Analysis and Design of Bituminous Pavements

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Lecture - 01

Pavement Cross-sections and Pavement Design Process

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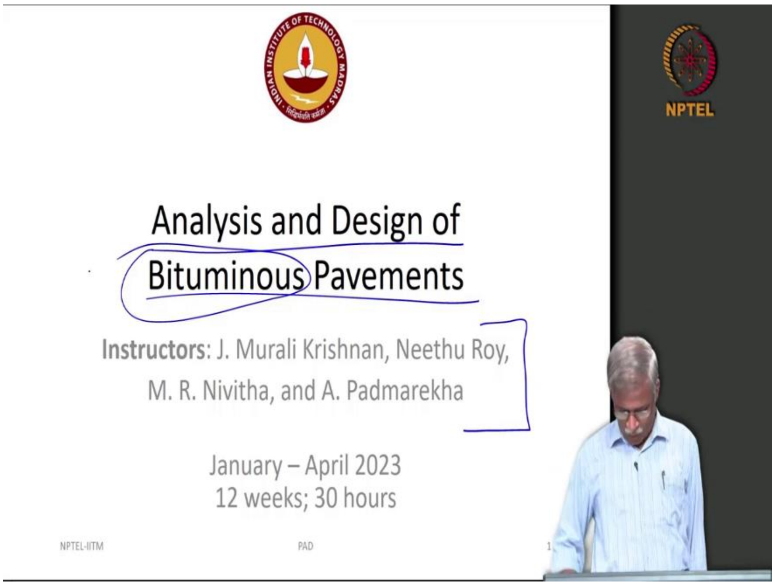

Hello everyone. So, welcome to NPTEL course on Analysis and Design of Bituminous Pavements, we met earlier in mechanical characterization of bituminous material the same team of faculty members who offered that course is offering this now.

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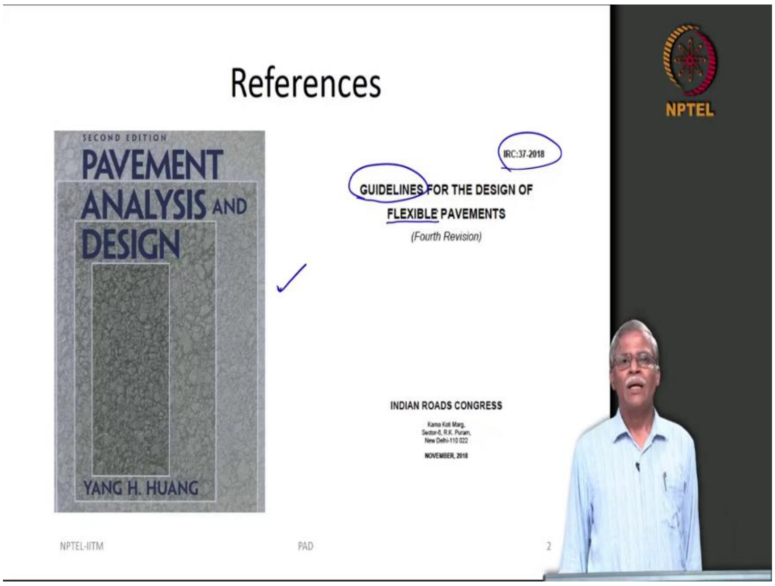

The first thing the most important thing what are all the course references that is needed ok. The first and foremost thing is Pavement Analysis and Design by Professor Huang, this is the classic reference in those days at least when I was a graduate student we used to read from Yoder and Witczak, but Yoder and Witczak was never revised and here also Professor Huang passed away a year back.

So, but as of now this is the current and latest reference for this, in addition to this what you really need to do is to get IRC 37-2018 this is the latest guideline ok for the design of pavements ok. So, now, you will be in curious to know that they have written it here as flexible pavement and I have written it here as bituminous pavement.

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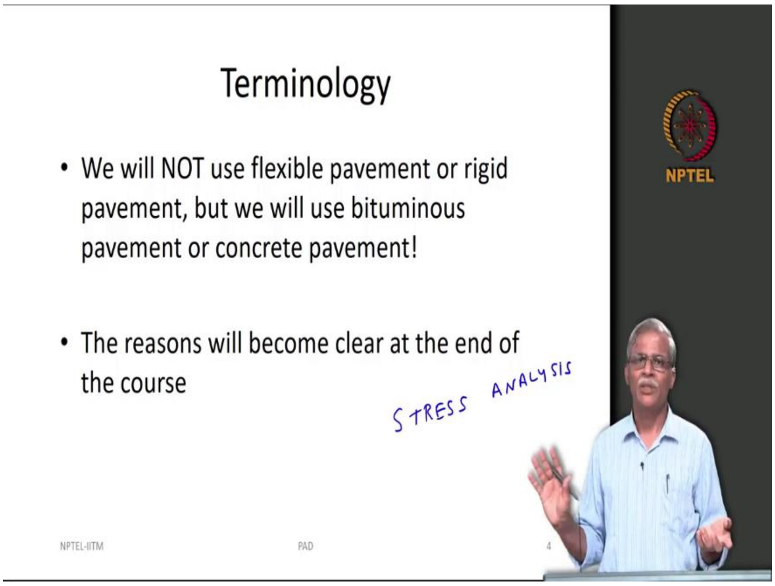

Throughout this course we will be using only this terminology, we will use only bituminous pavement and concrete pavement and not flexible pavement or rigid pavement of course, this course is only about bituminous pavement, sometimes later we will also be offering something on concrete pavement in a much more rigorous way. But as of now we will be talking about bituminous pavement and the terminology that will be used is only bituminous pavement.

Now, the reasons will become obvious to you as we go along, but I just want to give a hint the reason why one should stick to bituminous pavement or concrete pavement is basically related to the stress analysis procedure that is followed, for bituminous pavement we use what is really called as layered linear elastic theories, for concrete pavement we use what is called beam on elastic foundation, Winkler model, Pasternak model and all those things.

So, now it is possible that you can model concrete pavement using layered elastic theories it is also possible that you can model bituminous pavement using the Winkler foundation. So, there is nothing flexible or nothing rigid about it, right.

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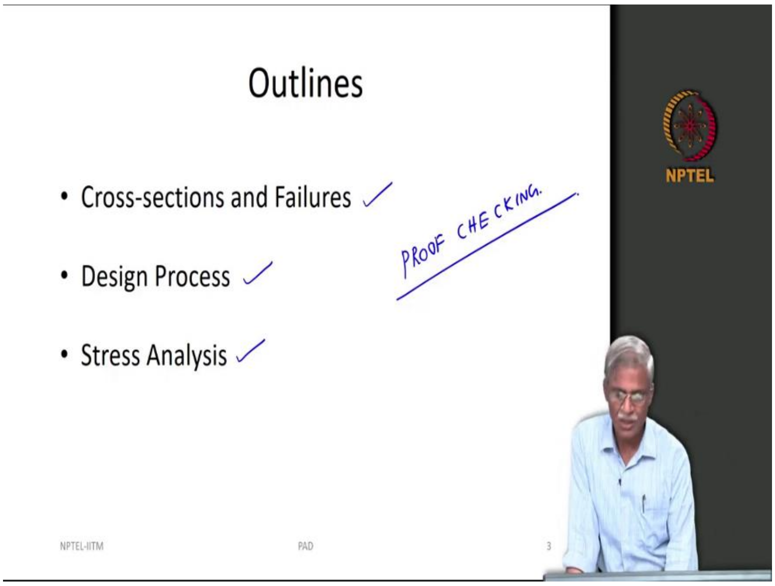

Now, what are all the things that we are going to do here is we will first look into the various cross sections and how a pavement fails. Then we will be talking about the overview of the design process and then we will talk about the stress analysis. Now, you must be actually wondering as to why I first talk about failure and then talk about the design process.

And in fact, many a time you will notice that and this holds good not only for pavement engineering, but also for many civil engineering infrastructure, what we do is always what we really called as proof checking. So; that means, most of the time based on the past experience we have a very clear-cut idea of what should be the kind of layer thickness that should be provided.

So, most of the time this comes more from the constructability aspect; obviously, when you are constructing a pavement you are not going to tell your highway engineer to construct 45.22 mm layer thickness that is not going to be possible. The nominal maximum aggregate size, the ability of the roller to compact, the relation between the maximum aggregate size to the layer thickness all of these things play a critical role.

So, what we first want to find out is these are the different cross sections and each cross section has a specific each layer in a cross section has a specific role to play. So, we will first understand intuitively what really are the failure conditions, then we will try to compute the critical stresses and strains related to those failure criteria and for that we need to use a stress analysis procedure. So, that is the outline that I am going to take here.

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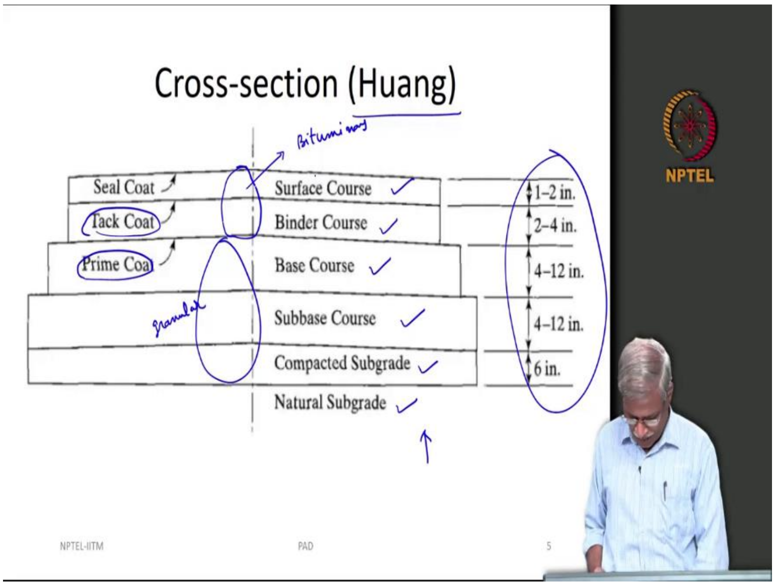

Now, very simple cross section which is listed in Huang and more or less this is the standard cross section that is followed you should be little bit careful about the units that are used here this is an American textbook. So, most of these things are given in terms of inches even in some of the example problems that you will be working out from this textbook which will be shared with you.

The units will be mostly pounds inches, but we will also be providing the conversion within the bracket. So, do not worry about it. So, if you go from the bottom you are talking about a natural subgrade then you talk about a compacted subgrade, a subbase, a base, a binder and a surface.

Now, these two layers are bituminous in nature predominantly, then these three layers are granular material and then you also have a prime coat between the base course and the binder course, a tack coat between the binder course and the surface course. It is not necessary that you need to provide a seal coat, but you can actually see that it is provided here right.

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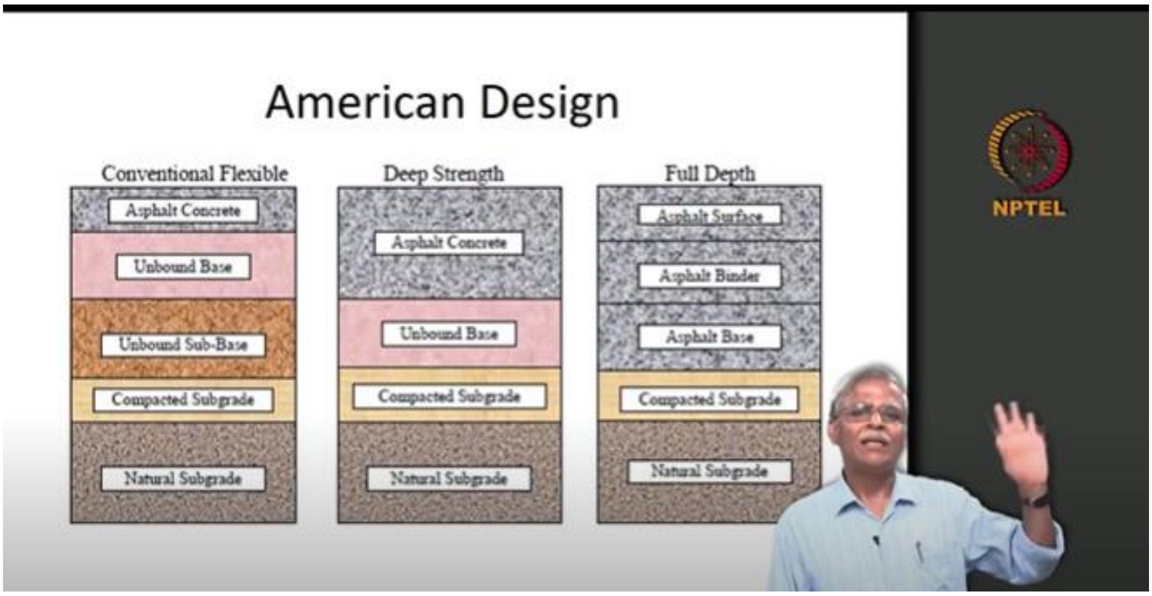

Now, this is the general cross section that you saw, but if you take a look at the typical cross section that is provided in American roads which is most of the design procedures that follow AASHTO and what we call as MEPDG mechanistic empirical pavement design guide.

So, you will see that there is a conventional flexible pavement now this is we call it as asphalt pavement or bituminous pavement. So, what you are going to see is there is a natural subgrade, there is a compacted subgrade, unbound subbase, unbound base and bituminous mixtures or asphalt concrete mixtures

So, this is something similar to the generic cross section that was presented to you earlier, now there is something called as a deep strength pavement perpetual pavement and all those things. So, you will see that it is the same the natural subgrade the compacted subgrade is has a slightly more thickness, this is the unbound base and then what you are going to see here is the thickness of the asphalt concrete layers are substantial more or less.

It consists of the layer thickness of the unbound base as well as the asphalt concrete ok. So, this is the deep strength pavement. In addition, of course, you have what is really called as a full depth pavement and such kind of pavement were propagated by asphalt institute of United States. So, this is a non-profit organization which is basically promoting the asphalt related products. So, you will see that everything is asphalt.

So, what you really see is a compacted subgrade then you have an asphalt base, asphalt binder course, asphalt surface course so; obviously, the cost of these constructions are going to be very expensive some of these constructions are normally used in runways, sometimes in heavy duty industrial flooring. So, that is the American design.

Then you also have different in inverted cross sections here. So, there is a natural subgrade, there is a compacted subgrade, then you have a cement treated layer and an unbound base and an asphalt concrete layer. Now, why is this called as an inverted layer, now the common tendency here is to see that as you go from as you go from the bottom to the top the modulus value keeps increasing. So, if you call this as E_1, E_2, E_3, E_4 and E_5 you are going to see these kind of relation. So, the topmost is going to be the material having a higher modulus now what exactly is the modulus we will worry about it later, but what you see here is this particular layer can actually have a modulus value slightly higher than this unbound base and so that is why these sections are actually called as inverted sections.

Then this is an unfortunate terminology what is called as semi rigid or you can say a combination of concrete and bituminous pavement because bituminous pavement, bituminous pavement and then you can actually have what is really called as a unbound sub-base, compacted subgrade, but the most important thing that you see here is an asphalt treated base.

So, it is not really a full bituminous mixture except you kind of try to use some amount of bitumen in it that bitumen could be in the form of a foam it could be in the form of an emulsion. Now, this is your cement treated base. So, instead of using an asphalt treated base that you see here you use a cement treated base here rest of the cross sections are more or less the same.

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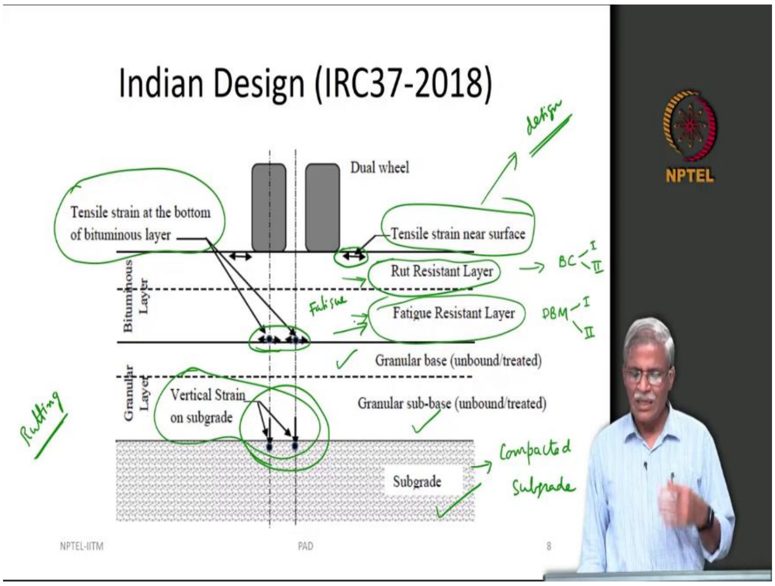

So, let us come to the IRC 37-2018 cross section and see what it says; now there are many design aspects are also that are introduced here. So, let me just kind of give you a clue about what are this design aspects, these words that you see here, fatigue resistance layer, vertical strain on the subgrade, rut resistance layer. So, all these things that are written comes from the perspective of design.

So, first let us take a look at the cross section, the cross section is the same, you have a subgrade, it could be an unbound or a treated granular base. Now, this subgrade should be called as a what you can say as a compacted subgrade, then you have a base here and then there are two bituminous layers. So, what we call in India as bituminous concrete and this could be called as dense bituminous macadam. So, there are going to be two grades here depending on the binder content used and the gradation that is used here. Now, let us look into the design aspect what it says, so first and foremost thing is there is a common perception that this vertical strain that you see here, whatever that strain means if is limited there will not be any what we can say failure related to rutting, we will see what are those rutting and fatigue as we go along.

Now, in the same way if the strain at the bottom of the bituminous layer is limited you can actually see that there could be less probability for the bituminous pavement to fail due to fatigue and this also can happen at the top. So, there is also tensile strain at the top tensile strain at the bottom of the bituminous layer. So, it is expected that you will construct these layers as rut resistance or fatigue resistance layers. So, this is the general cross section with the design aspects also integrated part of it.

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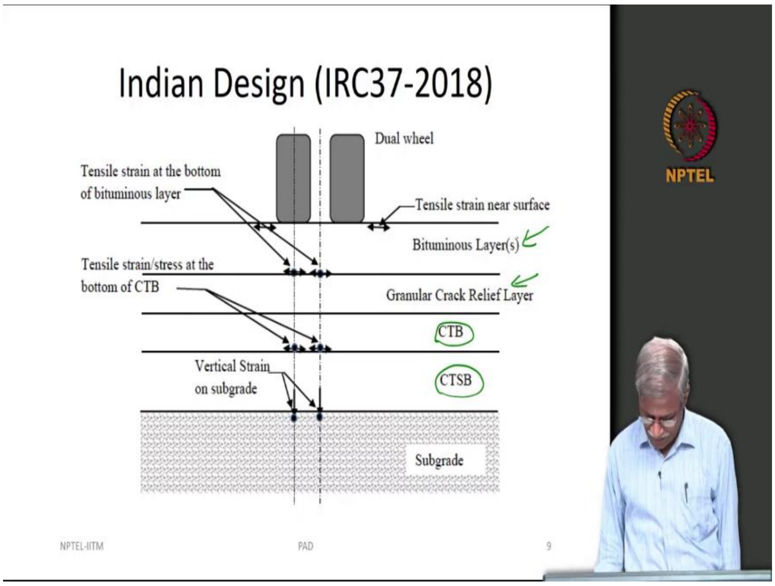

There are many other cross sections that are given in IRC 37 you are advised to go and take a look at it, but I will just go talk about there is a cement treated sub base, there is a cement treated base and because of this stiffness there is a necessity for something like a crack relief layer and then the bituminous layer rest of the things remain the same.

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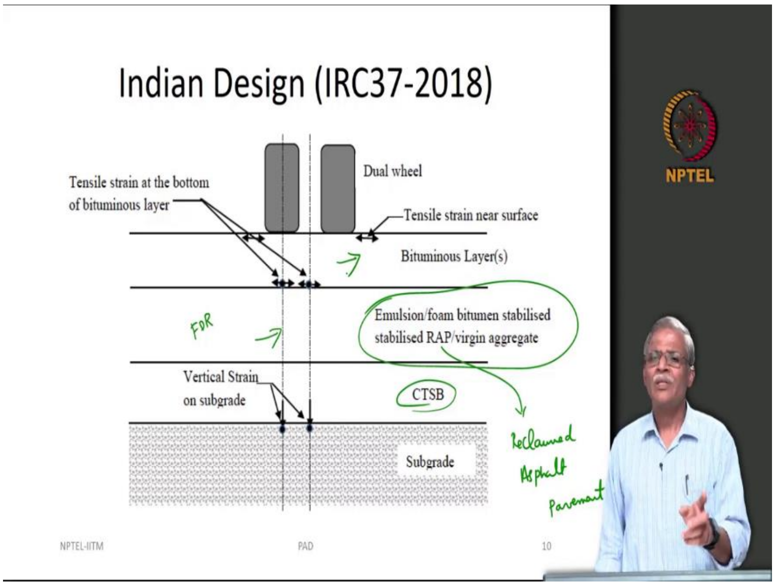

Then in addition to that there is also one more cross section, which we will be discussing as we go along it is about what is really called as cement treated subbase and this is the foam stabilized or so, this is your reclaimed asphalt pavement. So, if you constructed a bituminous pavement and if it requires rehabilitation what you could do is to do what is really called as the full depth reclamation and take all this material add it with the new material add a binder in the form of a foam or an emulsion and lay it here. And then on top of it you can have the regulars bituminous layer.

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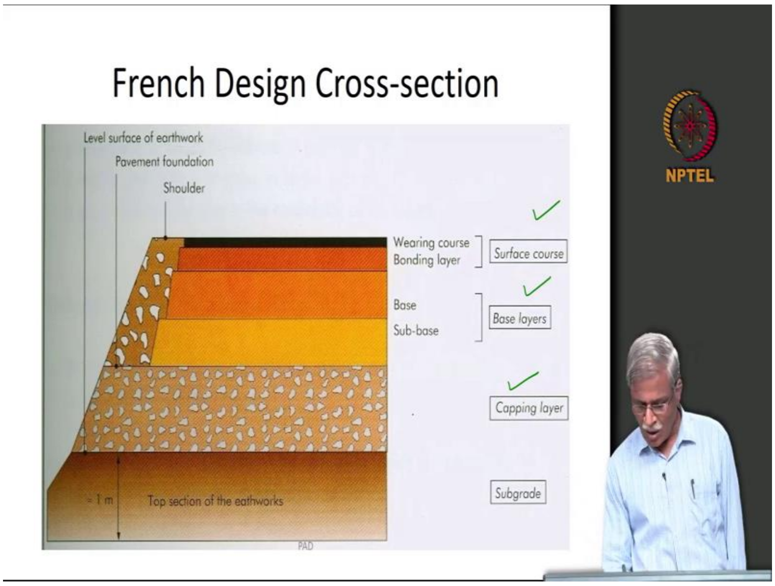

So, there are many ways in which one can construct such cross sections we will slightly go out and see what happens to the French cross section, the French cross sections are empirical works very well. So, they do not give you much flexibility about what should be used. So, there is a surface course, there is a base course and this is called as a capping layer what is normally so, it could be a drainage layer it could be anything. So, this is called as a capping layer and this capping layer is constructed on top of the sub grade.

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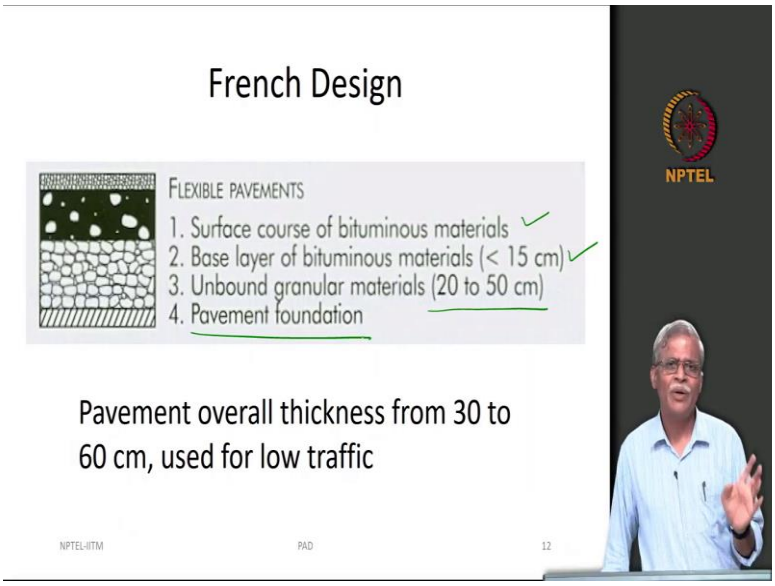

And there are many design strategies that are followed. See for instance you can have surface course of bituminous material, base layer of bituminous material less than 15 cm and the most important thing is unbound granular materials that can go as high as 50 cm and this is what is really called as a pavement foundation.

I have a reason for emphasizing all these things because at the end of the course what you are going to do is to take any of the existing IRC 37 cross sections use the distress functions, apply the load, compute the critical strain and substitute these critical strains in this distress functions.

And see whether design the equivalent standard axial load for which it has been designed, whether it actually meets or not you are going to check it and sometimes you will be surprised. So, watch out for that right. So, the same thickness could be for low traffic I mean the same cross section design could be used for low traffic, medium traffic as well as for high traffic as far as the French design is concerned.

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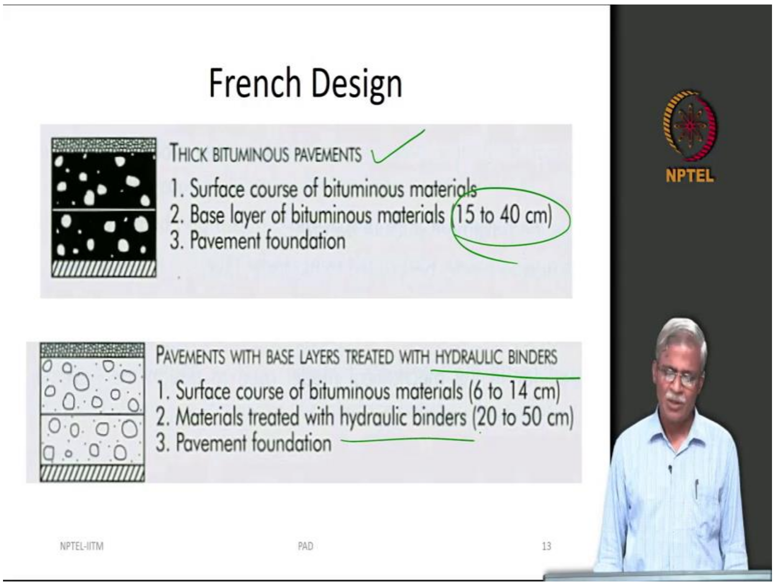

There is also what is really called as a thick bituminous pavement now this thickness can go as high as 40 cm. So, within the Indian context you should be able to understand and appreciate it because if you add up the total bituminous layers in within the Indian context we normally do not exceed 15 or 16 cm whereas, these people want you to provide something like 40 cm more than twice as much as normally that is produced. And there are also some cross sections with hydraulic binders, hydraulic binders are nothing but using cement as a layer. So, you can treat call it as a cement treated sub base or cement treated base.

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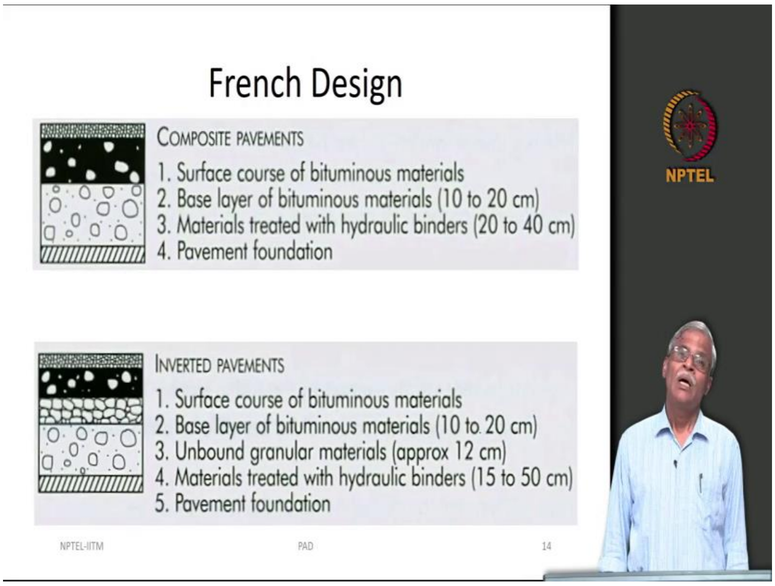

In addition to that the French people also have what is really called as a composite pavement. So, you can have bituminous layer surface and base and then you can have a 40 cm thick cement treated base. And again you can have what is really called as the inverted pavement in which you can have the material treated with hydraulic binder below, which has a lot more stiffness and on top of it there is an unbound granular material.

Now, there are some issues related to computing the critical stresses and strain when you are using this kind of inverted pavements. It will become obvious as we go along because the stress analysis procedure that you follow basically assumes that E_1 is greater than or equal to E_2 greater than or equal to E_3 and so on and so forth. So, sometimes when you are going to have the modulus value of the bottom layer slightly more than what you see for the top layer, you might have some interesting scenarios we will see .

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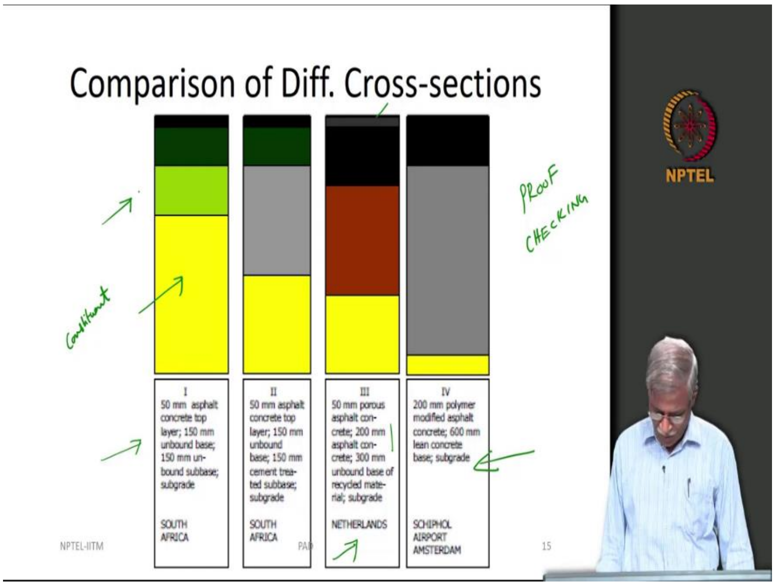

So, to compare all these cross sections what you will see is. So, there is you can see South African cross section then there is cross section from Netherland and this is a typical airport Amsterdam Airport cross section. So, you see there is 200 mm polymer modified asphalt, 600 mm lean concrete base. So, this is what is available as far as the Schiphol Airport in Amsterdam 200 mm.

If you look into the Netherlands cross section again it depends on the country when you are going to have lot of water lot of rain you are going to have some kind of porous structure that you construct at the surface wherein you allow the water to drain through and collect it through some of these drains. So, you can have 50 mm porous asphalt concrete 200 mm asphalt concrete and 300 mm of unbound base.

But, on the other hand if you look at the South African cross section you can have 50 mm bituminous layer 150 mm of unbound layer and 150 mm of cement treated base. So, there are many combinations that are given and now this is where I again want to emphasize to you about what is really called as proof checking, because most of this designs seems to have worked out already.

You will see that you will be asking a question. So, what is that to design because these guys have already worked out, all the thicknesses now what you really need to find out is what is the constituent here? What goes inside this material? Number 1, number 2 is how long this pavement will withstand? So, these are some of the issues that you will be able to answer.

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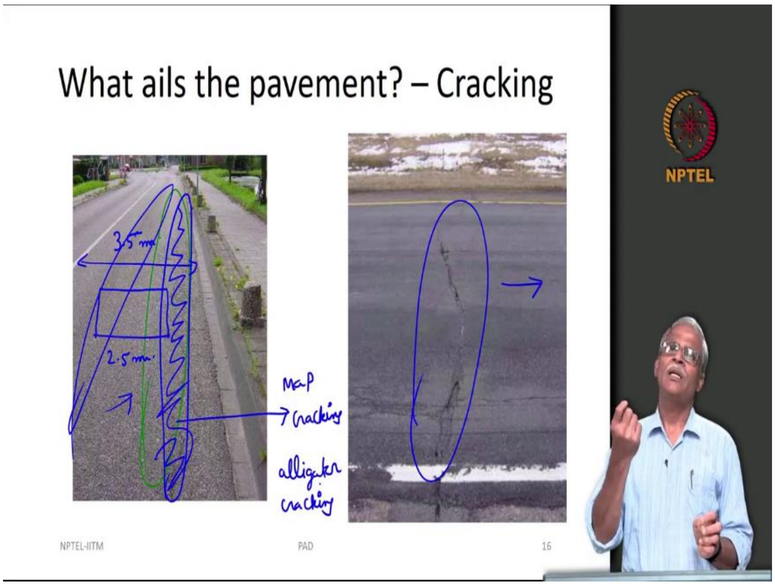

Now, let us start talking about what really happens and these are all nice pictures that you have seen. So, there are going to be failures, now these are the failures that are going to be the problem for you because this is where you are going to be seeing here. So, this is your traffic direction. So, you are going to see what is really called on this right hand side as low temperature cracking and what you see here is the fatigue cracking.

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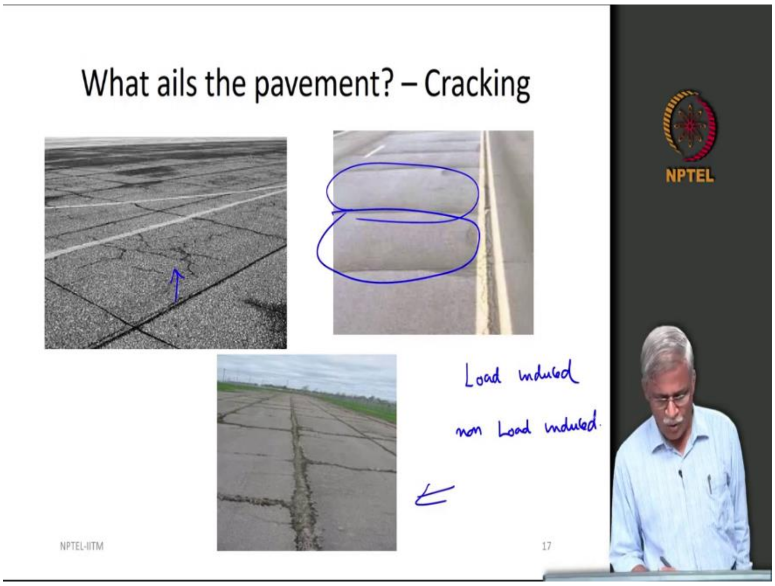

So, this is the kind of cracking that can happen there are many types of cracking that you can have most of this that form crack like a block. So, this could be due to your low temperature cracking there could be some of these cracks that could emanate from the bottom and come to the surface something called as a reflection cracking and you can have many types of cracking. So, what I would always call as two types load induced and non-load induced.

So; that means, if you are going to construct let us say a pavement and you can think of it this way. So, this could be let us say 2.5 m, now what will be around. Sorry, this could be 3.5 m now normally what will be the width of the vehicle that you see here it will be roughly around 2.5 m.

So, there will be one location on either side where the layer is going to be subjected to repeated loading and this repeated loading will cost you all this what is really called as the map cracking are also called as alligator cracking. Now, when you keep driving restricting yourself to the positioning your vehicle in the lane and when you are driving on top of it continuously there is one portion on either side of your where your truck is there the pavement is going to be subjected to repeated load.

And because of this repeated load there is going to be an accumulation of strains, there is going to be accumulation of damage and this is going to result in some kind of a cracks that basically come to the surface. So, this is the main issue as far as the cracking is concerned.

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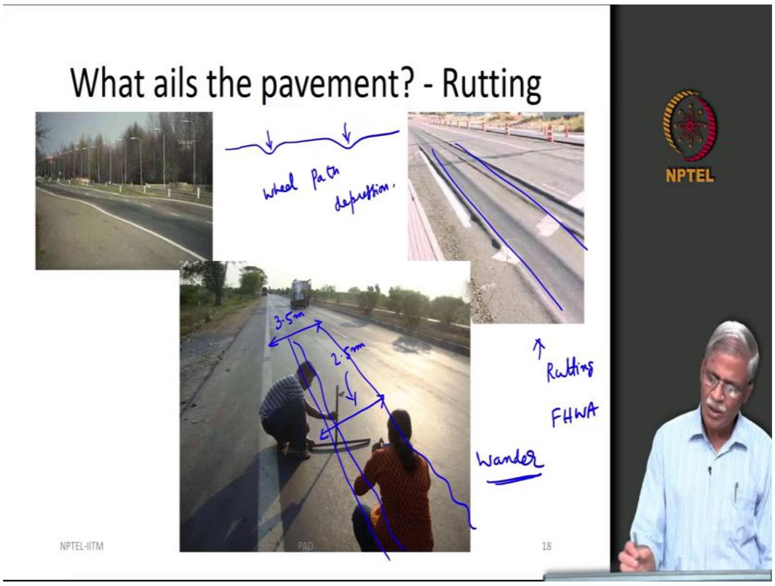

Now, the next thing that we want to really talk about is what is really called as the rutting and you can actually see again all these things happen in the wheel path this is an extreme case of rutting, you can actually see such pictures if you go to the federal highways administration site and in fact, you can see. So, there is a lane here this lane let us have 3.5 m and you can actually see that this could be roughly 2.5 m.

So, typically you know when you are driving the driver will position his vehicle let us say half a meter from this lane edge and another half a meter from the lane edge this has something to do what is really called as the vehicle wander. So, you are going to see that there is going to be considerable rutting here.

Now, what will happen is if you take a look at the cross section you are going to see that there is a depression in the wheel path depression. So, this is what you are going to call it as rutting. And in fact, if you recollect the IRC 37 cross section you will notice here that the top most layer is designed to be a rut resistance layer, but they also tell you that if you limit the vertical strain on the subgrade to some specific value we may not really have the expected rutting.

So, that is a story that will slowly we will be able to unravel as we will go along because I just want in the first lecture give you a flavor of what we are going to do here.

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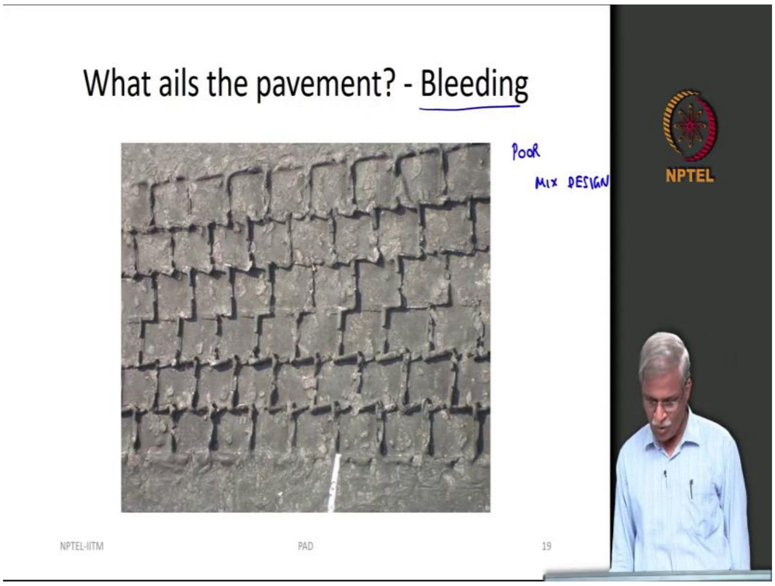

Then you can have bleeding which is due to poor mix design means using an inappropriate bitumen at a specific location. So, you using a VG 30 bit VG 10 bitumen where you should be using a VG 30 bitumen or using more binder content than what is needed are not providing the enough aggregate gradation fines and all those things.

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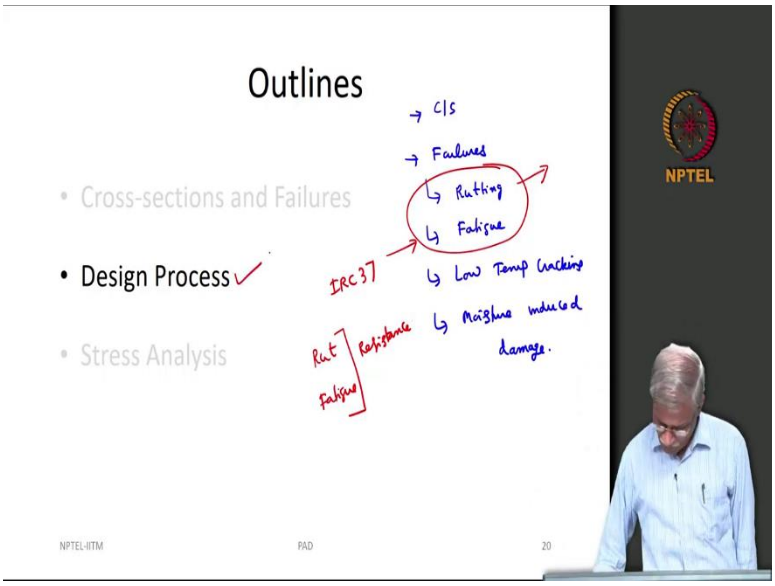

So, this is more or less a general overview that I really wanted to talk about. So, what did we talk about we talk about the cross sections, we talked about the failures and as far as the failures are concerned let me list everything. So, you can have rutting, you can have fatigue damage, you can have low temperature cracking, you can have moisture induced damage. But normally when we talk about the failure in bituminous pavement especially relating it to the cross section we will be focusing our attention on rutting and fatigue.

And in the IRC 37 cross section we also saw that there was a rut resistance layer, there was an also a fatigue resistance layer. And you also saw that the critical strains related to this rut resistance and fatigue resistance were measured for rutting at the bottom of the pavement or on top of the subgrade and for fatigue at the bottom of the bituminous layer.

So, these are some of the earlier assumptions that have been made, these assumptions need not have to be true and you will be exploring it as we go along. Now, let us understand what is really called as the design process.

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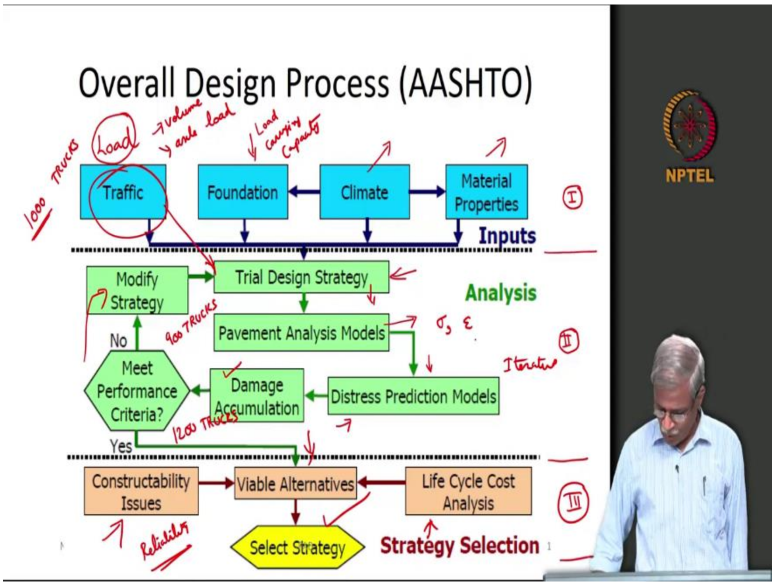

Now, this needs to be discussed in detail and you will see that over the period of this course three of my colleagues are going to cover different portion of it. Now, let us define this separately. So, this is the input that you are going to give, this is the analysis that you are going to do and this is finally, the strategy selection. So, what each of this basically means?

So, let us assume that you know you are going to construct a bituminous pavement. Now, this construction could be a brand new pavement or it could be widening and strengthening existing 2 lane road into your 4 lane road or a 6 lane road it could be anything.

Now, first and foremost thing is what is that you want to really ask and please understand this design process not only necessary to be followed for pavement engineering, but for any civil engineering structure for that matter. So, here the load that is coming here is your traffic. So, that is the most important thing. So, when we are talking about traffic we are talking in terms of two things; what is really called as the volume count? What is called as the axle load?

So, when I say axle load what are the different types of axle combinations that you are going to see and how each of this truck having a different combination of axles what is the total number that you are going to talk about. So, that comes under the load or traffic. The next thing is where is the road going to be constructed, what is the load carrying capacity of the existing soil.

So, what we really call as the foundation. Now, this is where I want to keep making the distinction as we go along. So, when you are going to construct your bituminous pavement depending on the country you live someone will say that you know go find out the CBR value of the subgrade. If it is going to be for bituminous pavement, if it is going to be for concrete pavement they will tell you go find out the modulus of subgrade reaction.

The soil is the same the road that you are going to construct has only some changes in the constitution the layers type of materials that you use, but since the stress analysis procedure demands modulus of subgrade reaction for concrete you will be measuring the same for the subgrade material, but for the same subgrade material if you are going to construct a bituminous pavement you are going to find out some CBR, some resilient modulus or something like that.

So, the most important thing is what is the foundation, you can say the load carrying capacity and this is where you will also be able to relate what is called as a compacted subgrade. So, many of the design charts that are given in IRC 37 talk about the thickness to be provided on top of a subgrade having 10% CBR.

Now, what will really happen if your actual CBR of the road is 3%? So; that means, you are going to constructed a compacted subgrade such that it will have around 10% or 15%CBR, simple. The third and the most important thing is climate.

Climate plays a critical role, more so, in the within the context of India because what will really happen in India is whatever the cross section that you are going to use in the Northern part of the India may not necessarily work out in the Southern part of the India or the Eastern or the Western part of the India, because it has something to do with the maximum pavement temperature, minimum pavement temperature, presence of the water table and so on. And this depending on the temperature the material properties especially the bituminous properties also will change which means the load carrying capacity will change which means the damage accumulation also will be at a different rate at a different month, time, period in a year; climate plays a critical role. And then the material properties are you going to use unmodified bitumen, modified bitumen, are you going to use stabilized base, stabilized subbase, crack relief layer, what are its properties and everything.

So, these are the various inputs that you need to have so; that means, before you start designing your pavement you need to have these four things in your hand; the traffic, the foundation, the climate and the material properties. So, after having found out all these things we go to the next step, which is the analysis. And now this is what I said there is a trial design strategy that you need.

What does the trial design, so; that means, we already have a clear cut idea of what should be the thickness of each of this layer. So, it could be a bituminous concrete layer 40 mm, why 40 mm? Because your nominal maximum aggregate says may be 13.2 and typically 3 times the nominal maximum aggregate size is what you are going to use for your layer thickness. So, 40 mm more or less comes there.

So, you take the trial design and then there is something called as the pavement analysis model, what exactly are this analysis model so; that means, given any pavement cross section how do you compute the critical stresses and strain at a different spatial location. So, this is what is really called as pavement analysis models, then after that what do you do is you come to the distress prediction models.

So, we will be explaining as we go along so; that means, for this pavement cross section that you have taken as a trial with the material properties that are giving given as input and using a computational mechanics procedure that you are going to follow what will be the critical stresses and strains and how this critical stresses and strains can be related to the expected life of the pavement, in terms of rutting in terms of fatigue.

So, this comes under the distress prediction model and then finally, what we do is we do the damage accumulation and when you do the damage accumulation you basically are checking against your estimates that you made in air traffic with the trial design that you have taken. So, let us assume I do not want to use the load equivalency factor here because it has not yet been introduced let us assume that I am designing a road for 1000 trucks just giving a simple example.

So, this is the traffic part that comes in and I take a trial design strategy and after doing all the calculations I realize that oh this can withstand 1200 trucks. So, what you really do is you immediately say yes, but let us say you find out that oh this cross section can actually take only 900 trucks then what you do is you modify the strategy. So; that means, you probably increase the thickness or you increase the modulus value of the constituent layer by using let us say polymer modified bitumen or anything like that and then you come to the next stage. So, this is an iterative process as can be seen and then you come to the next option.

So, one is coming from the constructability issue another comes from the life cycle cost analysis and I will also talk in terms of little bit in terms of reliability. So, using all these factors you do what is really called as the strategy selection right. Now, what I am going to do is to introduce some basic design concepts and straight away get into the pavement analysis models that is what I am going to do.

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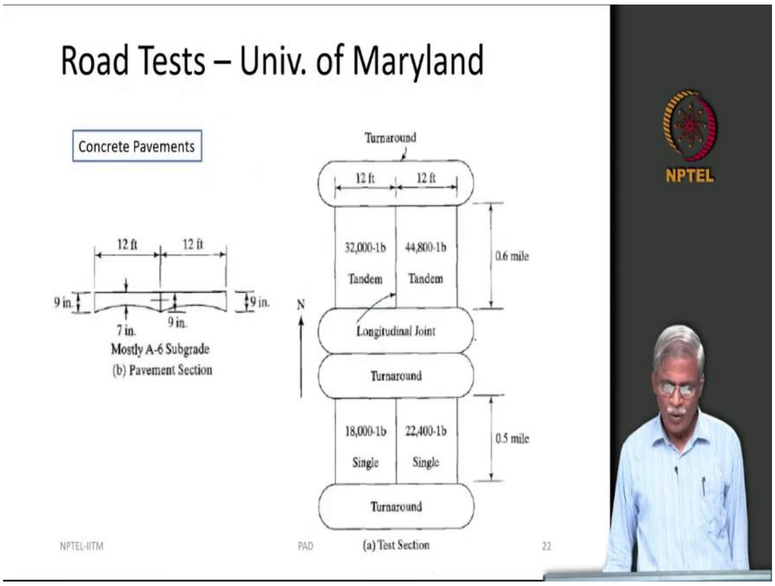

And within this context there are some road tests that have been actually carried out over a period of time at many places in the world and that is something that we will discuss in the next lecture.

Thank you very much.