Introduction to Transport Engineering
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Lecture - 28
Pavement Materials - II

Hello students welcome to lesson 4.5 of module IV.

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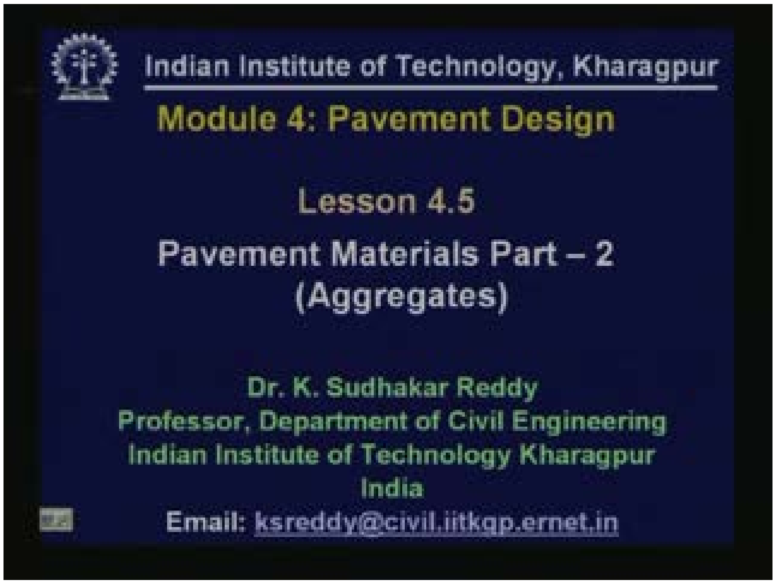

Module IV as you know was about pavement design. In this module we have so far covered various aspects such as principles of pavement design. We also discussed about general aspects of pavement materials characterization. In the previous lesson we have talked about characterization of subgrade soils for the purpose of design of flexible pavements as well as concrete pavements. This lesson is about aggregates and has been titled as pavement materials II.

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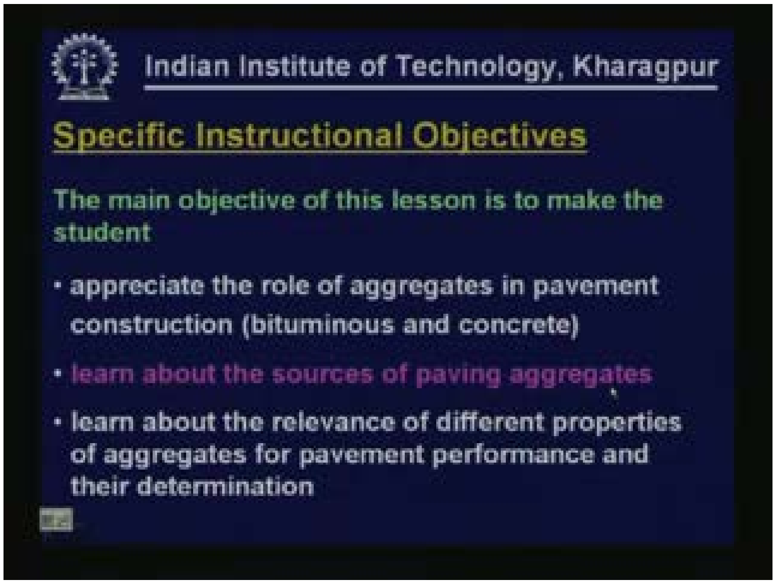

The specific objective rather the main objective of this lesson is to make the student appreciate the role of aggregates in pavement construction of both types of pavements bituminous as well as concrete pavements, learn about the sources of paving aggregates, natural and then manufactured aggregates and also learn about the relevance of different properties of these aggregates as far as the pavement performance is concerned and also to learn about the determination of these properties.

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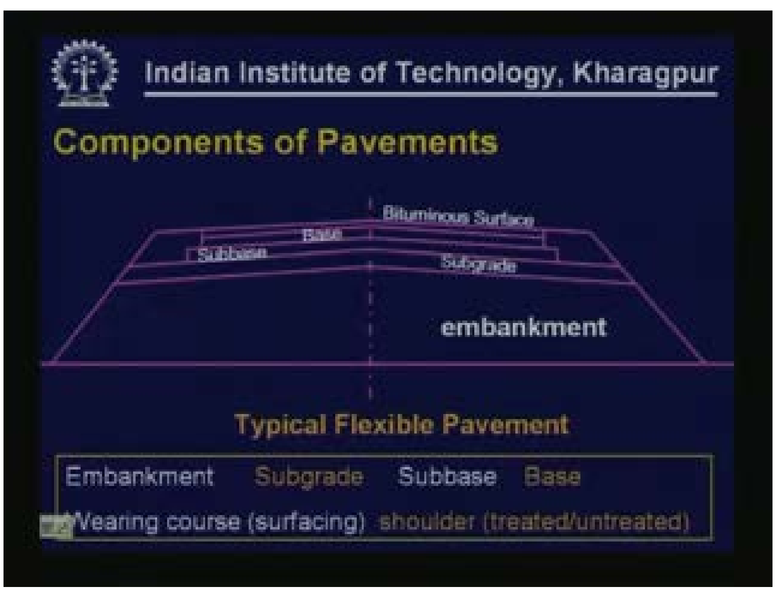

As we have seen in the earlier lessons flexible pavements and concrete pavements have different components. What you see here is a typical sketch of flexible pavement. it has as listed below embankment, subgrade etc. Subgrade as you know is a prepared portion of that foundation, subbase, base, wearing course which also is called as surfacing and it will also have shoulders either treated or untreated. We are going to use aggregates in almost all these components especially bituminous layers base and sub bases and in shoulders also.

This is a typical sketch of a concrete pavement again having embankment, subgrade, base and the concrete slab. This will also have shoulders. This is a typical representation, this may be on embankment, this may be in cutting, the concrete slab may or may not have a base. In general now-a-days for highways we normally provide granular base also. So here also we use aggregates for different components of this. As you know for concrete you require aggregates, base also you require aggregates and shoulders also we may use aggregates.

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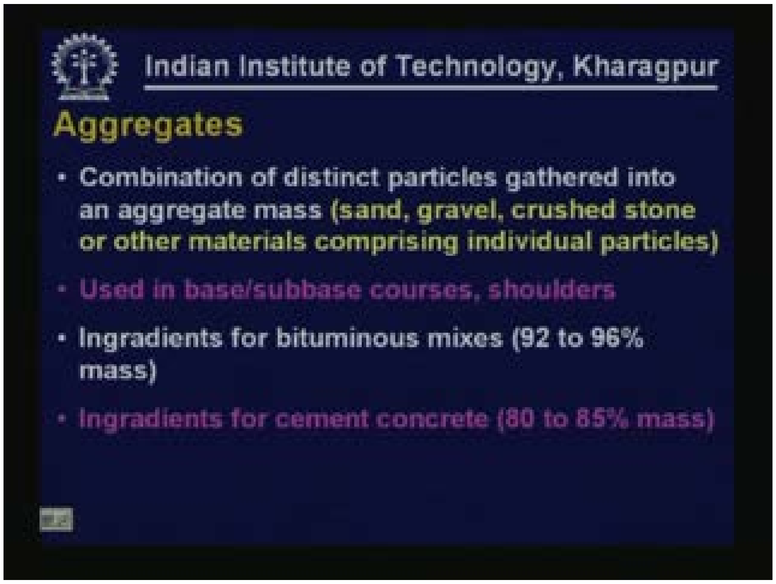

The term aggregates normally represents a combination of distinct particles gathered into an aggregate mass. This can be sand, gravel, crushed stone or other types of materials comprising individual particles. These are not normally cohesive masses. As has been indicated here these are individual particles brought together to form a mass. These are normally used in base and sub bases and in surface courses both in bituminous pavements and also in concrete pavements and of course also in shoulders. Typically aggregates form about 90 to 96% of the ingredients in case of bituminous mixes which we use in bituminous layers and they form about 80 to 85% of the mass of cement concrete. So we can understand the importance of the aggregates because they constitute the major portion of either bituminous concrete or bituminous mixes or cement concrete.

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Aggregates are available from various sources. They can be classified as natural sources or manufactured sources. Natural sources are those aggregates that come from natural source or obtained from large rock formations. These are obtained by quarrying this rock and this excavated rock is usually crushed to obtain aggregates of different sizes. Because for different structural member we use aggregates of different sizes or even in a particular structural member we use different proportions of aggregates of different sizes.

So, as a result the aggregate that is quarried from rock mass has to be crushed and processed to get aggregates of different sizes. Whereas manufactured aggregates come from rather they come as a bi-product from various manufacturing processes typically they come as slag which is a bi-product of metallurgical industries where steel, tin or copper are produced. In some layers of pavements even broken bricks which are not natural aggregates and over-burnt bricks are also used.

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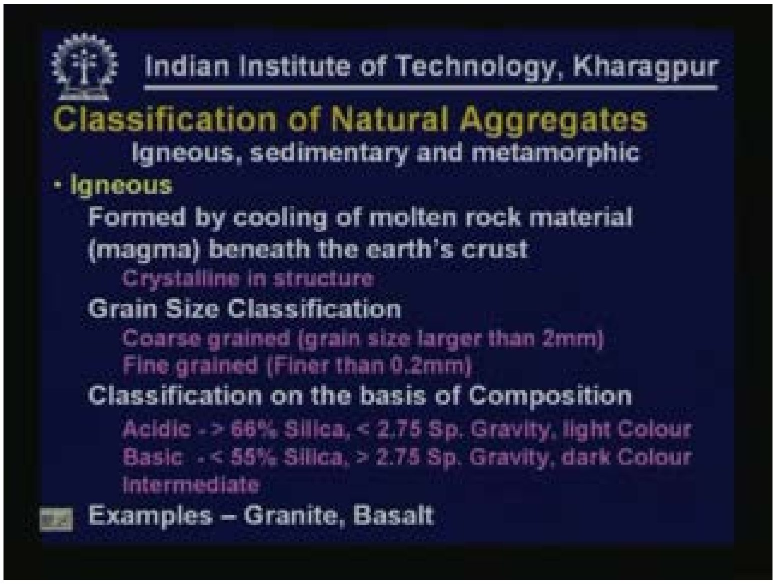

Based on their natural geological formation the rocks are classified into igneous, sedimentary and metamorphic rocks.

Igneous rocks are formed by cooling of molten rock material which is also called as magma which is beneath the earth's crust. These are usually crystalline in structure. Depending on the size of the grain these are further classified as coarse grained aggregate, coarse grained rocks or fine grained rocks. In coarse grained rocks the grain size will normally be more than 2mm in size whereas in fine grain rocks the grain size will be finer than 0.2mm size.

Similarly on the basis of the chemical composition of these minerals the rocks can be classified as acidic which typically have more than 66 percentage silica and in general the specific gravity will be less than 2.75 and they will be light in color. On the other hand basic rocks will have typically less than 55% silica and their specific gravity will be normally larger than 2.75 and these are usually dark in color. And we have intermediate variety aggregates having properties ranging from acidic to basic. Typical examples of igneous rocks are granite and basalt.

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Coming to sedimentary rocks these are insoluble materials which have been deposited on the bottom of ocean or lake floors and which are transformed to rock by heat and pressure. So these are transformed rocks and these are usually layered in structure. These are further classified based on the predominant mineral because they may not have one type of mineral only they will normally consist of different types of minerals but depending upon which mineral is predominant these are further classified as calcareous, a typical example being limestone, siliceous example being sand stone, argillaceous example being shale. And typical examples of sedimentary are; some of them are already listed earlier namely limestone and sandstone.

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The third type of classification that we have considered is metamorphic rocks. These are either igneous or sedimentary rocks which have been subjected to heat and or pressure. It could be just heat or a combination of heat and pressure and transforming these rocks which were either sedimentary or igneous into a new form the mineral structure gets changed when metamorphic rocks are formed compared to its parent rock. Examples of metamorphic rocks are quartzite, marble and slate.

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We will next consider a few important road making stones. There are so many types of aggregates that we can get but I will be discussing only a few of them which are normally used in road construction. The most important among them is granite which is an igneous rock. Its color can vary from blue to pink and it will be fine to coarse grain and it will be hard and durable. We will discuss about the significance of the aggregates being hard and durable also the significance of the aggregates having good resistance to abrasion and so on in the next few slides. So, as I was indicating these are hard and durable. They usually have good resistance to abrasion. They have low water absorption. They are very good materials for bituminous as well as cement concrete works. Obviously they are going to be good for other types of layers for such as base and subbase materials both in flexible pavements and in concrete pavements typically the specific gravity of granite will range from 2.6 to 2.7.

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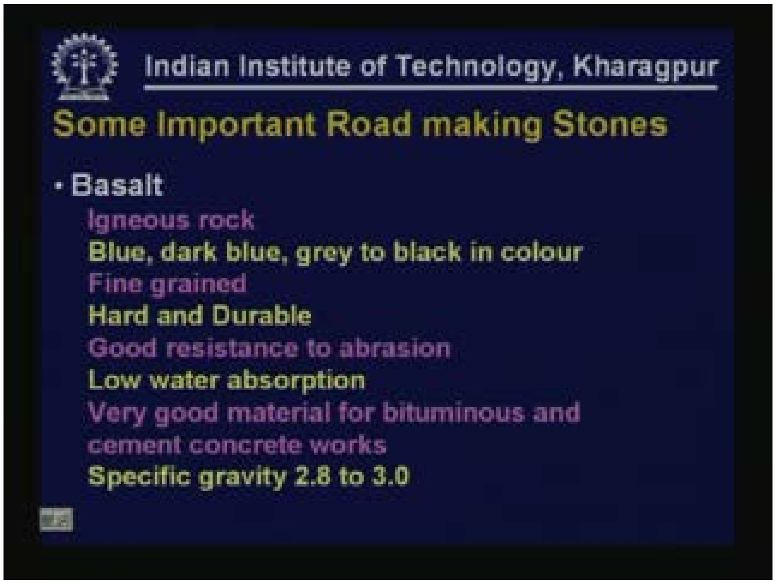

The next variety of rock that we will discuss is basalt. This is also an igneous rock. Its color could be blue, dark blue, grey to black and it comes in various colors normally fine grain, this is also a hard and durable material, this will also have good resistance of abrasion, also will have low water absorption. These are very good materials for bituminous and cement concrete works. Compared to granite basalt has higher specific gravity in the range of 2.8 to 3.

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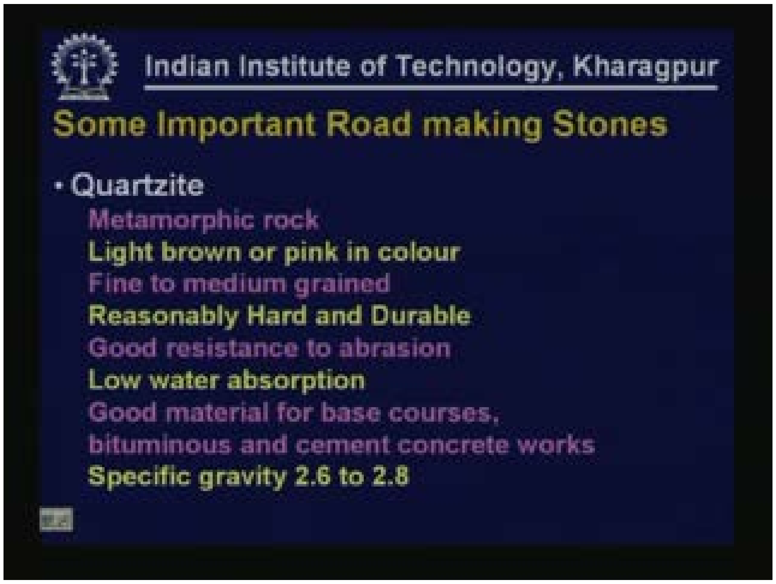

Quartzite is a metamorphic rock light brown to pink in color and has fine to medium grains, reasonably hard and durable, obviously not hard as granite or basalt, has good resistance to abrasion, also has low water absorption, this is a good material for base courses, bituminous and cement concrete works. The specific gravity ranges from 2.6 to 2.8.

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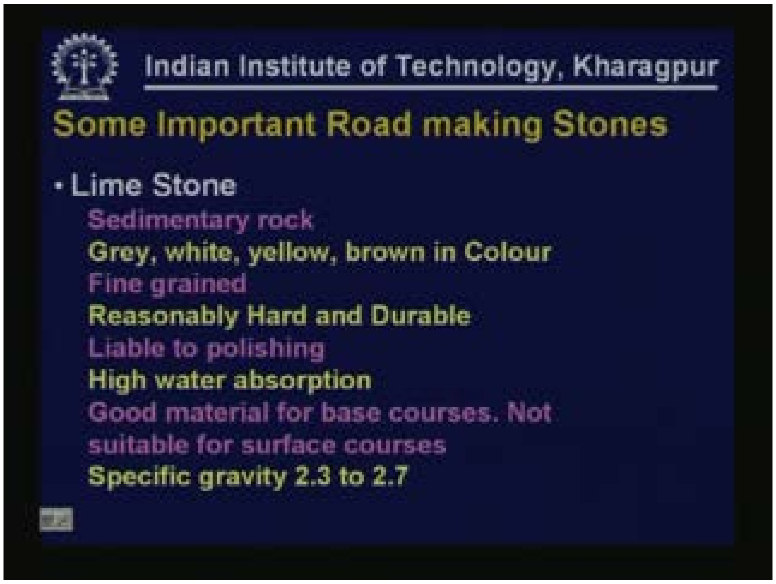

Limestone is a sedimentary rock coming in various colors such as grey, white, yellow and brown, fine grained, material reasonably hard and durable but this is liable to polishing and has high water absorption. This is a good material for base courses but because of its liability to polishing and also because of its high water absorption it is not very suitable as a surface course especially in the case of bituminous pavements. The specific gravity ranges from 2.3 to 2.7.

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Sandstone is another sedimentary rock coming in colors such as grey, red, blue, green. The grains will be of fine to medium size. These are moderately hard and durable, this is even a very good material for base course. Its specific gravity ranges from 2.2 to 2.8.

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Let us consider some desirable properties of aggregates when these are used for flexible pavements and as material in concrete pavements. The aggregates in general be clean and free of clay and organic matter. They should be angular and not have excessively flaky nature. We will again discuss what is the importance of each one of these aspects, how to quantify this, what is the significance of each of these parameters when we consider these aggregates for either flexible pavements or concrete pavements.

Aggregates should be strong enough to resist crushing during mixing, during laying process, during compaction using rollers or other types of construction equipments, during consolidation and during its service life period when they are subjected to various loads applied by traffic forces. They should also be resistant to abrasion and polishing when especially the surface courses are exposed to traffic. They should normally be non absorptive. But hardly any aggregate is completely non-absorptive each aggregate observe water to some extent. But what we will see later is how much is acceptable when these aggregates are used in different layers. If you are using these aggregates for bituminous pavements they should normally have good affinity to Bitumen.

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We are concerned about certain chemical properties of these aggregates as these chemical properties effect the performance of bituminous pavements and concrete pavements. These are important both for bituminous as well as cement concrete mixes.

In the case of bituminous pavements the surface chemistry of aggregates determines how well these aggregates adhere to the bitumen rather bitumen adheres to the aggregates. If the adhesion is not good poor adhesion would result in stripping causing premature failure of pavements. This has been a very common failure that has been occurring in several flexible pavements. This is a very serious failure that occurs normally. Hence we should be concerned about the surface chemistry of these aggregates and also the adhesion that is there between bitumen and the aggregates.

In PCC pavements we are concerned about the presence of reactive silica. When it is present in aggregates it reacts expansively that is the problem the reaction is expansive in nature with the alkalis in the cement paste. Expansion which is an increase in volume leads to cracking, pop outs and spoiling of concrete.

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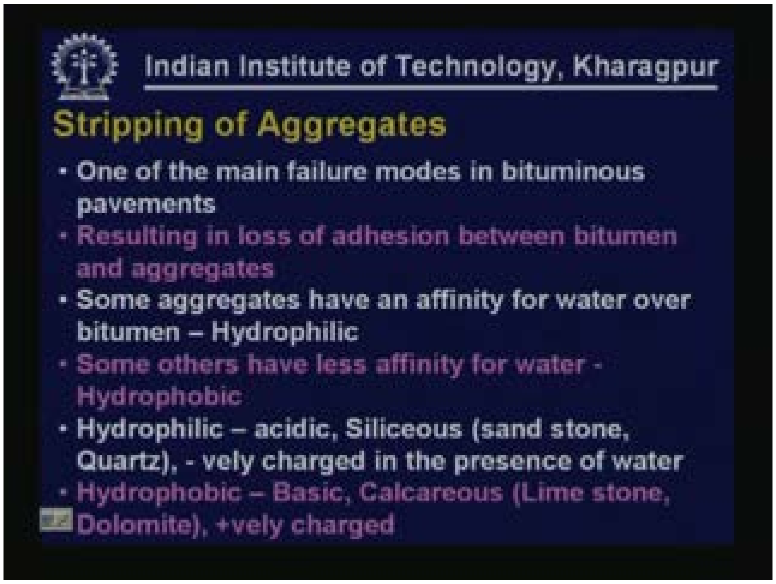

Stripping of aggregates as you said is a major concern in the case of flexible pavements or bituminous pavements. This is one of the main failure modes in bituminous pavements. This result or rather this is caused because of loss of adhesion between bitumen and aggregates. Some aggregates have good affinity for water compared to the affinity that it has got for bitumen. These aggregates are called as hydrophilic that is water leveling aggregates, they will have water compared to their affinity towards bitumen whereas some other aggregates have lesser affinity to water compared to bitumen. These are called as hydrophobic or we can term this as water hating so obviously water hating or hydrophobic aggregates are better as far as the bitumen mixes are concerned because they have better affinity to bitumen.

Hydrophilic aggregates in general are acidic in nature, siliceous such as sandstone, quartz these are usually negatively charged in the presence of water. On the other hand hydrophobic aggregates are usually basic in nature, typically calcareous such as limestone, dolomite and these get positively charged in the presence of water.

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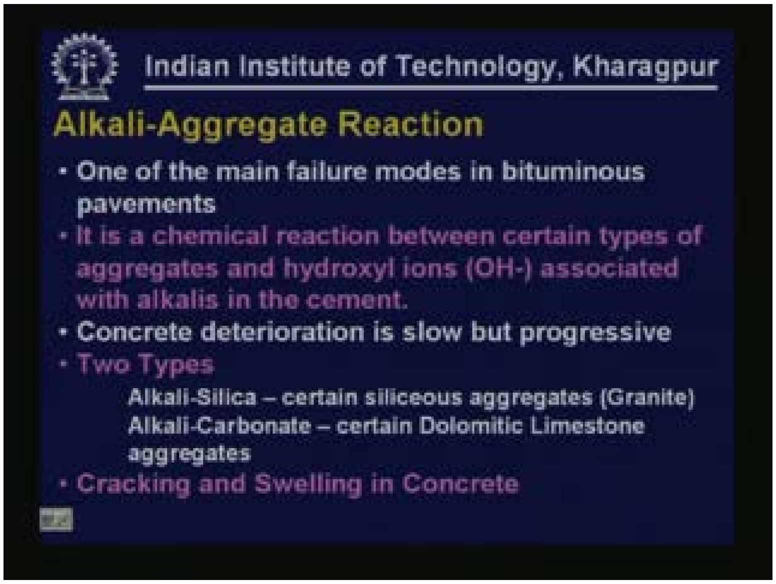

Coming to alkali aggregate reaction is the main mode of failure especially in concrete pavements as we discussed earlier. This is the chemical reaction between certain types of aggregates and the hydroxyl ions associated with alkalis in the cement. Because of this the concrete deterioration is slow but progressive. We can have two types of alkali aggregate reactions that is alkali silica in which certain siliceous aggregates such as granites aresusceptible to this problem and alkali carbonate reaction, certain dolomitic aggregates such as limestone or susceptible to alkali carbonate reaction. Because of this alkali aggregate reaction there is cracking and swelling in cement concrete.

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There are various physical properties of aggregates that were interested in. as these properties affect the performance of aggregate various aspects related to the handling of the material and the construction of the material and the thicknesses of different layers in which these materials can be constructed. We are interested in the gradation of aggregates that we were using, we are interested in the maximum size of aggregates that we were using, we are also interested in the toughness and abrasion resistance of the aggregates, durability and soundness of these aggregates, particle shape and surface texture of the particles, specific gravity of the aggregates, cleanliness and the presence of deleterious materials in these aggregates etc so we are concerned about all these aspects.

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Let us take up the effect of gradation and size on bituminous mixes. The gradation and size that we consider affects the workability of the bituminous mixes. It affects the thickness of the layer that can be constructed. The maximum size of the aggregate that we use typically influences the thickness that can be constructed. It also influences for a given thickness of layer the complete layer may not be constructed in one single layer. It may be constructed in different layers may be one layer, two layers, three layers so in such cases each one is called as separate lift so the size of the aggregate rather the maximum size of the aggregate also influences the maximum or minimum thickness of the lift that can be constructed.

The gradation and size; when we refer to size we are talking about the maximum size of the aggregate, the gradation and size also affect the stability of the mixes, it affects the stiffness of bituminous mix, they affect the resistances to deformation of these mixes when they are subjected to load, the fatigue strength of the mixes gets affected by the gradation and size that we use, even the durability gets affected, the permeability of the mix changes with gradation and then maximum size and they also affect the surface texture and frictional resistance of especially the surface bituminous layers.

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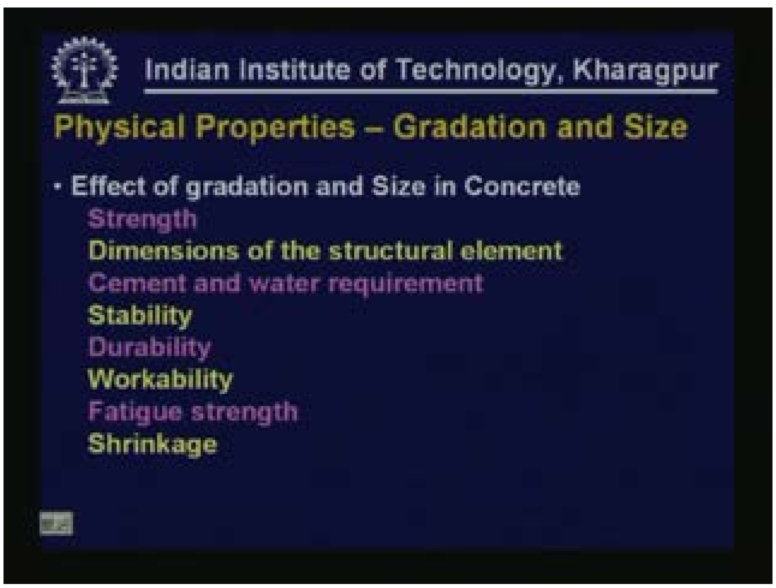

This is how the effect of gradation and size in concrete is considered. They affect the strength of concrete, they also affect the dimensions of the structural element as in the case of bituminous layer. The size of an element, the cover to be provided, the spacing present such as different reinforcing bars and reinforce concrete element is a function of the maximum size of the aggregate that is used, it also affects the cement and water requirement in cement concrete, it affects the stability, durability and workability of the concrete, it also effect the fatigue strength and the shrinkage of concrete.

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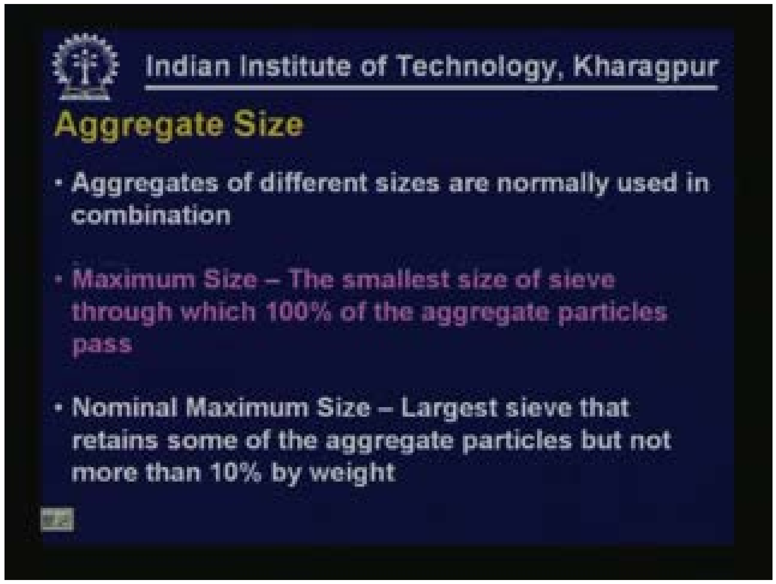

Coming to aggregate size as I indicated earlier we are referring to the maximum size of an aggregate that we were using in any given layer. Aggregates are of different sizes and are normally used in any layer; we don't normally use aggregates of a single size they are used in combination. Maximum size is the smallest size of sieve through which hundred percent of the aggregate particles pass whereas we use another term to represent the largest size that we use in combination. This is nominal maximum size. This is the largest sieve that retains some of the aggregate particles but the retained portion should not be more than 10% by weight. We will see the meaning of these two terms in the next line.

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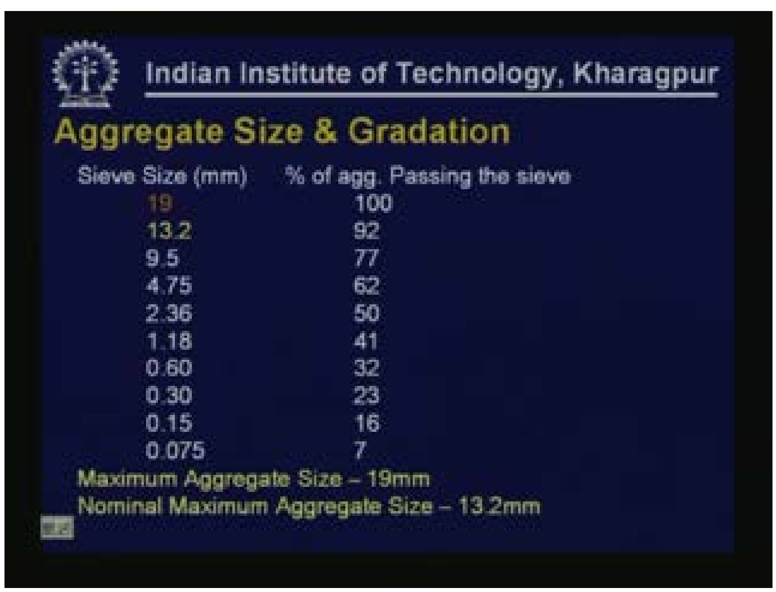

For example if you have an aggregate graded in this fashion. For example hundred percent of the material passes through 19mm sieve size and 92% of the sample that you have taken passes through 13.2mm sieve and so on in this case obviously the maximum aggregate size for this gradation will be 19mm because this is the smallest size. Obviously higher sizes would definitely be having hundred percent passing. So this is the smallest size through which hundred percent of the material is passing. If you examine 13.2 sieve and the corresponding material passing that is 92% then 8% of the material is retained on 32.2mm size thus 32.2mm is a nominal maximum aggregate size because there are certain materials that is retained on this size but which is not more than ten percent in this case it is 8% so for this gradation maximum aggregate size is 19mm and nominal maximum aggregate size is 13.2mm.

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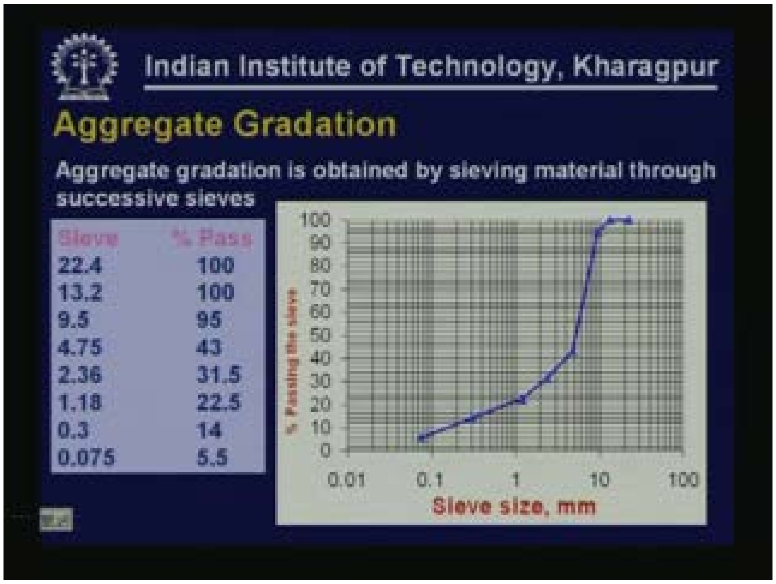

Typically the aggregate gradation is represented in a semi log format where sieve size is presented on log scale and y axis will be percentage passing which is on normal scale.

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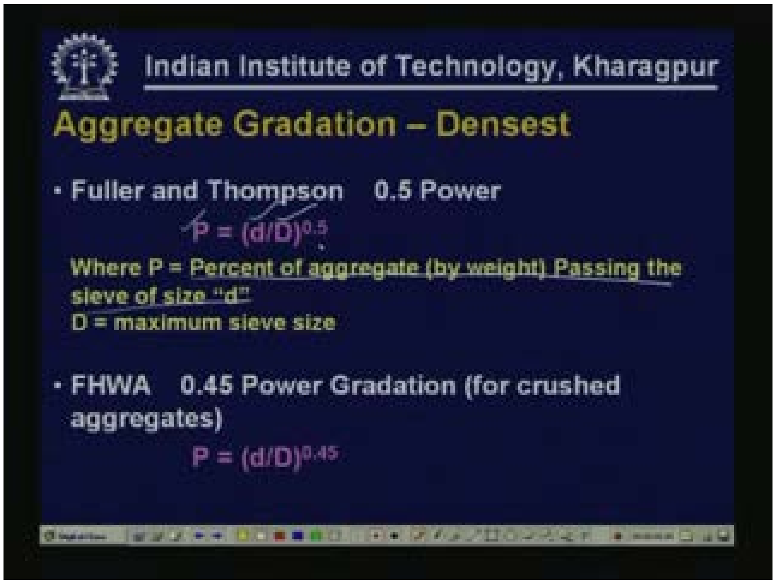

Normally whenever we examine these gradations we refer to them to the densest possible gradation for the given maximum size of aggregate. So with reference to that we will examine a given gradation whether it is dense, whether it has got more voids, whether certain fractions are missing and so on. Densest gradation for a given maximum size is expected to be obtained if it follows Fuller and Thompson formula which is given by 0.5 power which is represented as P where P is the percentage of aggregate passing the sieve size D and D is the maximum sieve size. For example, if 25mm is the maximum sieve size we are trying to find out for the gradation to be very dense what should be the percentage of material to pass through let's say 13mm size so we will be putting 13 here divided by 25 to the power 0.5 that would give you whatever percent into 100 of course so if you can take material in such a fashion that would give you the densest gradation that as per Fuller and Thomson.

But Fuller and Thomson gradation is considered to be applicable for spherical particles. FHWA has modified this slightly by considering what is known as 0.45 power gradation which has been observed to be applicable for crushed aggregate which are obviously not rounded in shape or spherical in shape. So in this case the percentage passing for a given size of sieve that is d will be given as d by capital D to the power 0.45 into 100.

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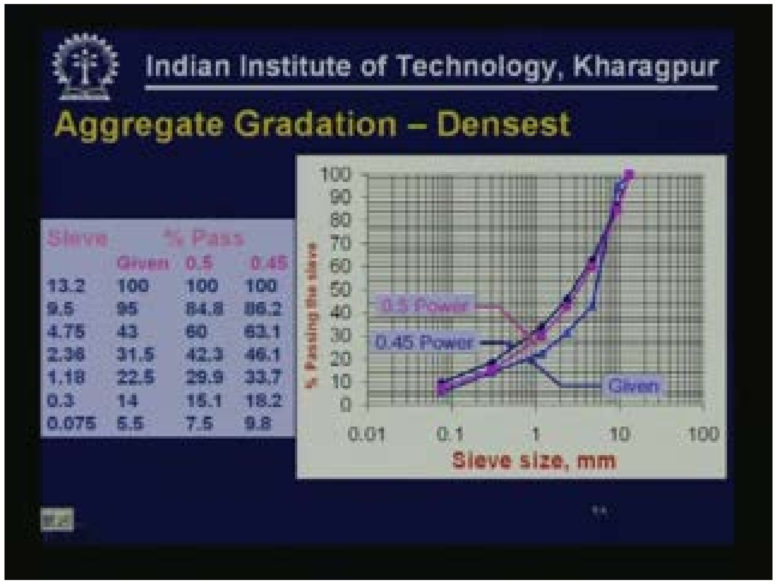

This graph here shows; for example I have taken given gradation having maximum aggregate size of 13.2 through which hundred percent of aggregates are passing. For the same gradation I have calculated what should have been the gradation if it were to be densest gradation as per 0.5 law and also what should have been the gradation as per 0.45 power law. As you can see here obviously the given gradation in this case is quite different from both the 0.5 power and then 0.45 power and 0.45 and 0.5 power are slightly deviating from each other.

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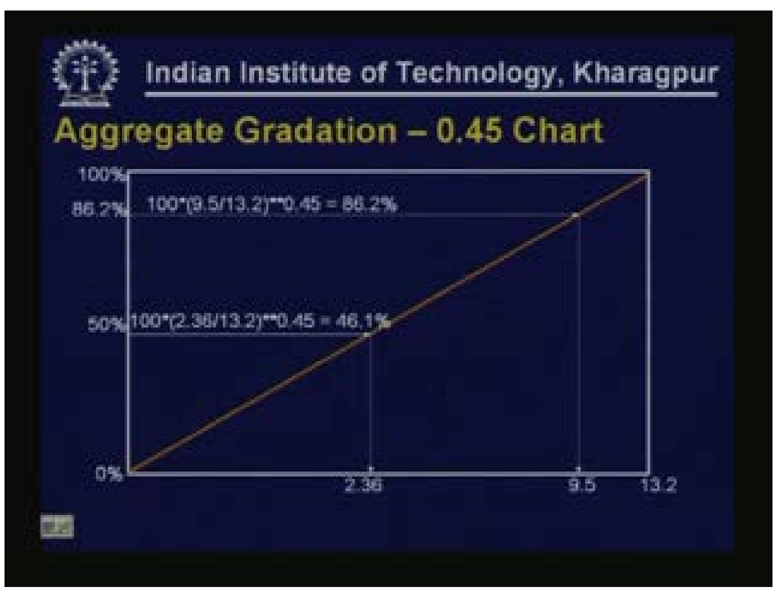

For representing different gradations and comparing them to the densest gradation which in this case is the 0.45 gradation a very convenient method of presenting all these gradations is the 0.45

chart. This is the typical aggregate chart that is used given by FHWA. How this is developed is, for example, if you are considering the previous gradation that we have considered where the maximum size of aggregate is 13.2 through which 100% is passing we will take a convenient y axis and divide this equally so this is a normal scale so this would be divided into equal parts and then this will have a range of 0 to 100 and the x axis also is taken over a convenient length. So since this is the maximum size of aggregate we are putting 13.2 here, we know that 100% has to pass through 13.2 size so this is one point that we get and then we join 0 to this 100, and draw a straight line.

What we then do is identify different sieve sizes on the x axis, there will not be neither as per normal scale not as per log scale, we will have to identify where on this axis 9.5 is to be located where on this axis 2.36mm size has to be identified. Therefore what to do is we know that 9.5mm size is for maximum gradation but for densest gradation the percentage passing should be 86.2 obtained as 9.5 divided by 13.2 to the power 0.45 into 100 that gives us 86.2% so we will identify 86.2% on the y axis and then come down on to the x axis this is 9.5mm.

Similarly, I am trying to identify 2.636 on x axis. For 2.36 the percentage passing should be 2.36 by 13.2 to the power 0.45 multiplied by hundred that is 46.1 so we will start of from 46.1 on the y axis and then come down to the x axis that should be 2.36. Similarly we can identify other sieve sizes on the x axis so that gives us the chart on which we can plot any other gradation that we have and compare that with the densest gradation that is available.

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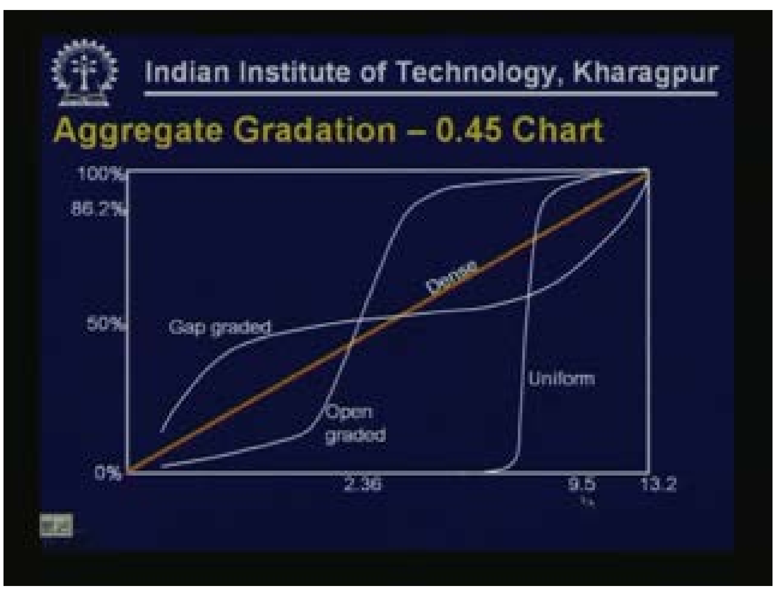

In this case the red line represents the dense gradation for a maximum aggregate size of 13.2 and compared to that I have drawn different aggregate gradations and we can see that they are different in shape. I have labeled them as uniform, open graded and gap gradations. We will see the meaning of each one of these gradations.

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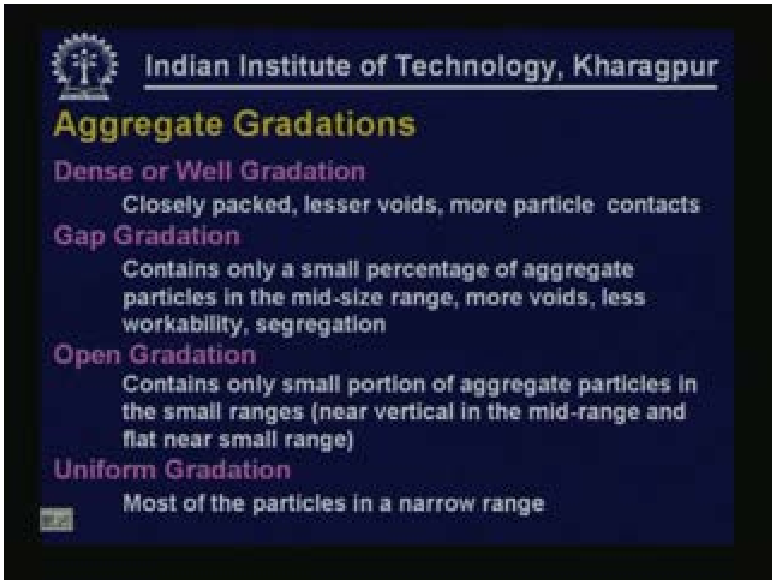

The dense or well graded which was represented by the red line in the previous slide is closely packed, obviously we are referring to dense gradation. Here the aggregates are closely packed, they will have lesser voids and the aggregate to aggregate contact will be more in number here. Whereas when we consider gap gradation this contains only a small percentage of aggregate particles in the mid size range. So as a result it has got more voids, this will have less workability, this leads to segregation in the case of bituminous as well as concrete mixes. The open graded aggregate that you saw in the previous slide contains only a small portion of aggregate particles in the small ranges which is near the vertical, rather this gradation is almost vertical in the mid range and very flat near the small ranges. Coming to uniform gradation most of the particles are in a very narrow range.

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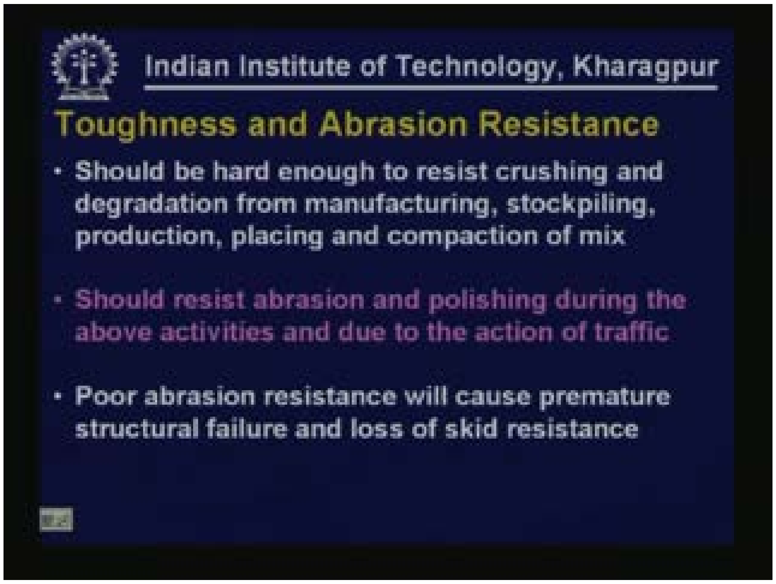

The toughness and abrasion resistance of aggregates is that the aggregates should be hard enough to resist crushing and degradation from manufacturing, stockpiling, production placing and compaction the mix undergoes various operations rather the aggregates undergo various operations before it is finally used. So in all these operations the aggregates should not get degraded they should not get crushed during traffic operation and before all these operations are completed. They should resist abrasion and polishing during the above activities and also due to the action of traffic. Poor abrasion resistance will cause premature structural failure and loss of skid resistance.

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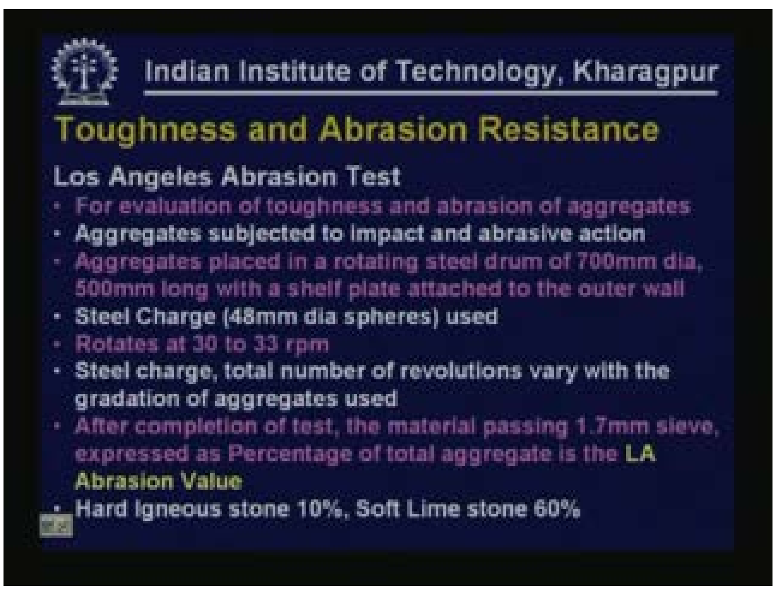

The toughness and abrasion resistance can be measured using a popular test known as Los Angeles abrasion test which is used for evaluation of toughness and abrasion of aggregates. In this the aggregates are subjected to impact and abrasive action. The aggregates are placed in a rotating steel drum of 700mm dia, 500mm wide and this drum will have a shelf plate attached to its outer wall that is inside the drum itself. This shelf will ensure that the aggregates do not slide along the wall of the drum and they get thrown into the drum and then these aggregates get thrown against each other. There is a steel charge abrasive charge that is used where we have used 48mm dia steel spheres.

The drum gets rotated at 32 to 33 r p m the number of steel bars that we use the total number of revolutions vary with the gradation. For different gradations we use different steel charge and also the number of revolutions for which the drum has to be rotated. After completion of this test obviously the gradation of the aggregate is going to change and some fines are going to be formed because of the abrasion. The material passing 1.7mm sieve expressed as a percentage of the total aggregates that we have taken is the Los Angeles abrasion value. Very hard igneous rocks will have about 10% LA value whereas the soft stone such as limestone can have almost 60% Los Angeles abrasion value.

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The photograph here shows two different views of Los Angeles abrasion value or Los Angeles abrasion test.

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The next important test that is normally conducted on aggregates is aggregate impact test. This is used to measure the resistance to crushing under sudden impact load. Aggregates of 12.5 to 10mm size are used in this test. The aggregates are packed into 102mm dia mould which is 50mm deep. On to these aggregates a hammer of 13.5 to 14 kg weight will be made to fall from a height of about 380mm and this is made to fall about fifteen times that's what is meant by fifteen blows. After this test the material passing 2.36mm sieve is expressed as the percentage of the total aggregate and this is the aggregate impact value.

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This photograph shows a typical apparatus used for aggregate impact test.

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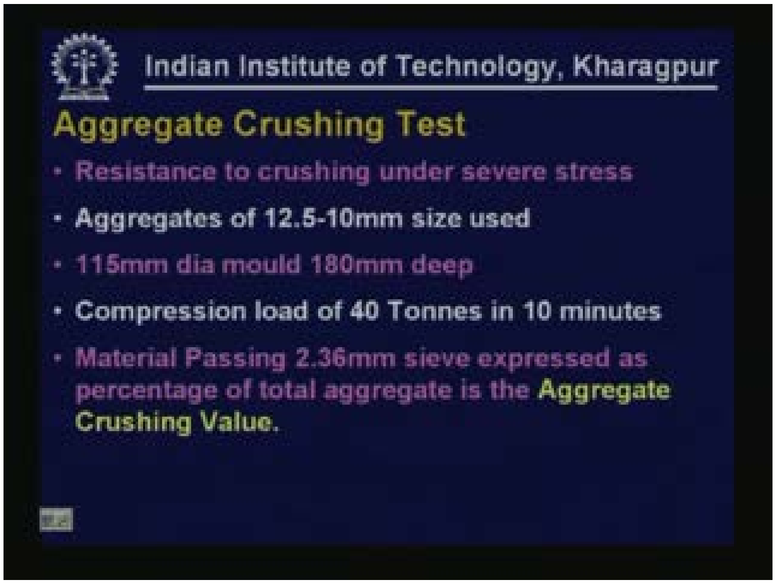

Aggregate crushing test is normally used for cement concrete. This test is used to measure resistance to crushing under severe stress. The aggregates that are used in bituminous mixes are not normally subjected to such severe stresses. Aggregates of 12.5 to 10mm size are used. 115mm dia mould is used here and the aggregates would be having 180mm depth. A compression load of 40 tons is used upright time period of ten minutes gradually. After this test the material passing 2.36mm sieve is expressed as percentage of total aggregate that is aggregate crushing value.

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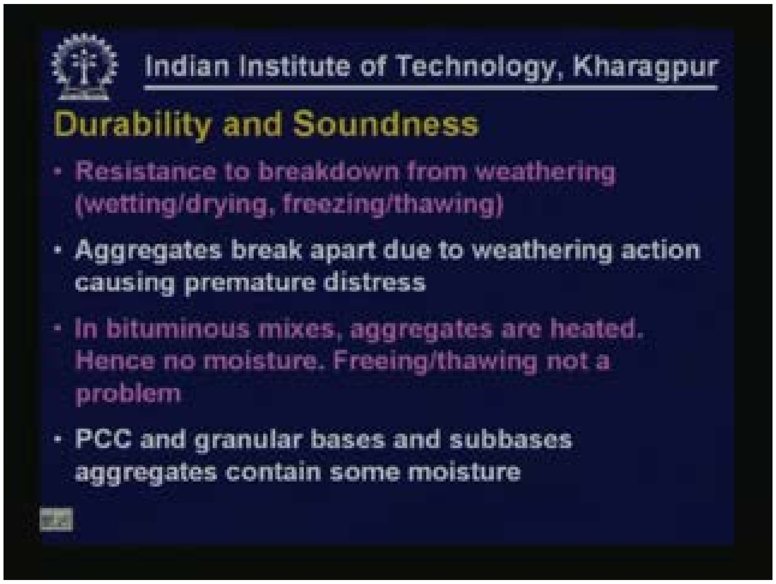

Durability of soundness is the resistance to breakdown of the aggregates from weathering which is wetting and drying process and also freezing and thawing. Aggregates break apart due to weathering action causing premature distress of different types of layers that is use such as bituminous layers and concrete layers. In bituminous mixes normally aggregates are heated so there will not be normally any moisture so freezing and thawing should not normally be a problem. Whereas PCC and granular bases and sub-bases the aggregate normally contain some moisture because we don't heat these aggregates. If the aggregates have pores then they may contain moisture so we should be concerned about the durability of such layers.

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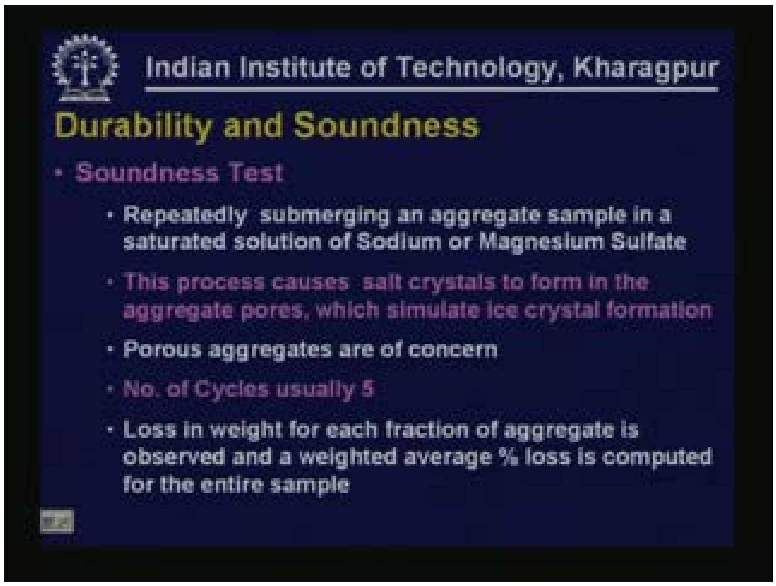

There are various soundness tests that can be conducted. The commonly used soundness test involves repeatedly submerging the aggregate sample in a saturated solution of sodium or magnesium sulfate. This process causes salt crystals to form in the aggregate pores, this is to simulate the formation of crystals and aggregates when freezing occurs and subsequently they are thawing. In this case we are only concerned about porous aggregates. The number of cycles of submerging the aggregates in the saturated solution of sodium or magnesium sulfate and their drying typically is about five cycles. The loss in weight for each fraction of aggregate is observed at the end of this test and the weighted average percentage loss is computed for the entire sample.

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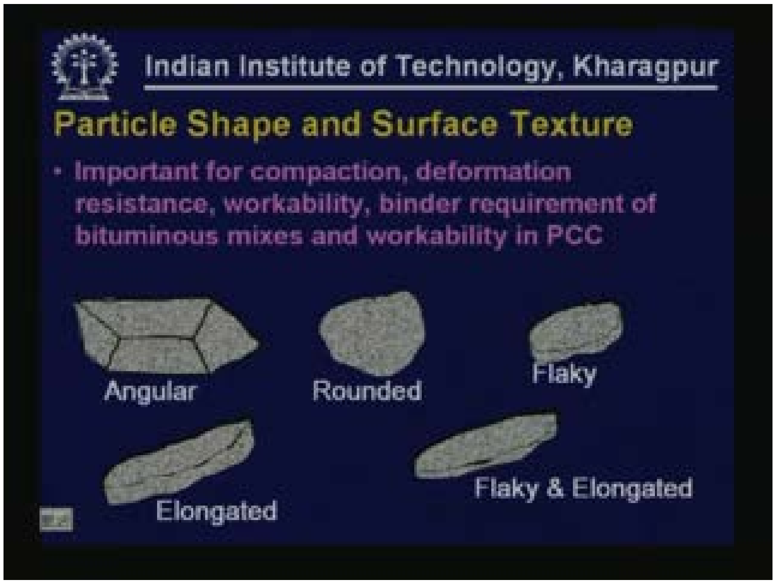

There could be various shapes and surface textures of aggregates. these are important for compaction, these are important for deformation resistance of mixes, workability of mixes, binder requirement of bituminous mixes because depending on the surface area that has to be quoted with binder different shapes and different textures would require different quantities of binders.

The first sketch that you see represents angular which look more or less like a cubical not perfectly cubical of course. The second one is a rounded shape, third one represent a flaky which is flat, fourth one is elongated which is long and fifth one is both flat and elongated.

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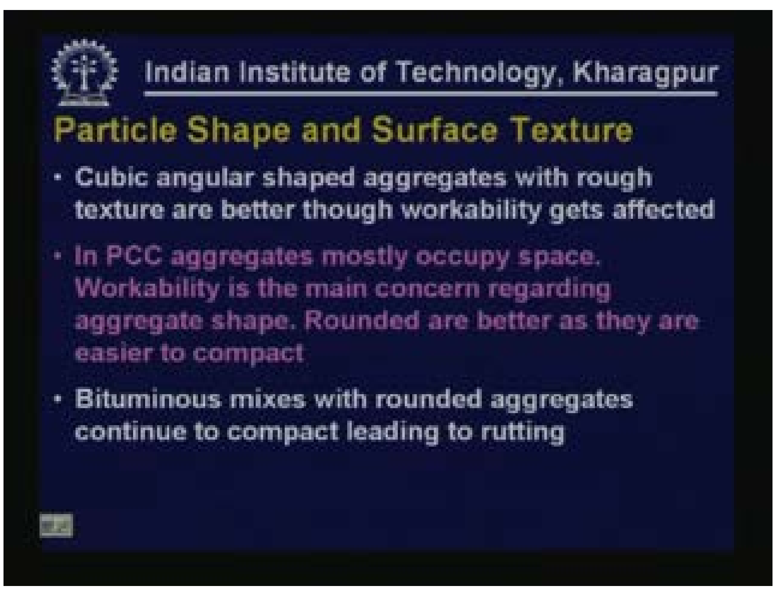

How these are measured and what is the significance of this. These are cubic angular shaped aggregates with rough texture usually are better though the workability gets affected. In PCC the aggregates mostly occupies space and strength provided by aggregate is not very significant whereas the workability is a main concern regarding aggregate shape. Rounded aggregates are definitely better as they are easier to compact. Whereas in the case of bituminous mixes with rounded aggregates the stability is little poor compared to the angular aggregates as these mixes continue to compact leading to rutting.

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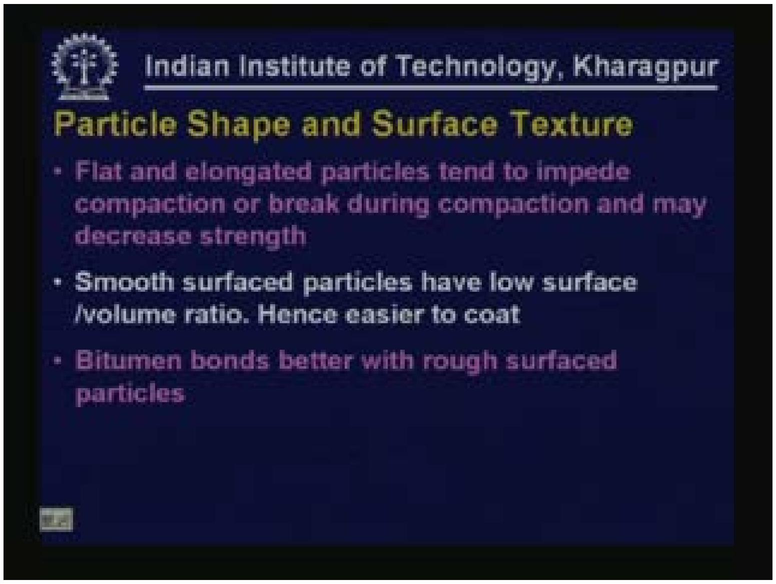

Flat and very long aggregates elongated particles tend to impede compaction they break during compaction and may decrease the strength of these materials subsequently. Smooth surfaced particles have low surface to volume ratio and they are easier to coat. Bitumen bonds better with rough surfaced particles.

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There are various ways of measuring the particle shape and surface structure. One of them is particle index. We can also use other indices such as percentage of fractured faces, fine aggregate angularity, flat and elongated particles, flakiness and elongation indices and so on. We will take up these indices one by one and discuss them.

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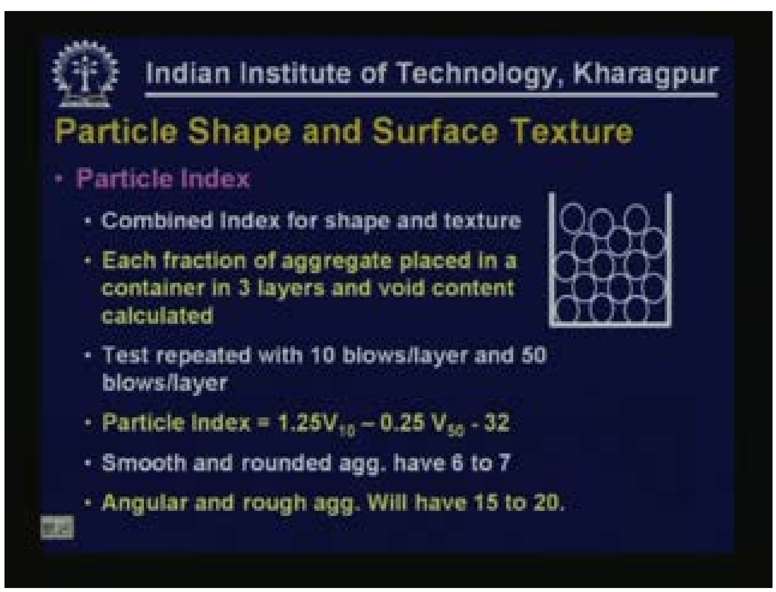

Particle index is a combined index which represents both the shape and texture of the particles. What you do with this is each fraction of aggregate is placed in a container in three different layers and the void content is calculated. it is done in two different ways. in one test each layer is compacted with ten blows and in another test each layer is compacted with fifty blows. Particle index is calculated as 1.25 times void ratio obtained for ten blows minus 0.2 times void ratio obtained for 50 blows minus 32. If you know the volume if you also know the specific gravity of these aggregates we can calculate void ratio for both cases. Typically smooth and rounded aggregates have a particle index of about 6 to 7 and angular and rough aggregates will have a particle index of about 15 to 20.

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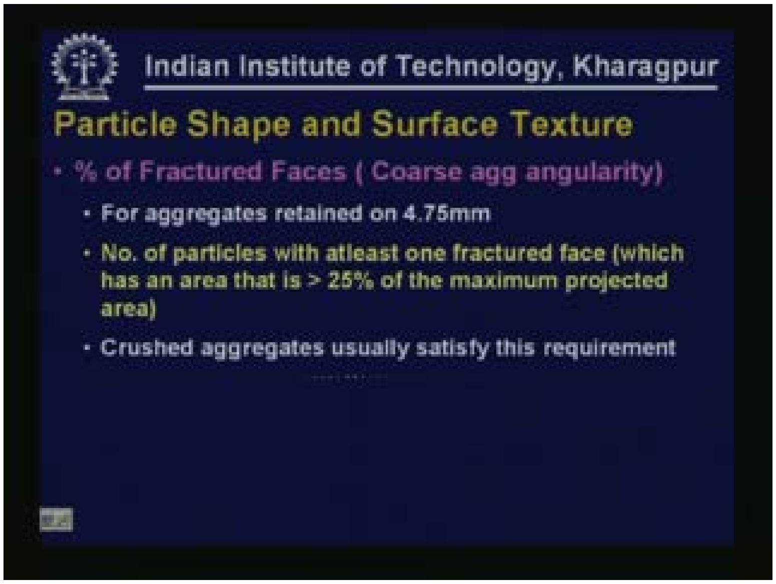

Another index that we use for representing particle shape and surface texture is percentage of fractured faces which is also called as coarse aggregate angularity. This is normally used for aggregates retained on 4.75mm coarse aggregates. This is nothing but the number of particles with at least one fractured face fractured face being identified as face having an area at least more than 25% of the maximum projected area.

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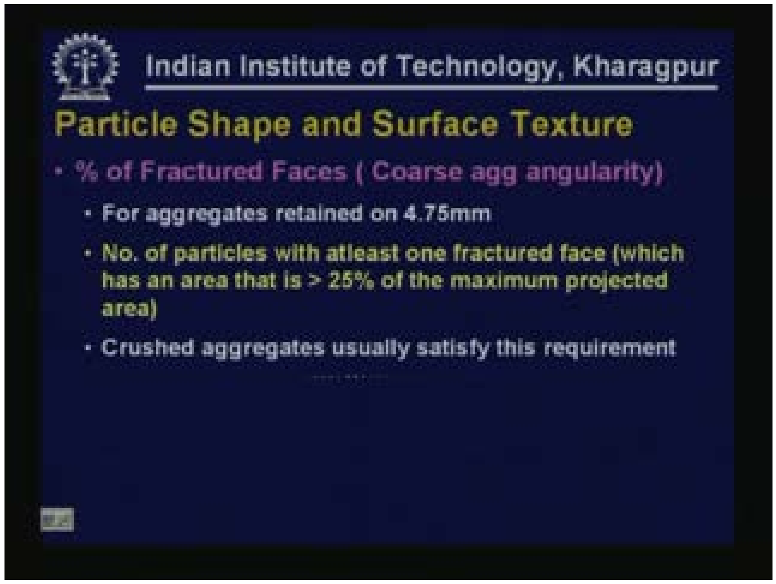

We count out of the total sample that is available how many aggregates have got more than one fractured surface, more than two fractured surface and that number is expressed as percentage of the total number gives an idea what is the percentage of fractured faces which in turn gives an idea about what is the course aggregate angularity.

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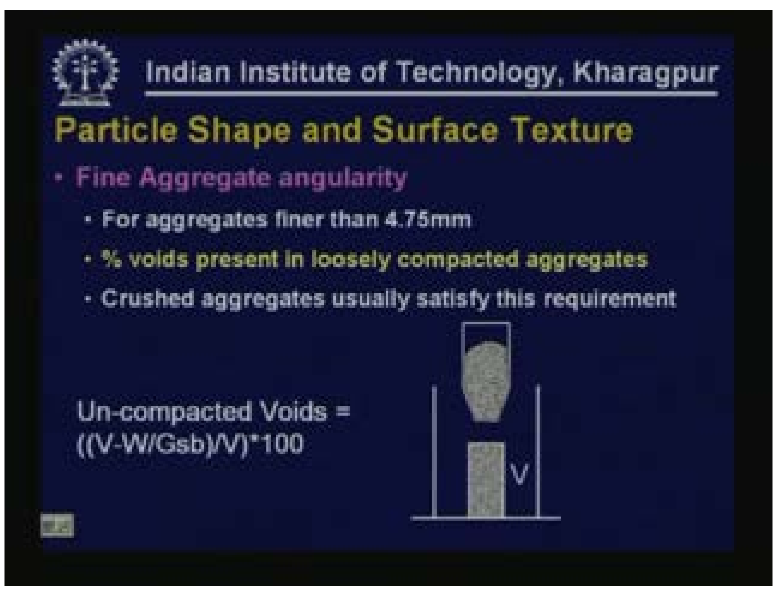

When we come to fine aggregates which are finer than 4.75mm a commonly used term is fine aggregate angularity. This is the percentage voids present in loosely compacted aggregates fine aggregates. If crushed fine aggregates usually satisfy the requirement what you do here is the fine aggregates are poured into a cylinder having a fixed volume from a certain height so we know the volume, we know the weight of the fine aggregates collected in the cylinder so if you know the specific gravity bulk specific gravity of this fine aggregates then we can cal calculate the uncompacted voids of the fine aggregates that is the representation of the fine aggregate angularity.

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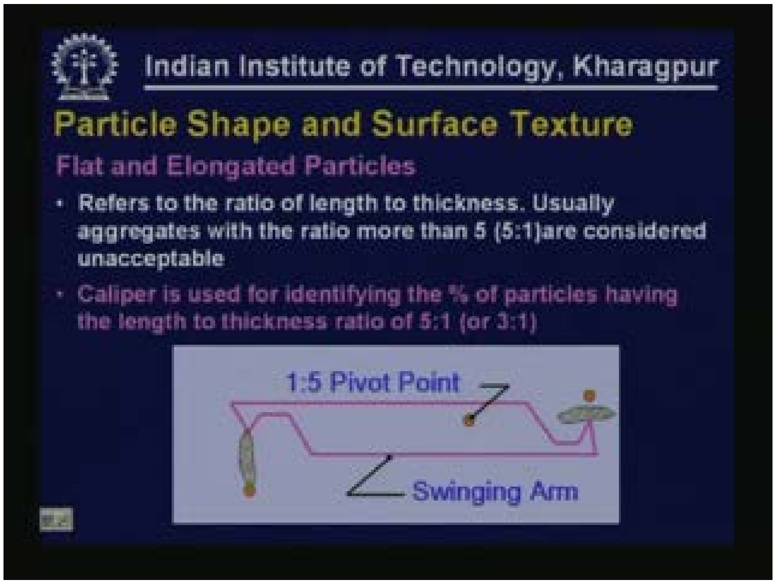

There is another test that is normally used rather than index that is normally used which is known as flat and elongated index. This is a combined index which talks about flatness of the aggregate and also the length of the aggregate. This refers to the ratio of the length to the thickness.

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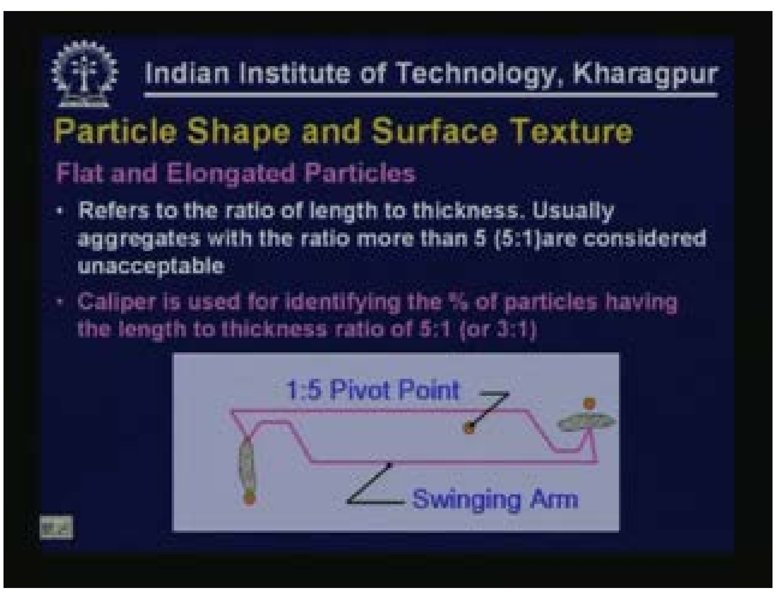

Usually aggregates with ratio more than 5 that is length to thickness more than 5 are considered to be unacceptable tool for bituminous pavement construction. There is a caliper that is used for identifying the percentage of particles having the length to thickness ratio more than 5:1. This is pivot about which this caliper can be rotated this way. There are two fixed struts attached to the base frame and this basically is the swinging arm. What we would do is the aggregate is placed along its longest dimension and then it is fixed in this position so the distance from this point to this point and from this point to this point is in such a way that the distance between this and this will be about one fifth of this dimension. Therefore if you try to pass this aggregate through this opening here if it passes it means that its length to thickness ratio is more than 5. So we can identify the percentage of aggregates that pass through this slot and then represent that as the percentage of flat and elongated particles.

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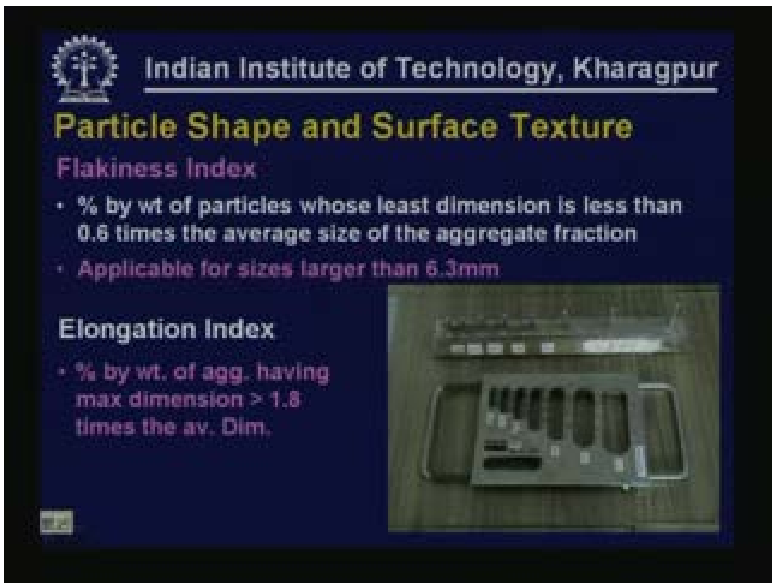

There is another term that we normally use rather a set of terms flakiness index and elongation index, this is what we adopt in India. Flakiness index is the percentage by weight of particles whose least dimension is less than 0.6 times the average size of the aggregate fraction. If you consider an aggregate fraction let's say 13.2 to 9mm and we know what the average size is and we are talking about particles whose least dimension is less than that average size by about 0.6 times this is applicable for sizes larger than 6.3 mm. Whereas the elongation index is the percentage by weight of all those aggregate particles having maximum dimension larger than 1.8 times the average dimension. Here you can see the two gauges that we use to determine flakiness index and elongation index.

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The ministry of surface transport normally gives specification in terms of what is known as combined flakiness index and elongation index. This is flakiness index plus elongation index but in this case the elongation index test has to be conducted on non-flaky aggregates. That is, after conducting the flakiness test the non-flaky aggregates are to be taken for conducting the elongation index. Then both the indices will have to be added.

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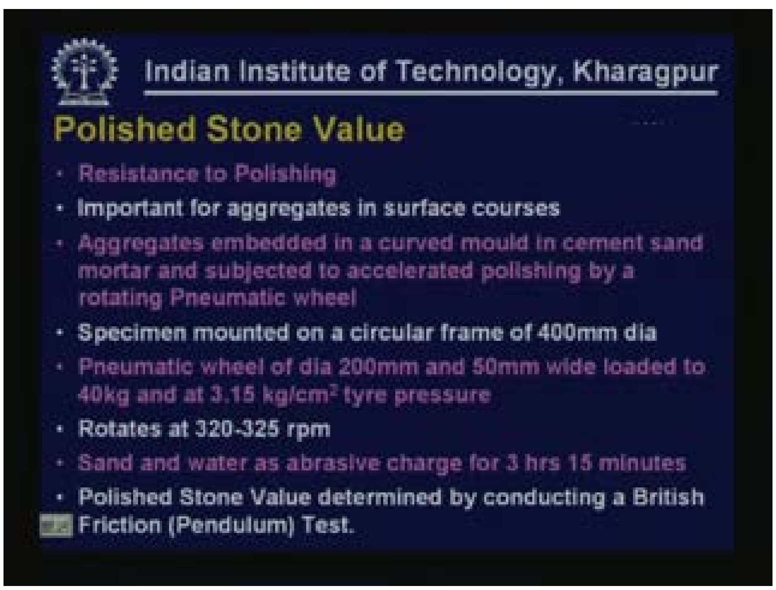

There is another test that is normally used for aggregates that are used in surface course as these aggregates are subjected to polishing because of the action of traffic. This is a measure of resistance to polishing. This is important for aggregates which are used in surface courses. In this test the aggregates are embedded in a curved mould in cement sand mortar and these aggregates are subjected to accelerated polishing by a rotating pneumatic wheel. The specimen is mounted on a circular frame of 400mm dia, a pneumatic wheel of dia 200mm and 50mm wide loaded to about 40 kg and at 3.15 kg per centimeter square tyre pressure which acts on the aggregates which are mounted on the mould and it rotates about 320 to 300 and 25mm rotation per minute, sand and water is used as abrasive charge for three hours fifteen minutes and the value that is obtained from this is represented as polished stone value.

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The surface that is obtained at the end of this test is subjected to a British pendulum test which measures the coefficient of friction of the abraded surface.

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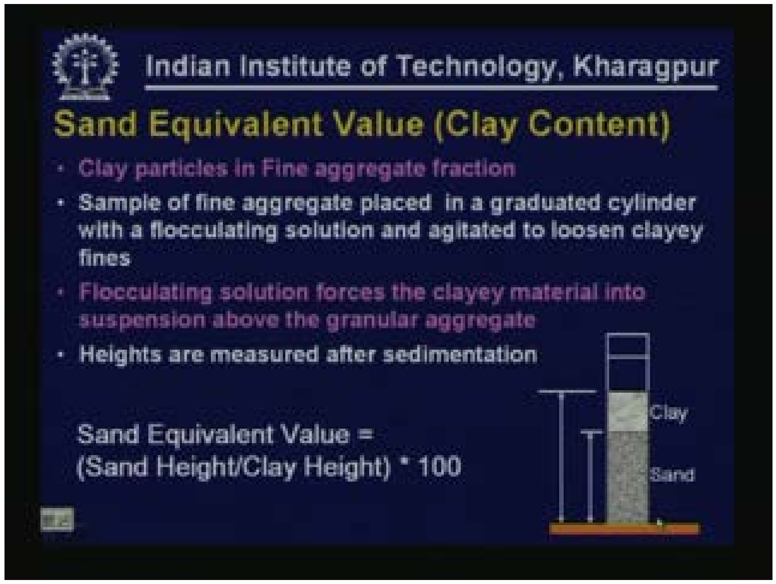

Similarly, we have another parameter that we use normally to determine the clay content in fine aggregates. The clay particles in fine aggregate fraction are obtained by taking a sample of fine aggregate which is placed in a graduated cylinder with flocculating solution and which is agitated to loosen the clayey fines. The flocculating solution forces the clayey material into the suspension above the granular aggregate. As you can see here the clay comes to the surface and sand gets separated at the bottom.

Sand is basically representation of fine aggregate here. The heights are measured and sand equivalent value is nothing but sand height divided by clay height expressed as percentage.

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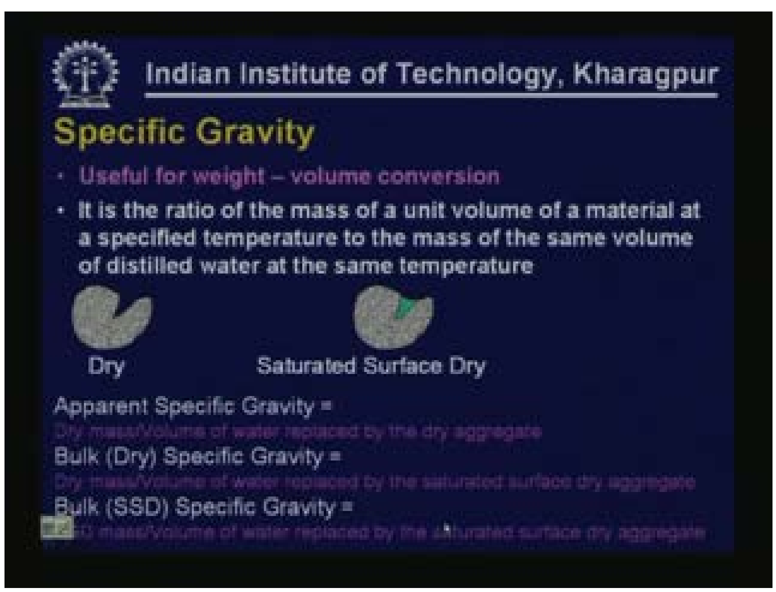

The specific gravity of different aggregates is important as far as the weight to volume conversion is considered because normally bituminous mix design is done in terms of volumetric proportions so we need to have these specific gravities of various proportions to convert weights into volumes. We have various types of specific gravities namely apparent specific gravity, bulk specific gravity etc. In bulk specific gravity we have two types; dry and saturated surface dry. On the left side of the sketch what you see is a dry aggregate bound dry absolutely no moisture whereas on the right side you see the saturated surface dry aggregate where the pores are filled with water.

Apparent specific gravity is by taking dry mass without any water and the volume of water replaced by dry aggregate we are considering only the volume of dry aggregate whereas in the case of bulk specific gravity we consider the total volume including those volumes of pores which are penetrated by water. But in bulk and dry specific gravity we consider the dry marks, in bulk saturated surface dry specific gravity we consider, and in saturated surface dry marks the weight of aggregate including the weight of moisturize is also considered.

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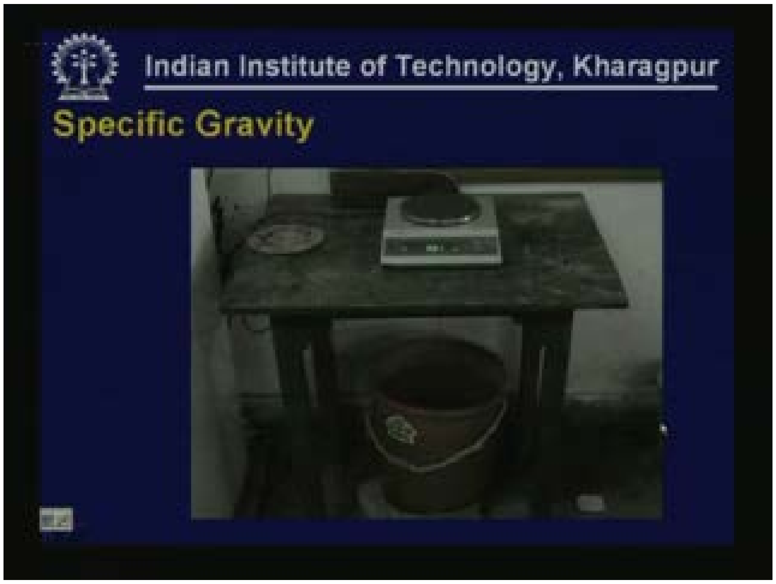

This is how we normally determine the specific gravity.

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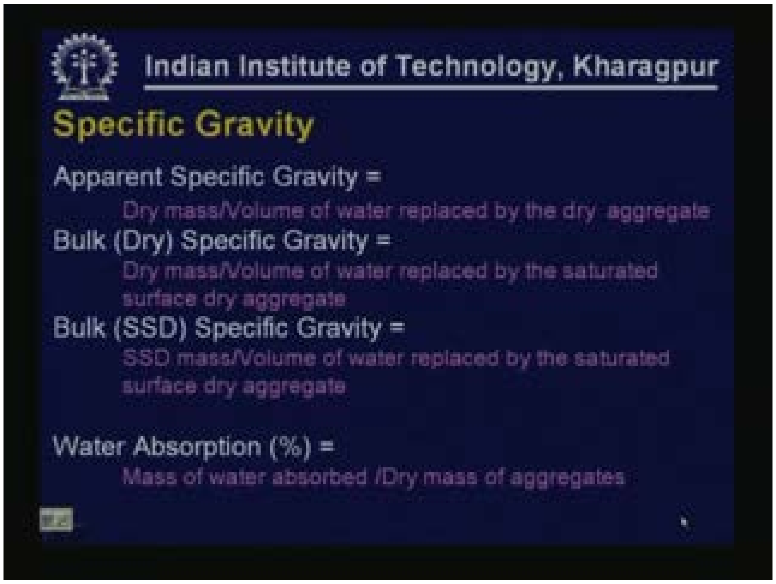

We have given the definitions of apparent specific gravity, bulk dry specific gravity and then bulk saturated surface specific gravity already. Using this we can also calculate water absorption.

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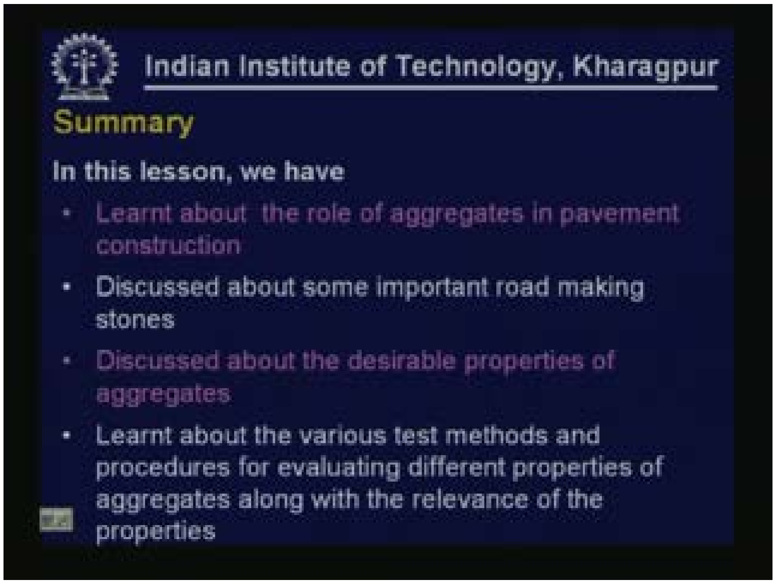

To summarize; in this lesson we have learnt about the role of aggregates in pavement construction. We had discussed about some important road making stones. We also discussed about the desirable properties of aggregates. And we have learnt about various test methods and procedures for evaluating different properties of aggregates along with the relevance of these properties for the performance of flexible and then concrete pavements.

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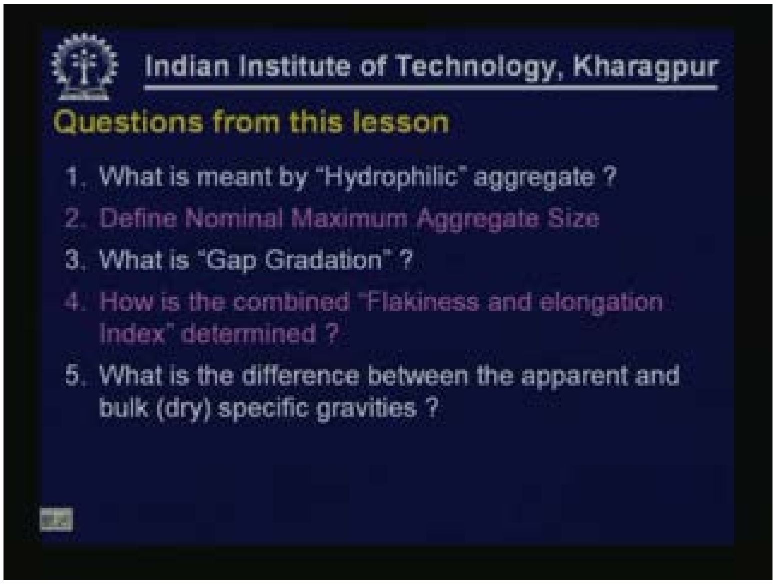

Let us take up some questions from this lesson.
What is meant by hydrophilic aggregate?
Define nominal maximum aggregate size.
What is gap gradation?
How is the combined flakiness and elongation index determined?
What is the difference between the apparent and bulk dry specific gravities?

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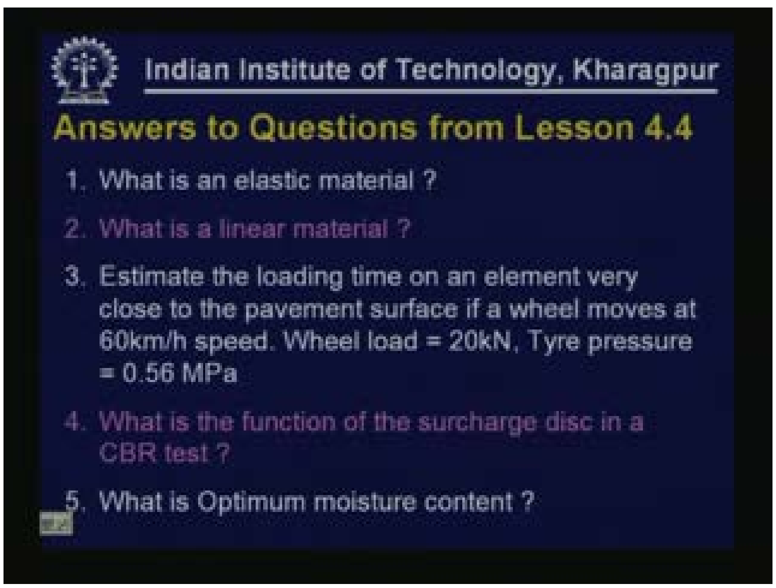

Let us quickly consider the answers to the questions that we have asked from lesson 4.4. What is an elastic material? Elastic material pertains to the response of the material when the load that is applied on the material is released. if the material recovers completely that is elastic in nature, if the material can recover instantaneously or it can recover slowly with time so accordingly it can be elastic, it can be viscoelastic etc, it may not fully recover also so the recovery is considered to be elastic. A linear material is where the stress to strain ratio is constant. That is stress is proportional to the strain.

Next question was to estimate the loading time on an element which is very close to the pavement surface. If a wheel moves at 60 km/h speed with a wheel load of 20 kilo Newton and tyre pressure of 0.56 MPa. Assuming that this is the pavement surface and this is the load contact area I am quickly calculating the radius of load contact area to be. You can check this afterwards, this will be about 106.6mm approximately and the total will be twice this. Therefore this is the distance to be covered. So this divided by the speed at which the vehicle moves gives us about .013 seconds. Thus it would be the loading time of load pulse that gets generated at the surface level.

What is the function of the surcharge disc in a CBR test? This in fact we did not discuss in the previous lesson so I thought I can discuss it now. We normally use a disc on top of the soil sample to stimulate the thickness of the pavement that you normally have on top of subgrade. Hence depending on the thickness of the pavement that we expect to have on top of the subgrade the corresponding weight of this surcharge disc is placed on the CBR sample.

What is optimum moisture content, this is the last question.

Optimum moisture content is the moisture content at which the soil can attain its densest state for a given compaction effort. We know that as we vary the moisture contents the dry density increases then it subsequently decreases so there is moisture content for a given soil and for a given compaction effort which gives us maximum dry density which is what is known as optimum moisture content.