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A very warm welcome to all of you. I am Rajen Choudhary, a Professor in the Department of Civil Engineering at the Indian Institute of Technology, Guwahati. Instructor for the NPTEL MOOC Course on Pavement Construction and Technology, funded by the Ministry of Education, Government of India. Today's lecture will be under module 12, where we will be discussing the recycling of bituminous pavements, with more focus on hot mix plants as well as hot in-place recycling. 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. Now, as the term itself says, recycling is putting something to reuse after reprocessing it.

So, recycling typically refers to the process of recovering any product that can be recycled. So, in the case of bituminous pavements, it is the already distressed layer that is there. So, we will recover it, we will reclaim it, and reprocess it. Therefore, in the process of recovering and reprocessing materials, there has to be a specific process, and specifically, we need to identify what materials we are going to look for; these are the materials that have already fulfilled their initial intended function.

So, any layer that has already served for a number of years or has shown some premature signs of distress and failure can be a candidate for recycling. So, recycling typically refers to the process of recovering materials and reprocessing materials that have already fulfilled their initial intended function in order to convert them into usable new materials for the production of new products. So, for the construction of a new course, we are going to say that if you are using the existing bituminous pavements by making some additions to them or by reprocessing the material, then it will be a recycling of bituminous pavements. So, what are the main steps involved in recycling asphalt pavements? Involves the recovery of the existing material and reprocessing it. So, there is some addition of aggregates, some addition of binder, resonating agents, certain additives, and the reuse of existing pavement materials.

So, by this particular one, we are reusing these materials to construct 1 or 2-layer bituminous pavements. So, these materials can subsequently be utilized, and the recycled materials we produce can be used for resurfacing; for example, an existing surface showing extensive signs of distress can be reprocessed, and a new surface layer can be applied using that particular material for resurfacing. Repaving involves putting up some new layers

using that particular material or reconstructing the pavement when we go for a greater depth. So, it is a reconstruction of pavements that may be there, and all these exercises will depend on the factors; it will first depend on the existing pavement condition. So, if we process only the surface layer, it will be if the defects are restricted to the surface layer.

If the defects are, say, for the underlying base and bituminous binder cores, this has to go down deep to those lower layers as well. So, it will depend on the existing pavement condition. The engineering properties of the reclaimed materials raise the question of what reclaimed materials we have. We have aggregates that are already coated with aged binder. So, what are its properties, what sizes of aggregates are we able to get, how much coating of binder is there, and what is the condition of that aged binder? So, these properties of the reclaimed material will play a role in what we can do with those materials.

The selected reprocessing technique and the technique we are using. So, there are different processes under recycling; we will discuss those in the upcoming slides. The specific treatment requirements and, finally, what we desire are also important; I want this product to be used on the existing or reclaimed, distressed bituminous pavements. Now, for this particular one, we have IRC 120:2015, which is a recommended practice for the recycling of bituminous pavements. Along with it, many other Codal specifications can be referred to in addition to the MORTS 2013 specifications for roads and bridges.

We also have the Asphalt Institute manual series number 20 on Asphalt Hot Mix Recycling. Now, when this process of reclaiming is present, we need to justify how this process can be good enough, specifically, what benefits one can derive from the recycling of bituminous pavements. So, the justification for the recycling of bituminous pavements, which consist of aggregates and binder, can be justified in terms of both economic factors and environmental factors. What is the environmental justification that we have? So, the important part is that the aggregates used in pavements are natural resources, and disposing of, say, one layer that has distressed. So, there is no sense in having that layer.

So, it needs to be removed, and that particular material if you are discarding it at some place. So, you are discarding the aggregates you are disposing of. So, if we are disposing of natural resources like aggregates, some dump sites become unserviceable after a pavement. We are not only putting these valuable aggregates to waste, but it also harms the environment because they have a coating of binder on them. So this impact is further compounded by the fact that if we are not using it simultaneously for preparing more layers, we are either extracting natural resources or utilizing existing natural resources.

So, that way, we are also harming the environment by extracting more and more natural resources, which will definitely create a difficult situation for upcoming generations, where we will be facing a shortage of natural resources in the coming years. We have both the things we are disposing of as waste, which is not good for the environment. Secondly, we

are extracting more natural resources, which is also not good for the environment. So, we can justify that we are making use of the aggregates, the existing material present in the distressed layer. So, environmentally it can be very well justified; the economic justification says that recycling allows the reutilization of aggregates, which are costly components, and there is also binder available.

So, that is again a very costly component. So, from the economic perspective, we are making use of both aggregate and binder. So, it can be very well justified in terms of economic operations. So, it thereby reduces the demand for costly virgin aggregates and bitumen. Now, only what the cost may be new is any specific cost involved in the reprocessing of these materials.

So, what additional cost is required when you are reclaiming this material or reprocessing that material? So, if we can compare what we are saving and what we have to add in terms of the reprocessing part, we can justify it very well. But yes, it is clearly visible that it is good from an environmental aspect as well as from an economic aspect. Now, some of the things that have been put together specifically for recycling existing asphalt pavements to produce new pavement materials lead to significant savings in materials, with savings ranging from 30 to 50 percent of the materials. So, cost and energy are significant because a lot of energy is required in the extraction or production of virgin materials, the crushing of the aggregates, and the production of the binder, which involves a lot of energy. So, the key benefits we can derive from recycling are cost savings; this is important because recycling substantially lowers overall costs and material expenditures in comparison to reliance on virgin sources.

So, material dependency, as I said, we can use a good percentage of the existing material in the construction of bituminous layers. So, we save a lot of money in terms of virgin aggregates and binder. Reduce haulage costs, and there are many processes where we can do the recycling at the site itself; we call it in-place recycling. So, even the transportation of that material, the distressed material, and the reclaimed material through the plant is also not required. So, transportation or haulage costs are also reduced.

Economic necessity is due to the fact that we presently have a lot of infrastructure to be developed. So, there will always be a shortage of funds, and in addition to this particular issue, the cost of materials, specifically aggregates and binders, is increasing day by day. So, that is why recycling is very important to consider at this stage. Conservation of natural resources, as I said, will save our natural resources aggregates, specifically saving in aggregates and binder. We will definitely reduce our requirements for virgin aggregates and binder if we are able to use the existing distressed ones.

And this is again definitely true that in some locations the aggregates may be available in good quantities, but there may be certain locations that are already experiencing a shortage

of aggregates. So, this option of recycling could be a very viable one because the aggregates are unavailable, and if you have to get good-quality aggregates from faraway places, the cost increases significantly. The quality of recycled materials may be one concern; what you are obtaining is of inferior quality. However, these materials have qualities on par with what your virgin aggregates can provide, and in certain cases, they perform better because we are using aggregates that are already coated with the binder. They have already absorbed the binder; no more binder will be absorbed because they have already done so during their course of time, and whatever reduction in their sizes could happen under the traffic has already occurred.

So, in certain ways, these aggregates may be even better compared to your virgin aggregates. Structure is strengthening because what I am able to do with this particular one by using these materials will definitely strengthen my existing pavement. So, I am using these materials to put some new layers of bituminous mixes over the existing ones. Preservation of pavement geometry is again a very important concept regarding what happens if we keep putting on overlays. It will disturb the geometry, the cross-section, the geometrical features of the roads, the roadside elements, the height of the median, the height of the shoulders, and the drainage.

All those aspects, and even some of the CD structures, will increase the live load significantly. So we also disturb the geometry of the road by adding more and more old days every time. So the best part is if we remove the existing distressed one, which is not adding anything to our structural strength, and then put a new layer over it. Some of these recycling processes, as I mentioned, which are done in place, even take less time, so the traffic disruption is even less compared to the standard rehabilitation processes, and there are energy savings because you are reducing the dependence on or the requirements for virgin aggregates and the neat binder. A lot of energy is consumed specifically in their production, as well as when you are doing in-place recycling, and there are methods where we use cold in-place recycling or cold mix recycling, so a lot of energy is saved in those options as well.

Environmentally, this is when we save our natural resources; it always adds environmental benefits. Now, the five major types of recycling activities or recycling technologies that are quite popular are mentioned here. One is hot in plant recycling; hot in place recycling, as I mentioned, is something that is done at the site itself, while something that is done at the plant level is hot in plant recycling. Now this is, as the term says, hot, so higher temperatures are involved. Then, we have cold in-place recycling; also, it is similar to hot in-place recycling.

Similarly, we have cold in-place recycling, we also have cold in-plant recycling where the hot mix plant is involved, and then there is full-depth reclamation as well. So, these three are specifically more related to cold mix technology, and the first two are more related to

hot mix technology. Now, there are five different categories that can be worked on. So, there is a requirement to investigate some preliminary options for these different kinds of recycling. We will discuss those recycling options.

So, in the beginning, one definitely needs to pick which recycling option to choose. So, some information about the existing pavement structure is required. So, a comprehensive evaluation of the existing pavement structure is essential before selecting any recycling option. So, the results of the existing investigation of the existing pavements are primarily analyzed in three terms: we analyze those investigations; one is pavement serviceability, how good it is at serving the purposes; the extent of surface defects, how the surface defects have extended to what level; and what the remaining structural strength of that particular pavement structure is. So, when we talk about the serviceability of the payment, specifically, that refers to some index which indicates the riding quality or user comfort, and when deterioration exceeds certain acceptable limits, recycling becomes a viable option.

Now, in addition to other maintenance activities that we have already discussed when we talked about the IRC-82-2015, the different kinds of maintenance treatments that are possible. So, if these distresses extend beyond a certain limit, recycling becomes a viable option, and as per IRC-120-2015, it states that recycling can be considered when the distresses come under the category of high severity, as per IRC 82, when these distresses are considered to be of higher severity. Second, when the road roughness increases, the smoothness of the surface is reduced to the extent that the road roughness is 3000 mm per kilometer. And when the rough depth on the surface exceeds 20 mm, and even with all the surface renewals where the surface has to be repaired or improved, they can form a candidate for your recycling. So this exercise needs to be carried out to see the extent of severity of the distress, what the road roughness is, what the amount of cracks is, or say what the rut depth is that is present, and then we can decide what could be a possible recycling option.

The extent of the surface defect, as I mentioned, is another important thing that needs to be understood: it is essential to determine whether the distress is limited to the surface course, because we need to understand what type of distress it is and what the extent of that particular distress is; only then can a recycling treatment option be selected. Otherwise, it may not be good enough; it may not serve the purpose, and that distress may recur as well. Whether the distress is limited to the surface course only, then surface recycling can be good enough, or if it has extended to lower layers, such as bituminous, and even if the distress has gone down, or if the problem exists with the granular courses or even up to the subgrade level, then that needs to be understood. So, for this, you can do the coring, cut down the trenches, and see the extent and type of distress, as well as the layer involved in that particular distress. Recycling should preferably match the depth of the layer that is having the problem, because we will prefer to go up to that particular depth.

So, if confined to a bituminous basis, recycling combined with a strengthening overlay is mainly confined to bituminous courses if there are no significant distresses in the earlier line course. Then, we can go for the overlay, and if the surface one has shown extensive signs of distress, it can be recycled, along with an additional overlay that may be provided over it. If extended into granular or bound courses, if it goes down into the granular courses, then what we can do is, because if an improvement is required at those granular courses, we can reclaim the bituminous materials, and that the lower one can be whatever your bases can be pulverized, stabilized, and relayed again with the overlay of bituminous material using those reclaimed bituminous materials on the top. Structural strength, as I mentioned, is another important aspect that we need to work out: how much current strength there is and for how many more years the existing pavement can serve. If it can serve a purpose for a good number of years, say 4-5 years or more, then we can work it out by just providing an overlay as well.

So, if a structural evaluation indicates that the pavement has sufficient residual life to withstand traffic loads, say for the next 5 or more years, recycling may be limited to the surface layers only, with the top layer, which has shown some distress, being a candidate for recycling. However, if the pavement does not show adequate structural capacity, then the recycling should be combined with a strengthening overlay. So, even the recycling of the surface course has to be followed by a properly designed overlay for strengthening to ensure long-term performance in that particular case. The next important aspect in recycling is the removal of the existing pavement. So, basically, this removal of the existing bituminous pavement is quite often done by two popular methods.

One is milling, and the second is ripping with subsequent crushing. These are two quite popular methods that are used for the reclamation of the existing bituminous pavement to obtain reclaimed asphalt pavement for our recycling purposes. So, we will discuss these two methods: milling, as well as ripping and subsequent crushing, which are there. So, milling is the controlled removal of the existing pavement to a specified depth using specialized equipment that we call a milling machine fitted with replaceable tungsten carbide cutting teeth. This is a picture of that particular milling machine.

You can see that this drum is there; the rotor drum is there, which is fitted with these replaceable teeth. It is fitted with replaceable tungsten carbide cutting teeth, mounted on a rotor drum powered by the milling machine. So, this is a typical milling machine; now, with this particular one, you can remove the surface to a predefined depth, and you can also give a camber to that particular one. So, it has various advantages; because of this milling machine, recycling has also become quite popular and easy to do in that case. It is the most popular way to reclaim the bituminous pavement material.

It is mostly used following a cold process, and that is why you will often find that in milling, they mention it as cold milling. So, because it is a cold process mostly done following a

cold method. Now, cold milling of existing asphalt pavement is usually carried out under circumstances when this can be widely done. To improve the rideability, skid resistance, and cross slope, if there are some minor depressions or issues with the cross slope or camber, or if the surface has become very smooth, specifically the top surface, these are some challenges related to your surface course only. So if you can mill to a slight depth of your surface course, that surface can be corrected for your grade camber and will also give you enhanced skid resistance.

So this milling operation can quite often be used to improve the skid resistance and the camber of this road surface. To lower the finished grade adjacent to the curb or shoulders prior to resurfacing, many times what happens is that whenever some overlays require resurfacing, you find that some previous overlays are there and they are not at grade. So in that case, with these milling operations, we can bring that existing surface to a required grade in order to maintain a proper height with respect to your shoulders, medians, and curves. So this is another advantageous feature for which cold milling is widely popular. And the third one, especially the complete or partial removal of any particular layer, addresses any particular distress, such as the bituminous layer.

Here, you can see this particular one has been removed to a given depth, because it has been observed that the top layer of the bituminous pavement has completely distressed, so this milling operation has been carried out to remove that particular top layer. Now, once this reclaimed asphalt material is with us or the RAP is with us, it is usually either used in one process at the site itself by hot in-place recycling, or many times it is transported and stockpiled at some location, and then whenever it is required, it is used. So, the work of cold milling can also include transporting, stockpiling, and otherwise disposing of the removed pavement material at a suitable location. Now, cold milling requires specialized machines that are capable of achieving precise depth and cross-slope. This is important, and what are the common key features of this epic cold milling machine? You can see the surface being milled, and from the chute, this is being moved to this particular tipper, and then it will be transported where it is going to be stockpiled.

We can see the surface after it has been milled out. So, adjustable cutting capabilities have to be present with these milling machines. So, whatever depth is required to which you are observing any distress, and the surface needs to be removed, this milling machine should be able to do it by maintaining the cross slope and the proper camber as well. The dimension should be good enough in that particular case that we are able to go for good widths, say typically 2 meters; normally, you have these ones of 2 meters; it may be more than a lane. Also, nowadays, more robust milling machines are available. An advanced mobility feature is essential because when it moves over the existing asphalt pavement, it should not damage the surface.

So, that is why their tracks are fitted with track pads specifically to avoid any damage to the existing pavements. And then, since a lot of fine dust is generated, there should be a system to control or minimize this dust. You can see that this is a cover shoot. So, it is important to generate less dust, as this will limit your use of this RAP during recycling. Additionally, from an environmental aspect, it is important to have provisions for reducing any pollution caused by dust emissions during the milling operations.

Now, the second method, which is popular for reclaiming bituminous pavement or even the lower layers of the pavement, is ripping and crushing. It is an alternative method to cold milling that involves ripping and crushing. The key features of this particular method include the types of equipment that can be used; we can use scarifiers, grid rollers, or rippers. As you can see, this is a ripper that is breaking the asphalt material, especially the distressed sections. The large chunks need to be transported for crushing operations to be brought down to usable sizes.

Now, what type of equipment can we use to crush this existing pavement needs to be decided on the basis of what big sizes of these chunks can be accommodated during the crushing operations. So, if we have to look for smaller chunks, we need something that provides smaller chunks so that it can be accommodated into your aggregate and into your crushers. Suitable for roadway upgrades or small projects, specifically quite suitable when small projects are present or where it is difficult to have a milling machine. In that particular case, when we require greater depths, we can opt for these ripping and crushing operations. Retrieved material needs to be here now; an important aspect is usually that the chunks are of variable sizes, so they need to be crushed, sieved, separated, and then stockpiled.

Even if granular, if you are going deep into the underlying layers where the problem exists with your granular courses, then again, with this ripping, you may have to bring those bigger sizes. So, the crushing operations, along with the pulverization, may be present when we are dealing with the lower-layer materials. So, now once you have this reclaimed bituminous material with us or the material from other pavement layers, then we will go for the recycling one. So, here we will discuss the two most common recycling operations, specifically regarding the bituminous layers. The one that is hot in plant recycling is very popular; it is also known as hot mix recycling.

So, the word itself says that it is the recycling that takes place at the hot mix plants. So, hot in plant recycling is the process of producing and laying hot mix asphalt using a blend of reclaimed asphalt pavement (RAP) material, which we obtained from milling operations or ripping and crushing operations. This material is already coated with aged binder; the binder over the RAP is in an aged condition, mixed together with virgin aggregates and virgin binder to meet the design requirements. So, the design requirements will be what we expect from a virgin mix; we will expect the same requirements from this recycled mix as well. Design requirements may be in terms of air voids and stability, as they are the same

because we are going to use it according to whatever requirements are needed if that particular mix is used as a base course, binder course, or wearing course.

So what requirements are there with your virgin mixes will be the same for your recycled mixes also. Recycled, as most of the time they are the same as your virgin mixes, can be produced using both batch-type and drum-type hot mixes. There are some key considerations, specifically in hot plant recycling, when done with batch-type and drum-type plants; we will discuss both of them. Hot in-plant recycling generally follows the conventional hot mix production process. It is usually the same, but there are some specific key differences or key provisions when we are attempting this hot in-plant recycling.

Instead of using only fresh aggregates and bitumen, RAP is incorporated in the case of these recycled mixes, and a typical percentage of this hot in-plant recycling or hot mix recycling is around 30 percent; it is a typical percentage. For some plants, batch-type plants it is slightly lower; for drum-type plants, it is slightly higher. Regenerators are added; this is another important feature during the production of the recycled mixes by these batch-type or drum-type plants, as the binder present in the RAP is a highly aged binder. So, it needs to be regenerated. So, for that particular one, different kinds of regenerators are popular to restore the aged binder, and third, unlike virgin aggregates, RAP is not directly heated.

This is an important feature because there is a binder that is already present, so it cannot be directly heated in the same manner as we do for the virgin aggregates; otherwise, this binder will get further aged. In the case of the virgin mixes produced through the batch-type plant or the drum-type plant, where the aggregates are directly heated, a RAP is not directly heated. So it is not directly heated at high temperatures due to the risk of excessive fume generation and the excessive aging of the binders. So these factors are mainly managed by modifying the hot mix plant. Some amount of or some typical modifications are popular for both types of plants.

So as to specifically address the concerns related to the feeding of these rap to these plants, some necessary adjustments to the production process are required. We will discuss these for both the batch-type plants and the drum-type plants. So, first of all, hot implant recycling or hot mix recycling uses a batch-type plant. So, what type of modification can be made, and how can this RAP be prevented from direct heating, as in the case of virgin aggregates? So, hot recycling utilizes the heat-transfer method. Now, this is the important feature that has to be taken care of to soften the RAP to permit mixing with the virgin aggregates, asphalt binder, and recycling agent.

So, we need to have some heat transfer from the virgin aggregates, which are heated to higher temperatures. So, from the conduction of heat from the superheated, we can call them superheated virgin aggregates. The RAP will be raised to higher temperatures so that

the aged binder becomes soft, and then the mixing can occur with your new aggregate, your virgin bitumen, as well as your rejuvenating agents or recycling agents. See, the most widely used method specifically in batch-type plants is the maple wood method, which is there. And this maple wood method is particularly popular because it was first tried in Maplewood, Minnesota, in the USA.

That is why it is often known as a maple wood method. And what is specifically done in this maple wood method is that virgin aggregate is first superheated in the dryer; here we can see a picture of a batch-type plant, so we have the aggregate dryer, and then we have the elevated hot screens; the hot bins will be there. So, here the virgin aggregates that are to be used are superheated, and then this particular one is to be transferred to the hot bins, and when it comes to the weigh hopper, we will be introducing our RAP. So, this will transfer these superheated aggregates to virgin aggregates, which will transfer the heat to the RAP in the weigh hopper, which is at ambient temperature. So, a separate RAP bin supplies material via a conveyor belt to the weigh hopper of the batch plant, which has already been charged with superheated aggregates; this is an important aspect. RAP, when deposited, once you have the superheated virgin aggregates over which the RAP gets deposited, becomes warm, and the heat transfer warms the RAP and further heat exchange takes place; a small amount of mixing is done with the superheated aggregates, and then later on, the heat transfer occurs again when subsequent.

Wet mixing is also done with the binder. So that is why this slight modification is specifically present in batch-type plants; a very popular modification is to introduce RAP in order to restrict the direct heating of the RAP. Now, this is because we are introducing it to the level of the wave hopper, and this rap is getting warmed through the superheated aggregates. So, there are limitations on how many percentages of rap can be used in a recycled mix. Some of the concerns that control or are key contributing factors to the percentage of rap that can be used in the recycled mixes, specifically with batch-type plants.

One is the moisture content of RAP. So, if the moisture content of RAP is higher, the production capacity is reduced because you need a greater amount of heat transfer to bring those RAP aggregates to the desired temperature and to remove any presence of water from them. The temperature of the superheated aggregates has a limit to the temperatures to which the natural aggregates can be heated. So that superheated temperatures depend on the fact that we can also use them because if a higher percentage of RAP has to be introduced, then we need to heat the remaining percentages of aggregates to a higher temperature. So this is also an important aspect of how much the virgin aggregates can be heated. The temperature of the RAP is another concern, finally, because it may be at ambient temperatures or it may be a very cold season, and during cold seasons, the temperatures of the RAP may be quite low.

The target temperature of the recycled mix is important, as certain additives can allow compaction at low temperatures. Another concern is what percentage of fines is generated because milling operations usually produce a larger amount of fines. So that further restricts the percentage of RAP that can be incorporated into the recycled mixes. And in practice, around 30 to 35 percent of RAP is usually considered an upper limit, but typically, through batch mix plants, you go for a percentage of RAP in the range of 10 to 20 percent at most of the batch-type plants with these small modifications that are required. Now, the other type is the hot in-plant recycling, specifically with the drum mix plant.

So, the first one we discussed regarding the modification was for the batch-type plants here for the drum mix plant. Now, in this case, RAP cannot be directly processed in a conventional drum mix plant. Because we do this for the virgin aggregates, a direct contact of this RAP with the burner flame produces excessive blue smoke, which is also harmful to the environment. This issue is further aggravated by the buildup of fine aggregates and bituminous binder on the metal flights and end plates of the dryer of the drum mix plant. So that's why a popular method of modification is the center entry method, which is there.

It is the most widely used technique for hot mix plants in drum mix. And what has been done? In this process, RAP is introduced into the drum through a collar located downstream of the burner flame, where it is blended with the superheated virgin aggregate. So, you can see there is a drum mix plant, this is the flame that is there, these are the virgin aggregates that are entering, and downstream, this is the point from where your RAP is getting introduced. So, this RAP will be heated through the already superheated virgin aggregate. So, there will be a wheel of virgin aggregates.

These RAP will not be directly exposed to the burner flame. And then you have the regenerating agent along with your binder, which is to get your recycled mix that is being produced. So, this is again a modification that is quite popular, specifically with the drum mix plant. So hot in plant recycling using a drum mix plant. The hot virgin aggregates transfer heat to the RAP material primarily again through conduction. Now, here also, how much percentage of RAP can be typically used in the drum X plant will depend upon the moisture content of RAP, the ambient temperature of RAP as well as virgin aggregates, and the desired production rate, because you need to give some time for the transfer of heat from the virgin aggregates.

So, a little more time is required for mixing your virgin aggregates with the RAP and finally mixing in your regenerating agents and the virgin binder. Target temperature of the recycled mix, if that has to be high, then you need to have more time, and you need to have more divergent aggregates heated to higher temperatures. But the typical percentages usually recommended are around 30 percent; ranges can be 30 to 50 percent, and with some more modifications, higher percentages have also been tried, but a typical percentage is around 30 percent for the recycled mixes through the drum mix plant. Now, many times

these drum mix plants are preferred for recycled mixes specifically because they are portable, require a shorter period for installation, and are more portable compared to batch-type plants. Versatility is important because you can make these modifications much more easily compared to what is required in your case with batch plants, and you can accommodate the way the hopper functions.

As we have seen in the case of batch plants, there is a limitation on how much RAP can be introduced, but that limitation is less in the case of drum-type plants. Production capacity, normally up to a certain percent, does not get affected specifically for the drum mix plants and mixing quality because, in this particular case, it is blended with the virgin aggregates, and it is easier to maintain the mixing. You can add to the mixing time; you can give more time when this virgin aggregate is introduced, depending upon where you are introducing the RAP into it. So, on the basis of the design of your drum mix plant.

You can even get good quality from your recycled mixes. So, these are some key features that make drum mix plants more popular in hot in-plant recycling compared to batch-type plants. Now, the other common recycling technique is hot in-place recycling, or we can say on-site recycling, which is available. And this is again to rehabilitate deteriorated asphalt pavements while minimizing the need for new materials. Here, specifically when we are targeting some surface layers that can be easily modified, the distresses are restricted to the surface layers; this hot in-place recycling is quite popular. So, the main steps involved in this particular process, because it has to be done at the site itself, are first to heat the existing asphalt surface to soften it, and then it is scarified because we have to remove the distressed layer.

So, scarifying or a mechanical remover of the softened material layer. Now, this softened material, if it is short of, say, binder, short of a particular size of aggregate, or if the binder is inadequate or highly aged, can have virgin aggregate, virgin binder, or even a virgin mix added to it. So, blending with reclaimed material, usually with a recycling agent, a new binder, or even a new asphalt mix, is followed by laying and paving the recycled mix back onto the pavement surface. So, all this needs to be done on-site. So, in hot in-place recycling, a train of equipment is usually employed to perform multiple operations that are to be carried out together. So, sequential operations include infrared heating to bring the existing surfaces to a desired temperature; thereafter, the pavement surface needs to be milled off or scarified, conveying the milled material to the pug mill mixer, where it is transferred to the mixer in that particular train itself and fresh mix, fresh binder, or regenerative agent is added as per the design requirements.

For thereafter, this mixed recycled material is to be discharged through integrated paving scripts, which are incorporated into this particular equipment, and finally, the rolling and compaction of the recycled layer will take place. So, these are the key features of hot in-place recycling, which happens, or we can call it on-site recycling. So, this is a big train; it

is a set of equipment in line that is there. So, we will have the key considerations in hot in-place recycling: at what temperatures the pavement needs to be heated, up to what depth it needs to be scarified, the collection and conveyance of reclaimed bituminous material (RBM), the addition of regenerators, fresh mix, fresh binder, fresh aggregates, and thereafter followed by paving and compaction. So, a hot in-place recycling equipment can either integrate all these functions within a single unit.

So, you can see this is a single unit or employs a synchronized train of equipment. So, either a single piece of equipment may be there, or there are synchronized units; one unit is doing the heating, the second unit is doing the scarifying, the third unit is doing the mixing part, and the fourth unit is giving you the mix through the screed, and finally, you are rolling for compaction. So, it can be a single unit, or there can be synchronized units that work all together. So, good control is required over heating, specifically material feeding, mixing, and laying operations. Hot in-place recycling may be carried out as a single-pass process; a single-pass process may be there, in which case you have produced the recycled mix where clarified material is compacted in place, and you can compact it, or a multiple-pass process is there where, over this particular one, you can put up a new fresh mix also, and then it is compacted. So, there may be one recycled mix layer along with a layer of fresh mix, and then they may be compacted together or individually.

So, the typical treatment depth is hot because this heating has a limitation. So, typically, this hot-in-place recycling or hot-in-situ recycling is done for depths of 1 to 2 inches. So, in that case, we can consider it to be basically restricted to your wearing course or surface courses as well. And the temperatures that are usually achieved are in the range of 110 to 150 degrees centigrade. This is a small sketch that shows how the process works.

So, we have these infrared heaters that are there to heat the existing surface. Then we have these scarifiers, which are going to remove the softened pavement surface to a desired depth. And then we have the first mixer where you are going to add the rejuvenating agents, and it is going to mix here. Thereafter, depending on the requirements of the mix, if it is falling short of a certain particular range of aggregates, the binder or aggregate, or even a new mix, can be added and mixed in the second mixer. So, it depends on what type of recycling unit it is.

And thereafter, you have the screed which gives you the desired thickness. So, initially, what thickness have you milled, and what final thickness are you having that is later compacted? So, this is the benefit of hot in-place recycling because all these processes are done inside itself or in the institute itself. So, hot in-place recycling offers the following key advantages: road elevations and overhead clearances are preserved because the thickness does not increase; only a small variation may occur depending on the lack of materials that were falling short. So, on the basis of this, you can see that these are different units working altogether; you have these propane heaters, which are there. So, here you

can also see that it can be one unit or different units working in synchronization with each other. The process is comparatively quick and economical because there is no transportation or hauling of material required; everything is done at the site itself.

The aggregate gradation or bitumen content of the existing asphalt surface can be slightly modified because, depending on the requirements, we can modify the aggregate gradation as well as the asphalt content. Surface friction, due to the modification in the aggregate gradation, definitely allows us to achieve a surface with a higher amount of skid resistance. Since this is done at the site itself, there is no need to bring in the mix, and there is no transferring of RAP to the field and then bringing the recycled mix to the site. So, all these activities are not involved, and that is why this particular hot-in-place recycling has fewer traffic control requirements and delays. But yes, this is more or less restricted to topping your 1 to 2 inches of distress, where this can be very well done.

So, these are some of the recycling methods that fall under the category of hot in-place recycling or hot in-plant recycling. Thank you so much.