Introduction to Transportation Engineering
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Lecture - 32
Design of Bituminous Mixes - 1

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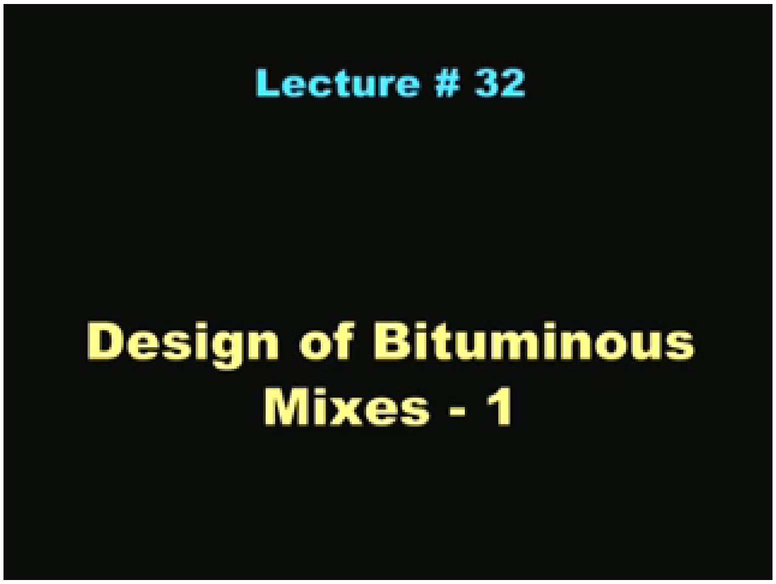

Welcome to lesson 4.9 which is on design of bituminous mixes. We will be covering this topic in two parts. This lesson will be on part I of design of bituminous mixes. This is a series of lessons that we are covering under pavement design module which is module IV.

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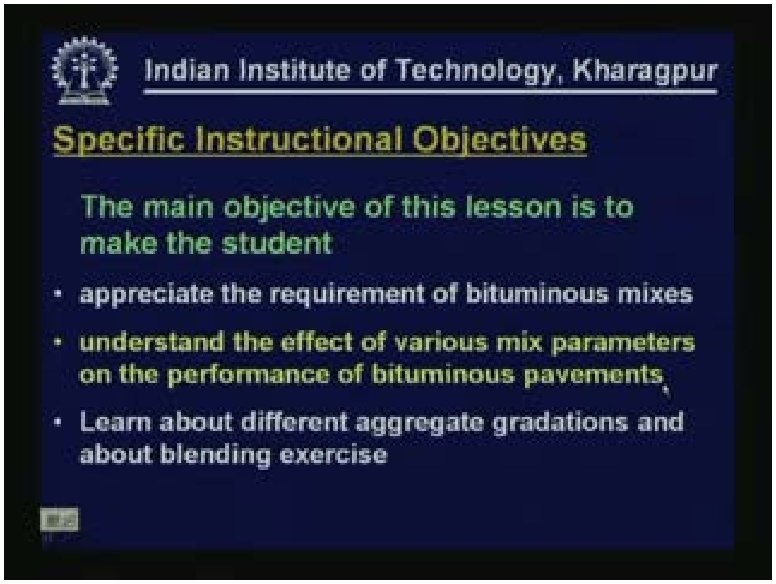

In the previous lessons we have covered a few lessons on pavement materials starting with sub grade soils, granular materials and different types of bituminous binders such as bitumen, tar, emulsion, cutback and modified binders. Though the properties that we are going to discuss in this lesson and the subsequent lesson are not directly correlated to any inputs that we use in pavement design.

You recollect that this is a module on pavement design but it is generally seen that many of the pavements which have been constructed recently have been failing mostly not because of any problem with pavement design but many of these problems have been associated with the failure that has been occurring in bituminous mixes themselves. So that's why I thought it fit to cover some aspects of bituminous mix design because this is an essential aspect and in fact this has become a very difficult art in the recent past. This is because of lack of experience that we have in India about how these mixes are going to perform. Because we have not observed the performance of thick bituminous layers for quite sometime and as a result what are the exact specifications to be adopted for designing these mixes is still is not so well known in India.

The main objective of this lesson is to make the student appreciate the requirement of different types of bituminous mixes, mix that is used in surface, mix that is used as a binder course which is subjected to different types of loading conditions, different stresses so as is the requirement of different types of bituminous mixes will be different. We will try to understand those requirements.

It is also expected that the student will be able to understand the effect of various mix parameters on the performance of bituminous pavements. Basically mix design is nothing but finding out in which proportion different components of bituminous mixes should be mixed and then adopted. So, in adopting different proportions we are going to have different mix parameters either in volumetric or other structural strength parameters, which of these parameters have got better correlation with the performance of the pavements, we will try to understand that also.

It is also expected that the student will learn about different aggregate gradations and also if is supplied with different aggregate sources how to blend them and then obtain a decide gradation. This is just the part one of mix design process. in the next part we will be covering how exactly the mixes are to be prepared, tested and how optimum combinations of different components of mixes are to be obtained.

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What you see here is a typical bituminous pavement. In fact this is a section of national highway VI. Especially bituminous mixes that are used for high volume roads are subjected to various conditions such as number of repetitions of loads, and heavy loads. Often we see lot of overloading that is occurring in India and we have various climatic conditions including various temperatures like low temperatures, high temperatures and also these are subjected to various moisture conditions. so the mixes that we are going to use either in surfacing or in the binder course have to sustain various loading and climatic conditions. Accordingly different mixes will have to adopt different specifications in terms of volumetric proportions in terms of other mechanical properties.

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Bituminous pavement fail in different face. They fail by cracking because this is a bound layer bound material so it is likely to crack. Cracks can be initiated from the bottom especially caused by flexure. As the layers get fluxed there are tensile stresses developed at the bottom leading to development of initiation of crack at the bottom which gradually progresses to the top. These are what are known as bottom of cracks. Usually these are caused by repeated application of loads or repeated application of thermal cycles or other environmental cycles. So the cracking can be initiated mostly from the bottom.

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But we can also have cracks that initiate from top and progress downwards as can be seen in the core of bituminous pavement that has been taken out. You can see the crack that is initiated from the top and progressing to the bottom. These are what are known as top down cracks caused by various reasons and various conditions. These also need to be taken into consideration while designing the mixes.

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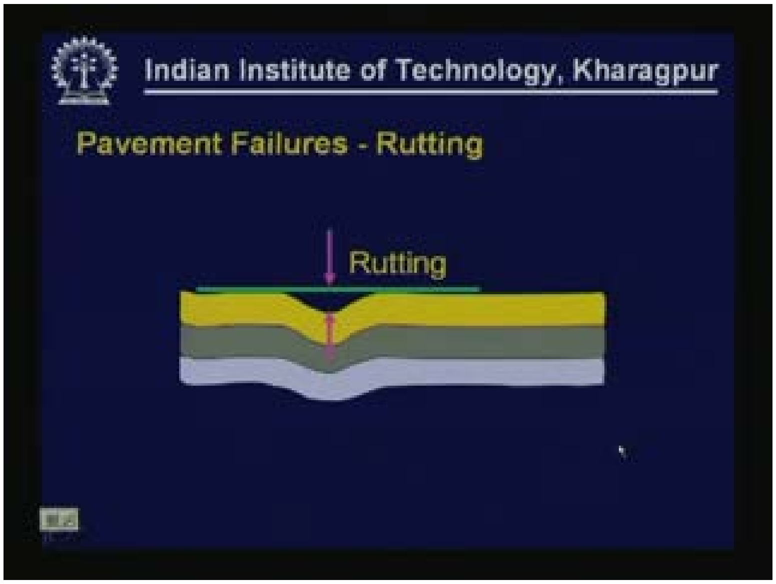

But a more serious problem that is being encountered in India is rutting. As we discussed in the initial lessons of this series rutting is caused by permanent deformation in different pavement layers. It can be in the sub grade layer, it can be in granular basis or it can be in bituminous layer also. All these layers or some of these layers can undergo permanent deformation which gets reflected in the surface in the form of rud depth. Many of the recently constructed pavements having thick bituminous layers have shown this problem.

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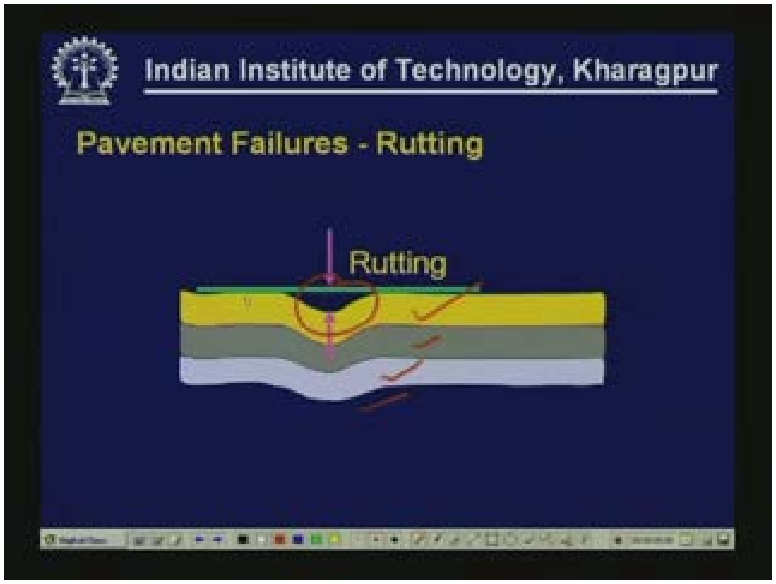

On investigation it was revealed that the problem was mainly confined to the thick bituminous layers that were used. So this is the problem that is related especially to the mixes that has been absorbed in the recent past especially on thick pavements. So this is not so much of a problem but is arising out of either subgrade sub-base or base. Of course in a given situation permanent deformation can occur in subgrades, sub-base, base and in bituminous layer also. So what we would see will be an accumulation of all the permanent deformation that is occurring in different layers. But what we are concerned about in designing mixes is to see that the mixes in a given condition do not undergo excessive permanent deformation. We cannot design mixes which do not undergo any permanent information at all during its service life period but that should not be excessive.

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Another failure that is more or less related to rutting or caused because of similar reasons such as bleeding which is the occurrence or presence of excessive bitumen film at the surface. Though it's not a major structural failure but this reduces the skid resistance of the pavement surface and also it does not give a good impression of the pavement that is constructed.

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As we have seen in the previous slides there are various types of failures; fatigue cracking is a cracking that is caused by repetition of load or thermal stresses, top down cracking, low temperature cracking and so on. Cracking can also be because of very low temperatures, mix trying to shrink and the restrain that is provided to the mix from being shrunk can cause low temperature cracking. Usually these are in the transverse direction occurred at different spacing but normally these are confined to areas where there is very low temperature especially in winter. We also talked about rutting failure and bleeding failure. There can of course by various other types of failures which get initiated. Once fatigue cracking take place or other types of cracks take place and once rut forms there is accumulation of water there is infiltration of water through these cracks which starts damaging the bituminous pavement.

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There are of course different types of bituminous mixes that we use. Some of these layers are thin, some of them are thick and they have different gradation of aggregates different characteristics used for specific purposes. Some of these are premix carpet, surface dressing, mixed seal surfacing, these are thin bituminous surfacing courses usually of the order of 20, 25 mm thickness and having various characteristic in terms of the voids it has got and also in terms of the stability it has got. Then we have bituminous macadam, dense bituminous macadam semi-dense bituminous concrete. Bituminous macadam and semi-dense bituminous macadam are usually adopted for binder course.

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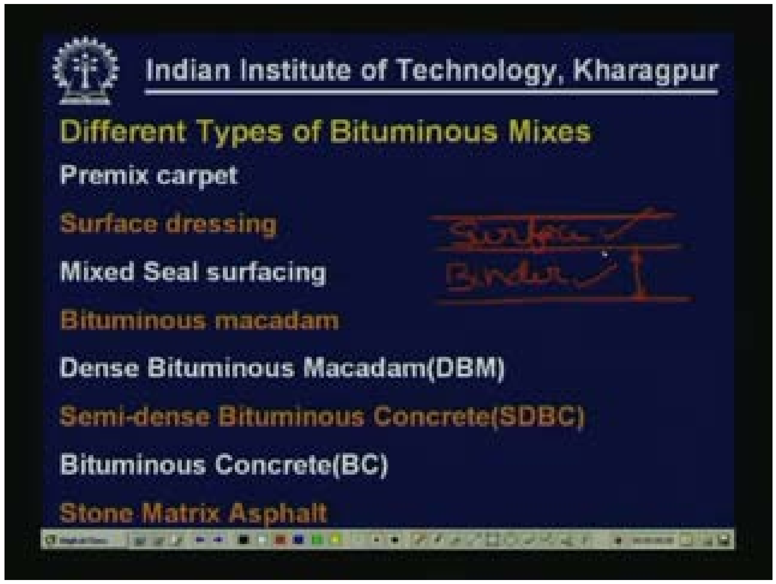

What are known as binder courses? For example, if a bituminous layer is constructed in a thick layer the main structural layer will be binder course whereas the surface will have 25 to 40 mm or 50 mm thick layer so this is the one that is exposed to the surface and below that there will be thicker binder course. Obviously the requirement of a surface course and requirement of a binder course will be different and we have bituminous concrete and semi-dense bituminous concrete SDBC BC used as surfacing courses. And we also have a new type relatively new in India a mix that is used as stone mix asphalt where usually the gradation is of coarser side especially used when there is excessive problem of rutting.

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As I indicated these are thin surfaces. There are also thick surfaces. We would consider some of those surfaces whose thickness would be 20 mm, 25 mm to be thin and surfaces having 40, 50 mm thickness as thicker surfaces, we can have thick binder courses and the mixes can be cold mixes as well as hot mixes.

Cold mixes are those mixes in which we generally use emulsions where there is no requirement of heat so those are called as cold mixes. But the design or mixes that we will be discussing about will be about hot mixes. So the term that we normally use is HMA hot mix asphalt. So we will be discussing about hot mixes. These mixes are subjected to different traffic loading conditions, different temperatures and different moisture conditions. Basically in different project sites you can expect different loading conditions, different traffic and different climatic conditions.

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The objective of hot mix design is to develop an economical blend of aggregates and asphalt which were otherwise called as bitumen that meets design requirements. For a given specific project there are specific requirements so we have to find an economical blend and that blend of aggregates and binder.

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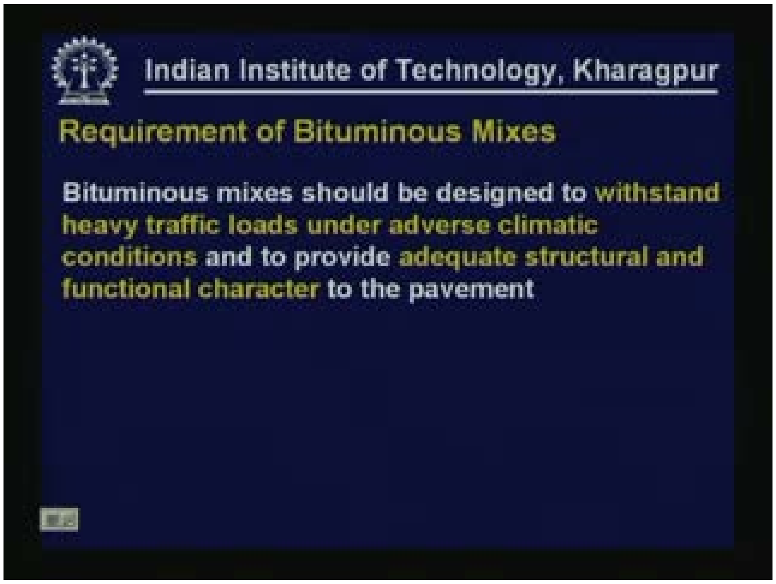

What are the requirements of bituminous mixes?

Bituminous mixes should be designed to withstand heavy traffic loads under adverse climatic conditions and to provide adequate structural and functional character to the pavement. Although I have indicated these to be heavy traffic and adverse climatic conditions what I really meant was that they should perform under varying conditions. Obviously we are not going to design same type of mixes for all climatic conditions. Depending on the climatic conditions that is specific to a specific project and also the traffic loading that is expected and number of load deputation that are excepted at a given location we are going to have a specific mix design for that particular site.

It should have adequate structural strength and it should also have adequate functional character. what we mean by functional character is when it is mostly used as a surface layer it should provide adequate functional performance that means the riding surface that is going to be provided should also be satisfactory.

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Continuing with the specific requirements of bituminous mixes it should have sufficient stability that means it should have sufficient resistance against flow it should have sufficient durability because the mixes have to serve for a period of ten years, fifteen years without failing so that's a time dependent service that we are expecting so during this time period they should also be durable when they are subjected to various climatic conditions. They should be sufficiently impermeable depending upon where we are reason this material. If it is surface it also should provide an impermeable surface so that water does not go down to the layers and then cause damage to different pavement layers.

The mix that we design should be sufficiently workable with the equipment that we normally use and it should have adequate flexibility. It should not be too rigid so that when load is applied it's not able to deflect and as a result it is going to induce cracks so adequate flexibility should be provided. It should have sufficient fatigue resistance. It is a resistance to with stand repeated application of loads or repeated application of cyclic variations of temperature, stresses and it should also provide sufficient skid resistance. This is one of the important surface characteristics that we try to attain while designing the bituminous mixes.

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In order to fulfill all those criteria what is required is the mix should have sufficient binder to ensure a durable pavement. The binder should be sufficient to coat thoroughly the aggregate particles, we know that bitumen has got the water proof quality and it should be sufficient to provide water proofing property and bind the aggregates together under suitable compaction. Whatever is a compaction effort that is selected under that compaction effort the bitumen should be sufficient so as to coat all the particles and then bind them together. And the mixes should have sufficient stability for providing resistance to deformation. Under sustained loads depending on the project site it may be the load that is applied for longer periods or load that is applied for shorter periods but repeatedly. So under both conditions it should have sufficient resistance deformation under sustained loads and repeated loads. This resistance in the mixture is obtained from mostly aggregate interlocking and cohesion within the bitumen which is generally developed due to binder in the mix. The mix has got cohesion because of the binder that is available there but the aggregate interlocking that can be mobilized is of more importance when we talk about stability.

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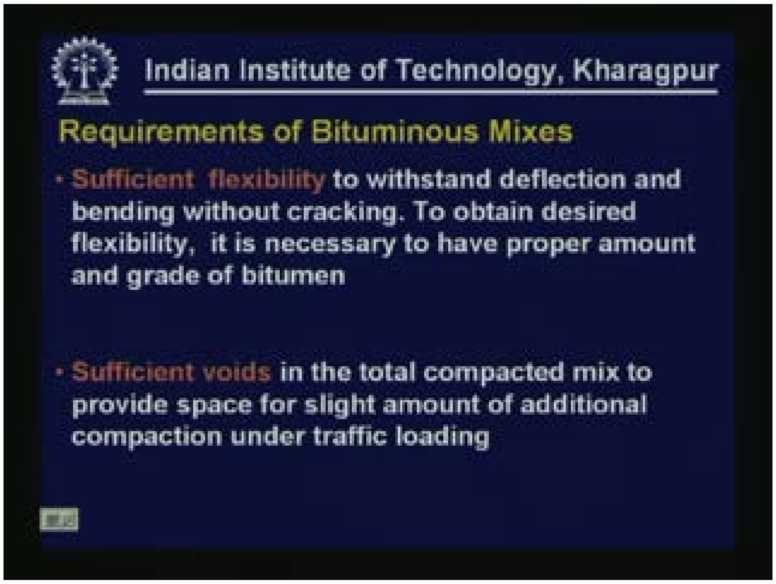

As we said earlier it should have sufficient flexibility also to withstand deflection and bending without cracking. To obtain desired flexibility it is necessary to have proper amount and grade of bitumen. If you use too (( )) (00:18:48) a bitumen too smaller a binder content the mixes are going to be stiff will not be flexible then they are more likely to crack. They should also have sufficient voids in the total compacted mix sufficient to provide space for additional compaction that is expected to take space during the service life period because subsequently traffic loads are going to be applied they going to cause further compaction known as secondary compaction so there should be enough space to provide for the additional compaction that is anyway going to take place because of secondary compaction and also the mixes should have sufficient workability for an efficient construction operation in laying the paving mix and the finished surface should have adequate skid resistance.

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For example, a bleeding surface which is rich in bitumen too much of binder is provided and this will result in reduction in skid resistance.

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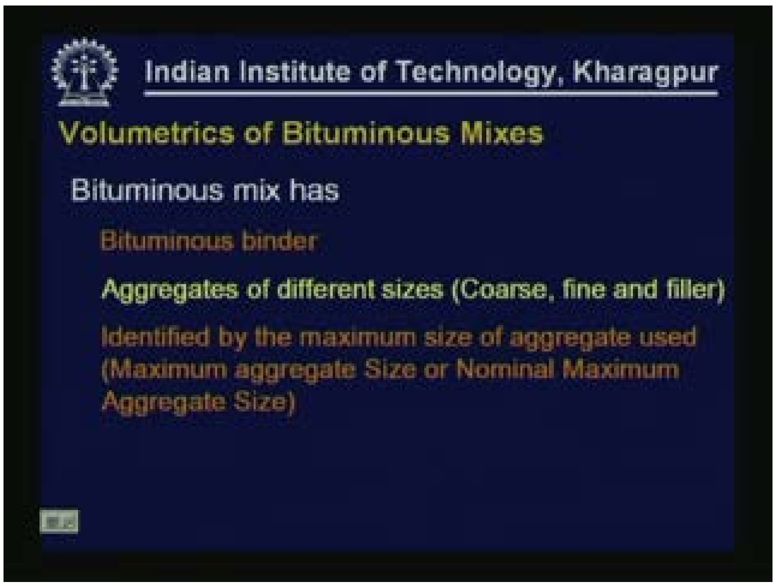

Bituminous mix usually is designed in terms of its volumetrics. We will discuss later why we design in terms of volumetrics. Bituminous binder has got aggregates of different sizes, coarse, fine and filler. The aggregates are identified in terms of the maximum size of aggregate which in turn can be represented in terms of maximum aggregate size or nominal maximum aggregate size.

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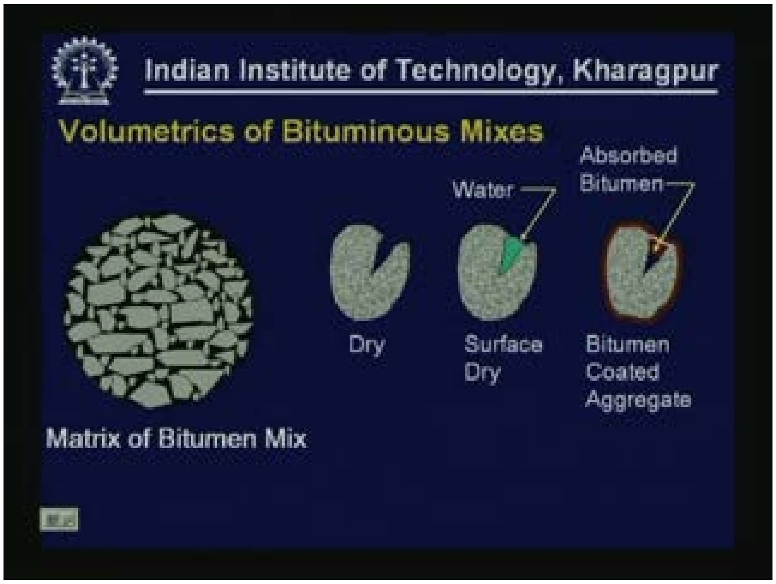

To convert a given quantity of bitumen say 100g of bituminous mix into volumes of the corresponding constituents that is volume of aggregate, volume of binder and obviously there is also going to be some air void content so to calculate those air void contents we need to have the specific gravity of all these components. If you know the weights and also if you know the specific gravities we can of course calculate the volume of each component and then express in terms of percentages.

Bituminous mix typically can be represented like this. It is matrix of aggregates, coarse fine and filler and bitumen and there would be some air voids also in the material. So this typically is a bituminous mix and this consists of mostly aggregates and the aggregates can be in three different conditions. It can be dry, it can be surface dry, surface dry being the surface pores filled with water as you see here but there is no water on the surface of the aggregates which has been dried. This is what is known as surface dry condition of aggregate and this is an aggregate which has been coated with bituminous film on the surface and a part of the bitumen has penetrated into the surface pore but not fully. Whatever volume that could be filled by water normally cannot by filled by bitumen because of the higher viscosity. Hence this is the coated aggregate so you have the volume of aggregate, you have the volume of binder that is coating and part of the binder has gone into the pores. This is what you have to consider when we examining the volumetric of bituminous mix.

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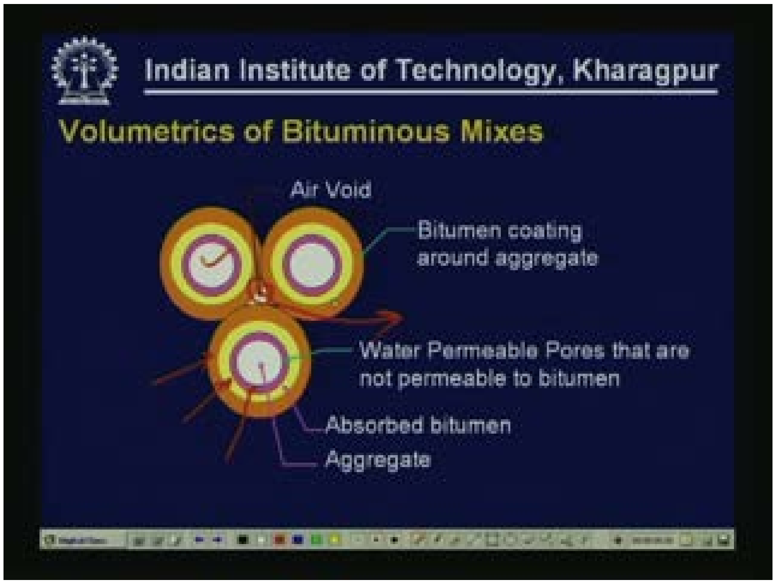

The same thing is represented in this sketch. at the center you have the volume of aggregate and this one here is the water permeable pores which cannot be permitted by bitumen and the yellow portion is that part of the surface pore of the aggregate which is permeable to bitumen and the outer ring represents the coated film of bitumen and in between these aggregates we have air voids. So we have number of aggregate particles which have been coated with bituminous binder and in between we have air voids.

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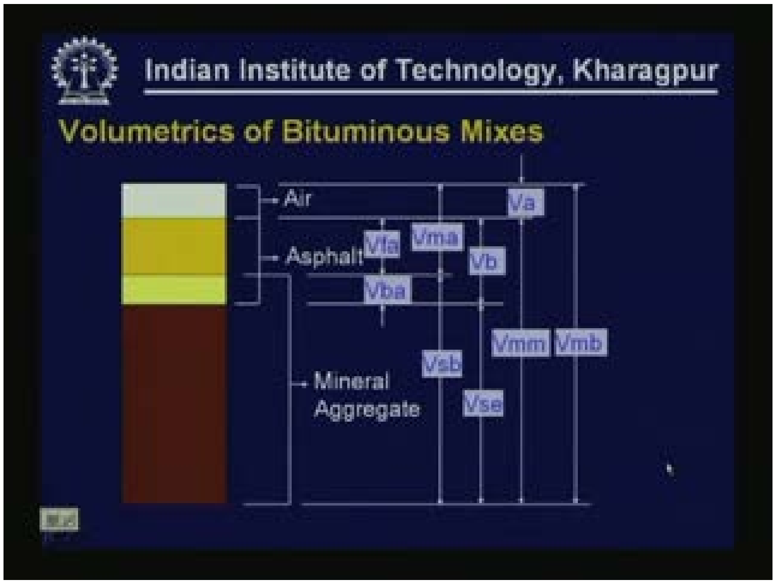

This is again represented in this schematic arrangement. We have volume of mineral aggregate, part of this has been filled with bitumen assuming that there are surface voids which can be filled by bitumen. (Refer Slide Time: 23:25) This is the total asphalt that we are using and part of that is going into the aggregates because of the surface pores that are available and there is also some air void content between the coated aggregates, particles so we are using various terms to represent the volumetrics; Va is the volume of air void, Vb is the volume of binder, Vmb is the bulk volume including air void binder content and the total volume of aggregates and so on. We will discuss about these terms on the next slide.

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Various terms that we have used in the previous slide are Vma: this is the volume of voids in the mineral aggregate, Vmb: this is the bulk volume of the compacted mix. Obviously we are going to use aggregates we are going to use binder put them together, heat them and then compact them using certain compaction effort so what you finally get is a compacted mix and within that mix there will be some air voids so we are referring to the volumetrics of the compacted mix.

Hence there will be some voids within the mineral aggregates that we have provided and for part of these voids within the mineral aggregates if you consider only the aggregates skeleton structure then those voids that we are going to have in the mineral aggregates is going to be filled partly with bitumen and the remaining is going to be air void content. hence Vma is a volume of voids and mineral aggregate, Vmb is the bulk volume of the compacted mix, Vmm is the void-less volume of paving mix, if you do not consider the volume of air voids what you get is the void-less volume of paving mix and then if you compare Vmm with Vmb you get an idea of what the air void content is, Vfa is the volume of voids in mineral aggregates filled with asphalt, Va is the volume of air voids, Vb is the volume of asphalt or binder, Vba is the volume of absorbed asphalt, Vsb is a volume of mineral aggregates calculated using the bulk specific gravity of the aggregates, and Vse is the volume of mineral aggregates calculated using the effective specific gravity of the aggregates.

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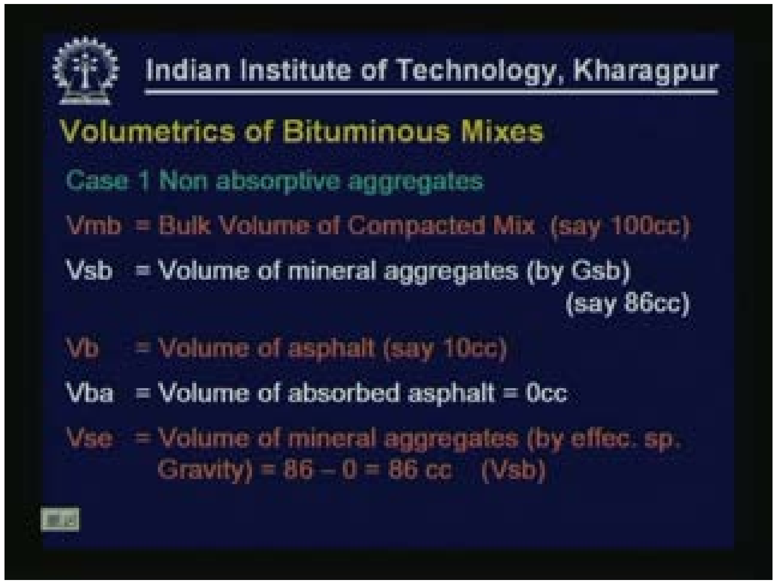

Let us consider two different cases and see how the volumetric is different. Case one is we are considering aggregates that are non absorptive. There are no surface pores so neither water nor bitumen can penetrate into the surface pores, let's consider that case. Let us consider the bulk volume of the compacted mix let us say 100 cc represented by Vmb. Let us consider the volume of mineral aggregates that has been used in the mix.

We know the weight of aggregate that we are used in the mix and we know the bulk specific gravity of the aggregates so we know the bulk volume of aggregates that has been used in the compacted mix. So let's say that is about 86 cc and let us also consider the volume of asphalt that we put is 10 cc. Again we know the weight of binder that is used, we can also find out what is the specific gravity of the binder then we can calculate what is the volume of binder that we have used in 100 cc compacted specimen. Then Vba is the volume of absorbed asphalt or absorbed bitumen.

Since we have considered non absorptive aggregates obviously no bitumen is absorbed so we are considering this to be 0. Vsc volume of mineral aggregates is assessed in terms of effective specific gravity which is equal to Vsb because there is no absorption here so there is no difference between effective specific gravity and bulk specific gravity so we get 86 cc for effective volume of mineral aggregates both by effective specific gravity calculation and also by bulk specific gravity calculation.

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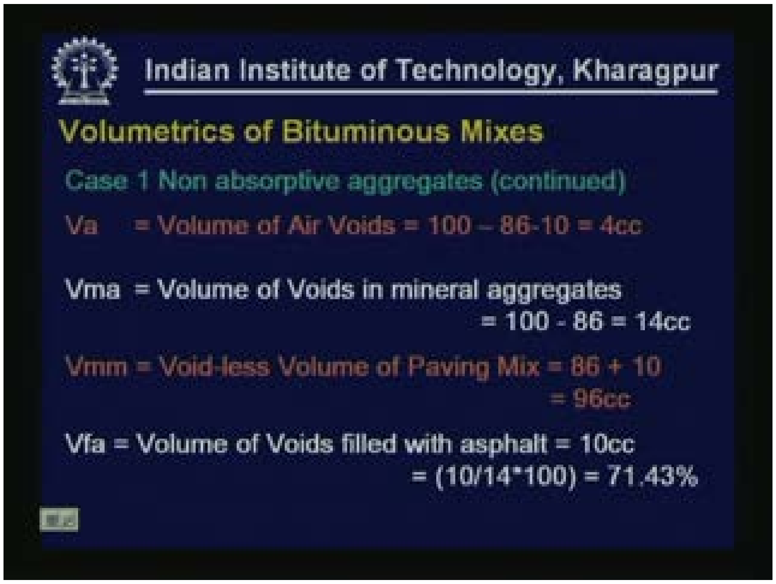

So the volume of air voids will be 100 cc which is the total volume or bulk volume of the compacted mix and out of that 86 cc is the volume of aggregates, 10 cc is the volume of binder so obviously the remaining is 4 cc. We have put 10 cc of bitumen in the mix and none of these material has gone into the aggregates so the air void content here is 100 – 86 – 10 = 4 cc. If you express in the terms of percentages this will be 4% air void content. Similarly, Vma volume of voids in mineral aggregates is 100 minus volume of aggregates that is 14 cc, void less volume of paving mix will be 86 + 10 that is aggregate plus bitumen 96 cc, Vfa volume of voids filled with asphalt is 10 cc. this is normally expressed as a percentage of the total voids and mineral aggregate which was 14 cc or 14% so 10/14 into 100 is the percentage of volume of voids filled with asphalt.

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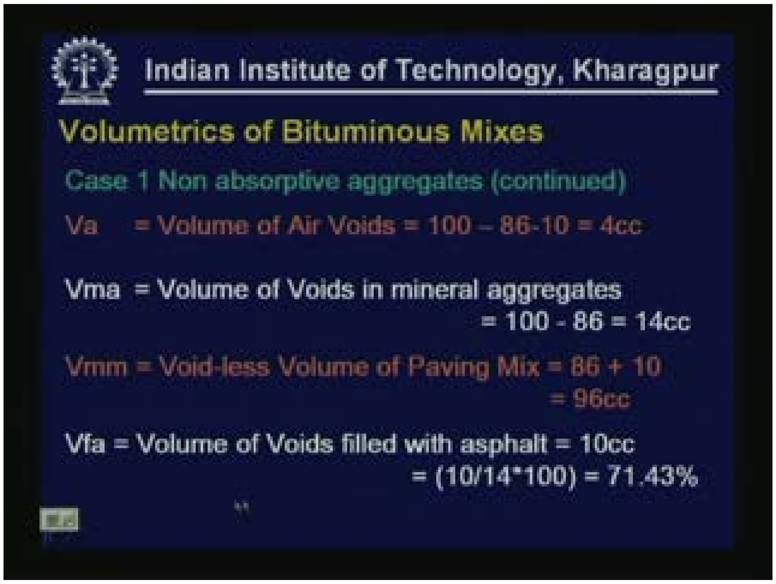

Let us consider another case where the aggregates can absorb some amount of bitumen. So let's consider again Vmb to be 100 cc, Vsb to be 86 cc we have put the same quantity of aggregate, we know the mass of aggregate that is taken so calculating this volume by bulk specific gravity we get the bulk volume that is 86 cc, volume of asphalt or bitumen let us say again is 10 cc, let us assume the volume of asphalt absorbed to be 2 cc out of the 10 cc that is absorbed in the aggregates. Thus the volume of mineral aggregates calculated by effective specific gravity will be 86 – 2 = 84 cc.

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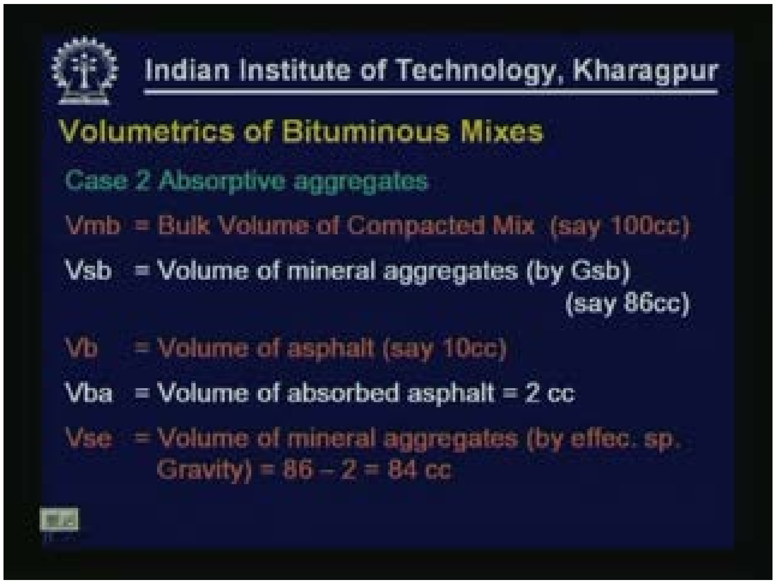

Volume of air voids will now be 100 – 86 – 8 because 2 cc of bitumen has gone into the aggregates so volume of air void is 6 cc here and expressed in terms of percentage it will be 6% air void here. Vma is volume of voids and mineral aggregate so it will be 100 – 86 = 14, void less volume of paving mix will be 86 + 8 = 94 cc, volume of voids field with asphalt will be 8 cc that is 10 – 2 and when expressed as percentage this will be 8/14 into 100 = 57.14.

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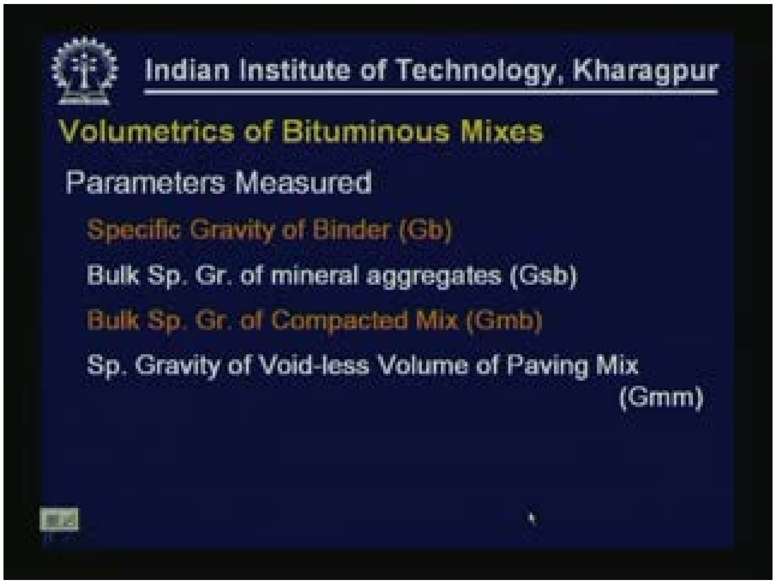

To calculate all these volumetrics the parameters that we need to measure will be specific gravity of binder, bulk specific gravity of mineral aggregate, bulk specific gravity of compacted mix, specific gravity of void less volume of paving mix that is Gmm.

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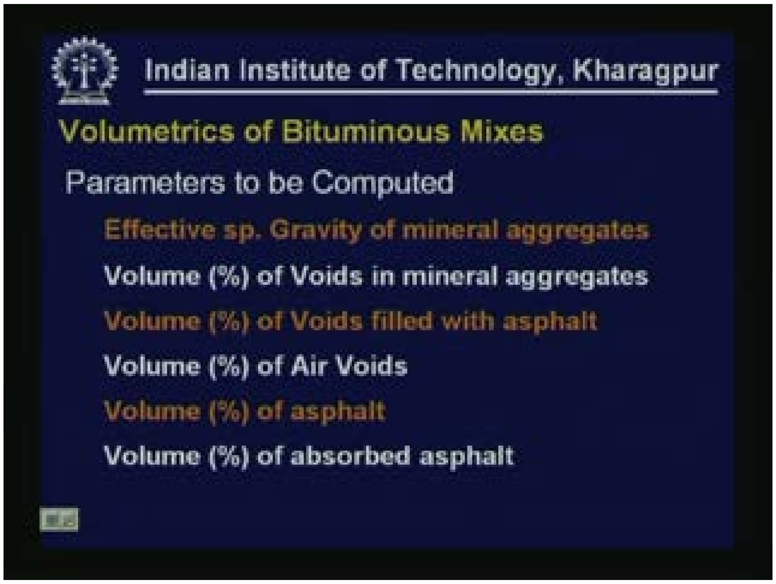

Using this information we can calculate effective specific gravity of mineral aggregate, volume of voids in mineral aggregate, volume of voids filled with asphalt, volume of air voids, volume of asphalt, and volume of absorbed asphalt.

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We have discussed about bulk specific gravity of aggregates in the lesson on aggregates, let us consider that again. Bulk specific gravity is a dry mass of a specimen divided by the volume of water replaced by the saturated surface dry aggregate whereas the bulk specific gravity of the compacted mix can be obtained by getting the dry mass of the compacted mix divided by the volume of water replaced by the saturated surface dry specimen. We have to first have the specimen saturated surface dry then take its weight in air and weight in water then see what is the volume replaced so that is the bulk volume. Therefore dry mass divided by this bulk volume that you get gives you bulk specific gravity of compacted mix.

We can also get this specific gravity of void less volume of paving mix which is Gmm also called as maximum theoretical specific gravity of the mix by preparing loose mix which is not compacted and then finding the dry mass of the loose mix and then finding the volume of water replaced by the saturated surface dry loose mix. What you see here is a photograph of the arrangement that we normally use to measure the specific gravities of mixes and aggregates.

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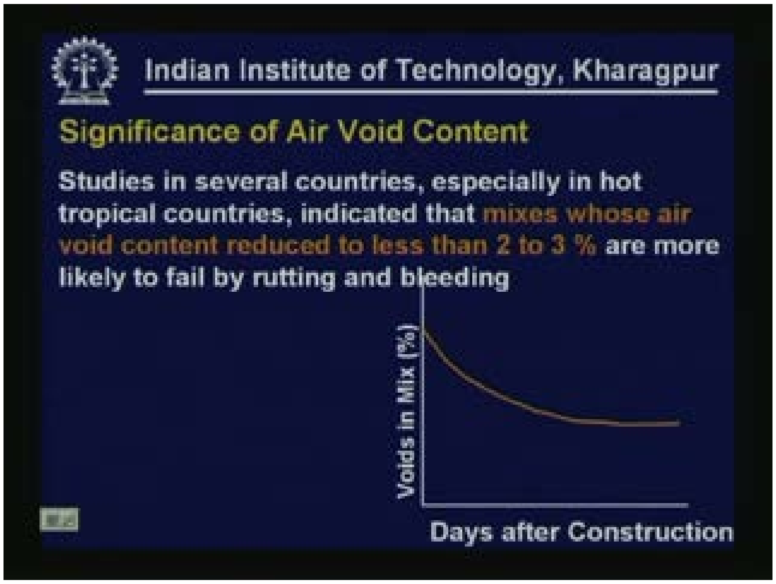

As I indicated here I mentioned that will discuss about the significance of volumetric parameters and their correlation to the performance. Air void content is the most important volumetric parameter that is considered having great significance or great influence on the performance of the pavements. There were several studies conducted in different countries especially in hot climatic country such as India. These indicate that the mixes whose air void content gets reduced to about 2 to 3% after serving some years of traffic say 2 years, 3 years, 5 years, 10 years then if the air void content gets reduce to 2, 3 or even lesser these are mixes that are likely to fail by rutting or bleeding.

If you construct a pavement using a certain mix after sometime if you take the core and find out what is the air void content in the mix if the air void content is found to be less than 2% or 3%these are mixes that are more likely to fail by rutting and then bleeding.

What you see here (Refer Slide Time: 35:04) is a trend of how air voids vary with time. obviously initially air voids are going to be let us say 6%, 7% as to whatever is initially designed and then with traffic that is with secondary compaction air void content is going to get reduced. But for the mixes to perform satisfactorily this air void content should not get reduced to less than 2 or 3%.

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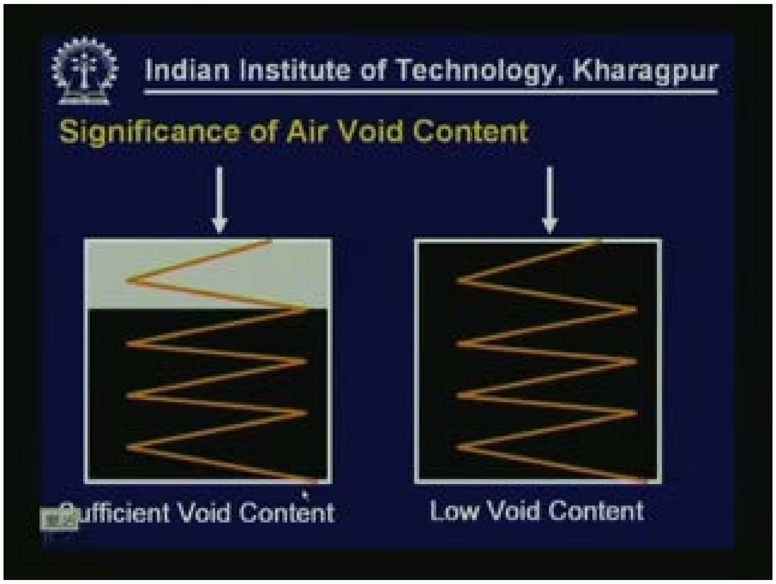

Let us see what is the meaning of this. if you have sufficient air void content if you consider the aggregate to aggregate interaction can be represented by a spring and for the spring which is put in a bituminous medium there is sufficient air void content as shown in this diagram on the left side, when load is applied it is a spring that takes the main load, only when it gets so much compacted or so much deformed then only the bitumen comes into play and that is when you have sufficient air void content. But on the right hand side there are no air voids, the complete medium is filled with bitumen and as soon as we apply load the bitumen starts taken load and the bitumen by itself will not be having sufficient strength to carry loads so as a result it starts flowing. This is just to illustrate the importance of having adequate air void content.

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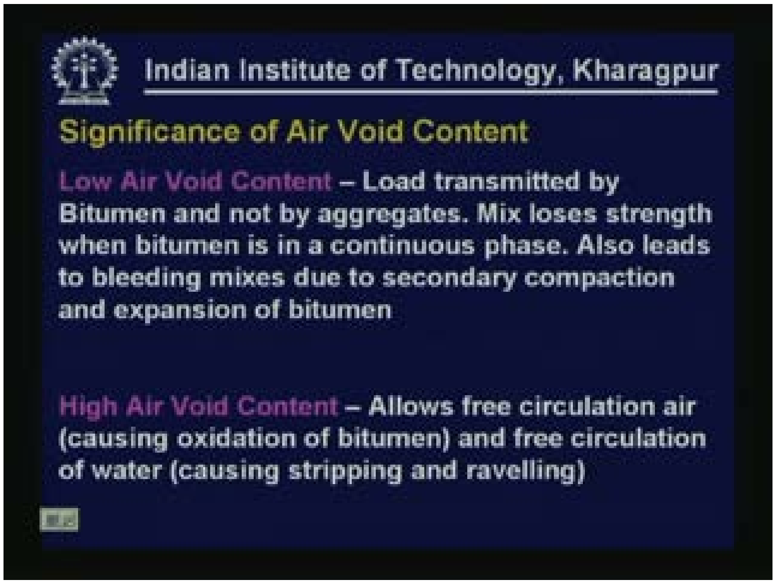

If you have a very low air void content in the bituminous mix the load transmitted by the mix is through bitumen and not by aggregates. So mix loses its strength when bitumen is almost in a continuous phase. This leads to bleeding because of the secondary compaction and also when bitumen expands because of increase in temperature. But on the other hand if you try to have more air void content those larger air void content allows free circulation of air within those air voids this causes oxidation of the bitumen and the bitumen becomes stiffer, it loses its flexibility and it is more likely to crack. Also, it permits free circulation of water within those pores and water as you know can damage bituminous layers and it can cause stripping and then raveling.

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The Ministry of Shipping and Road Transport Highways recommend 3 to 6% air void content for bituminous concrete mixes and DBM mixes. But most agencies design mixes to have an air void content of 4% after years of traffic. What we have to remember is we are targeting at air void content which would be obtained after years of traffic.

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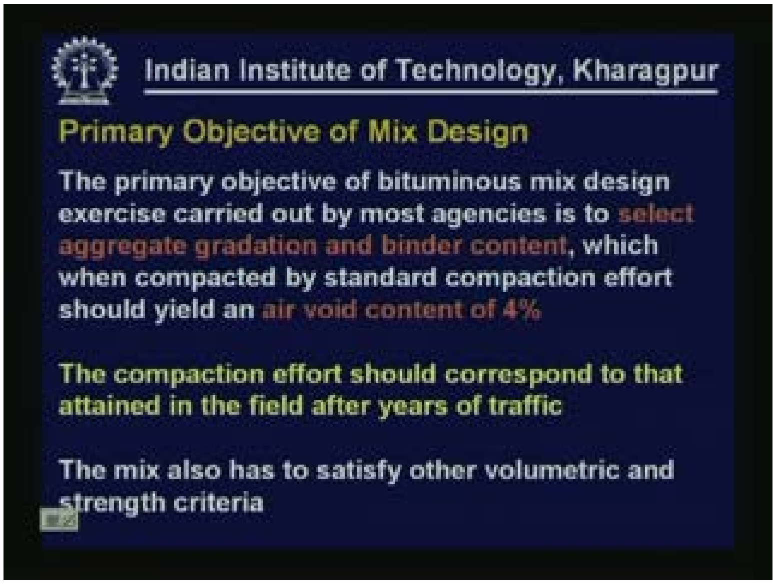

So the primary objective of mix design is to select aggregate gradation proper aggregate skeleton and the corresponding binder content where this mix when compacted by a standard compaction effort should yield an air void content of 4%. This is what most agencies try to do. They try to prepare a mix which when compacted by a standard compaction effort will yield an air void content of 4%. This standard compaction effort normally should be simulating the secondary compaction, initial compaction that is attained after years of traffic. Therefore this is the compaction that is expected to be there after years of traffic. The compaction effort as I just indicated should correspond to that attained in the field after years of traffic. The mix also has to satisfy obviously other volumetric and strength considerations because air voids is not only the consideration but there will be other considerations to take care of other problems.

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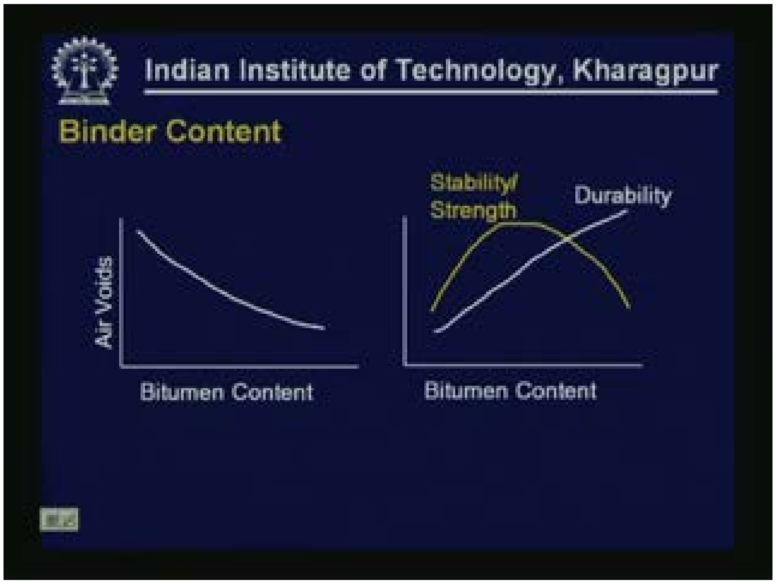

Now the most important task that is to be done is you have to select and aggregate skeleton structure, then you have to select an appropriate binder content to be used, optimum binder content. What happens when you go on increasing the bitumen content for a given aggregate gradation structure? Obviously the air void content is going to get decreased. And when you gone increasing the bitumen content this stability increases up to a certain point then it starts decreasing.

Initially as you go on increasing the binder content it would lubricate all the particles and enable the particles to get into denser positions so as a result it attains greater strength. but after a certain point the additional bitumen that we add does not add to additional compaction effort or attaining better density but it will only the increase the thickness of the film then it will not add to any additional strength.

But if you gone increasing the bitumen content it is going to be more durable because you are going to put more bitumen, film thickness is going to be more so in the long run aging is going to be reduced, and it is going to be a more durable thing. Therefore it’s a fine balance of getting an appropriate binder content which will give durable mixes, which will also give appropriate air void content, which shall give strong stable mixes, some of these are contradictory, if you increase bitumen content durability will increase, if you increase bitumen content air void will decrease and by increasing the bitumen contents stability will increase and after some point stability will decrease so bitumen content will have to be carefully selected.

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Let us consider the effect of aggregate size and gradation on mix properties. The size of aggregate and gradation affect the workability of the mix, they affect the thickness of the layer that can be adopted, they influence the thickness of the individual lift that we are going to compact in the field so obviously they are going to affect the stability and stability is mostly provided by the interlocking of these aggregates and not mostly because of bitumen. They contribute to the stiffness of the mix, they contribute significantly to the resistance of the mix to deformation and they also influence the fatigue strength of the mix where fatigue strength is the resistance to failure caused by repeated application of loads or repeated applications of thermal cycles and they also influence the durability of the mixes to some extent, permeability of course is a function of the gradation that we select for a given binder content, as they vary the gradations the permeability of the mix is going to be varying and surface texture and frictional resistance also is a function of the maximum size of aggregate that we select and also the sizes of various tractions. Basically the gradation that we adopted influences the surface structure and the skid resistance that is going to be available.

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It also affects the strength, dimensions of various structural elements etc, this is especially in the case of concrete pavements so we will not discuss about this here.

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Coming to aggregate size this has been briefly discussed in the earlier lessons but I will quickly go through this. Aggregates of different sizes are normally used in combination, large size will be there, coarse aggregates will be there, and fine aggregates will be there, filler will be there so different sizes are put together. This is the smaller size of sieve (Refer Slide Time: 43:15) through which hundred percent of the aggregate sample particles pass but there is another term that we normally use to represent the larger size.

Nominal maximum size: this is the largest sieve that returns some of the aggregate particles but not more than 10% by weight. The minimum thickness of a layer is about two to three times the maximum aggregate size. So accordingly depending on the thickness of the layer that we intend to provide the maximum size of the aggregate can be selected.

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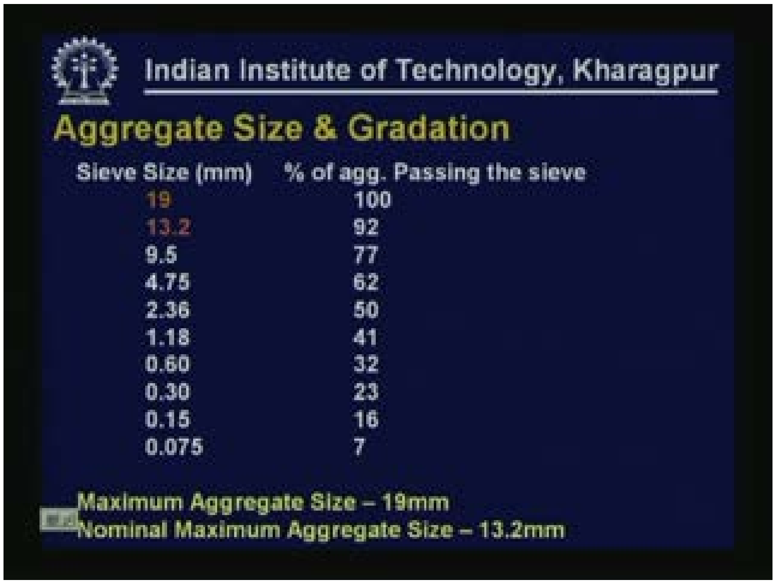

For example, if you have gradation given as given in the slide you have on the left hand side sieve size on the right hand side you have the percentage of aggregates passing through different size by weight so you have 19 mm size through which 100% of the material is passing so that is the maximum aggregate size, you have 13.2 mm size through which 92% is passing some material is retained which is not more than ten percent so this can be considered as nominal maximum aggregate size.

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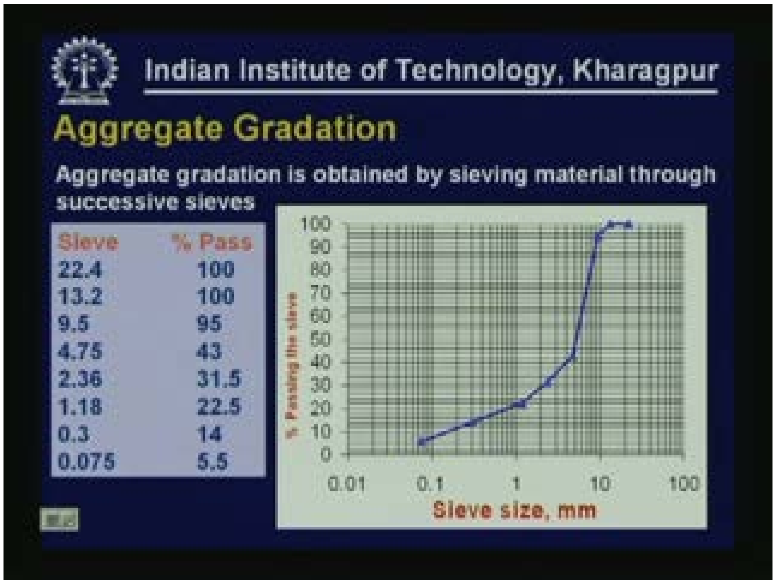

Normally this is how we represent the gradations in a graphical form. The x axis would be sieve size on a log scale and y axis will be the percentage passing through the given sieve which will be on a normal scale.

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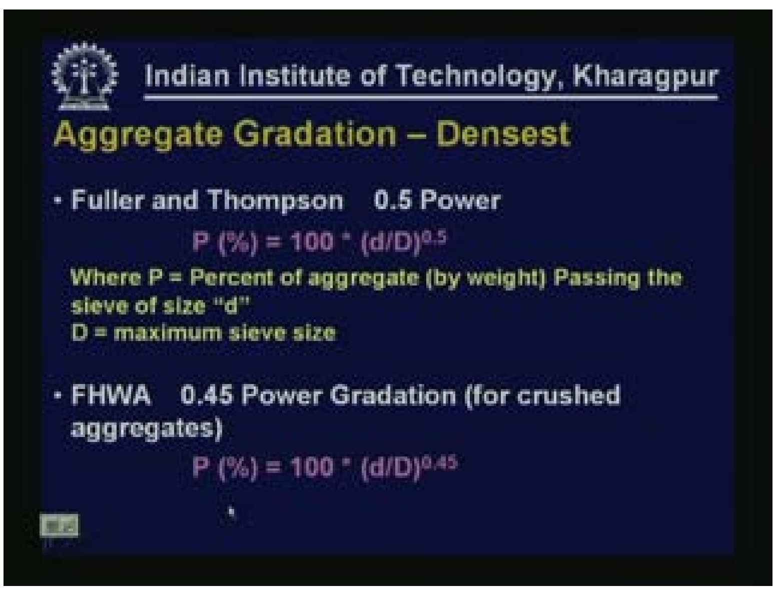

We also discussed in the earlier lesson that any given gradation that we are using normally is discussed in terms of how it is compared with the densest gradation that is possible with the given maximum aggregate size. The densest gradation that is possible with a given maximum aggregate size is given by different agencies. We have Fuller and Thompson gradation where the percentage passing through a given sieve will be 100 into d/D to the power 0.5 where d is the sieve under reference and D is the maximum sieve size so accordingly for each successive sieve what should be the percentage passing through that particular sieve can be calculated. But there is a more practical gradation that is given by FHWA which is known as 0.45 power gradation which is applicable for crushed aggregates which we normally use in pavement construction. Here percentage passing through a particular sieve is given as 100 into d which is the sieve under consideration divides by maximum size to the power 0.45.

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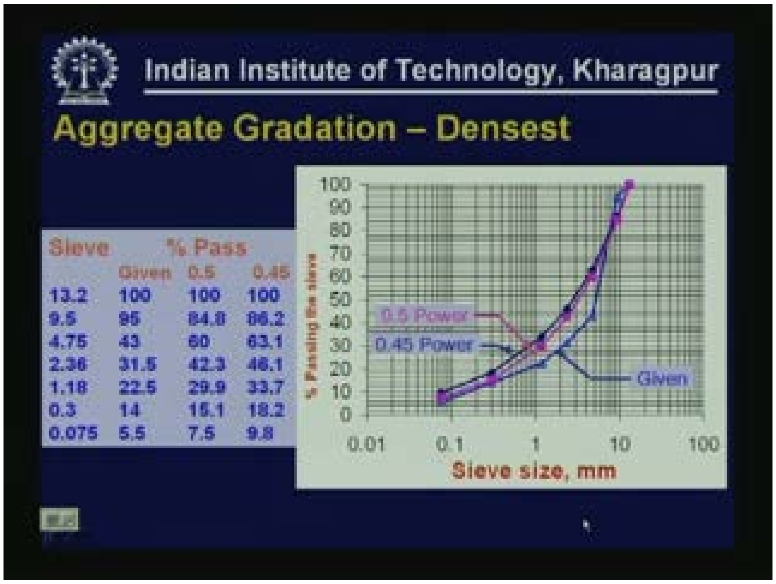

This diagram shows that for a given set of sieves what will be the gradation that would give us maximum densest gradation as per 0.5 power and also as per 0.45 power.

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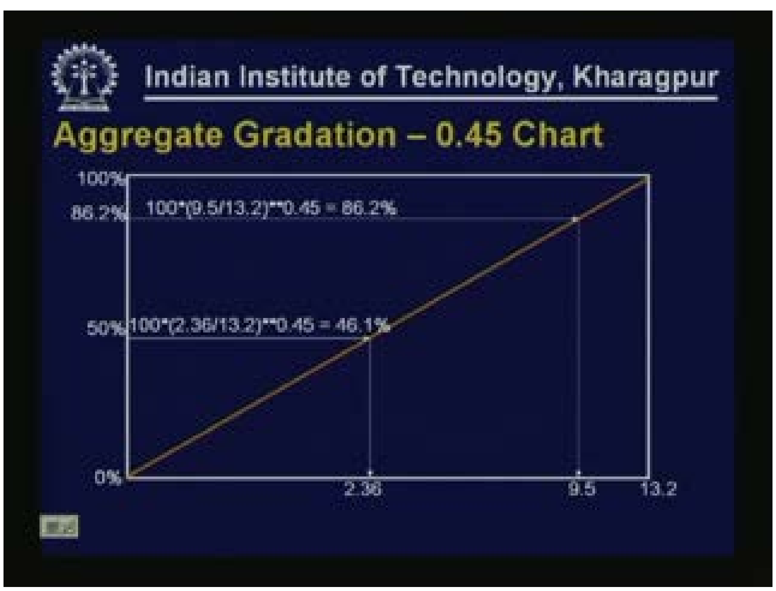

Normally most of these gradations are represented with reference to a 0.5, 0.45 chart which can be constructed in this manner. If you are referring to 13.2 as the maximum size so on the x axis we take a convenient length and then represent the maximum size at the end that is 13.2. And then if you want to find out where 9.5 sieve size is going to be there on this axis so we will have to calculate as to what will be the percentage passing through 9.5 size sieve as per 0.45 long so 9.5 divided by the maximum size of aggregate 13.2 to the power 0.45 into 100 that would be 86.2. So you identify 86.2 on the y axis, the y axis is a normal scale which would be divided from 0 to 100, identify 86.2 on the y axis and then get the corresponding location of 9.5 on the x axis.

Similarly, you can identify the location of 2.36 on the x axis, 2.36 divided by 13.2 to the power 0.45 into 100 that is 46.1. So start of from 46.1 on the y axis and this is where 2.36 has to be located on the x axis. Similarly, you can locate other sieve sizes on the x axis then this is the chart on which you can plot various gradations.

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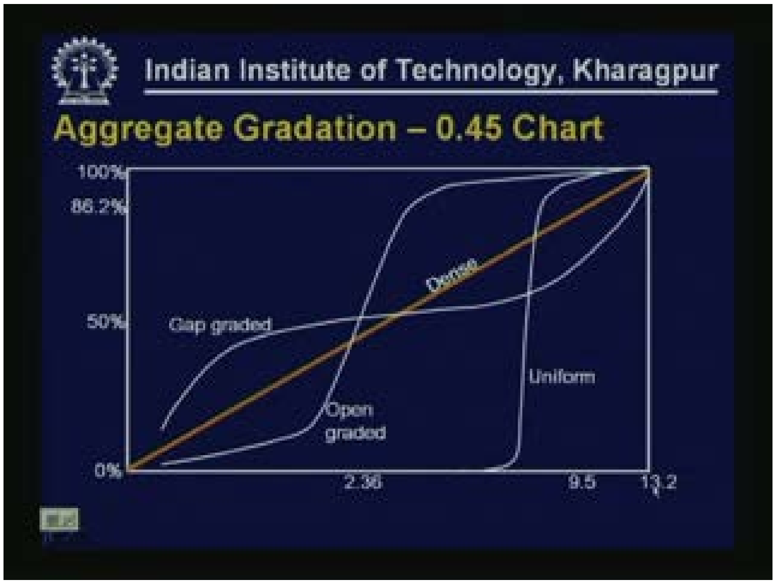

Typically dense gradation line is shown for a maximum size of 13.2 with reference to that how various other gradations can look like are shown here.

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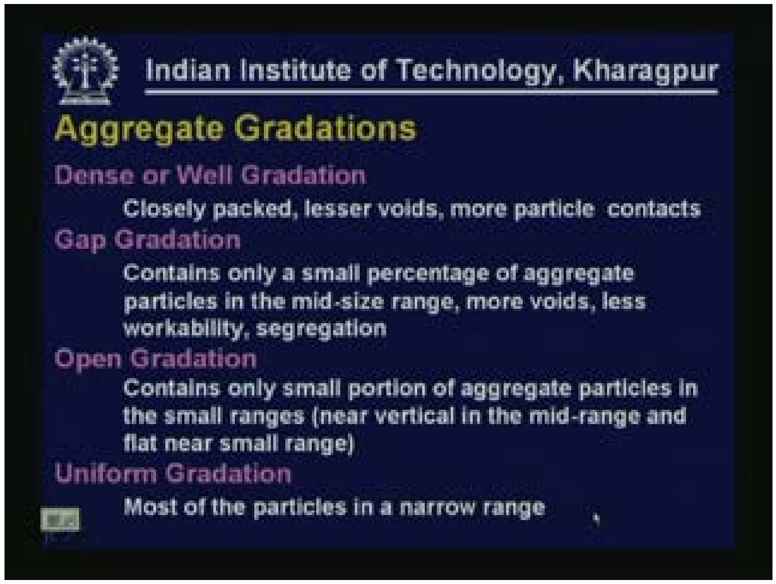

Aggregate gradations can be in terms of the gradations selected. It can be dense gradation, it can be gap gradation, it can be open gradation, it can be uniform gradation also. So depending on the layer in which we are going to use these aggregates, depending on the purpose for which this particular mix is used we can select various gradations. It is not always that we are trying to get the densest gradation. At times purposefully we try to deviate from the densest gradation, we try to provide coarser fractions, in other cases we try to provide finer fractions depending on the requirements we have to meet, it is not always the densest gradation that we are interested in.

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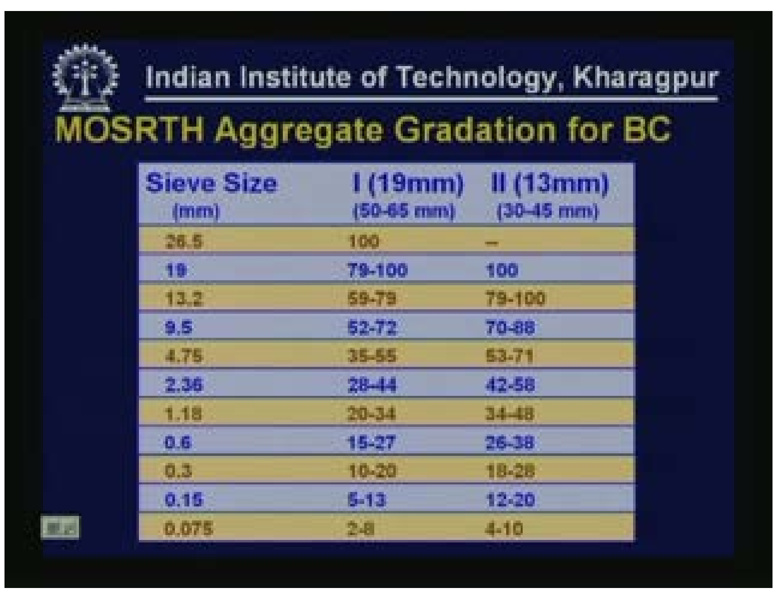

Sieve Size (mm)	I (19mm) (50-65 mm)	II (13mm) (30-45 mm)
26.5	100	--
19	79-100	100
13.2	59-79	79-100
9.5	52-72	70-88
4.75	35-55	53-71
2.36	28-44	42-58
1.18	20-34	34-48
0.6	15-27	26-38
0.3	10-20	18-28
0.15	5-13	12-20
0.075	2-8	4-10

Typically this is the ministry of surface transport aggregate gradation that is mentioned for bituminous concrete. Similarly, specifications are available for other types of mixes also as given by MORTH. We have two gradations given here; one has maximum nominal size of 19 mm and the other one has got nominal maximum size of 13 mm which is suitable for 50 to 65 mm layer thickness and 30 – 45 mm layer thicknesses.

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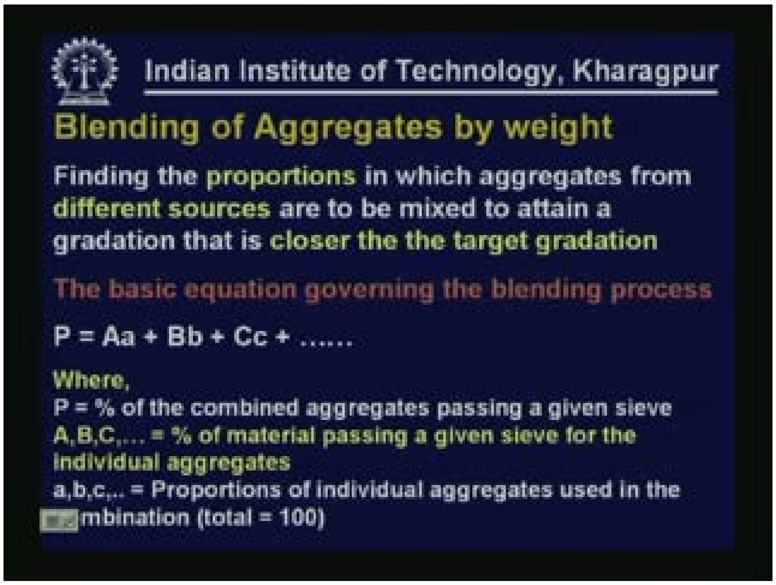

What we normally get is we get aggregates of different sizes. Suppose for a given mix for example BC if 13 sieves are specified we are not going to sieve all the aggregates through each one of those sets and then take those thirteen individual fractions and then blend them together. But what we have to normally get is two or three or four sources from different quarries or in different sizes. Each one of those sizes will have different gradations. We have to blend them together in certain proportion so as to get the decided aggregate gradation. That is what is known as blending of aggregates. So for each project this is the first exercise one has to be doing.

So, blending is nothing but finding the proportion in which the aggregates from different sources are to be mixed to attain a gradation that is closer to the target gradation. Target gradation is what is given by this specification. For example, we have seen the gradation given for bituminous concrete by MORTH. The basis for the equation governing the blending process is percentage P of the combined after blending is given as Aa + Bb + Cc and so on where A, B, C are the percentage of material passing a given sieve for the individual aggregates and ABC are the proportions that we are taking for these individual sources.

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We will take up a blending exercise. There are various methods of blending these. mathematical solutions are available, graphical solutions are available but nowadays it has become more convenient if you can put all these gradations in an excel sheet then it will be a very convenient because we don't have to get a very accurate mathematical solutions because at times we would heuristically attain certain fractions, we would like to have certain fractions more certain fractions less so if you get accurate solutions by optimizing the blending process and all those things you may not get a desirable solution. So what I am trying to do is I am trying to minimize this and then open an excel sheet where we have done some exercise.

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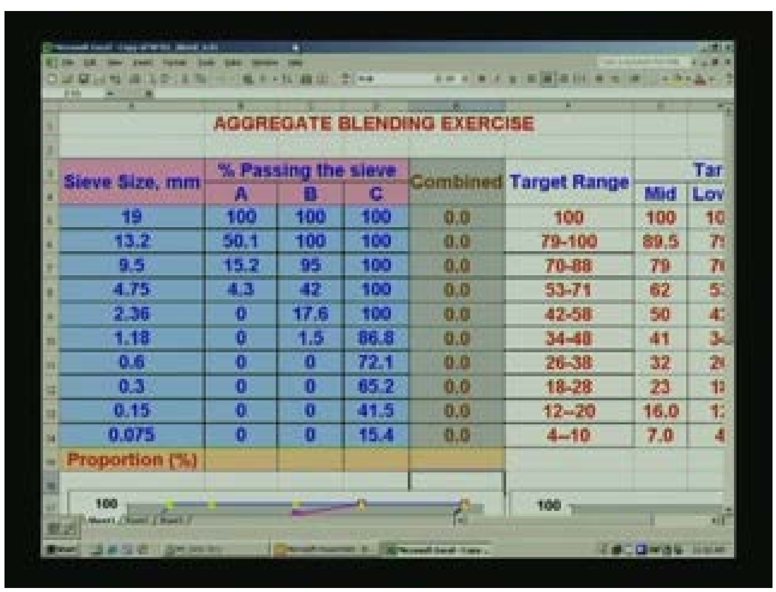
AGGREGATE BLENDING EXERCISE

Sieve Size, mm	% Passing the sieve A	B	C	Combined	Target Range	Mid
19	100	100	100	0.0	100	100
13.2	50.1	100	100	0.0	79-100	89.5
9.5	15.2	95	100	0.0	70-88	79
4.75	4.3	42	100	0.0	53-71	62
2.36	0	17.6	100	0.0	42-58	50
1.18	0	1.5	86.8	0.0	34-48	41
0.6	0	0	72.1	0.0	26-38	32
0.3	0	0	65.2	0.0	18-28	23
0.15	0	0	41.5	0.0	12-20	16.0
0.075	0	0	15.4	0.0	4-10	7.0
Proportion (%)						

What we have here is we have the sieve sizes here and we have three different sources of aggregates A, B, C, those materials have been sieved, the gradation of A is given, percentage passing 19 mm, 13.2 and so on is given, similarly gradation of B is given and gradation of C is also given. The target range is also given in column F here. This is the target range and this is the midpoint of the target ranged subsequently are also provided what are the lower and upper ranges of the target ranges. So we are trying to combine certain proportion so that we are going to be getting something closer to the target range. Let me put these values.

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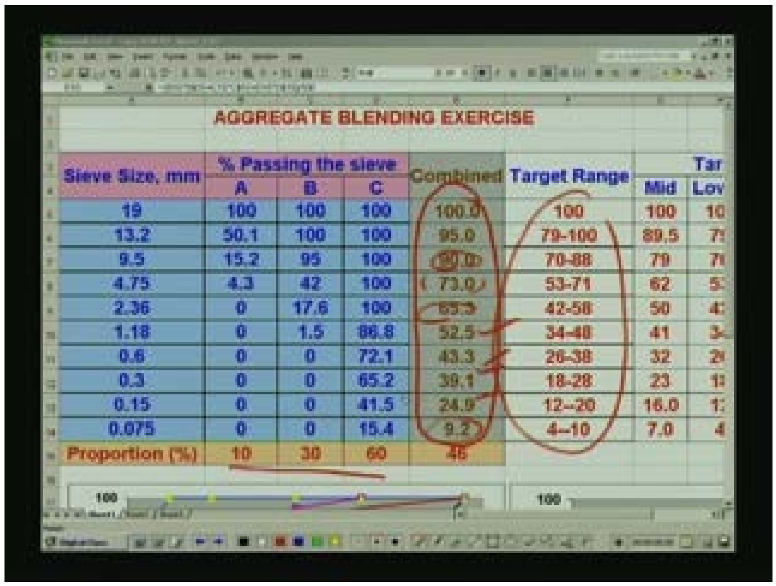

AGGREGATE BLENDING EXERCISE

Sieve Size, mm	% Passing the sieve A	B	C	Combined	Target Range	Target Mid	Target Low
19	100	100	100	100.0	100	100	10
13.2	50.1	100	100	95.0	79-100	89.5	[illegible]
9.5	15.2	95	100	[illegible]	70-88	79	[illegible]
4.75	4.3	42	100	73.0	53-71	62	[illegible]
2.36	0	17.6	100	65.3	42-58	50	[illegible]
1.18	0	1.5	86.8	52.5	34-48	41	[illegible]
0.6	0	0	72.1	43.3	26-38	32	[illegible]
0.3	0	0	65.2	39.1	18-28	23	[illegible]
0.15	0	0	41.5	24.9	12-20	16.0	[illegible]
0.075	0	0	15.4	9.2	4-10	7.0	4
Proportion (%)	10	30	60	46			

This is the proportion in which I am going to blend A, B and C. Let me say ten percent thirty then balance would be sixty and this is the combined gradation that I am getting. If I mix these three sources in this proportion this is what I am getting. Let us see how this is compared with the target gradation 100, 95 is between 79 and 100 this is outside the range, this is also outside the range, outside, this is also outside so only this is satisfactory (Refer Slide Time: 52:57) obviously this is not a satisfactory solution. So we can go on trying various combinations of these proportions. I have already done this exercise so let me show you as to what will be the better arrangement here.

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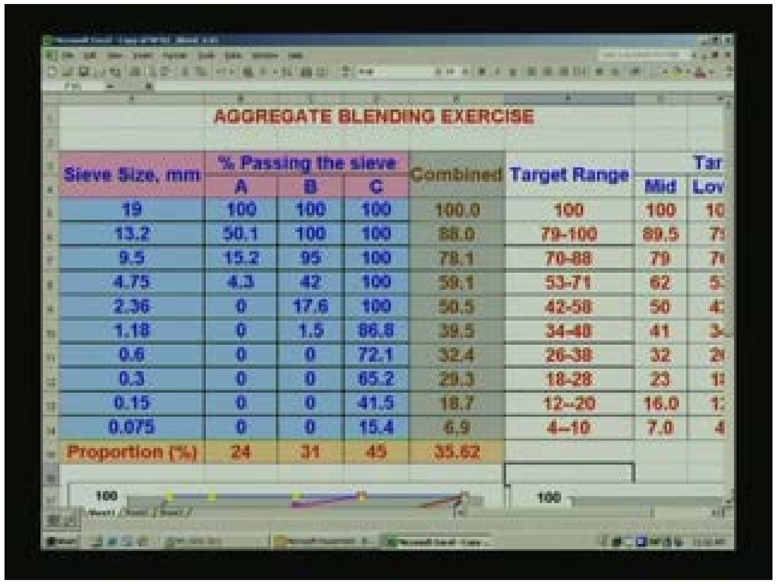

Let me put 24 here, 31 here and 45 here. Now let us examine this gradation 88, 78, 59, 50, 40 so this more or less satisfies the required gradations.

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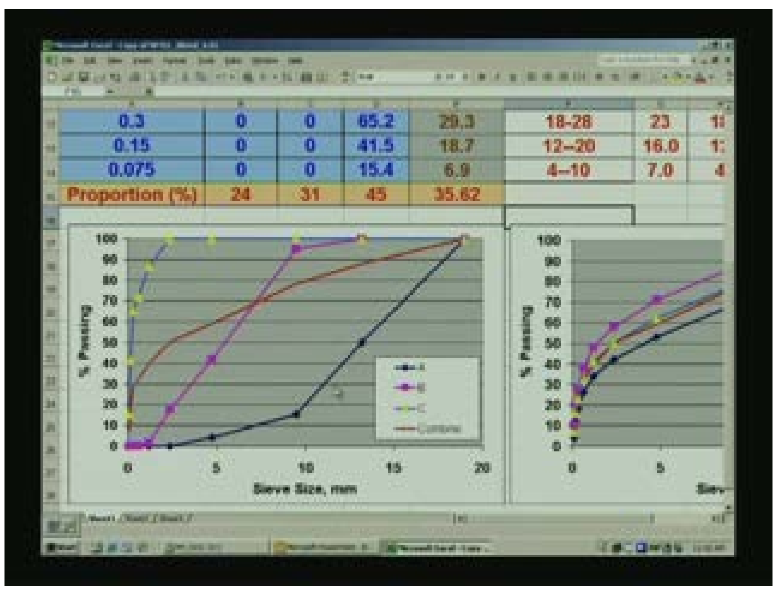

What you see here are the given charts given gradations for A, B, C and then this is the combined gradation. Let us see how the combined gradation compares with the specifications.

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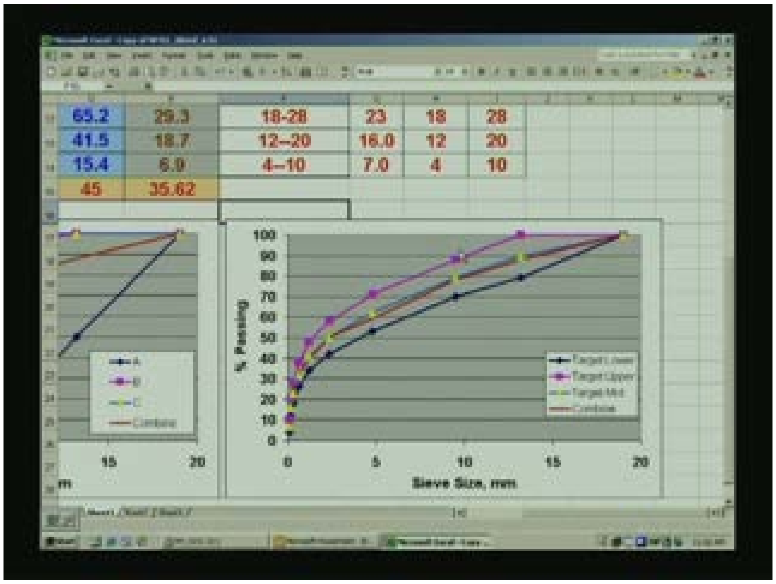

These are the upper and lower limits of this specification and the red one is the combined gradation and the blue middle line is the midpoint gradation. In this case we have attained a gradation by combining these three aggregates to get a gradation that is very close to the midpoint gradation. It is of course not necessary that we should always get very close to the midpoint gradation. At times it will be required to go away from the midpoint gradation to satisfy certain requirements.

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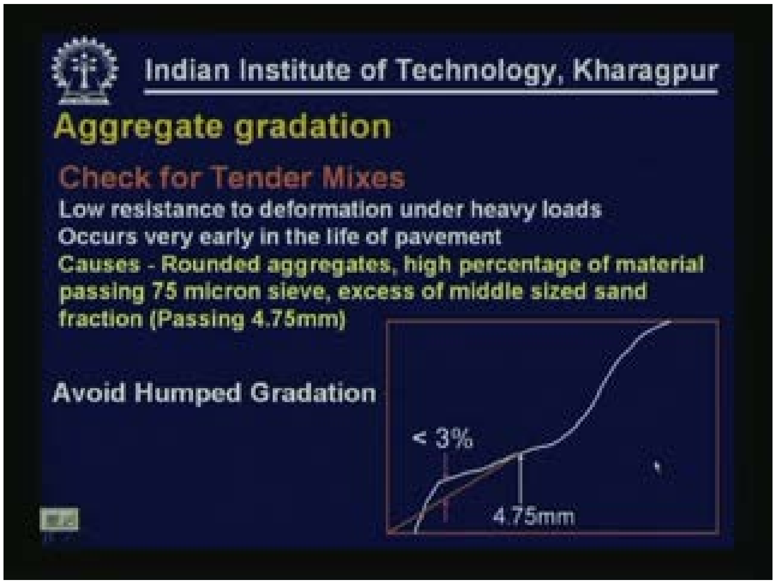

There is another requirement that we have to normally satisfy. We have to check the given gradation that we are selecting for what is known as tender mix. We should not have tender mixes forming because these have low resistance deformation under heavy loads. This occurs very early in the life of pavement. The problems that are occurring because of tender mix is especially the surface will be abraded when high tyre pressures are going to be applied. The main reason why this happens is if you are using rounded aggregates and also if you are using high percentage of material passing 75 micron sieve also excess of middle sized sand fraction sand in the sense those aggregates passing 4.75 mm size so if you have higher percentage of that there is a problem of tender mixes forming in it. How to avoid this is there is a simple technique that is given. The given gradation joins the origin line to 4.75 sieve location. Then with reference to that line if the given gradation deviates by more than 3% at any location that is known as a hump. We should not how humps which are defined by deviation from the line with joins origin to 4.75 mm size by more than 3%. This is how we ensure that tender mixes do not form.

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To summarize; in this lesson we have learned about the main modes in which mix bituminous mixes are going to be failing. And we try to understand the importance of designing the mixes properly. We also try to identify important parameters to be controlled in mix design. We have tried to understand the volumetric analysis of mixes and also we have tried to understand the significance of aggregate gradation mix design and we have just seen one blending exercise of aggregates.

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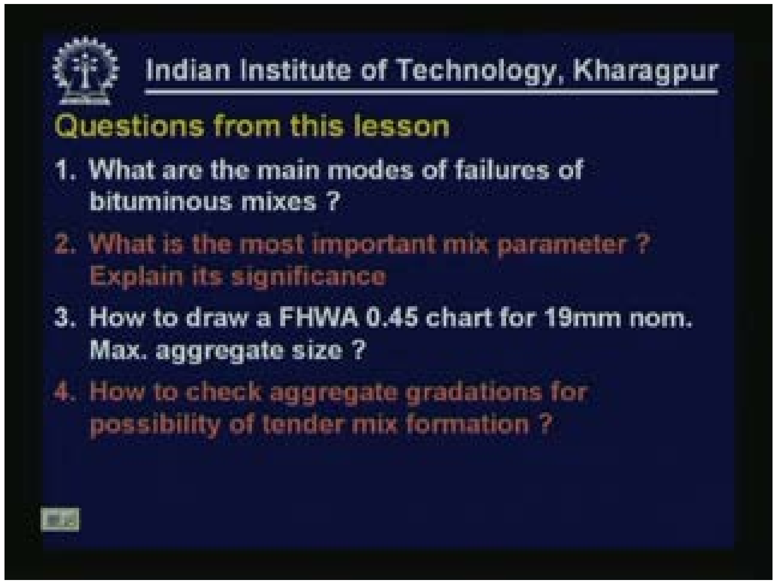

Let us take of a few questions from this lesson.

1) What are the main modes of failures of bituminous mixes?
2) What is the most important mix parameter and explain its significance.
3) How to draw a FHWA 0.45 chart for 19 mm nominal maximum aggregate size?
4) How to check aggregate gradations for possibility of tender mix formation?

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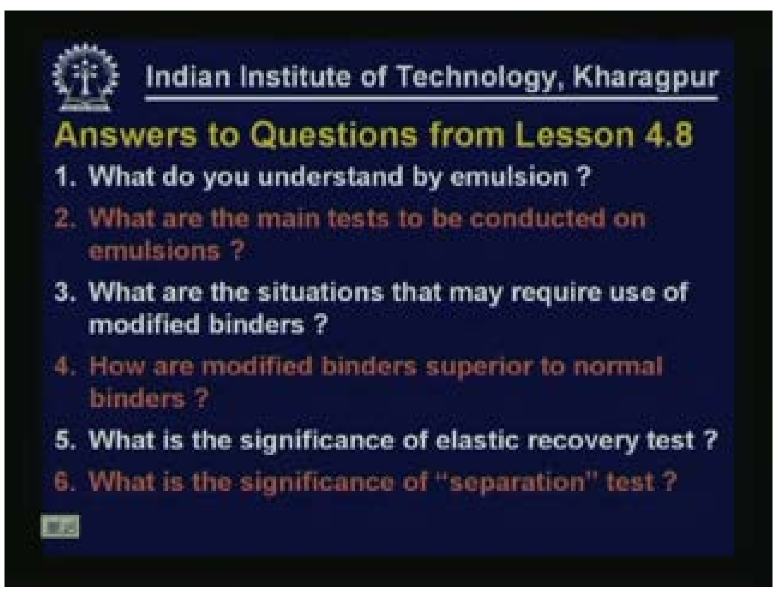

Next let us take up the answers for questions that we asked in lesson 4.8 which was on bituminous binders.

What do you understand by emulsion?
Emulsion is a two face system containing water and bitumen. Bitumen globules are in fine suspension in water. This suspension is made possible by the addition of emulsifier. So we can use emulsions without heating because they have low viscosity.

The next question was, what are the main tests to be conducted on emulsions?
The main test we conduct on emulsion is to ensure that we do not have any separation. So we conduct a test what is known as storage stability test, we also conduct a test to find out what is the residue, we test the properties of the residue. Basically these are the main tests we conduct on emulsions. We also find out the viscosity of emulsion.

What is the situation that may require use of modified binders?
The use of modified binder is required under special situations having heavy loads, lots of load reputations, adverse climatic conditions, high temperatures, low temperatures and so on, stationary loads and so on.

How are modified binders superior to normal binders?
Modified binders are normally superior in terms of fatty performance. more importantly superior in terms of rutting performance, also they have better temperature susceptibility, they are usually better in terms of their resistance to moisture damage.

What is the significance of elastic recovery test?
Elastic recovery test is carried out to find out what is the capability of the material to recover when the material is stretched. It is done by normal ductility test by stretching the sample, cutting it and then observing how much the binder is capable of recovering.

What is the significance of separation test?
Modified binders are usually prepared by adding some modifies to the binder which in many cases have the tendency to separate on storage so this is the test that is conducted to find out what is the tendency of the modified binder to separate, thank you.