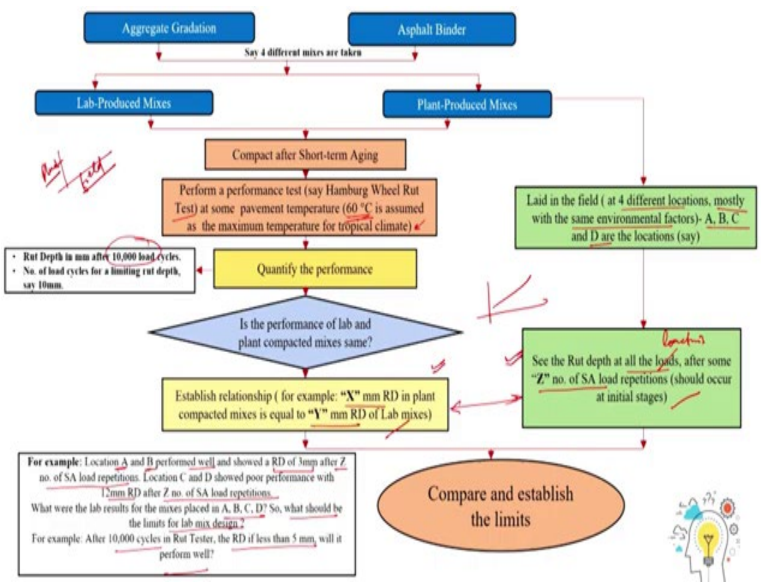

So, first I have to select the aggregate gradation and the asphalt binder, let us say I have selected an aggregate gradation and I have selected an asphalt binder. And I have prepared for different mixes, which means, maybe if I am fixing the asphalt binder and the binder content, maybe I am wearing the aggregate gradation list let us say I have four distinct types of mixes available with me, I can use this combination to produce lab mixes, but not necessarily lab mixes will be always similar to the plant produce mixes.

So, our suggestion is that we should parallelly look at the plant produced mix also because it is the plant produce mix which is going to be laid in the field which is going to be compacted. So, that will give me a more appropriate indication about the actual mix which is being produced.

Now, in order to handle this lab and plant produce mix again there is some idea which can be used. So, the plant produce mix is laid in the field. So, we have 4 different mixtures, let us say we are laying this 4 different mixtures in 4 different locations. So, we should have some test sections before we develop the performance of the balance mix design.

So, we are laying the mix at four different locations. And I am assuming mostly all they have the same environmental factors maybe they are laid at the at similar location one after another. So, let us say the locations are A B, C and D. Now, we have the lab produce mix, we have the plant produce mix, we will compact them after subjecting the mix to short term aging.

Now, this is also very important because when we open the our pavement to traffic the mix is already subjected to short term aging. So it is better to analyze the short term age specimens, then only the Virgin specimens so compact after a short term aging then I will perform a test now selection of the test we can either develop a new test method or let us say I am selecting a test method which are already available.

So, I am using a Hamburg wheel rut test for quantification of rutting I have to fix at what temperature I am going to do these tests. So, let us say I am taking 60 degrees Celsius. So, this is the standard temperature at which I will perform the test or this temperature can also be the maximum temperature which is anticipated in that particular project location. So, 60 degrees Celsius is assumed as maximum temperature for tropical climates.

So, this I am fixing for this particular analysis. Now I have to quantify the performance. So what I am doing, I have the lab and planted use mixes, I am carrying out the wheel rut test on it, and I am observing the rut depth after 10,000 load cycles, so I am fixing the load cycle I am not varying it. I will stop the test after 10,000 load cycles. So, after 10,000 load cycles, I will observe the rut depth, alternatively what I can do, I can fix the rut depth, let us say I will stop when the sample has undergone 10 mm rut depth and I will note down the number of load cycles. So, either of the 2, I can do.

Now, I have to see whether the lab produce mix and the plant produce mix, are they giving the same result using the Hamburg wheel rut tester. If the results are not same, then we can establish a relationship, we can establish a relationship between plant and field if the results do not match, so, this will act as a correction factor in the future for the lab produced mix.

So, establish relationship for example, X mm rut depth in the plant is equal to Y mm rut depth in the lab. So, this is just a correction factor between lab and plant produced mixes. Once I have that, then the one which is laid in the field, I will observe the pavement for some time. So, I will see the rut depth at all the locations basically it should be at all the locations after some Z number of standard axial load repetition.

So, I also have to ensure that when I am comparing these mixes, they have been subjected to similar level of loading.

So, let us say, all the mixes have been subjected to 3 MSA or 2 MSA of loading and then I am looking at the rut depth in the mix. So, I will look at the rut depth of in the field and I will compare and establish the limit. So, these this is the limit of obtaining the lab and this is the rut depth option in the field and I will develop a correlation and then I will identify the specification limit.

For example, let us say location A and B performed well and show the rut depth of 3 mm after Z number of standard axial load repetition, let us say location C and D showed poor performance with 12 mm rut depth after Z number of load repetition. So, after that number of nodes repetition A and B are showing a rut depth of around 3 to 4 mm. Let us say and C and D are showing a rut depth of around 10 to 12 mm let us say.

Then I will see that what were the lab results for the mixes A, B, C and D, if A and B are showing lower rut depth, in the field they should also show lower rut depth or maybe high resistance to rutting in the lab, this is what I am expecting, but I will get a different value maybe I am seeing if the rut depth after 10,000 load cycle it will not be 3 mm, it will be some other value.

So, I will look at that particular value. That good mixes when we have good mixes in the field, what is the corresponding rutting value in the lab. So using that what should be the limits for lab mix design so this is what I am going to develop for mixes in the field showing 12 mm rut depth, what is the level of rut depth in the lab for that particular mix.

For example, after 10,000 cycle in rut tester, the rut depth if less than 5 mm will perform well maybe the mixes which are shown 3 mm ratting have shown 5 mm rutting in the lab, but they are good mixes. So, I will set the limit to 5 mm I will say that if your mix is having 5 mm of rotting at 60 degrees Celsius after 10,000 Roll reputation in the lab that mix is going to perform satisfactorily in the field and so you have to produce a mix which satisfies this particular criteria.

So, I hope this idea is clear to you. And similar idea can be generated for fatigue cracking also, but an important point here is that we need field samples as well, we need either samples whose performance are known from different surveys from different extracted samples or probably we have to make new test sections to and then monitor the performance over a period of time before this relation between lab and field can be made and finally the performance criteria's can be developed.

So with this I will end here today. I hope that the concept on the approaches and the concepts related to performance based mix design is clear to you and we will now meet in the next presentation which will be our last topic to discuss and which is on the characterization of bituminous mixtures. Thank you.