Pavement Materials
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Lecture: 34
Role and Desirable Properties: Mix Design

Hello everyone, today we are going to discuss or we are going to start or begin our discussion on the mix design aspects related to hot mix asphalt. And today we will start before we jump into understanding the mix design process talking about different types of mix design, today we will try to first understand about the role and the desirable properties of hot mix asphalt and what should be the basic objective or the philosophy of mix design. And we will also look at before we begin the mix design process, we will also look at some of the historical developments that have taken place in the procedural development of mix design for hot mix asphalt.

So, in the last lecture, we have talked about the production of bituminous mixtures, we have discussed about how the bituminous mixtures are produced in the laboratory compacted in the laboratory and how the production and compaction is done in the plant and in the field. So, today, we will as I said we will start discussing about the role and desirable properties from the perspective of mix design. So, if we try to see the behavior and the importance of different materials in the mix. So, in the hot mix as filed, we basically have usually only two types of material, we have binder and we have aggregates and we also have air voids, but that is not a material.

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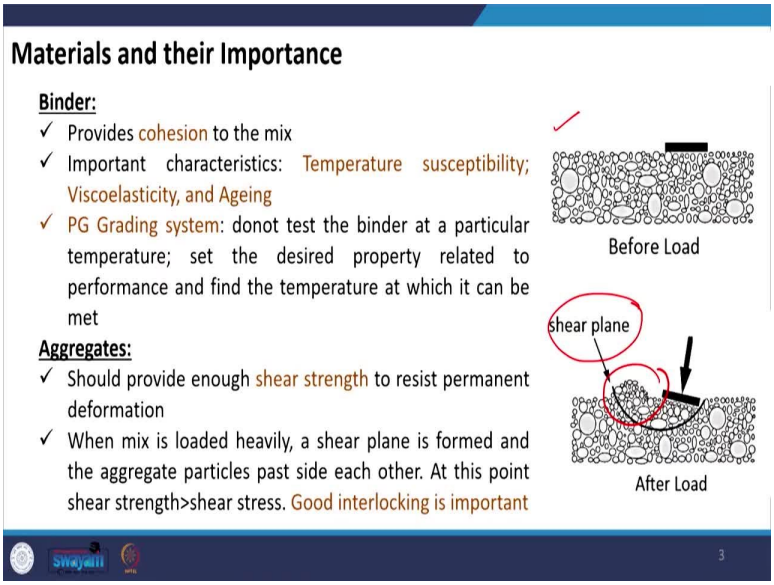

So, the binder the main purpose of using a bitumen or a binder is to facilitate or provide cohesion to the mix. So, this binder is keeping these aggregate particles of different sizes together in the dense mass. So, we have already completed our discussion on bitumen. So, I think by now, you will agree that the important

characteristics of bitumen it includes its temperatures acceptability, because the actual mix will be exposed to a range of temperature in the field. So, we have to ensure that changes in properties are not very significant during this range of temperature when it is exposed to this change in temperature in this range.

Viscoelasticity is of course, an important property it will tell us about how the material will respond to any given loading condition under different temperature conditions and under different frequency conditions that is speed of the vehicle. And of course, ageing is related to the durability of the mix. So, we also have to ensure that when the mix has been exposed to different temperature level, different oxidation level, during its in service life, the changes in properties should not be such that there are occurrence of distresses like rutting and fatigue cracking or low temperature tracking.

This can be ensured using a system such as a performance grade grading system about which again we have discussed in detail, that one of the main attribute of this grading system is that we do not test the binder at a particular temperature, but we have some set desired properties, some values have been set and we have to ensure that at the field temperature at which the binder will be exposed to these desired properties are within this specification.

Now, let us talk about aggregates. So, if you try to imagine the hot mix asphalt, the aggregates are in point usually in point to point contact with each other and then they are interlocked with each other. So, they their main purpose is to provide enough shear strength, so, that the mix can resist permanent deformation or the movement of the particles. So, it should not move under the action of load. So, that is why proper shear strength within the mixture is very important.

So, usually when the mix is loaded, which you can see in the first picture, we have an aggregate mass. So, when the aggregate mass is actually loaded, a shear plane can be formed. And here in this shear plane we have to ensure that the shear strength of the aggregate mass is higher than the shear stress to which it is being exposed. If the shear stress exceed the shear strength, then there can be movement of the particles which can cause occurrence of distresses, for example, shoving. Here we also have to ensure that the aggregate particles are well interlocked with each other, so that it can increase the shear strength of the mix and it can resist the movement of the aggregate particles at the shear plane interface.

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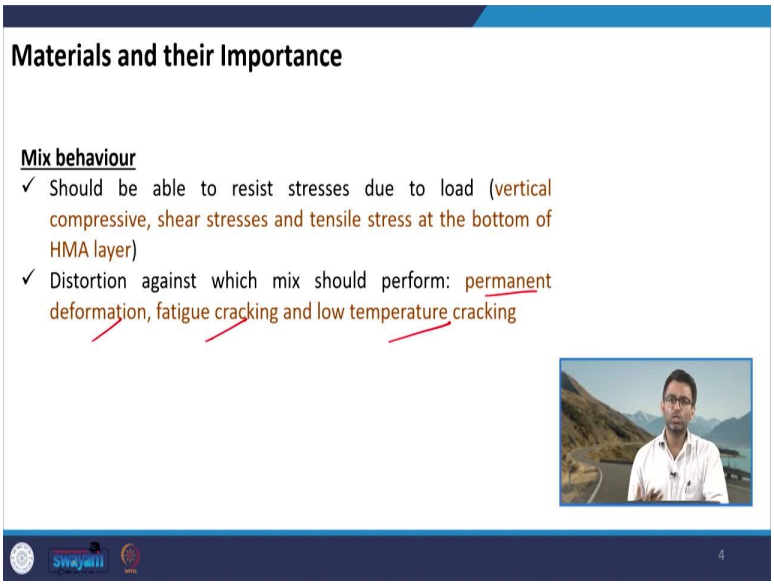

So, now, we have discussed about the bitumen and we have discussed about the aggregates what are the desirable properties. Now, the final mix which is produced by mixing these aggregates with the bitumen, it should be finally, the aim is that it should be able to resist stresses due to different types of load, the load can be vertical in nature or it can be compressive, it can be there can be shear stresses, there can be tensile stresses at the bottom of the HMA layer and we want that our mix should be capable of resisting these stresses.

The main are the critical failures for which we are designing the mix it includes permanent deformation, which is rutting, then occurrence of fatigue cracking and occurrence of fluid temperature cracking. So, these are the three primary distresses against which the mix should perform.

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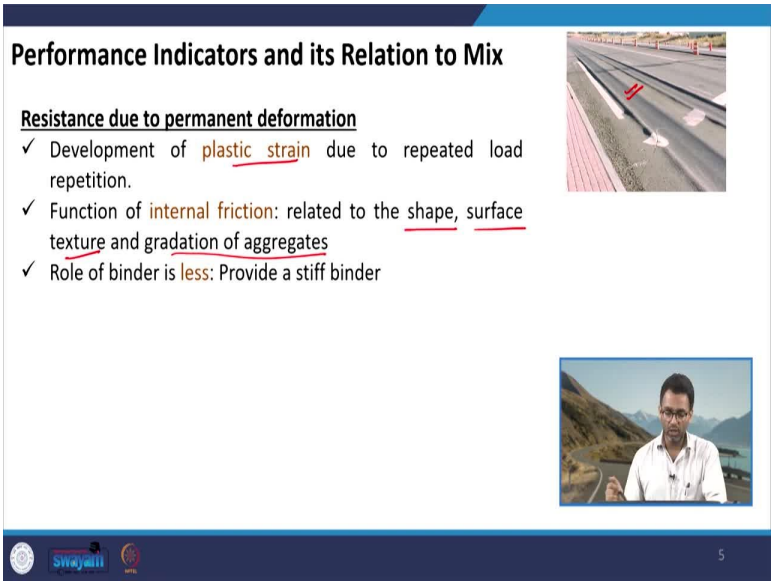

So, now, let us discuss about various performance indicators and its relation to the mix. So, the first performance indicator is that the mix should be resistant to permanent deformation. So, the rutting or the permanent deformation can appear something like this which you are seeing in this picture along the wheel path, it happens because of the development of plastic strain due to repetitive loading, plastic strain is the strain which cannot be recovered again. So, this is a permanent strain.

So, this plastic strain is a function of both the properties of aggregate gradation, types of aggregate, and bitumen which we are using, but predominantly it is a function of the internal friction which is developed in the aggregate mass. So, this internal friction is not very easy to quantify it is basically related to the shape of the aggregate particles, we have discussed that angular shape is desirable, the surface texture of the aggregate particles and of course, the gradation of the aggregates.

So, these are the parameters which will affect the amount of internal friction which is developed in the mix. The role of binder here in development of plastic strain is relatively less and a thumb rule can be that in order to have lower plastic strain from the perspective of bitumen, we can use a stiff binder. So, stiffer is the binder less will be the amount of plastic strain.

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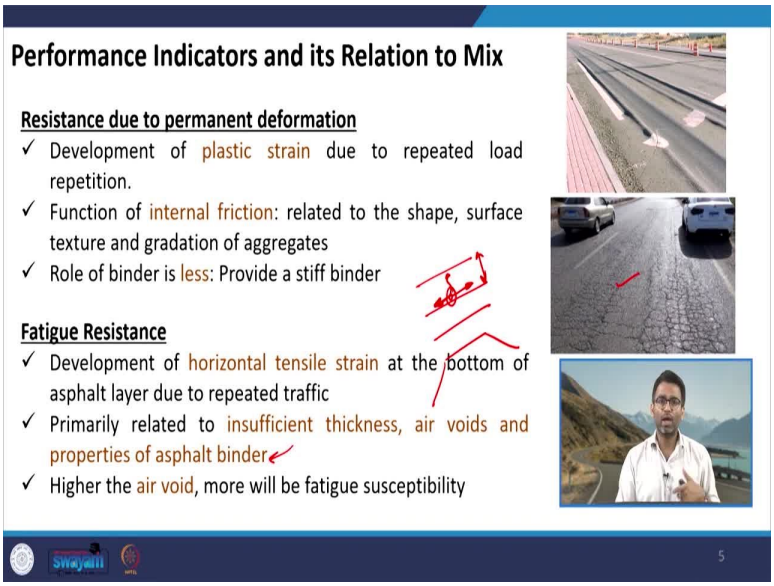

So, talking about the fatigue resistance, again, fatigue which is one of the critical distresses in the pavement and example of which you can see here. So, this fatigue occurs because of the development of horizontal tensile strain at the bottom of the bituminous layer due to repeated movement of traffic.

If you see a layered system if this is the bituminous layer, so, this strain is occurring here and it is not only because of movement of a single truck or few number of trucks, but because of this repetitive action what

happens the strain starts getting accumulated at this point. If the magnitude of the load is very small, then the strain will be small, so, everything will get recovered, but if the magnitude of the load is high, the strain will keep on increasing over a period of time.

When this accumulated strain, it exceeds the strength of the mixture, the material will crack here because it will release the stress by cracking. And this accumulation of strain is a function of various parameters of the mix, for example, it can happen because of insufficient thickness of the bituminous layer, because a thin layer are more susceptible to cracking because the deflection is higher, air void is one of the factor and of course, the properties of the asphalt binder.

So, asphalt binder in fact provides flexibility to the mix which is directly related to fatigue cracking or the occurrence of fatigue. So, the appropriate choice of binder and appropriate properties of binder is very critical here. In contrast to what we discussed about permanent deformation where the rule of binders is relatively less in comparison to the mixture. The mix attributes for example, air void also affects the occurrence of fatigue, a dense mass will ensure better or higher resistance to fatigue damage.

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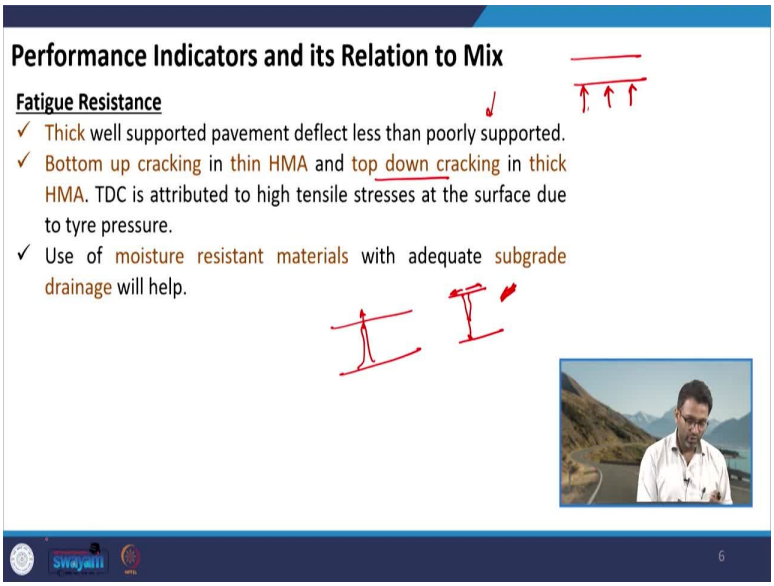

In addition to that, as I was talking about the thickness, if the thickness of the bituminous layer is high enough so a thick well supported pavement it will deflect less than poorly supported. So, this also indicates that the support of beneath the mix also plays a critical role in influencing the occurrence of fatigue. So, usually if the hot mix asphalt layer is thin, maybe let us say 100 to 150 mm typically or even lower then bottom of cracking will be the predominant mode of fatigue failure, bottom of cracking is that the cracking will start from beneath the pavement and it will appear at the top.

Whereas, we can also have occurrence of top down cracking now, this phenomena is more critical for thick pavements were because of the high tensile stresses at the surface because of the movement of the tire pressure or the movement of the vehicle. So, high horizontal stresses the crack starts from the top and it goes to the bottom. In order to increase the resistance we also have to use moisture resistant materials with adequate drainage because the movement of moisture also affects the occurrence of fatigue failure or aggravates the occurrence of fatigue failure we can say.

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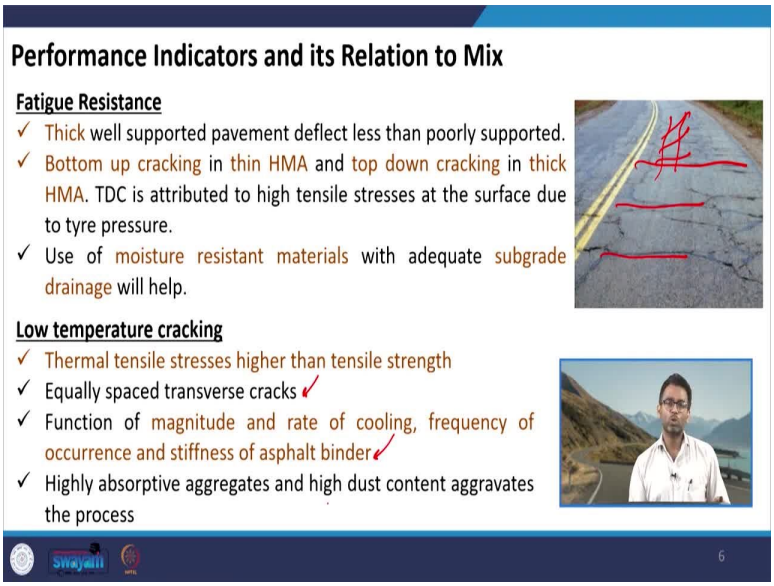

Then, the third critical distress is the low temperature cracking. In the low temperature cracking which is also the thermal cracking, the thermal tensile stresses becomes higher than the tensile strength. So, and usually the fatigue cracking will be more of longitudinal or joint type whereas, thermal cracking will more of in the lateral direction, these are typically seen as equally spaced or transverse cracks. The occurrence of thermal cracking is a function of parameters for example, magnitude and rate of cooling of the mix which depends on the environmental aspects.

Then frequency of occurrence, I mean how many cycles are occurring during that period of time and the stiffness of the asphalt binder, because stiffer is the asphalt binder, the chances of cracking will be higher. So, in addition to that, it is because this is a function of how freezing is also taking place, which is a function of the movement of the water. So, highly absorptive aggregates and high dust contents, it can aggravate the process, so we have to choose the aggregates accordingly and we have to ensure that larger amount of dust particles are not present in the mix.

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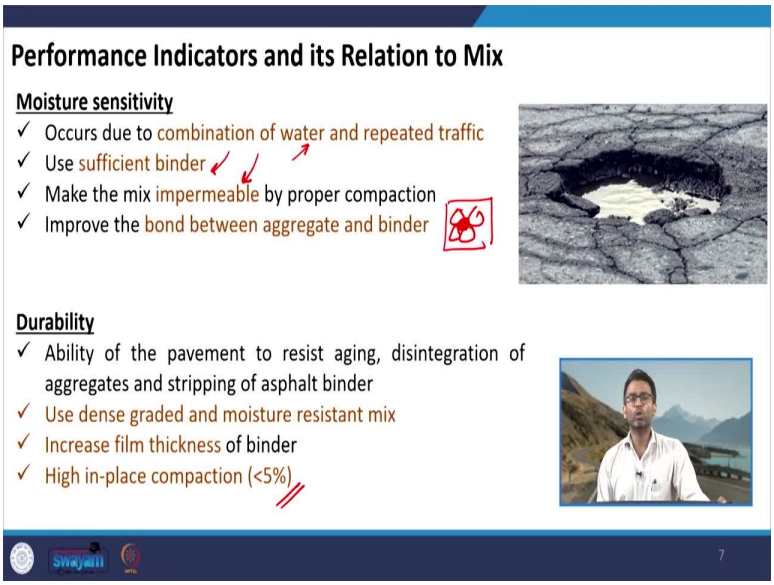

Moving forward we have some other parameters or performance indicators in addition to the three critical distresses which we have discussed and these parameters are somehow related to these. So, here the first is the moisture sensitivity.

Now, moisture sensitivity it occurs or the moisture related failure occurs due to the combination of water and repeated traffic, we have discussed previously that water can remove the bitumen film from the aggregate surface, so which can lead to stripping of the mix and failure in the mix, so that is the effect of water and if the void within the mixture is high, then because of the repeated movement of the traffic pore the pore water pressure which gets generated it will separate the aggregate particles and again it will lead to failure in the mix.

So, one way to resist moisture related damage is to use sufficient binder to make the mix impermeable, when I say impermeable it does not mean that we are targeting for 0 percent air voids, but we should not have air voids higher than a particular range or particular value, which will facilitate the collection of water within the mix.

So, if these are the aggregate particles, so, this water should not get collected here, accordingly the permeability becomes critical. We can also resist a moisture damage by improving the bond between the aggregate and the binder, this can be done using various chemical additives and proper selection of aggregate and bitumen.

Durability is related to more of the effect of ageing. So, it is the ability of the pavement to resist ageing, to resist disintegration of aggregate and also to resist stripping of asphalt binder. So, the one way of doing is to produce a dense graded mixture with less amount of voids and to also use moisture resistant mixture.

The bitumen film thickness also should be appropriate so that excessive ageing does not take place because if the film is thin, more will be the propensity of or more will be the chances of extent of ageing within the mixture. And we should go for high in place compaction, we should not go for high in place voids. So the void, in place voids typically should be kept less than 5 percent, so this will also ensure a durable hot mix asphalt.

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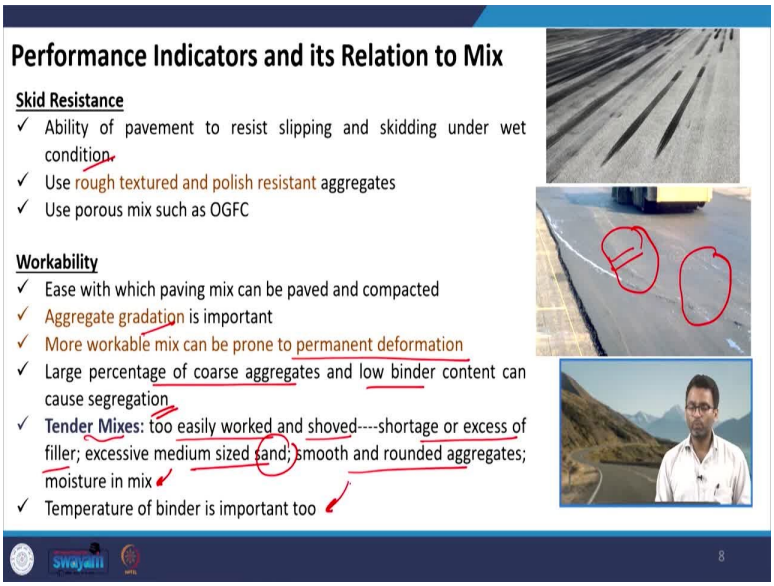

Then specifically for the surface or the wearing course, it is important that the surface should be skid resistance, this is for safety and this will prevent slipping and skidding of the vehicle specially under wet conditions. So, for this one way is to use rough textured aggregate and polish resistant aggregate, we can also use mixtures for example, open graded friction course, which will increase the frictional characteristics of the surface layer.

Then finally, we have workability as one of the performance indicator. So, workability can be defined as the ease with which the paving mix can be paved and compacted we have already discussed about the compaction process previously. In order to produce because sometimes if you can see in this picture, sometimes irregularities can occur and this is attributed probably to the either to the process of compaction, either to the temperature of the mat or probably to the poor mix which is sometimes also called as a tender mix. So, aggregate gradation is very important here.

So, depending on the aggregate gradation, the densification or the movement of the aggregates and orientation of the aggregate will change. We also have to ensure that the mix is not excessively workable, because this can also be prone to permanent deformation because, we have already discussed in when

we were discussing about aggregates, that when the aggregates are rounded they are more workable, but these type of aggregates has they will lead to further densification under the movement of the traffic which can lead to occurrence of permanent deformation.

We also have to see that in degradation we do not have large percentage of coarse aggregate because large percentage of coarse aggregate and low binder content can lead to segregation. So, segregation can be also because of the improper or improper amount of binder because binder is finally the binding agent. So, if we do not have appropriate binding agent aggregate particles can be separated easily.

As I was talking about tender mixes, so, these are mixes which are too easily worked and shaped. So, when the rollers will move to compact you will see that it is not compacting vertically, but the mixes is moving longitudinally. So, a shortage of filler or the filler can be an excessive amount, there can be excessive amount of mid-size sand, which are more rounded in nature. We can have rounded and smooth, smooth and rounded aggregates which will also lead to occurrence or the production of tender mixes and there can be also moisture in the mix. So, maybe the drying is has not been done properly and the there is some moisture in the mix which can also lead to tender mixes. So, and as I mentioned the temperature of the binder is important to or during compaction.

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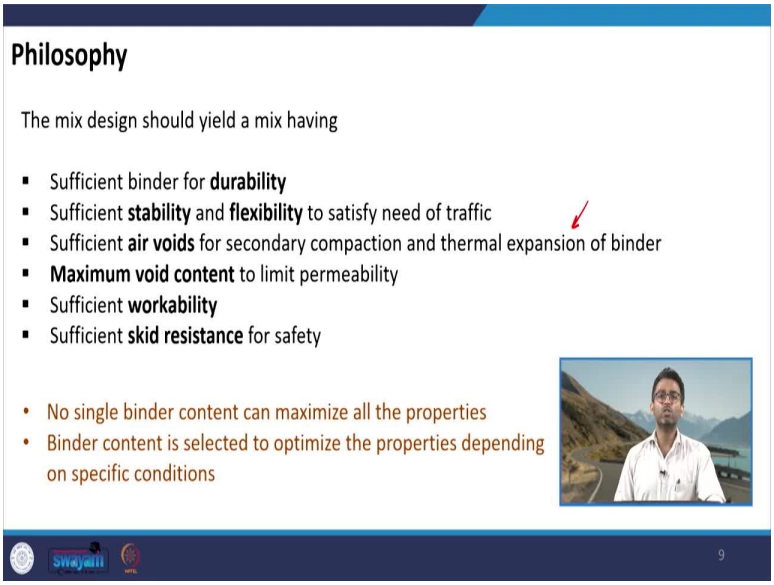

With this, let us now talk about the philosophy of mix design. So, the mix design which we are targeting to do should finally yield a mix having some desirable properties and these properties we have just discussed now. So, the mix should have sufficient binder, so that we can ensure a production of a durable mix. The mix should have sufficient stability and flexibility to satisfy the need of the traffic.

The mix should have sufficient air voids for secondary compaction to happen and for thermal expansion of binder, this is also very important that we do not want excessive air voids to increase the permeability and then this permeability can lead to moisture damage, but we do not want very less voids, we want certain level of air voids and this certain level of air void is required to facilitate secondary compaction when the pavement will be open to traffic. So, some amount of further compaction will take place. So, we have to allow that we have air voids to accommodate this compaction.

And then during summers because bitumen is a viscoelastic material, the volume of the binder may increase during summers. So, to allow for the thermal expansion of the binder also there should be certain level of air void present. But again, as I mentioned maximum void content has to be limited to limit the permeability. The mix should have sufficient workability, so that it can be placed and compacted easily at the site. Especially for surface mixtures or varying course, we also need sufficient skid resistance for safety.

So, you can see that there are so many attributes which we desire or properties which we desire from the mix, but of course, all these properties they are sometimes at the opposite end of material spectrum. And in fact, no single binder content in the mix can maximize all these properties. In the mix design process, what we do the binder content is selected, an appropriate binder content and the combination of mineral aggregates they are selected to optimize the properties depending on specific conditions, we will talk about this condition in further slides.

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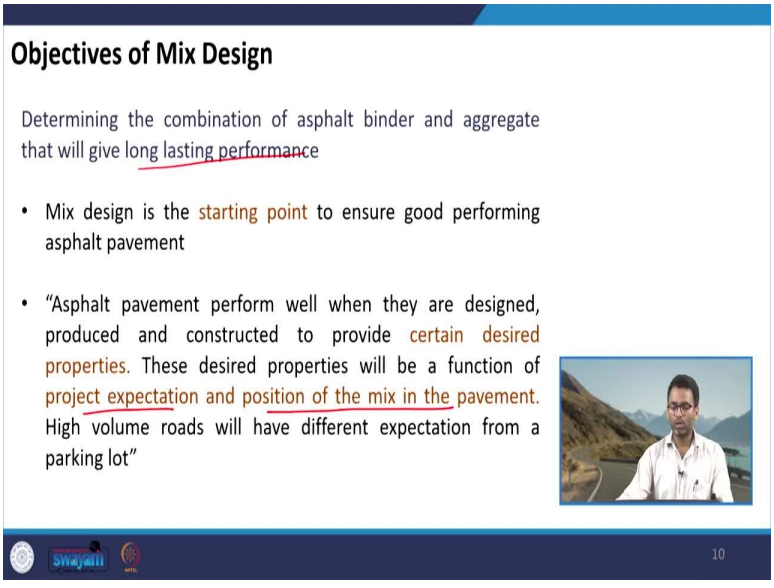

So, before that let us understand about the objectives of mix design. So, as we have just discussed, our the objective of mix design finally, is to determine the combination of asphalt binder and aggregate that will give long lasting performance. Now, here when I say long lasting performance, I have to define what do I mean by performance. And in fact, mix design is just the starting point to ensure good performing asphalt

pavement because construction is and quality control during construction is one of the main factors that will affect the final performance of the mix.

So, studies have shown that a relatively poor mix design and good construction works better in comparison to a good mix design and poor construction. So, that is why we say that mix design is only the starting point to ensure a good performing asphalt pavement but this is not the only aspect to ensure good performing pavements.

So, asphalt pavement, they will perform well only when they are designed, produced, and finally constructed to provide certain desired properties and as I was as we say desired properties, so, these desired properties will be a function of project expectation. So, we for different projects, different locations, different type of traffic, there can be different expectation from the mix.

So, once the designer knows about these expectations, the mix design can be accordingly changed or accordingly it can be altered. And the desired properties also depend on the position of the mix. So, we can have a usually the if you see the bituminous layer, we can have a base bituminous layer, we can have a binder course, we can have a surface course. So, the requirements the expectation from all these layers can be different.

So, depending on the position of the mix, also the mix design will change, but we have to ensure that we are not compromising the performance, be it a base course, binder course or surface course, because whatever is a binder course or whatever is the wearing course today will probably become the binder course when the pavement is overlaid. So, we have to ensure that we are not compromising with the properties of the mix.

Also, it depends about the facility which for which we are designing the mix for example, the requirement of high-volume roads will be very different from the expectation which will have from a parking lot. So, based on the facility also the expectation and accordingly the mix design will be will have to be controlled.

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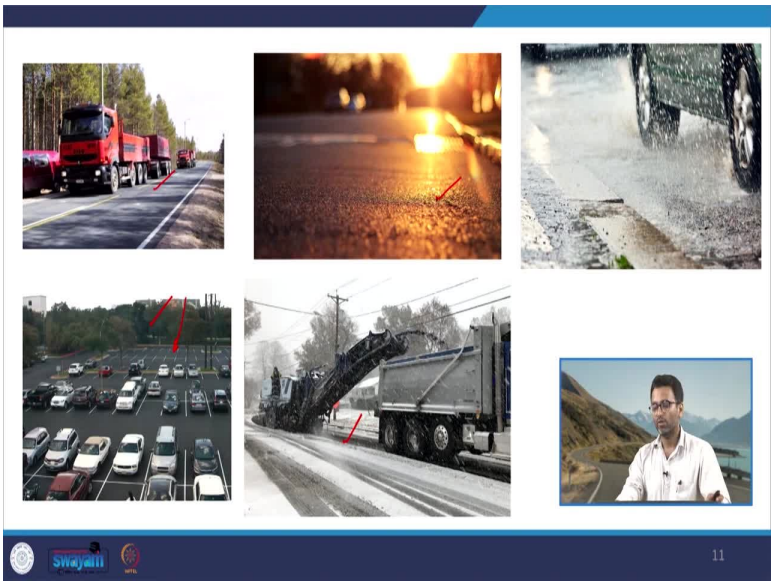

So, these are just some random picture showing different conditions and just to understand that how and why we say that for different types of location, we will have to think about different ways of designing or choosing the mixed parameters. So, you see that we have high volume road and we have parking lot, in one location, the stresses are high, vehicles are moving at a particular speed. In another location we have mostly cars that are standing and then again they are static in nature. So, here the type of loading changes, so the expectation of the mix will change.

While designing the mix for different climates we have to consider various parameters. For example, the requirement for a mix which will be placed in a very hot weather condition will be different from the mix which will be placed in a cold weather condition. For example, in hot weather condition, we will have a tendency to use stiffer binders, whereas in cold weather condition we will have a tendency to use binder with lower stiffness. Then of course, moisture is one of the factors at location with extreme rainfall we have to take in we have to take several other considerations, so that our mix performs when it is finally open to the traffic and to the environment.

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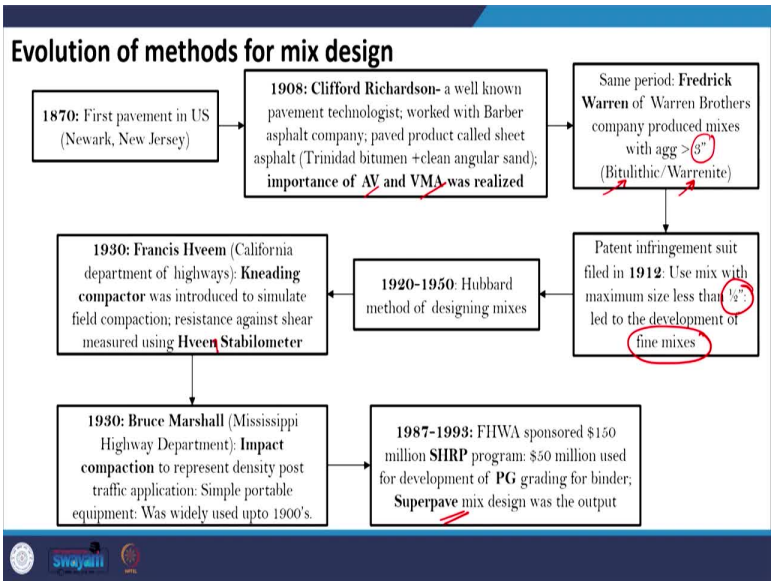

Now, finally, let us discuss before we jump into the mixed design aspects, let us discuss about the historical development of mixed design. Of course, the actual evidence of the first use of bitumen because this historical aspect we have already covered in the third module, it is debatable and the evidence of using bitumen can be dated back to about like 3000 B.C. and even before but here we are talking more about the construction of pavement, which is more related to the use of actual bitumen rather than other types of bituminous material.

The first pavement in US has been reported to be constructed in 1870 in Newark, New Jersey, then around 1908 Clifford Richardson, he was a well-known pavement technologist and worked with the barber asphalt company. So, he developed a product or paved a product which is which was called as sheet asphalt and sheet asphalt was a mixture of clean angular sand and Trinidad bitumen which is the natural bitumen, and this was the time when the importance of air voids and the voids in mineral aggregates.

So, air voids and voids in mineral aggregates they are volumetric aspects of the mixture we will discuss in detail about them. So, this was the time when the importance of volume matrix was realized that mixes with different volume matrix can perform significantly different from each other. In the same period. Frederick Warren of Warren Brothers Company started producing mixes with aggregate size larger than three inches.

So, these were basically large stone mixes, and they were tightly packed with minimum voids. So, this type of mixtures were produced and they acquired a patent for it, they initially call it a bitulithic pavement or bitulithic mix, which was later improved and it was marketed under the name of Warrenite.

In 1912 the Warren brothers they filed a patent infringement suit for their patent and then the court ruled that not to violate the patent rights anyone can produce a mix with maximum size less than half inches, because of this there were developments related to the production of fine graded asphalt mixtures. Then further around 1920 to 1940 you can say one of the initial or the first mix design method was developed which was named as Hubbard method of designing mixes.

So, the Hubbard method it used stability tests to determine the performance of the mixture some form of stability test was used. Then around 1930 Francis Hveem who was working with the California Department of Highways, he did some significant work for developing a complete mix design process using kneading compactor and it was known as Hveem mix design and it was also used by various states for designing the mixes.

So, kneading compactor was used and kneading compactor was basically selected to simulate fill compaction and the strength of the mixes was determined using Hveem Stabilometer, which measures the resistance of the mix against shear. However, the Hveem mix design method did not become very popular, because during the same time Bruce Marshall who was working with the Mississippi Highway Department.

He developed an impact compaction process to represent the density of the mix after years of loading and this was during the time of World War 2 where they needed the government needed pavements to land aircraft at remote places. And since the compaction process, the equipment which was proposed by Marshall was easy to handle, it became more popular and then most of the states started using the Marshall mix design process. In fact, in India also presently we use the Marshall mix design process.

But however the initial Marshall method, which was proposed by Bruce Marshall, it was further modified to accommodate higher volume of traffic and it was specifically in US it was widely used up to 1900's but as I mentioned in India also we still use the Marshall mix design process and in the Marshall mix design process also the strength of the mix assessed using tests such as Marshall stability and Marshall flow, and the details of which of course, we will be discussing when we discuss about the steps of mixed design.

During 1987 to 1993, as we have discussed also previously, that Federal Highway Administration sponsored a 150 million dollars project under the SHRP program, of which almost 50 million dollars were used for the development of performance grading system, which included development of a new grading system for the binder and also for the development of the Superpave mix design process. So, Superpave mix design process is now a standard process which is used in US for the mix design of their bituminous mixtures.

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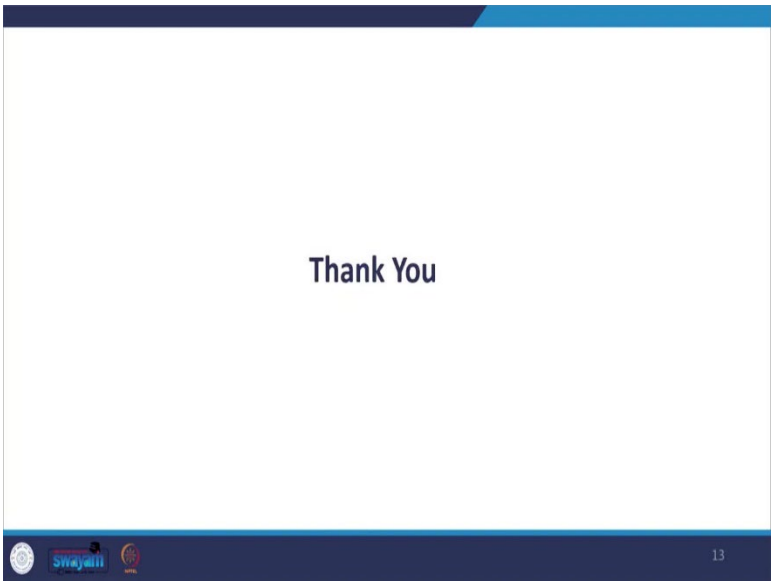

So, with this we will end here. So, we have today discuss about various desirable properties of from the mixtures and what are the performance parameters which we want to optimize, we have tried to understand the definition of mix design, we have also tried to understand that the mix design should be done based on different conditions related to the project. And then we have seen the historical and overview of the historical development of the use of bituminous mixtures and the development of different mix design process till date.

And from the next presentation in the next presentation we will start discussing about the volume metrics of mix design which is basically the backbone of any mix design process. So, in our module here we will be discussing in detail about Marshall mix design process which we use in India and Superpave mix design process. However, as I said that before we jump into the mix design process, we will spend some time in understanding the volumetrics of bituminous mixtures. We will start discussing about this from the next presentation. Thank you.