Pavement Materials
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Lecture 57
Mix Design of Pervious Concrete (Part -1)

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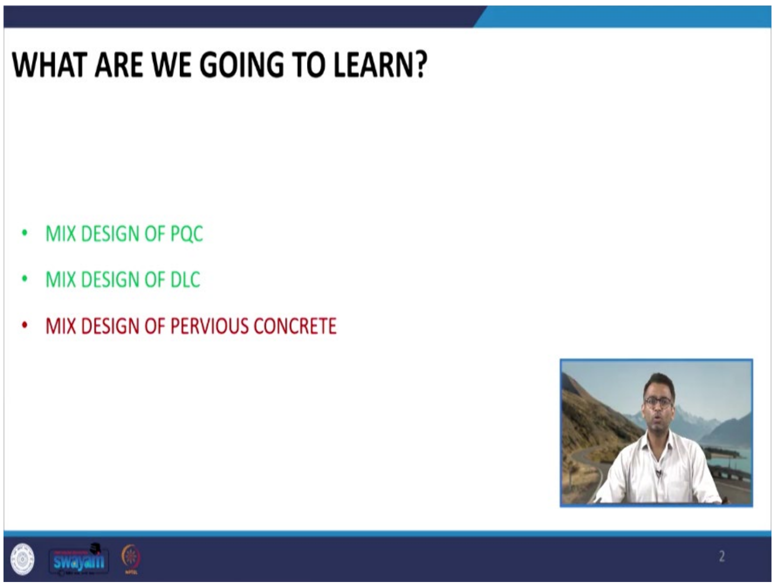

Hello everyone. Today is the last lecture of this particular module, where we are discussing about mix design of concrete mixtures. Today we are going to talk about the mixed design of a very special concrete that is pervious concrete pervious concrete typically we do not use conventionally in the construction of concrete pavements, when we talk about highways, but in special cases or in low volume facilities for example, pedestrian walkways or low volume pathways, these type of concrete can be used.

Moreover, presently, a lot of research is going on the use of pervious concrete even for facilities where vehicle load loading can be applied.

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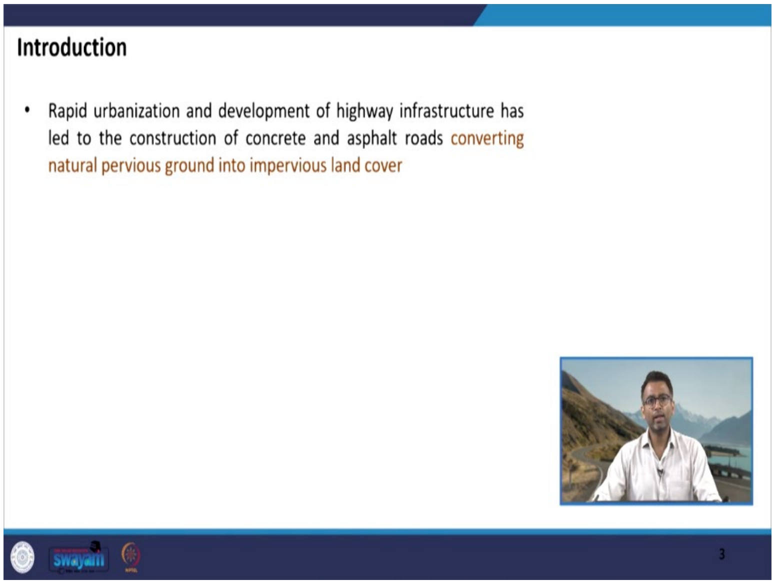

So, let us first discuss about the specialty of this type of concrete and why there is a need of adopting pervious concrete specifically. So, if we see the growth of urbanization if we see the amount of construction that is going on presently, it is anticipated that in the coming years a lot of problem can come in related to environment related to the use of raw materials.

Now, seeing the development of highway infrastructure, we can understand that the different types of roads are converting the natural pervious ground to impervious land cover. This applies both to concrete pavement as well as to asphalt pavement which we have already discussed, because of the impervious nature because of their dense configuration.

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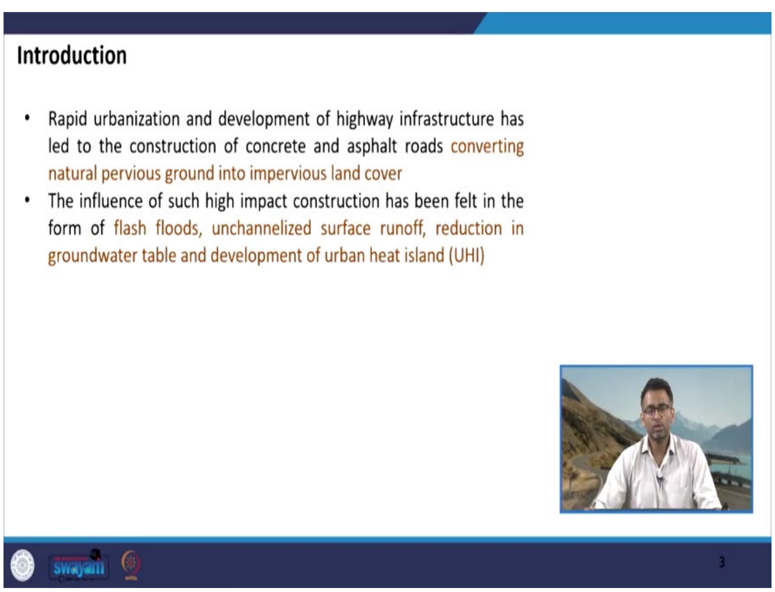

Now, what happens if the natural pervious ground gets converted into a mass which is filled with impervious layer like concrete and asphalt because there are various problems which can come in including flash floods, including un-channelized surface run off.

So, when there is a rainfall, water does not find appropriate way to move which further results in flash floods, which can lead to un-channelized surface runoff, it can also reduce the groundwater table because of this impervious nature of pavement water is unable to percolate in the ground and recharge the groundwater rather this runoff is very unpredictable and it gets wasted finally, the water which comes in get wasted in different forms. The use of pervious structures, it also leads to the effect which we call an urban heat island.

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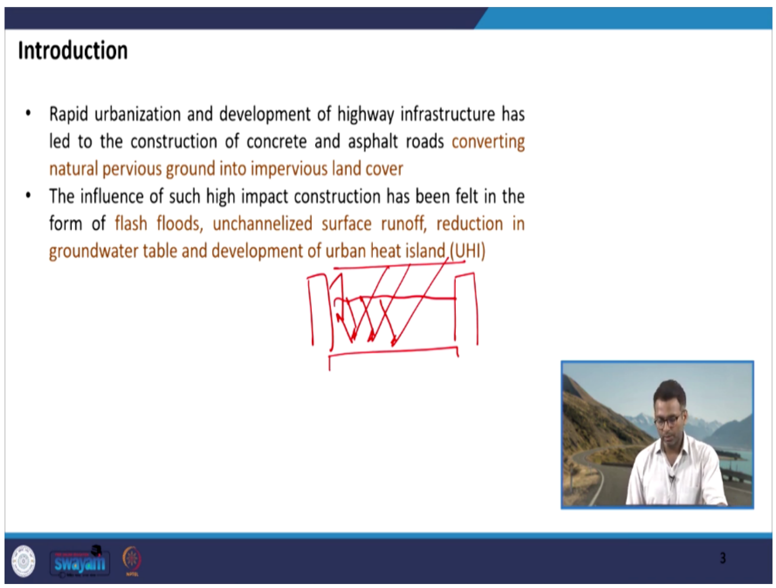

So, what is basically urban heat island, let us say you have an impervious road here and then in the city facilities you also have buildings, lot of buildings. So, when the sun ray come and it starts heating the atmosphere and the land the there is a reflection of these waves back now, because of the urban setup because of these buildings.

These waves, this heat waves or the incoming waves, they are not able to go back to the atmosphere properly and they remain on the surface to a particular height. Now, because of the accumulation of this heat within or in the vicinity of the surface, in general the temperature of the location increases and this temperature effect is called as the urban heat island.

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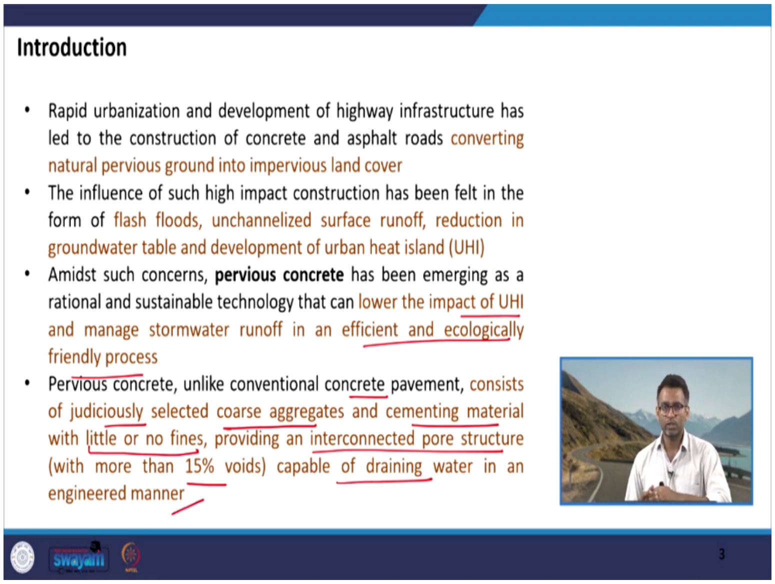

Because of these issues, there are various alternatives there are various methods that can be adopted so that we can deal with these effects. Now, use of pervious concrete is one effort towards this direction, where we are trying to reduce the effects related to flash floods, the effects related to un-channelized surface runoff the effects related to depletion of groundwater table and the effects related to urban heat island.

So, pervious concrete finally, leads or finally facilitates construction of a sustainable pavement that has lower impact of urban heat island. It can be used to manage the storm water runoff it can be useful for maintaining the groundwater table it can also be used as a process for rainwater harvesting. So, this is an efficient and ecologically friendly process which we are going to discuss however, there are shortcomings also associated with pervious concrete which we will also discuss which limits is its use only in specific areas only in specific category of roads.

So, how do we define pervious concrete what are the characteristics of pervious concrete so, pervious concrete unlike the conventional concrete pavement or the pavement quality concrete about which we have discussed consists of judicially selected coarse aggregates. So, we usually do not have I mean the pervious concrete structure or the skeleton usually do not contain fine aggregate it may contain depending on our the desirable properties which we want to have in the final mix.

But typically it is made up of coarse aggregate skeleton it can be single sized coarse aggregate or it can be combination of two different coarse aggregate again depending on the desired properties, which we want to achieve. So, judicially selected coarse aggregates and then cementing material which is the conventional material we have been discussing about with little or no fines, which I have already mentioned.

And this skeleton once the skeleton is created, once this mass is created, it provides an interconnected pore structure within the skeleton and the void content of in this particular mass is typically kept above 15 percent to facilitate the movement of water and it imparts draining capability to the structure that to in an engineered manner because we are creating the interconnected voids.

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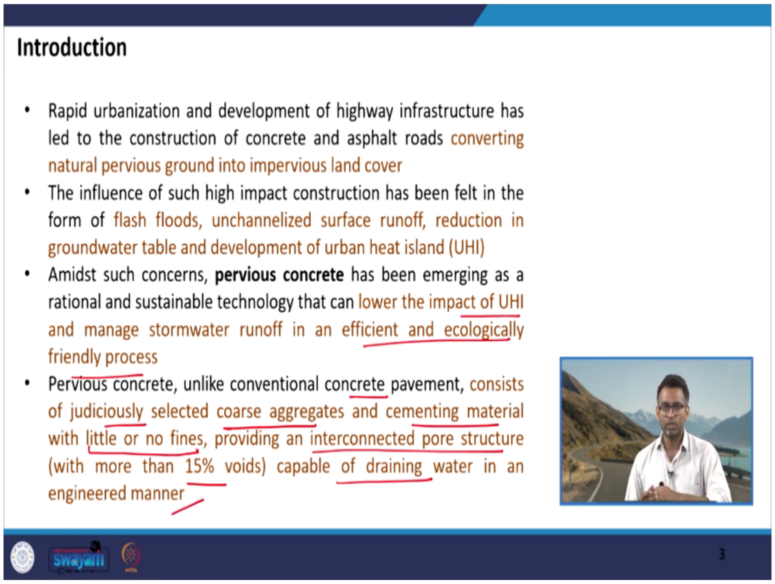

So, it is it is not like we are making a concrete and we are drilling a hole here so that water can pass, the skeleton itself is created in such a way that we have interconnected pore structure and through this interconnected pore structure, the water can move in and then this interconnected pore structure also needs to be stable so that it can take the anticipated load or it can be designed for a targeted strength.

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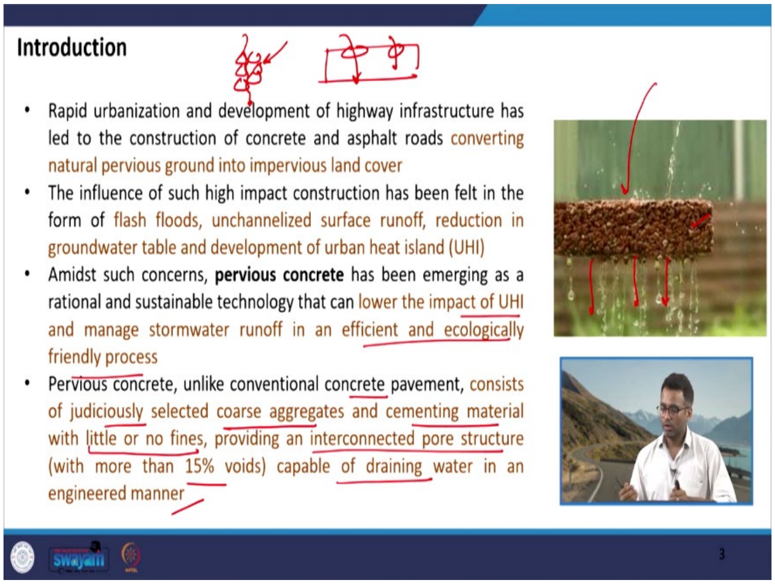

So, this is how a pervious concrete structure looks like you can see here and you can see if water comes in, it drains off from beneath, which means this is a pervious structure in contrast to the impervious mixes like the conventional concrete mixes, the conventional asphalt mixes.

Though today we will be discussing about pervious concrete using cementing or cemented materials, pervious concrete also applies to asphalt concrete, which means we can have a similar structure with asphalt binder as the binding agent. So, in in that way, we call it as a pervious asphalt concrete. So, it is just terminology, but today we will be discussing the pervious concrete where we are talking about cement as the binding material.

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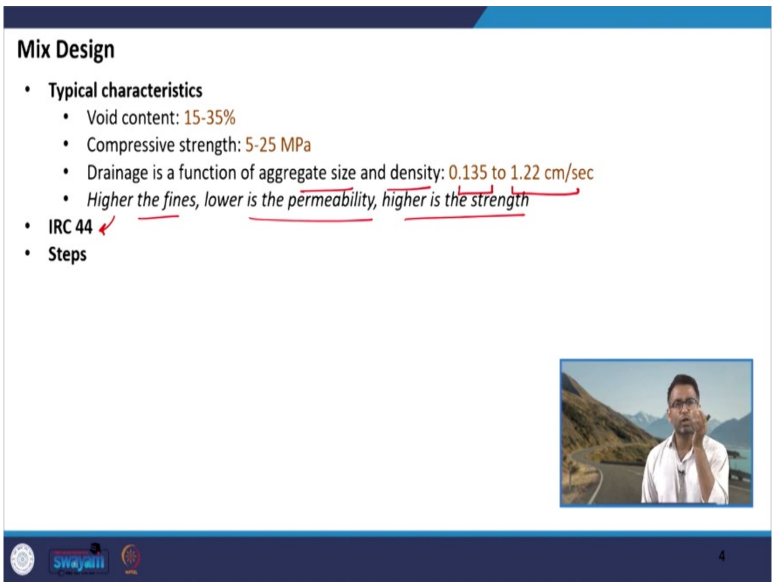

Let us look at the typical characteristics of the pervious concrete. So, as I mentioned the void content is typically kept higher than 15 percent. So, the ranges from 15 to approximately 35 percent the compressive strength of this concrete is lower in comparison to the conventional concrete which we have discussed and the design of which also we have seen.

So, the compressive strength of pervious concrete is varies from typically 5 to 25 MPa and the higher we go towards, I mean the higher strength we want to achieve the permeability usually reduces. So, we have to balance between the desired strength and the desired permeability, which we want to achieve in this type of concrete structure.

Here the drainage or the movement of the water or the percolation of the water is a function of the aggregate size and also the density and typically the permeability is kept within the range of point 135 to

1.22 centimeters per second. So, this is the typical range of permeability, which we can achieve using a pervious concrete.

So, as I mentioned, typically fine aggregates are not used in pervious concrete mixes, but depending on if you want to increase the strength we can also incorporate fine aggregates within the structure, so that the strength of the motor will increase but we cannot increase it beyond a particular limit, because higher the fines the lower will be the permeability and of course, the higher will be the strength. So, we need a basically trade-off between permeability and strength here.

So, the specification which we will be discussing today is again IRC 44. So, previously we have also discussed the mix design of PQC corresponding to the specification IRC 44. So, IRC 44 also has a special section on the mix design of pervious concrete however, there are few limitations in the present guideline again, which we will try to very quickly go through and since this is an emerging technology people areparallelly working around the globe in different countries.

At present, there are no specific guidelines, no standard guidelines for the mix design of pervious concrete because it is evolving, because there are certain parameters that influence the properties and then, these parameters needs to be optimized and people consider this optimization in different ways. So, it is still under development stage.

So, let us discuss the available specification which we have in India that is IRC 44. So, as per IRC 44, we will quickly go through the steps then, we will also see a video demonstration of pervious concrete from studies specifically done in India.

And then we will also talk about the limitation of IRC 44 we will try to see what are the available other available specification which are the other available specification that encounters those limitations and then we will try to again solve 2 problems from IRC 44 and we will discuss about some of the parameters there.

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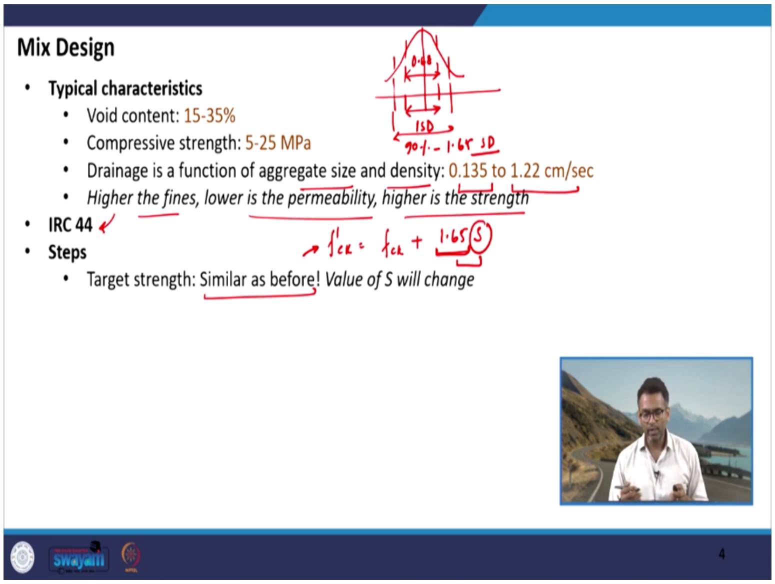

So, first thing which we have to decide for designing or in the mix design process of pervious concrete is to finalize or is to fix the target strength and this is what we have been doing previously also for example, we have to fix either the flexural strength we have to fix either the compressive strength and so on.

So, here we will fix the compressive strength first and the equation will remain the same that is target strength we already know is equal to fck which is the (characteristic strength+1.65×S). Now, many times students ask that why is this 1.65 maybe I was not I did not explain this in in the previous lectures then it just appeared to me that I should have discussed this.

So, this is actually simple like if you test a lot of samples in the lab, we expect that the the values let us say compressive strength will be distributed normally, so, we cannot expect all the values to be same is not it. So, the value will have some variation and this variation typically is in the form of a normal distribution. So, we have the mean and then we have standard deviation.

So, what is 1.65 into S, 1.65 standard deviation here. So, if you see the standard normal distribution, then you can calculate that 68 percent of the area is within one standard deviation. So, this this is like 0.68.

Similarly, if you again see the other points in the graph, so, almost 90 percent of the area of the standard normal distribution is within 1 point 65 standard deviation. So, this is how this 1.65 comes in so, which means that 90 percent of the value will be within this particular range which we are looking at. So, this is the target strength, so, not more than 10 percent of the sample should have a strength less than this particular value. So, that is why we take 1.65 standard deviation.

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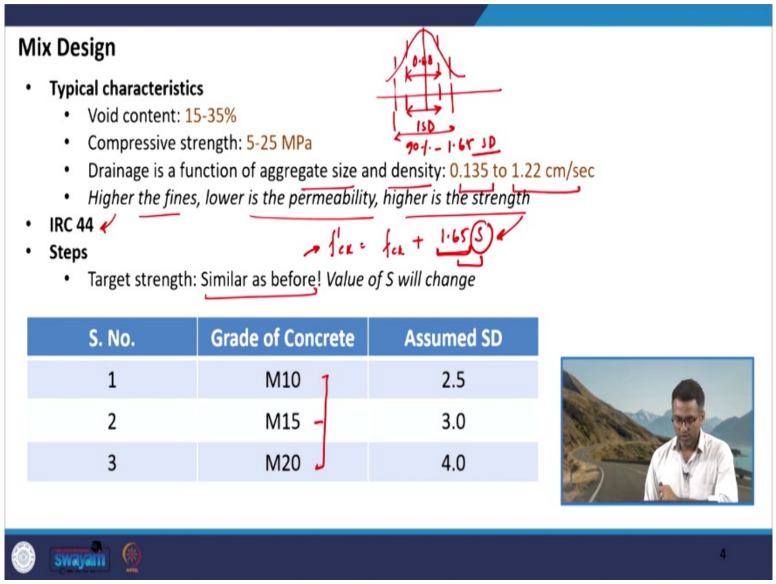

Now, anyways, so, depending on the grade, there are 3 available grades because this is a low grade concrete. So, M10 to M20 are the options available as per the codal specification and then depending on what is the grade of concrete we are choosing, we can choose the corresponding value of standard deviation. Then, what we have to do is we have to select the water cement ratio.

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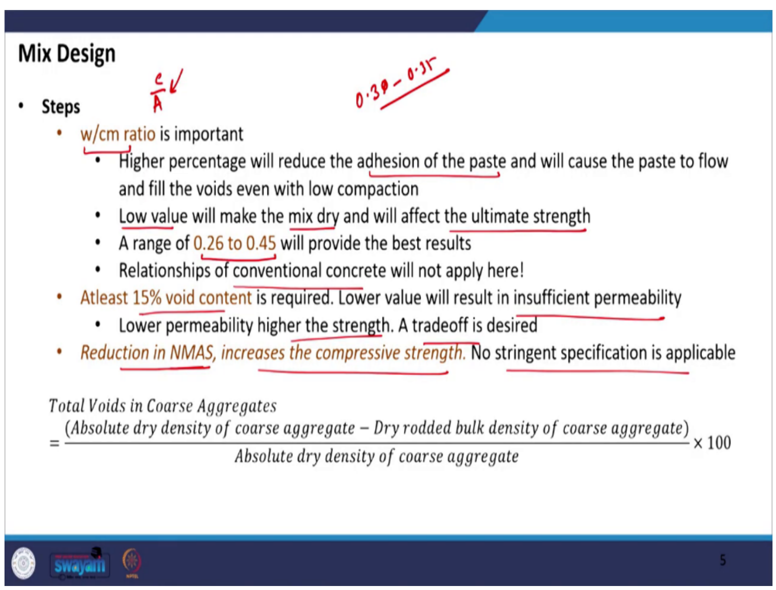

Now, this our code that is IRC 44 it mentions that water to cementitious ratio is an important parameter in pervious concrete it is true, but the available literature also states that in comparison to water to cementitious material ratio, cement to aggregate ratio similar to what we have considered in the case of Dry Lean concrete is more critical. And you see pervious concrete is also a dry mix, it is a zero slump mixture.

So, it is important that the cement to aggregate ratio should be chosen appropriately again however, the available specification mentions that we have to choose the water to cementitious material ratio very judiciously because higher percentage if the water to cementitious ratio is very high then it will reduce the adhesion of the paste now try to understand what is paste here it is cement and water a combination of cement and water and it has to bind the coarse aggregate particle and it has to maintain the stability of the coarse aggregate skeleton.

So, you can imagine that if we put in more water first the adhesion will be lost because the proportion of cement in comparison to water is reducing here and then the paste it will be too flowable. So, if the paste is too flowable, it will not be able to hold the aggregate particles together rather it will go inside the voids which are there the high amount of voids which are there it will flow in those voids rather than coating the coarse aggregate particles properly and keeping the mass together.

So, here again the amount of paste thickness is very important because if the paste thickness also becomes very huge very large then this will affect the amount of pores which we are intending to create. However, we cannot use a very low value also because then it will make the mix very dry and it will also affect the ultimate strength.

So, through experience it has been seen because the specification does not mention any rational reason why this range has been prescribed, but through various experiments, it has been seen that a range of 0.26 to 0.45 in case of pervious concrete will provide good results the available literature says that we can choose the ratio of point 3 to 0.35 also in this range, it gives you no good strength and then permeability too.

Here we cannot use the relationship of the normal conventional concrete which means, we are not seeing that how with change in water cement ratio the strength is changing rather than we are interested to see that how with change in the volume of paste thickness the strength properties alter because paste thickness is more critical in comparison to water to cement ratio alone.

Talking about the void content as I said that the void content ranges from 15 to 35 percent so, minimum 15 percent is required to actually call it as a pervious structure, if the void content reduces water will not specifically flow from the interconnected pores and the main reason of producing this mix is not met. So, a lower value will result in insufficient permeability as I mentioned that lower is the permeability higher will be the strength and that we understand that is logical and therefore, we need a trade off.

So, we have to optimize the parameters choose all the proportions in such a way that there is a balance between the desired permeability and the minimum compressive strength which we desire. Talking about the nominal maximum aggregate size in this particular specification IRC 44 there are 2 options we can either use 19 mm nominal maximum aggregate size or 9.5 mm again as I mentioned, this is a research area presently.

And various other gradations various other size have been tried even there are researchers available that say that you can use up to 4.75 mm nominal maximum aggregate size to achieve the desirable properties. So, usually reduction in nominal maximum aggregate size will increase the compressive strength because the surface area increases and then you have more cement paste to bind them and the strength therefore increases. However, there is no stringent specification as I mentioned and people are still looking at these aspects.

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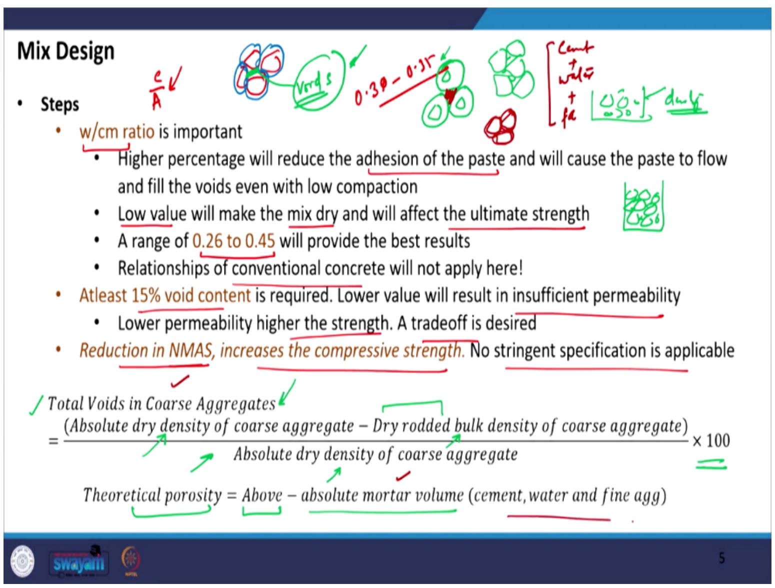

Talking about some of the calculations here one calculation which is desirable is to calculate the amount of voids in the course aggregate. So, you see you have course aggregate, this is the void now, these coarse aggregate will then be filled with cement paste or will be covered with cement paste and then the area which is left here, this is basically the void which gets created.

So, I am interested to see how many voids can be created for that I am first interested to see that the skeleton which I have chosen this depends again on the shape characteristics of the aggregate how much voids they create in between them. So, here how do we calculate the total voids in coarse aggregate we can use this simple formula where we say that the total voids = (the absolute dry density of the coarse aggregate – the dry-rodded bulk density of the coarse aggregate).

However, the specification does not specifically mentioned that how this dry rodded bulk density should be evaluated in the laboratory divided by the absolute dry density into hundreds. So, there is also an ASTM code that also gives a method to calculate the amount of voids in the pervious concrete we will talk about that though this formula is available in the specification which mentions about the voids in coarse aggregate we are not very strictly using this formula in the mix design process which we will be discussing.

However, if we know the total amount of voids in the coarse aggregate, then I want to find out this void you see, which I was talking about after the cement paste has covered the aggregate particles. So, the theoretical porosity which is the amount of space in the pervious concrete mixture should be =(the voids created in the coarse aggregate – the absolute mortar volume). So, what is that mortar volume, this volume because I am interested because porosity of the pervious concrete is this.

So, dry rodded was between the aggregate particles only now, this aggregate particles will further be covered by a volume of cement paste. So, you can imagine that the amount of space left between them will become less. So, I will deduct that voids which was created by the coarse aggregate with the volume of the mortar and this mortar will consist of cement plus water usually, but if you are using fine aggregate that will also become a part of the mortar. So, if we know the weight of these constituents, I can also calculate the volume of the mortar.

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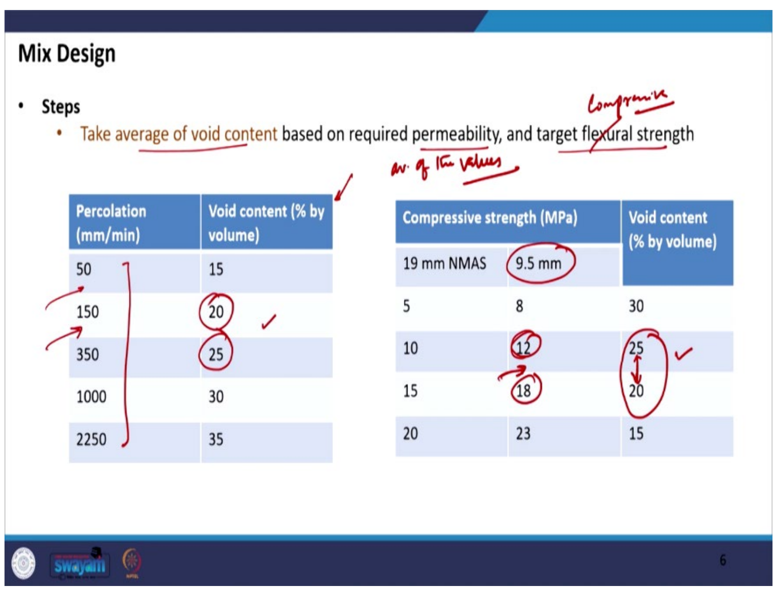

Here what they have given that the code says that there are 2 ways to choose the average void content based on the targeted permeability and targeted strength. So, as I say the trade off is required. So, the void content is a function of again the desirable permeability which I want to achieve and also the target should be compressive strength, so, the targeted compressive strength of the concrete.

So, based on the permeability these are the different values of permeability if our values is somewhere in between we will interpolate it so, depending on the volume we can choose the appropriate void content. So, this table will give us one void content. However, the code mentions that the word content should also be selected based on the targeted compressive strength.

So, say we are using a 9 point 5 mm nominal maximum aggregate size mix and our target the compressive strength is somewhere here so, between 12 to 18, which means our void content should be somewhere between 20 to 25 percent. And you get one value from this table one value from this table so, we will take the average of the values in the mix design process.

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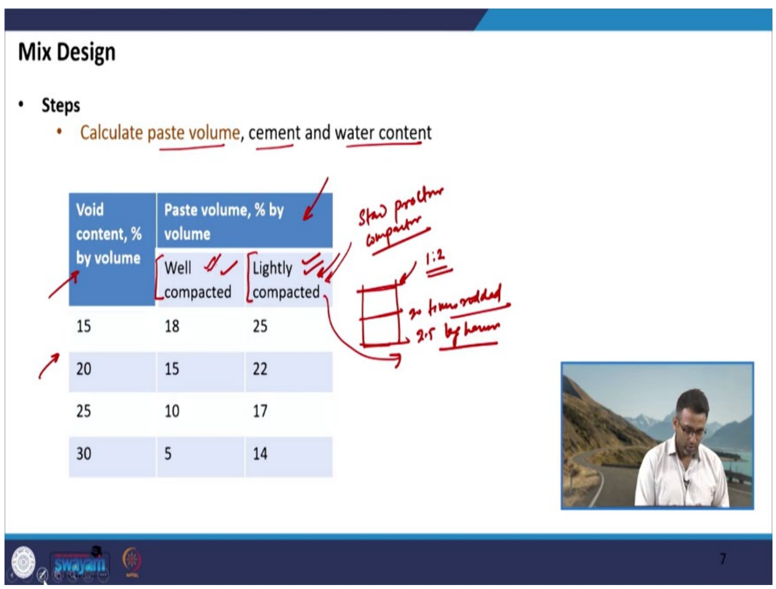

Then the next step is to calculate the paste volume the volume of cement and the volume of water. So, how do we do that? So, paste volume is a function of the void content which we have just calculated from the previous step taking the average from both the tables.

So, once you have the void content, then you can select from this table the paste volume. Now, here you have again 2 options. One option is to prepare a well compacted pervious concrete mixture and the other is to produce a lightly compacted pervious concrete mixture again in this specification, it is not mentioned that what do you mean by a well compacted mixture or what do you mean by a lightly compacted mixture.

So, what can be anticipated as of now, that well compacted mixture is those let us say which we are producing using a heavy compaction method and lightly compacted method are those mixtures which we are producing using light compaction method as we have discussed in case of Proctor density test.

One of the again shortcomings in the present form is that the code does not say how to produce the mixtures in the lab should it be produced in the similar way we are producing the concrete mixture, the answer is no then how to produce these mixtures in the lab because we have seen in the last class that a conventional concrete mixture is filled using a vibrator even the same we do in case of DLC mixtures.

But for pervious concrete if you apply a vibration or you f if you apply heavy rodding in the mix, it can lead to the drain down of the paste from the pore structure try to imagine this you are using vibration. So, because of this vibration the cement paste can flow out of the voids.

So, usually what we do we use a standard proctor compactor you can say so, what we do here we fill if it is a cylindrical mold and usually we make the samples in the ratio of 1:2 the diameter to height and we fill this in 2 layers and you can fill it in more layers also some literature mentions is better to fill in 3 or more layers, but the available ASTM code it mentions that we fill it in 2 layers and each layer should be rodded 20 times using the 2.5 kg hammer.

So, I I am anticipating that this light complexion refers similar to what we are discussing now. Well maybe well compacted mixtures are those which can be compacted using heavy compaction.

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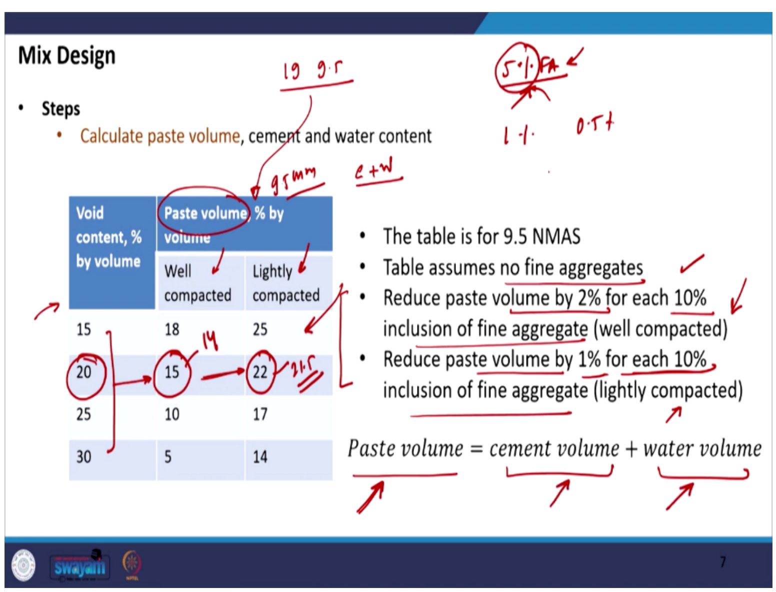

But in case of pervious concrete again too heavy compaction can lead to breaking of the aggregates. So, it is not very well established what we specifically mean by well and lightly compacted mixtures. Say that is a different thing here, but say we have 2 options, well compacted and lightly compacted. So, based on the void content, you can select the appropriate volume of the paste here.

Again though the code mentions that there are 2 options 19 and 9.5 presently we have only one table and this is meant for 9.5 mm, table assumes no fine aggregate now, this is again one important point that in this table this paste volume which is given here it comprises only of cement and water in case you are using fine aggregates which will also form a part of the paste then you have to apply some corrections.

How will you apply, reduce the paste volume by 2 percent for each 10 percent inclusion of fine aggregate if you are using a well compacted condition in case of a lightly compacted condition reduce the paste volume which means these values which you are taking for every 10 percent inclusion of fine aggregate which means let us say if you are using 5 percent fine aggregate then in let us say the paste void content is 20 percent.

So, I am using 5 percent fine aggregate without fine aggregate it was 15 percent but since fine aggregate has come I have to reduce 2 percent for each 10 percent inclusion, the inclusion is 5 percent so, the reduction will be 1 percent. So, instead of 15, I will take 14. In case of lightly compacted it says 1 percent for each 10 percent we have 5 percent so, we will reduce point 5 percent which means this will be 21.5 percent. So, I hope that this is clear to you and finally the paste volume = (cement volume + water volume) here.

Even if you use fine aggregate, we consider this 5 percent fine aggregate as a volume of the aggregate during (cal) calculation and not a part of the paste volume though it is a part of the mortar, but we are not considering it as the paste volume. So, this paste volume will comprise of the volume of cement and water.

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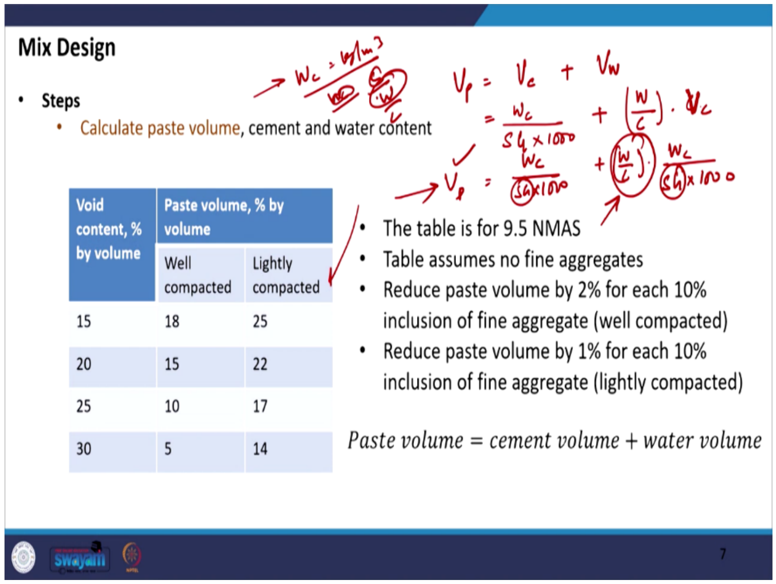

So, you see this this calculation can further be simplified. So, paste volume = (cement volume + water volume). So, this $V_C = \frac{W_C}{S_G \times 1000}$ this is what we have seen, volume of water can be written as $w/c \times V_C$.

So, this becomes equal to $w/c \times \frac{W_C}{S_G \times 1000}$. So, you know this from this table you know water cement ratio which we have assumed initially the specific gravity of cement 3.15 so, from this equation you can calculate the weight of cement in Kg/m^3, once you have the weight of water to cement ratio so, you can calculate the weight of water also. So, this paste volume using the paste volume we can find out the amount of cement and amount of water which we are going to use in the mix.

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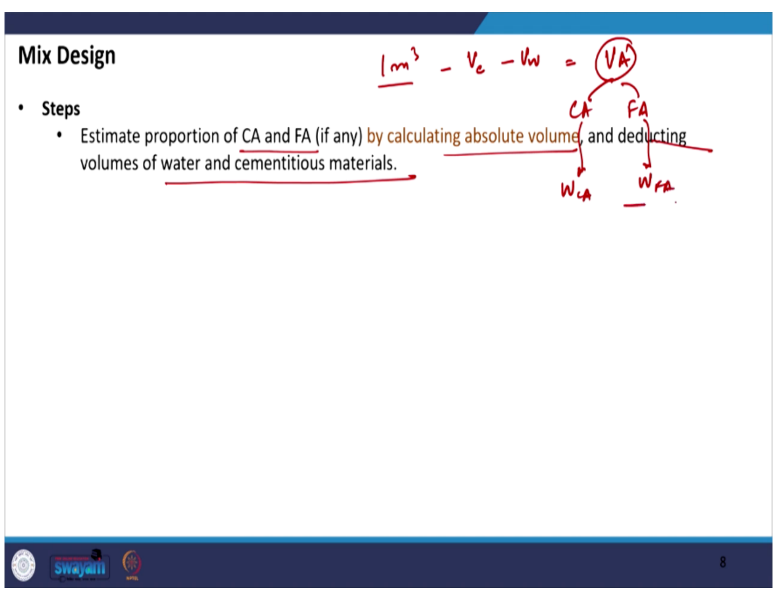

After that this is similar to what we have discussed in case of concrete mixtures also that we will estimate the proportion of coarse aggregate and fine aggregate if there are any fine aggregates by calculating the absolute volume and deducting the volume of water and cementitious material. So, this will be clear once we do the calculations again.

So, 1 meter cube is what we are trying to design and we will deduct the volume of cement and volume of water to get the volume of aggregates this volume of aggregate will comprise of coarse aggregate and if there are any fine aggregates again using their specific gravity we can calculate the weight of coarse aggregate and the weight of fine aggregate. So, other things actually remains the same which will not discuss today again it will be a repetition.

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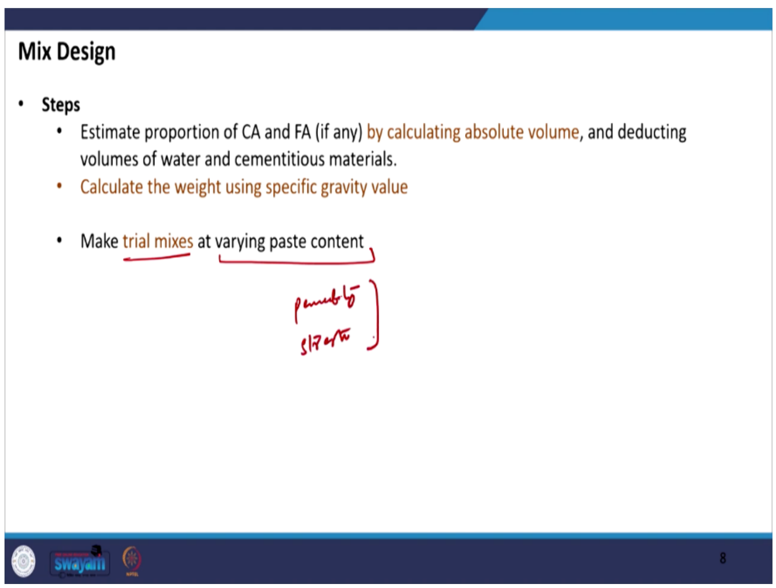

So, calculate the weight using specific gravity and then what we have to do here we have to make trial mixes and here we will we are going to make trial mixes at varying paste content. And then we will select the appropriate paste content to meet the desired criteria of permeability as well as strength.

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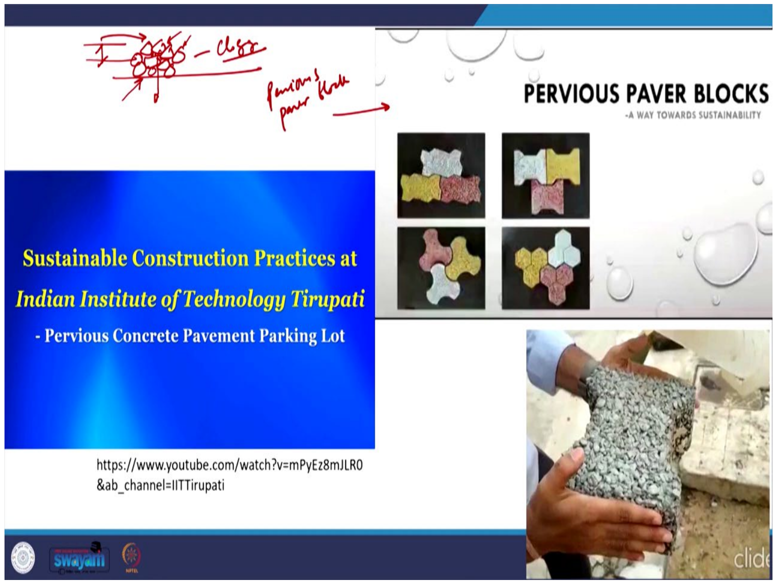

So, with this, before discussing again about few of the shortcomings, we have already discussed, while we are discussing the mix design steps and before solving any problem, let us see some of the videos here and these videos are taken from some works carried out in India, for example, you see in the pervious concrete one of the challenges is that with time try to imagine if you place a pervious concrete. So, water comes in water brings a lot many fine materials along with its when it is flowing.

So, this fine materials can stick here within the pores and over a period of time this can clog the pervious concrete mix and clogging is one of the major issues related to pervious concrete there are methods and this this clogging is basically limited to the top few centimeters. So, this can be removed through D clogging process using pressurized cleaning using sweeping for example, but that is again not very straightforward, it is challenging.

Another problem with pervious concrete is that a conventional curing method does not work because you see in in case of cement concrete you used to spray we can spray water and this water will stay on the concrete mix and it will cure it will increase the strength over a period of time. But in case of pervious concrete, if we spray water this water is going to go down. So, though various again curing techniques have been adopted there are no standard guidelines or appropriate control over the field curing of the concrete pervious concrete samples or pervious concrete layers.

So, in order to counteract these issues in order to improve the quality control a pervious paver block can also be used and then our research group in India they we did some work on pervious paver blocks also and the advantages being that if the clogging is local, you can remove clean and replace the blocks.

Moreover, since this is fabricated in the laboratory, it is a precast block. So, you have more control over the curing and the optimizing the strength properties of the mixture so that give you a positive angle of using pervious paver blocks. So, we will see these videos and then I have also provided reference to the papers, which can be further referred to get more insight on the use of pervious paver block as well as pervious concrete studies that have been done in India.

So, we will play this video the first video is from IIT, Tirupati available in YouTube, they have done a lot of work in the area of pervious concrete they also have constructed various sections within the campus in the vicinity of their city for the demonstration of the effectiveness of pervious concrete and, let us just quickly go through these videos to have some idea.

So, let us see this first video we are referring to studies done at IIT, Tirupati. This shows the ingredients these are some of the features advantages and then applications you can see that this picture identifies the location where a construction was done these pictures are shows the steps of the preparation of different layers spreading of the pervious mixture this is light vibration again. And you can see that how the water percolates very effectively in the mix and it shows that how the use of pervious concrete can be useful to the environment. So, we will stop here in this video.

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Let us look at the video of the pervious paver block also. This shows the difference between the conventional block and the paver block some of the benefits steps of producing the mixture and the block the ingredients so, these are pigmented blocks that were produced. This shows the different molds that can be used during the production light vibration for compaction this is Demolding.

So, control curing at the factory through spraying of sprinkling of water at different intervals this is some empirical form of permeability test just to demonstrate that how water percolates so, these are various applications where the pervious concrete can be laid.

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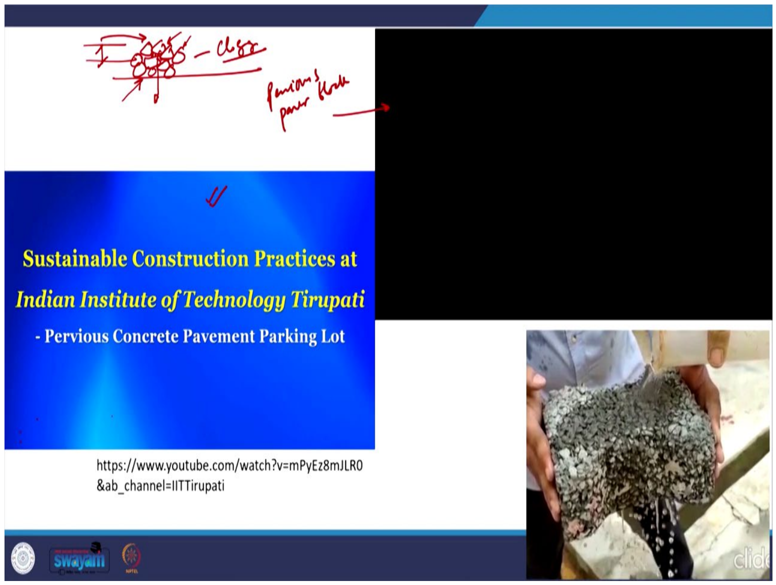

Now, let us look at the last video. So, this mixture was basically produced using recycled asphalt aggregates from asphalt pavement using the rap material you can see that the produced block is very intact we found good compressive strength for these blocks and you can see that how good the permeability is in these blocks.

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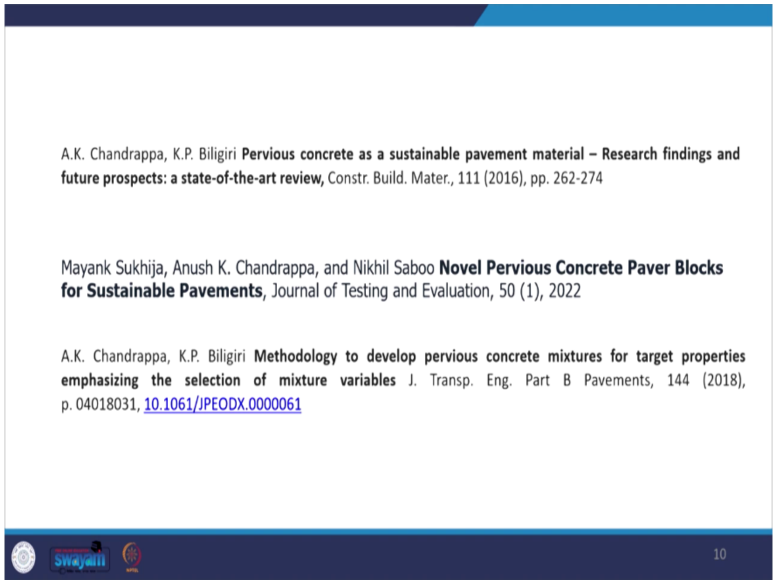

So, from here let us proceed ahead now, well these are some of the references, which can be referred for knowing more about these pervious concrete mixtures and paver blocks. So, let us now very quickly go through some of the aspects related to pervious concrete.

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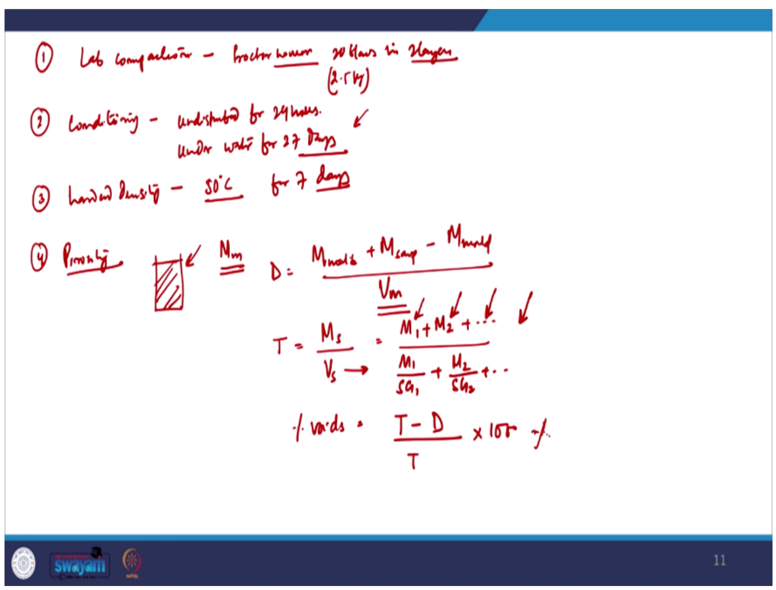

So, as I mentioned that the present specification does not tell us about lab compaction. So, if you are interested to produce pervious concrete mixtures in the lab you can use a light proctor hammer give 20 blows in 2 layers and this is a 2.5 kg hammer the specification does not talk about conditioning of the samples.

So, one way is to keep it undisturbed for 24 hours and then you can condition it underwater for 27 days. Another important property which is used for characterizing pervious concrete is the hardened density or the density of the mix this can be done after removing the sample after appropriate conditioning period of 27 days you can keep it in the oven at 50 degrees Celsius for 7 days and then you can calculate the density then as I mentioned that you can also calculate the porosity using the ASTM method.

So, here what you do here basically what you do once you have the proctor mold where you have compacted the specimen you know the volume of this mold. So, you calculate this first this you have the mass of the mold along with the sample then calculate the density as mass of the mold plus mass of sample minus mass of mold.

So, this will give you the mass of the sample divided by the volume of the mold. So, this will give you the compacted density and then you can also calculate the theoretical density which is the mass of the sample divided by the volume of the sample.

So, mass of the sample comprises of mass of different components M1+M2+……………., it can be like mass of cement, mass of coarse aggregate, mass of fine aggregate, mass of admixtures whatever are the ingredients and their corresponding volume which you can calculate using their individual specific gravity in saturated surface dry condition.

So, this will be equal to $\frac{Mass}{S_{G1}}+\frac{Mass}{S_{G2}}+\cdots$. So, depending on the number of ingredients that are involved and then percent voids can be calculated as the theoretical density minus the compacted density divided by the theoretical density into 100 in percentage sorry in percentage. So, this is again one important calculation to be done.

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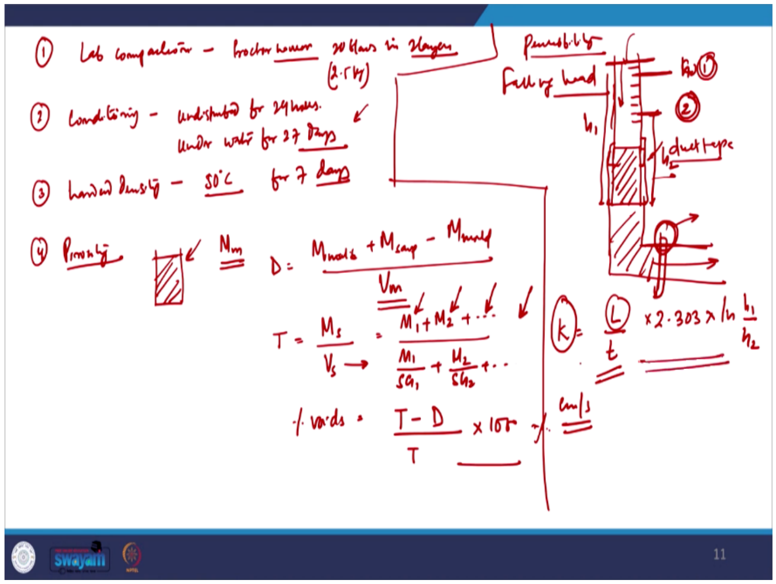

Then, further we also are interested in calculating the permeability there are various methods available we can use a falling head permeability method where you can have your sample cover it with duct tape, cover it properly with duct tape because it is a pervious sample otherwise water will come out then you have to use a you have to fabricate an arrangement here.

This will be the graduated cylinder properly attached to this ensuring that the water does not flow out then you mark 2 points 1 and 2, let us say these are different heads. So, this is let us say h1 and this is h2 the heads have different points and you note down the timing once you open the valve here first what you have to do, you have to completely saturate the sample.

So, your initial water will be here and the the sample will be completely saturated. So, this will be completely filled with water then you open this valve water will start to flow out the water level will decrease you note down the timing between point 1 and point 2 then using the standard formula you can calculate the permeability which is $\frac{L}{t} \times 2.303 * ln\frac{h_1}{h_2}$, L is the height of the sample and t is the time between time the water takes to drop from 1 to 2 and the units are in centimeter per second.

So, all the units should be chosen accordingly. So, using this equation again you can calculate the permeability of the sample. So, again this is one of the important measurements. We will stop here today and in the next class what we will do we will try to solve 2 problems using the available specification that is IRC 44 and then we will discuss few more aspects related to pervious concrete and that will be the end of this particular module in this lecture series. Thank you.