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A very warm welcome to all of you. I am Rajan Chaudhary, a professor in the Department of Civil Engineering at the Indian Institute of Technology, Guwahati, and the course instructor for the NPTEL MOOC course Pavement Construction and Technology funded by the Ministry of Education, Government of India. Today's lecture will be a continuation of lecture 16 under module 7, which is to discuss the construction equipment and the processes involved in the production of bituminous bound courses. Now, at the very beginning, I would like to acknowledge the use of text, information, graphs, and images sourced from various textbooks, codal standards, journal articles, reports, newsletters, and public domain searches. In the previous lecture, we discussed some of the aspects related to the construction of bituminous bound courses, where we covered the preparation of the existing base over which any bituminous layer has to be applied. So, here is how the surface has to be prepared: it has to be ensured that it is firm and clean from any deleterious substances.

Considering whether it is a granular surface or an existing bituminous surface, the prime coat and tack coat application must be done at the required specified quantities, and once that particular part is over, we need to look into the production of the mixes. So, there in the production of the mixes, we talked about the hot mix plant because we have to have a plant where the different types of aggregates, which have been proportioned during the job mix formula, can be arrived at there in the field. And finally, the controlled quantity of binder can be added, and the aggregates can be uniformly mixed to produce a homogeneous mix. So, for that particular purpose, we need to have certain facilities; specifically, a hot mix plant can help us achieve the desired targets we want from a bituminous bound course.

To begin again, just to have a quick glimpse, bituminous bound courses are extensively used in base, binder, and wearing courses in flexible pavements, which are very popular specifically. And as I mentioned, to produce those mixes in a controlled facility, we require the hot mix plants, which are central mixing facilities; some of the key features and requirements of those hot mix plants were discussed in the previous lecture. So, it is a central mixing facility with adequate capacity depending on the quantity of mix required in the field for a particular stretch. So, being capable of producing hot bituminous mixes with uniform quality and thoroughly coated aggregates is important. So, this is a typical requirement from a hot mix plant, and the discussion will refer to many codal standards, including some mentioned here, such as MoRTH specifications and specifications for road and bridge works guidelines for bituminous macadam.

Guidelines for the selection and operation, selection, operation, and maintenance of hot mix plants, specifications for dense graded bituminous mixes, a pocket book for road construction equipment, and guidelines on compaction equipment for road works. So, these will be referred to during this course of discussion. Now, coming to a hot mix plant, basically there are two types of plants: one is a batch type hot mix plant and the second is a drum type hot mix plant. So, we will start our

discussion first with the batch mix type hot mix plant. Now, this is what you can see; this whole facility looks like.

Here on this side, you can see these are the bins to take your aggregates of different sizes. So, since they are at ambient temperatures, we will call them cold bins. So, these are the cold bins which receive the aggregates of different sizes. Now from this particular one, the control proportion of these different sizes should go, and then there is a facility through the conveyor that goes to a drying unit. So, there it gets dried up; this particular aggregate is dried up and heated to the required temperatures we discussed regarding those mixing and compaction temperatures, as well as the temperatures at which a particular grade of binder and the aggregates are to be heated, so those temperatures need to be attained here when you want to mix it.

So, the aggregates are heated up, and simultaneously, you can see there is a dust collection system that will trap whatever exhaust gases come and the dust that will be present. So, there are two sets of controls: one is a primary dust collector, and the second is a secondary dust collector. So, they try to trap whatever dust goes with the emissions, and we will look into the reuse offered along with our aggregates as per the requirement because otherwise we may fall short of fines, specifically in the aggregate mix that we are going to produce. Now, they are particularly important once the aggregates are dried; they are lifted up by a hot elevator, and then you can see it mentioned at the hot screens. We will discuss these components again individually and then they will be separated out again.

So, it is a secondary screening unit that we have in a batch mix type hot mix plant. Once they are separated into sizes and stored in hot bins, they are heated, so they are stored in hot condition hot bins, and finally, it goes to a pug mill mixer. Where you have the required quantities of binder that come from your bitumen storage tanks, which get added to your aggregates in the pug mill. So, for a particular lot, which may vary depending on the capacity of that hot mix plant, specifically the pug mill. So, depending on how much lot mix is in one particular lot.

This adequate amount of binder will be added. It will be mixed in your pug mill, and thereafter it can be directly transferred to the tippers, so as to go into the field for laying, or if the production is more than what is actually being transported, there is a requirement for a certain period of time; it can be stored in your surge silos. So, this is a broad explanation. We will discuss the components again. Now, first of all, as I mentioned, comes the cold bins.

So, a cold bins feeder typically consists of 3 to 4 bins. So, we can accommodate at least four different sizes of aggregates, and as we discussed earlier, this avoids problems if we have a larger number of bins; particularly, this helps us control segregation at the plant. So, we usually have around 3 to 4 bins in a typical hot mix plant. So, to hold aggregates of different sizes, each bin at the bottom has a gate, a graded scale, and a graded scale to control the gate opening and regulate aggregate flow. So, it opens the gates at the bottom, and then the auxiliary conveyor takes the aggregates from an individual bin.

So, it will take from individual bins and then transfer it to the gathering conveyor. So, all these bins will transfer there from their own auxiliary conveyor to the gathering conveyor, and then the gathering conveyor comes, and there is usually a provision for a single-deck vibratory screen. So

here you can see the gathering conveyor has come, and this has transferred the material through this single-deck vibratory screen. Specifically, this is installed so as to separate out any large size particles which have by mistake is present in these different aggregates which we are using. So, we will separate those oversized aggregates with this vibratory screen here.

Once this is there, then you have the slinger conveyor which takes this particular one from this one to your drying drum. So, the dryer it is, the aggregates once they are screened, and then the slinger takes the material to your dryer. So, the cold elevator, or cold feeder conveyor, also called a slinger conveyor, transfers aggregates from the gathering conveyor to the dry drum. Now let us look at what the key features of a dry drum are. Normally, these dry drums are revolving cylindrical drums having a diameter of around 1.5 to 3 meters and a length of about 6 to 12 meters, and they are placed in an inclined position. Now what does it include? It includes a burner and a blower fan. So, you can see in this particular picture that this is there. So, which provides primary air for the combustion of fuel, whatever fuel we are using, light diesel oils are typically used specifically in the conventional plants that we use in India. So, for combustion of fuel and an exhaust fan to create a draft through the air.

So, the exhaust fan is there. So, a draft of this air is created in this particular drive. So, this is, and inside this particular one, you have these longitudinal channels; you can see these longitudinal channels are here. So, this is an inside look at longitudinal channels, which are also called flights, and these are mounted with nuts and bolts. What is the specific purpose of this? It lifts the aggregate, whatever the aggregate may be, which comes from the cylinder conveyor; this is finally lifted up by these flights and dropped in veils through the burner flame so that it gets dried and heated.

So, it moves, they move along the dry drum, and with the help of these flights, they fall through the burner flame, which helps them to get dried up and heated to the required temperatures. So, it is very important to look into the dwell time, especially for the time it remains in the dry drum, because that will help us attain the temperature required for mixing these aggregates with the standard grade of binder. The dwell time, or the retention time for aggregates in the dryer drum, mainly depends on the slope of the dryer drum, its inclination, revolutions per minute, the diameter, the length, the number of flights present, their arrangement, how those flights are arranged, and the efficiency of the burner, as well as how effective that burner is at heating those aggregates. So, these are some of the key features of the dry drum. Now, the important part is that there may be some natural moisture content present in aggregates that may vary from 2 percent to 4 percent, or even in some cases, higher up to 6 percent.

Now, the more moisture content there is, the more time is required specifically to reach the desired temperature; otherwise, the production capacity will be reduced because if there is a higher amount of moisture, it will take more time in the dry drum to first dry it and then heat it to the standard temperature. So normally, dryers are designed to heat and dry aggregates with a moisture content of up to 4 to 6 percent, and their capacity is also mentioned accordingly. Many times, you can see the capacity is mentioned; two capacities may be shown: 40 oblique 60. So, 40 may be a capacity when higher moisture content is present, 40 tons, so 40 tons per hour or 60 tons per hour, depending on how much it can produce, and that usually depends highly on the moisture content of the aggregates. So, if the moisture content of the aggregates' heat is higher, the feeding of aggregates

into the dry drum is reduced because more time is required and a lesser quantity of load has to be there, resulting in a drop in the hourly production capacity of the plant.

So, the production capacity of the plant will be reduced. So, the aggregate is now also very important to ensure the temperature to which the aggregates are heated. Because as soon as the binder is added to the heated aggregates, it quickly reaches the temperature of the aggregates, and if the temperature is high, then it may lead to the aging of the binder. So, we want to avoid excessive heating of aggregates; we have seen that we do not prefer to allow a temperature difference between aggregates and binder of more than, say, 14 or 15 degrees centigrade. So, the aggregates heated at high temperatures can harden the bitumen during mixing.

On the other hand, if heated aggregates are present, then it may not have a proper coating of bitumen. So, that is why the adequate temperatures that have been recommended for different grids need to be achieved through these drum dryers. Aggregate should be fully heated uniformly at appropriate temperatures to achieve a homogeneous mix. Homogeneous and uniform coating of the binder over those aggregates, and I mentioned that in many of the hot mix plants, light diesel oil or furnace oil is primarily used as fuel for burners. Now, at the dryer, we have the dust collection systems because it must be highly ensured that it does not lead to environmental pollution, whatever best we can do at the hot mix plant to reduce any damages or harms done to the environment.

So, for this particular one, we have dust collection systems, or we can call them pollution control systems. It can be called a primary pollution control system, a primary dust collection system, or a device as well. So, its main function is to remove any undesirable amount of dust coming from the exhaust. So, we want to trap that particular one, and specifically, there are two types: the primary dust collection system and the secondary dust collection system. So, the primary dust collection system is basically cyclonic in shape.

So, the dust is collected or separated out using this centrifugal force, and it is separated from the exhaust gases; this can be reintroduced depending on whether a good amount of dust is getting lost. Then the fines may be reduced in your mix. This may hamper your performance, or the desired quantity of different combinations of aggregates may be hampered. So, we may have to reinsert or re-add this particular fine dust which has been collected at the primary dust collectors. So, how much quantity needs to be introduced that requires attention? So, it is fitted at the rear of the dryer drum; you can see this is what your primary dust collection system is.

So, the primary dust collector system is there. The fuel gases leaving the dryer drum pass through these cyclonic type dust separators, which separate the dust particles. In addition to this particular one, the exhaust stack is there. Here again, before passing the exhaust gases through these exhaust stacks, they are also passed through the secondary dust collector systems. So, the exhaust gases are eliminated through the plant's exhaust stack.

These gases further pass through the secondary pollution control devices, many times called baghouse filters. So, bag house filters are there again; they are to trap the fine dust in the exhaust gas, for further filtration, and thereafter those gases are released into the environment. So, these are two very important components from the perspective of environmental aspects. So, it has to be well

assured that we have good primary and secondary dust collection systems. Then, once you have these aggregates heated up to the required temperature, we have this hot elevator.

So, the aggregates, after heating and drying, are carried up by a hot elevator, a bucket conveyor system, to the gradation unit. So, again to the hot screening unit. So, once this is done, you can see that this is your drum. Once this is there, then you have this hot elevator; this is the hot elevator that is there. So, through this particular bucket-type hot elevator, it is taken up, and then you have this hot screening unit.

So, this is a picture of it; you can see this is the aggregate that has been taken from the dryer, and now this is the elevator that moves up the hot aggregate and goes here to the hot aggregate screening unit. So, this water screening unit is normally referred to as a secondary gradation; it is also known as a second gradation unit because, again, there are different sieves where the aggregates get separated into different sizes. So, the secondary gradation of aggregates in hot conditions is carried out in the screening. You can see how the aggregates fall over it and get separated into different sizes, depending on the sieves: fine aggregate, medium coarse aggregates, and coarse aggregate. So, in this case, this is a specific feature of a batch mix type hot mix plant.

So, this is also known as the secondary second gradation control unit of a hot batch type mix plant. Now, once this is separated out, these different sizes collected from these particular screening units are gathered into these hot bins, as you can see. So, there are hot bins now, which we previously referred to as cold bins, after this dryer unit and this hot elevator screening. So, these are used to store the heated and screened aggregates of various sizes temporarily. Now we are going to release the individual quantities according to our requirements for producing the mix.

Now, once they are stored, you can see that these are stored in different hot bins, and different sizes are being stored. Now there is a way to hop. So, this way, Hopper says that we are going to open this particular one. A standard weight is going to be released, and that will ensure that the quantity of weight has been released; in this particular instance, the gate will get closed. It will come for the next hot bin, then the gate will open, the required quantity will be added, and the weight will be measured when it reaches that required quantity.

It will be because all of this goes through a control panel. This gate will automatically close, and then the third one will. So, in this way, the different sizes are being collected in the hopper. So, the aggregates are withdrawn from hot bins in the desired quantity through a load cell and accumulated in the weigh hopper. Now you have the desired quantity, what is required from each size of the hot bins? Aggregates thus collected in the way hopper are transferred into now; once this is done, they are then transferred to the pug mill.

So, thus collected in this way, they are transferred into the pug mill, where they are blended with the desired quantity of bitumen. Now, when it gets transferred to the pug mill, you can see this is the pug mill. So, from these individual hot bins, it goes to the weigh hopper, and from the weigh hopper, it goes to the pug mill. Now, there in the pug mill, we need to introduce the required quantity of binder along with these heated aggregates. So, there should also be a binder measurement system.

We say this is a weighing cylinder we have, and this is the pug mill that has been shown here. Now, what it says is that the bitumen unit mainly consists of a bitumen tank heating system. There are various ways of heating the binder in those bitumen binder tanks, and there is a bitumen pump and a delivery pipe. So, bitumen is weighed separately; it goes into this weigh cylinder, the required quantity is weighed, and then it is inducted into your pug mill. So that for a particular lot that has come up in that way, the hopper will transfer the required quantity of heated bitumen from the weighing cylinder to your pug mill.

And there in the pug mill, the mixing starts, and it is also important that the space between the paddles and the surface of your pigment is half the maximum aggregate size; we prefer to ensure that it is neither overfilled nor underfilled. So, usually we will try to fill up to this particular brain. So that we get a more homogeneous result. So, it is important that the lot be of such a size that it gets uniformly mixed. If it is in a very small quantity, as you can see there, it will not get mixed.

If the quantities are very high, there may be a certain amount of mix that will remain unmixed. So, that is why an adequate quantity has to be added, and this will depend on many features of the pug mill, including the pedals that are there, the shape of the pedals, and the number of pedals; all these will play a role in it. So, a pug mill is the chamber in which bitumen aggregates are thoroughly mixed to achieve a homogeneous mix. So, it requires time to mix your hot aggregates with the hot bitumen, and finally, once that is properly mixed, either I can directly transfer it to a tipper, or I need to transfer it to some storage silos for a specific period of time, and then later on, it can be transferred as per my requirement to the construction site through tippers. Now, there is another type of hot mix plant that is quite popular: it is a drum mix plant.

Normally, the batch mix plants are installed because they have a higher capacity; usually, their installation cost is a bit high, and their maintenance cost is a bit high. So, they are, but their gradation control is quite good. So, specifically for big projects where the production capacity is to be high, we can always prefer a batch mix plant; otherwise, for a smaller production capacity and for a smaller project where the installation is also challenging, the cost is certainly a concern. So, the drum mix plant is also quite popular, and by taking care of all the operations during the drum mix plant, a good homogeneous mix can be produced through the drum mix plant as well. So, in a drum mix plant, the important feature is that aggregate gradation is controlled at the cold field, and aggregate heating, drying, and bitumen mixing are done mainly in the same drum.

So, this is a unique feature that exists because there are no hot elevators; there are hot bins. This usually happens one or many times a second drum in that case. So, this takes place when there is no hot elevator to lift it to separate it out; it is not produced in batches, and it is a continuous production that happens. So, that is why it is often called continuous production or a continuous type of hot mix plant.

So, those are your drum mix plants. So, some of the specific features are its small portability. So, it can be placed comfortably at high efficiency because continuous production is present, allowing the rate of production to be higher. The economy is small; it requires a small space, small installation costs, and because capacity is low, fuel consumption is also low. Maintenance is a bit lower compared to your batch mix plant, and you can produce a relatively large quantity of mix at

a relatively low temperature. Now, in this particular drum mix type hot mix plant, there are two types of plants further classified into two types.

One is a parallel flow type, and the second is a counter flow type. These are the two main classifications under the drum mix plant, and the main difference between this particular one is the way in which the aggregates are inserted and the direction of the flame. So, as we have seen, there is a dry drum where a flame is present, and the aggregates need to be dried and heated in that particular drum. So, in the case of a parallel flow drum mix plant, aggregates and hot gases flow in the same direction inside the same drum. So, I can see here that this is the parallel flow one; these are the flame gases that have to be there in this particular direction.

The aggregates are also entering and going in the same direction. So, they move in the same direction here in this particular one. Here specifically, you are saying you can see some term wrap is mentioned, which is reclaimed asphalt pavement. Normally, when we discuss the recycling of asphalt pavements in later modules, we will discuss it because if that existing old bottomless material is required to be used in the production of these new mixes, then it needs to be introduced. So, here you can see there is a facility to introduce the reclaimed asphalt pavement in this particular drum at a certain length, and then once it passes through the flame, it reaches here; then there is an addition of binder, which is spread, and the hot bituminous mix comes out.

So, this is the specific case for parallel flow type drum mix plants; the second, which is most of the time preferred, is a counter flow type drum mix plant. So, here aggregates and hot gases flow in the opposite direction within the same drum. So, you can see this is the one where the flame is. So, this particular one is in this direction, and the aggregates that are going to enter here will be this exhaust system that is there.

Exhaust for the exhaust system. This is your virgin aggregates which are going to enter into it. So, they are entering in different directions. So it may be that once the aggregates are dried and heated up, there may be a small drum facilitated for mixing the hot aggregates with the bitumen. Under the counterflow type, there are specifically two types. So, the one is where the drying and mixing of aggregates and bitumen take place in the same drum.

So, this may be the one for the counterflow type. What will happen is that the flames are normally inserted and embedded at a certain depth, and then a portion of this drum will be available for your blending of bitumen, and then the bituminous mix comes out. And second, the second type of this counter flow type is one that has a dual drum plant specifically for counter flow type, where the drying of aggregates takes place in the first drum, and then the dried aggregates are transferred to another drum. So, there will be another drum where these aggregates, hot aggregates, and binder will get mixed together. Nowadays, there are also double-barrel systems, which are concentric cylinders. So, in there will be what will be happening in one drum; the aggregates are getting heated up, and then they are transferred to the concentric drum above it, where they get mixed with the binder.

But these are the two most common one-counter-flow-type drum mix plants. So, this is again a complete picture that shows this particular one. Here you can see that the cold-filled bins are there, so four bins are present. Then you have an oversized rejection screen, and a gathering conveyor

that takes material to the oversized screen from this particular one; the slinger conveyor takes it. Here, you have bitumen tanks that are installed where the binder gets heated to the required temperature. Then the material enters your dry drum, which may be parallel flow or counter flow, and the mixing takes place in this particular one.

Specifically, you can see that after a certain length, the binder is introduced; this is the introduction of the binder. The exhaust system should have a primary collector system as well as a secondary collector system, as discussed in the case of batch mix plants, so the pollution control devices are there. Then once the hot mix is produced, it is again taken up, and a certain quantity of it can be stored in your gob hopper, or it can be taken to storage silos, and then from this particular one, it is transferred to your tippers. So, all of these are controlled through a control cabin.

It is that most of the plants nowadays come with full control. So, sitting at this control unit, you can control the functioning of even cold-filled bins, gate opening, the speed of the conveyor belts, the speed of the dry drum, the time required, and the revolution speed; all these can be controlled from the control unit. So, we have very good plants available nowadays under both the drum mix type and the batch mix type. So, as I mentioned, specifically what is there is that you need to have a small capacity plant with a low cost; then this is quite the preferred one. It is an easily portable one; it is easy to install this particular one and to modify it. As I mentioned, in the case of the introduction of reclaimed asphalt pavement, some modifications may be required.

So, that modification is done more frequently specifically with drum mix plants. So once the mix is produced, now it is important that it needs to be transferred. So, when it is transferred, the tippers have to be clean enough because there should not be any contamination that will occur. If that happens, it may hamper the quality of your mix. So bituminous materials shall be transported in clean, insulated, and covered vehicles, so that the temperature does not fall below the temperature that is required for laying the mix.

The hot mix plant may be located far enough because you cannot put your hot mix plants in urban areas, so they are located far enough according to environmental regulations. So, while transferring it, you can see this, so you may have to clean up. So, normally another part is that they should not get stuck to your body on the steeper. So, we usually have a release agent that is there so that when it goes to the site and is emptied into the paver, the complete mix goes out.

It should not remain stuck to the surface of the steeper. So, a release agent, such as soap or lime water, may be added to the interior of the vehicle to prevent sticking and facilitate easy discharge of the material. But the controlled use of release agent has to be ensured; otherwise, it may again hamper a higher quantity because the binder is there. So, these release agents may lead to concerns with your bituminous mix. So, once the release agent is added to this particular one.

Then, the tipper takes your mix, and it is to be covered. It is important because, unfortunately, if some rainfall event takes place and if the transportation requires a good amount of time, the temperature should not fall. So, that is why they are covered and transported to the field. Now it is important to ensure the specific climatic or weather conditions required for the laying of these bituminous mixes. So, some of the general recommendations specifically for laying hot mix asphalt say it should preferably be suspended, so we do not go for laying bituminous mixes under certain

circumstances, and what are those certain circumstances? In the presence of standing water on the surface. So, there should be no standing water on the surface if there is any rainfall event; all the surface water should be removed.

So, when rain is imminent, the chances are there, and during rain, fog, or dust storms. If we have an idea that there are chances of rain, then it becomes difficult; once you start a hot mix plant, you cannot stop it immediately, as it is very costly. So, we need to ensure that at least a good quantity of mix is produced and laid once the hot mix plant is turned on. So, when the base and binder over which this hot mix plant is located are damp enough, it is also preferable not to put hot mix asphalt over it. Also, it says that when the wind speed at any temperature exceeds 40 kilometers per hour at a height of 2 meters, it is not preferred because that makes retaining the temperature difficult.

So, this is also a constraint. And when the air temperature on the surface is to be layered, it is less than 10 degrees centigrade. So even though there is a very high gradient between your mixed temperature and the atmospheric temperature. So, there will be a high fall in temperature, which will make your laying as well as compaction difficult. So, we will not prefer when the air temperature on the surface on which it is to be laid is less than 10 degrees centigrade. This is specifically for unmodified binders, need binders, and viscosity grade binders, which we have and are less than 15 degrees centigrade for mixes with modified binders because, as we discussed, specifically, the mixing and compaction temperatures are higher for modified binders compared to your unmodified binders.

So, these weather conditions ensure the surface over which, as we discussed during the preparation, needs to be ensured again that the surface is ready and that there are no deleterious substances present on it. The tack coat is applied over the particular surface on which this bituminous mix has to be placed. So, this needs to be ensured. Now, once that particular part is done, the mix is to be laid and spread over the width required for the construction.

So, for this particular one, the specialized equipment that is used is a paver finisher. This is what a paver finisher looks like. This is a picture of a paver, a traditional paver finisher that is there. It is quite popular in flexible pavement construction, specifically for bituminous-bound courses. It is very popular for bituminous bound courses and for non-bituminous courses as well; especially with the wet mix macadam, we prefer to use these paver finishers.

And for bituminous-bound courses, we definitely prefer to go with these paver finishers. The main functions of a paver finisher are the specific tasks for which they are preferred: to lay and spread the mix to attain a specified surface. And this also needs to take care of the surface quality, correct grade level, and finish to meet the design specifications. So, because these are my upper layers, upper bituminous layers. So, they should be properly laid with good control of the surface levels; good control of the surface regularity must also be ensured.

So, this is and that too done in a safe mode. So, this specifies equipment is required for this one. And to achieve specified camber and superelevation at different locations, considering the requirements, there may be a camber which may have cross slopes on both sides, and at certain locations, there may be a superelevation or a cross slope in one direction as well. So that needs to be taken care of or done with the help of your paver finishers. So, it helps us achieve the required

thickness and a uniform degree of compaction, also because a little amount of compaction is provided by these pavers themselves. Homogeneous quality of the mix during laying is important because now, what are the components here? You can see this is the hopper.

So, when will this paver move in this direction? So, the tipper will come up with the mix, get close to it, and drop this mix in the hopper. And then it goes through the conveyor here at the rear ends, and then you can see that these augers are there. So, the augers will distribute the mix over the entire width of this.

Your screed is here. What is this? Screed is there. And the screed width is extendable depending on the rear requirement; it may be, say, 5.5 meters, 7 meters, or 10 meters. So, screeds are normally extended, which can be formulated for laying to the desired width, and this is how the control option is available. So, when we do, as you can see, the tipper has come up; it is going to put the mix in the hopper, then the mix from the hopper will come towards the screed, and with the screed, it gets distributed over the surface.

So, it gives you control over the thickness of your mix. So, it is important to regulate the material delivery rate during this particular feature to ensure the continuous operation of the paver because the mix is highly important; there should be a continuous flow of the mix from the plant to the paving capacity. So, there should be no standing where the paver is standing because there is no mix available for laying. The paver speed and operating method should be adjusted so that bituminous material spreads evenly. Otherwise, it may happen that if you are going at a higher speed, you may push it hard.

So, there should be no dragging, tearing, or segregation. So, you can very well see this once the mix comes out of the screed. So, by visual examination, you can see there is no segregation happening. A small segregation may take place where the joints of the augers are. So, some of the fines can be added through some skilled manual workers. So, it is in restricted specifically now this is a big attachment, this is a big machine which is to be taken up.

So, it may not be possible to have pavers in small widths. So, in those cases, especially irregular areas where pavers cannot be used, such as confined spaces, footways of irregular shapes, varying thicknesses, and approaches to some joints, are present. So, we can go with trained staff who can spread, rake it, and make it to the desired levels using appropriate hand tools. But this is only for specific locations where the paver cannot go. Now, once you have laid it, you can go with this particular one. So, during this paving, it usually achieves a good amount of compaction because these paver screeds have a vibrating arrangement as well as a tamping arrangement.

So, they do a good amount of heating; tamping and vibratory arrangements are there. So, they compact the mat during the laying itself, and many times it attains a density that is around 85 percent of your maximum specific gravity. So, this gives you some initial compaction for the rollers to pass over the surface. So, this is important; thereafter, once this particular one is laid, it comes into the picture over the compaction process. So, bituminous materials shall be laid and compacted in layers because there may be one layer, say even for dense bituminous mixes; for bituminous macadam, there may be one layer as a base layer, then a binder layer, and on the top, there may be a wearing course layer.

So different layers have to be constructed, and the different layers will have different thicknesses. The thicknesses of base courses are greater than those of binder courses, typically more than those of wearing courses as well. Different courses will have different thicknesses and need to be compacted to achieve a uniform compaction and density. Compaction shall begin immediately after the paving because this is very important; as time passes, the temperature goes down. So, it is always preferable that the compaction starts simultaneously with the laying part, and there are different ways of doing compaction: breakdown rolling, intermediate rolling, and finishing rolling, which we will discuss in the upcoming slides. And longitudinal joints because there may be an existing part that might have been constructed one day before, or maybe an existing pavement, and then there may be a new one on which we are laying a new surface.

So, the longitudinal joints also need to be rolled simultaneously. Rolling should proceed from the edges, as we have discussed in other cases. For unbound granular courses, they preferably start from the edges and go towards the center, especially not at the super elevated or unidirectional cambered sections, where they process from the lower sections and go to the upper section, parallel to the upper edges and parallel to the center line. So, this normally continues until no roller marks are present, all roller marks are removed, and compaction is substantially complete before the temperature falls below the minimum. It is to be ensured that the minimum rolling temperature is maintained. After all this compaction, the required density should be achieved well before the temperature falls below the rolling temperature.

So, this is important. Now, as I mentioned, these rolling operations, also with this bituminous mat, have a good amount of initial compaction done by your screeds, as well as vibratory screeds that have a heating arrangement and tamping arrangements. So, along with the pressure, heating, and vibratory arrangements, it gives some initial densification. Then the first one comes, which is known as breakdown rolling. So, this is done immediately behind the paper screen to achieve the highest density gain.

This is the rolling technique where you get the maximum density out of the mix. And normally, we do this with three-wheeled static rollers. This particular one can be very well done. And within the given temperature constraints, this initial part should be done in synchronization with the paver speed, preferably when these three-wheeled static rollers are used for this breakdown rolling; they always proceed with the rear because the rear wheels are the drive wheels. So, they are the ones who have to proceed.

So, they always proceed with the rear-wheel drive moving forward in the paving direction. So, this is an important feature, specifically when these three-wheel static rollers are used. So, this is the breakdown: rolling is important where you achieve the maximum density. Then comes the intermediate rolling; once this particular one is completed, it supplements the breakdown rolling. So, further to attain the required density, this is where we achieve the maximum density required and the minimum density required, which we gain during the intermediate density, and this is done specifically when the mix is still plastic, not stiff enough to be compacted during this particular time.

So, this has to immediately follow your breakdown rolling. Now, what is normally done here in this particular case is that most of the time we prefer to use these pneumatic tyre rollers, and we

call them PTRs. So, it further compacts the mats and reorients the aggregates for improved compaction during this intermediate rolling. So that reorientation now for this particular purpose specifically for this intermediate rolling.

The PTRs, or pneumatic tyre rollers, are highly preferred. Why? Because they provide a uniform compaction. They enhance the surface sealing. Because of the kneading action, they enhance the sealing of the surface, which makes the surfaces impermeable to water. So, they help to make the surfaces impermeable. So, the PTRs help to orient the aggregates for greater stability, which is normally done when the traffic actually comes over the surface. So, that is why PTRs are highly preferred; you can use vibratory rollers as well, but PTRs are highly preferred for intermediate rolling because we achieve the reorientation of the aggregate particles, which helps us enhance the sealing of the surface to reduce permeability or to make the surface impermeable, and because of the kneading action, it provides uniform compaction as well.

So, what PTRs are preferred as they provide uniform compaction and surface sealing to reduce permeability and orient aggregates for greater stability, similar to the effect of traffic over time? So that is why these PTRs are highly preferred for intermediate rolling, and then the filing finish rolling, or the final rolling, comes into the picture again to make the surface smooth enough. So, that will make the surface smooth enough, and it is mainly accomplished with 6 to 8 tandem or vibratory rollers, but without any vibrations. While the material is still warm enough for the removal of roller marks, there should be no roller marks left after this finish rolling. So this has to be done well before the temperature falls below the rolling temperature. And the IRC SP 97 gives some guidelines about the speeds that can be followed to achieve complete and uniform matte compaction.

It says that if you are going for a static type roller for breakdown, these speeds are in kilometers per hour; this can be a speed for breakdown rolling. If I am using this for intermediate, it could be speed; this is for the final one. As I mentioned, the pneumatic one is the one that is highly preferred for intermediate rolling, and we can go for the vibratory one also if the pneumatic tire is not available. Now here during this compaction process, a certain rolling pattern also plays an important role; we need to understand in what pattern this bituminous mat has to be rolled. So, for example, if this is a case where a rolling pattern behind the paver on roads with curves exists, there are curves on both sides, so there is some confinement on both sides.

So, you can see the first rolling pass, which is going in this particular direction; when it goes here, it comes back. So, there it comes back, and it goes towards now. Here, in this particular one, your paver is moving in this direction, so it is laying in this direction. Your roller is going in this direction; it reaches the mat, then it comes back and goes on the compacted part.

This is the already compacted layer. From here to here is your fresh layer, which is getting constructed. From this direction, the fresh construction has started. So, it goes back on the compacted part, and then it comes over it again. So, when it comes over, it will do a small amount of overlap. So, you can see that this shifting from one lane to the other is done on a compacted mat, not on this particular fresh mat.

So, this is to be ensured when it goes back; here again it goes on the third one and comes back. So, this is how the rolling pattern is when confined edges are present. So, if there are confined curved stones, this can be done. If there are bigger lifts and no curves on the sides. So, there are no curves. So, in that particular case, it is preferred that the edges are not compacted first because there may be a chance that the mix may slide down because the edges may not be protected enough, especially.

So, we will prefer to start with compaction, leaving certain spaces. So, it can be left around 10 to 12 inches, and then we can start with the first pass over it. So, this is how you can see that this will start with the first pass here, then we will go for the second pass, and we will go for the third pass. And by the time what will happen is that the mat temperature will go down, it will provide a confinement when we are doing a rolling at this particular part, and after a certain time, we will come back, and by then this will become stiffer, allowing us to do a compaction over this particular one. So, a pattern needs to be worked out, and we can do very well with the trial stretches with the different kinds of mixes to decide the number of passes and to determine the rolling pattern for it.

So, trial stretches need to be constructed over this. The rolling pattern includes not only the number of passes. So, this always has to be worked out with the help of the construction of some trial stretches, and then we follow those patterns in the actual construction. But also, the location of the first pass, the sequence of the succeeding passes, and the overlapping between the passes. So, this compaction exercise is again an art to achieve a good, uniform density throughout its width. Now in addition to this particular one there will be the creation of joints.

The joints will be a longitudinal joint that may be there and a transverse joint that is there. So, they also need to be taken care of properly because the density at the joints may be less and these joints may be more vulnerable to distress. So, we need to ensure that adequate density is achieved at the joints. Now, where joints are and always will be, because a one-day construction work has to end up the next day when it is going to start, there will be a transfer joint created.

If I am doing, say, a width of 15 meters, and I have done a width of 7.5 meters in one go, then the remaining 7.5 meters that has to be taken up will lead to a longitudinal joint. So, where joints are made, the material should be fully compacted. Specific provisions have to be followed to properly compact along the joints and the joint made flush with the previously layered surface. There should be no bumps and no depressions that should occur at the joints. Now, specifically small important points that need to be taken care of in multilayer construction are particularly relevant when you are having 2 or 3 bituminous layers to be constructed.

The longitudinal joint in one layer shall offset the joint in the under layer by at least 15 centimeters. So, if I am constructing, say, a bituminous base course over that particular one, a bituminous binder course is going to come up; then I will try to ensure that the joint on the top layer has an offset of at least 15 centimeters. Now this is for longitudinal joints, so when you are going to construct it in a number of layers simultaneously, as mentioned, because one day's work will stop, then the next day's work will be carried out, there will be a transverse joint, so there you need to Note down where these joints have been constructed, what the location was, and the chainage at which the joints were created. So that you are well aware when you put up the next layer. So, all this information is well recorded while this construction operation goes on.

So, transverse joints in the successive and adjoining layers should have a minimum offset of 2 meters. So, this is very important if I am doing a laying down. So, this is one layer that has been laid, and a transfer joint was constructed when the next layer is to be built over it. So, then the next layer's offset should be at least 2 meters if some joint has to come up over it. So, this is highly important, specifically in taking care of the joints. So, the joints need to be well recorded and well taken care of because if these are the places where the densities are less, and if these are not at the same level, a bump will be created, leading to irregular surfaces, reducing riding comfort, and these are the points that are prone to distress at later stages.

So, this needs to be done properly. Now, once all these parts are ensured, the traffic needs to be opened up because during this particular construction phase, the traffic is to be closed, and we are working on a particular lane. During this process, it is always preferred that the traffic is not allowed on the surface until the paved mat has cooled down below a temperature of 60 degrees Celsius throughout its entire depth. Unfortunately, it should not happen that the laying has ended up at night and all the engineers have moved from the construction site while the traffic started flying over it. Because in that particular case the mat is still at a higher temperature, it will distress your mat. So, it is to be ensured that the temperature is maintained for the entire depth because at the lower end the temperatures will be higher compared to the surfaces.

So that is why it is mentioned that the entire depth of that particular mat, which has been laid, should reach a temperature below 60 degrees centigrade, and we prefer that it reaches the ambient temperature. So, around an overnight may be required for the mix to cool down to the required temperatures before it is opened to traffic. So, this is all for today's discussion. Thank you.