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Professor Name – Dr. Rajan Choudhary
Department Name – Civil Engineering
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A very warm welcome to all of you. I am Rajen Chaudhary, a professor in the Department of Civil Engineering at the Indian Institute of Technology, Guwahati, Assam. I am the instructor for the NPTEL MOOC course, Pavement Construction and Technology, funded by the Ministry of Education, Government of India. Today's lecture will be under Module 5, where we will discuss the different equipment involved in this upgrade construction and in the earthwork. At the very beginning, I would like to acknowledge the use of texts, information, graphs, and images sourced from various textbooks, codal standards, journal articles, reports, newsletters, and public domain searches. Now it is very important to understand what type of equipment can be used and how it can be useful for achieving good quality construction; specifically, here we will discuss the aspects related to earthwork.

The standard equipment for the earthwork includes IRC guidelines, such as IRC SP 97, which discusses the guidelines on compaction equipment for roadworks, especially for compaction equipment. Then there is one specific coded guideline, IRC 125-2017, which discusses dozers that are widely used in earthworks. Then we have this pocketbook for road construction equipment from the IRC from 2018. From the rural roads, we also have a manual on construction equipment for rural roads; it provides a good description, MoRD 2016, and gives a good description of the earthwork equipment.

Now, if I put this equipment under different categories, like we discussed in the previous lecture, we have clearing and grabbing as one of the major activities. So, what type of equipment will we discuss in the subsequent slides? So, in clearing and grabbing, you can have a dozer, a motor grader, a hydraulic excavator, a backhoe loader, a ripper, and a tipper truck. A truck trolley is there depending on how much work there is and what type of project it is. Then the construction of the embankment, including the earthwork, also includes the widening where the work has to be expanded, so you need to construct the embankment shoulder there, along with your subgrade part again. So, for that one, you again need to use a hydraulic excavator or backhoe loader, a tipper truck or tractor trolley, a dozer, and a motor grader.

Then there are certain attachments, such as a ripper, a scarifier, and disc harrows for mixing the soils, which can be attached to your tractors, dozers, motor graders, and hydraulic excavators to perform different activities. You need to have the dewatering pumps, a water tanker, and compaction equipment, which mainly includes vibratory rollers, static rollers, sheepsfoot rollers, padfoot rollers, and pneumatic tire rollers. We will discuss this in the subsequent slides. Now you are all aware that road development is progressing at a massive pace throughout our country, and because of this development in the road sector, both in terms of scale and technical demands, the standards have also been raised. To very high standards, we are constructing roads that can last for periods of more than 50 years, and the functional requirements have increased, the structural

requirements have increased, and the design standards have increased in due course of time, and there is strong pressure that the Construction has to be completed within a given small window of time.

So, along with that, what is happening with all these activities is that there is again a great shortfall of skilled labor. I am talking specifically about skilled labor or those skilled in these construction activities, which have led to a major shift towards large-scale mechanization in construction. So, the rapid growth of the road sector, both in scale and technical demands, along with a shortage of skilled labor and a push for shorter construction timelines, is concerning. You might have seen that the target is even as we are constructing roads at a pace of more than 20, or even reaching up to 30, kilometers of national highways per day in certain cases. So, this is what the current targets are in this road development sector, and because of this, a major shift has occurred towards mechanization.

Now, the earthwork equipment is usually classified into two broad categories. The first one is the track machine. They have a pair of crawler tracks; in particular, you can see that these are the crawler tracks that are there. So, this is one particular set of machines we call track machines, and they are mounted on a pair of crawler tracks that provide better traction. The important part is that you get good traction when using these crawler tracks and there is lower ground pressure, so these kinds of things are quite suitable if you are working on soft soils; if you are working in hilly terrain, you need a lot of traction, so this kind of crawler track is very important, and track machines play a good role.

Wheeled machines that are mounted specifically on pneumatic tires can travel faster; they can move from one place to another and cover long distances under their own power. In most cases where crawler tracks are present, you have to shift these machines with other machinery from one construction site to another. The ground pressure is higher, but since they have pneumatic tires, traction is a bit less, and it may result in slippage. So, this may be one concern specifically because the traction is less and is therefore not preferred on soft and sloping grounds. Now, let us see what different kinds of earthmoving equipment are available and how they are put to use.

So, one quite common piece of equipment is a bulldozer. Now it is a self-contained tractor; power is present, and it has both crawler-mounted and wheel-mounted options. So, with a blade attached to the machine's front, you can see this is the blade that is attached to this machine's front; it is quite basic, effective, and versatile equipment, widely used in construction projects, and it is very common in the construction process. It can perform various activities, and versatile activities can be done with the use of this dozer, and we have the IRC guidelines as well, guidelines on dozers for highway works, IRC 125. And they, in themselves, work as a support machine for some other major construction machinery or as an independent unit on construction projects.

And what purposes can they serve? They can serve the purpose of clearing land of timber, stems, and root mats; with these particular blades, we can clear the land. Excavation of earth and excavation of a length to a certain extent can be done with this for a short haul distance because, as I said, if crawler-mounted units are available, they can haul it to a shorter distance comparatively. Once they can spread it, if you put down some windrows of materials, they can spread that material, also spreading earth or rock fields, leveling the land, and they can level it. There are small ups and

downs or undulations on the land. Backfilling of trenches; if some existing trenches are present, then this can push and fill those trenches, clearing the floor of burrows, quarry pits, and construction sites.

Burrow areas, if you have them, can be used for cleaning and grabbing exercises, and they are also required at your stone quarries and construction sites for cleaning and clearing tasks. Now, this is another very common piece of equipment used specifically on most construction projects. It is a hydraulic excavator. It is a self-propelled one; you do not require anything to move it from one place, yes, but for longer distances, since it is a crawler, you need to have it moved from one place or side to another using some other equipment, especially trucks, to shift it from one construction site to another. It is a self-propelled machine on crawlers or wheels; sometimes you can see that this is a wheeled one, but the most common one we see is the crawler.

And it is capable of a 360° swing. So, you can see here, it can swing through 360 degrees. This is the wonderful part of the machine. So, it can work in all directions while standing in one place. mounted primarily designed for excavation and having a bucket.

So, you can see this bucket can be lowered and raised with the help of the bucket holder, and this particular part can be lowered and raised using the stick cylinder, and this entire boom can be raised to a great height with the use of these boom cylinders. So, this top one is a revolving structure that can rotate 360 degrees. So, it can work on slopes as long as a crawler unit is present, providing good traction, and with this particular bucket, it can be used for multiple purposes. An excavator work cycle normally comprises what it does: excavating, elevating, swinging, and discharging materials. So, it can pick up material from one place with a bucket and dump it at the other.

It can be used for site clearance and initial site preparation, which are required even in your clearing and grabbing exercise; it is also used for that purpose. Quarrying operations, cutting and filling operations, construction of embankments, and the lifting and handling of materials are involved. So, it is one that serves multiple purposes at construction sites. Now, the other motor grader is widely used specifically in earthworks as well as in the construction of granular courses. Now, again, you can see it is a self-propelled wheeled machine.

You can see there is a front axle, a rear axle, front wheels, rear wheels, and an adjustable blade. This is the specific blade that is adjustable. This blade can swing and become vertical instead of horizontal; it can also be raised and positioned vertically. So, this particular blade, which is shown here, can also be made vertical. So, you can have this particular one. Presently, the entire blade can be used for say scraping, for cutting down to a certain slope, for mixing.

If I raise, if I say, if I have a certain location on this site where I find this is a raised part, I can lower it; I can remove it to a certain depth. If I find that only a small width is required, I can raise the blade in this vertical manner, so I will scrap it for this particular width. So, it is wonderful equipment that is widely used. It is used for mixing, spreading the material, and bringing it to a finish. So, a motor grader is a self-propelled wheeled machine having an adjustable blade positioned between the front and rear axles that cuts, moves, and spreads materials.

So, with this blade, you can cut down any layer if you find that the subgrade for a particular layer has been constructed to a thickness that is more than desired. So, you need to cut it down to a certain depth. You can use this to cut down to a particular depth. And to a certain degree, because the angle can be adjusted for this particular blade, it can be adjusted; the angle can be adjusted, and you can adjust the angle of this blade. So, with this particular one, you are also able to maintain the cross slopes. General applications of the motor grader include finishing work.

Shaping, bank sloping, and ditching can be accomplished with this particular machine, as you can form the ditches along its edges by changing the angle of the blade, moving windrows, spreading material, and mixing. Two materials can be used with it: spreading, leveling, and crowning, because you can create the cross slopes using this particular method. It is used to spread the material, sprinkle water, and then use the motor grader blade to mix the sprinkled water with the soil. So, crowning landslide snow clearance for that particular purpose also uses general construction and maintenance of dirt roads and haul roads; specifically, the unpaved roads can be maintained with the help of these motor graders. So, this is one versatile piece of equipment that is again used for construction activities related to subgrade and granular courses.

Then there is another piece of equipment that is known as a scraper. It also serves multiple purposes. It is a self-propelled or towed crawler, or a wheeled machine. Both of you can see that this is a wheeled one and this is a crawler. Depending on the type of site and the challenges associated with it, if there is loose soil, soft soil, slopes, or steep slopes, you will prefer to use a crawler.

Having an open bound with a cutting edge, it is positioned between the axes that cut, load, transport, discharge, and spread the material through the forward motion of this machine. So, this can be done for shallow cuts and haulage of up to a short length of around 200 to 300 meters. Now, see what is happening. This is the loading part.

It is traveling in this direction. You can see that there is a bowl. This bowl is lower down; in this particular one, you have an ejector, which is currently in the rear position. This is called its rear position. Now you have this bowl, which is lower down, and there is an apron that is currently in a raised position. You can see there is a gap, so the apron is in a raised position, the bowl is lower down, so it will cut; it will cut into your soil.

Now, once this particular one is filled, the bowl is raised. Now you can see the bowl is raised, the ejector still remains in the same position, and this particular apron is now lowered to close it. So, this is what we are doing: we have loaded the material here, and now we need to carry this loaded material. So, I may need to do cutting in one place and filling in the other. So, I am cutting here, then I am taking that material, and I will dump that or spread that material where it is, where filling is required.

So, at the next one, what is happening here in this case when the spreading or releasing of the load is occurring is that this bowl is again lowered down, and the ejector moves forward. So, this material is pushed down, and the apron is raised. So, what we are doing here is cutting the material and finally spreading it. So, this is how it works. So, it serves purposes, and for short distances, it serves them well.

Now, this is another very common piece of equipment; many of us have seen it at numerous construction sites. Even small construction projects make use of backhoe loaders. So, there are two components here in this particular backhoe loader, and it is one of the most commonly used pieces of construction equipment nowadays; even at small construction sites, you can find this particular one. Now it is a self-propelled one; it can go long distances on its own. You might have seen it many times traveling alongside our passenger vehicles on the national and state highways.

Self-propelled crawlers are normally the most common; most of the time, you will find the wheeled ones. The crawler ones, as I said, are specifically used where challenging terrain is present. And it is specifically designed to carry both front-mounted equipment and loader attachments. This is the front part, and it has a loader. So, it can load soil mass here, or any aggregates; any other construction materials can be loaded in this particular front loader.

And there is a rear-mounted piece of equipment, which is a backhoe attachment. This is the backhoe attachment that is here. So, we call it a backhoe boom because we have a boom in the case of a hydraulic excavator, as well. Similarly, this is a backhoe boom that is present. And this is the stick part that is there, or the arm of this particular one.

And this is the backhoe bucket. So, it can pick up, dig, cut down, and shift the material from one place to another in this case. In addition to this one, when working on challenging sites, we also have these stabilizer legs to make them more stable. So, it can work on sloping ground with the help of these stabilizing legs as well. So, it is useful for light excavation; small-scale and large-scale excavations are where we can use those hydraulic excavators. Trenching, small trenches, or drains need to be constructed, and earthen drains need to be prepared very well for this particular task.

Backfilling along the CD structures, such as culverts and other areas where small trenches are present that need to be backfilled, can use this particular one. Material handling can be used to move the materials with the loader that is there. Light underground utility work can be carried out; side clearance can also be done with the help of front loaders, as well as loading and other miscellaneous tasks. Now, the capacity of the backhoe loader is specifically in the range of 1 to 1.2 cubic meters, and the backhoe bucket that is there has a capacity of around 0.2 to 0.3 cubic meters. So it is versatile equipment again used for earthwork. Now, with this particular one, there comes the requirement that once you have brought the soil, dumped the soil, and spread the soil with the help of the dozers and your gridder. Now you need to compact it. I have not discussed the water tankers that need to sprinkle water because we discussed them in the previous lectures. So once the soil is spread, you put water over it through water tankers, ensuring that there is a proper sprinkling arrangement for the uniform distribution of water, and then you can mix it.

You can also mix it with the use of a ripper. You can see that there are rippers there; I will just show you. Yes, Grader. This grader, which you can see at the back, has rippers. These can be used again simultaneously. So many more attachments can be attached to this particular one; the rippers can serve simultaneously, and the harrows can be attached to it to serve other purposes, or they can help us with the mixing.

Now, once that particular part is there, the compaction needs to be started, and compaction is a very important process; it is a mechanical process in which the soil particles are reoriented and brought close to each other, reducing air voids and confining water within the soil mass. So, we try to make this compaction help us improve the bearing capacity, shear strength, density, and impermeability of the soil mass. So, here we perform the compaction through a mechanical process using different kinds of compaction equipment. The soil in a field should have maximum density, which we try to obtain from our laboratory-scale designs, through which we figure out that these soils can achieve this kind of density at a particular moisture content, and we want to achieve a certain percentage of that density in the field as well. And so, once these densities are achieved, the soil is capable of supporting the remaining portion of the roadway yet to be placed because the upcoming layers are going to come over your earthwork, the embankment, and the subgrade construction.

And this compaction equipment helps us; by rolling through the movement of this compaction equipment, we can achieve the desired density. Various types of these rollers, which we commonly refer to as rollers, are used for compacting soils in embankments and subgrades, and we will discuss many types of rollers and where they can be used. So, the choice of the roller: I can use a static three-wheel roller, as shown in the picture here; you might have seen this one working in some places, or I may use something like this one, which is called a sheep's foot roller or a pad foot roller. A similar appearance is present, or I may use a vibratory roller, or this could be a pneumatic tire roller. So, there are different rollers that can be used in combination or for various purposes.

So, their application depends on the layer thickness we are targeting and the properties of the materials that are compacted. So, we will discuss some of the compaction equipment and rollers. The one widely available and used is the static roller, as the word itself indicates that we are going to have some static mass to compact the soil. So, a static roller typically consists of a smooth wheel drum. You can see that this is a smooth wheel drum manufactured in three rows or tandem rows of self-propelled units.

You can see that this is a two-wheeled tandem roller with two wheels, one at the front and one at the rear. We can refer to it as a three-wheeled design, with one smaller wheel in the front and two larger but less wide wheels at the rear. So, it works on the principle of static pressure; as the load is present, it applies static pressure, which is defined as the ratio of static weight. So, the more the weight, the more the pressure that will be applied, and the length of the contact of the rolls with the surface, as well as the diameter of these particular drums, will help us know how much static pressure can be applied to them. The detailed guidelines for this construction equipment are given in IRC SP 97.

Now, in this case, when you have these static, specifically three-wheel rollers, they have two driving steel rear wheels and a steering steel wheel in the front. So, they specifically said this is the one that moves, and this is the one that is driven. So, here this particular static three-wheeled vehicle has two driving steel rear wheels and a steering wheel in the front. So, this is the one that is going to drive, and this one moves in front. Now the contact pressure exerted by the roller helps to densify the underlying material, and they come in different capacities.

The usual one comes in an 8-ton capacity. When we refer to it in terms of tons, it is an 80 kN capacity, which is the usual weight of the roller, but it can also be as high as 100 kN. Normally, what is done is the induction of sand, gravel, and water in front of and behind the rear wheels to increase the weight of these rollers. So, this is how it looks; you can see this is the top. This is one of the conventional three-wheel rollers; there is one at the front, one at the rear end on this side, and the other one will be on the other side. Now, another very common piece of equipment that is used specifically in the compaction of soil is the sheep's foot roller or padfoot roller.

This is how it looks, and the name comes from how the projections on the front drum resemble a sheep's foot. So, what is specifically here in the sheep's foot is that it has metal projections of various shapes; specifically, these have a cylindrical or circular shape, and they penetrate and compact the lower portion of the soil as they go down. It has one or more hollow steel cylindrical drums, typically having one hollow steel cylindrical drum with rows of steel studs mounted on it like a sheep's foot. So, these are the steel studs that you can see on this particular one in the sheep foot roller. Now it compacts the soil from the bottom; the typical process that happens when this sheep's foot roller moves over a soil mass is that the pads penetrate through the top layer, specifically where loose soil is present.

Initially, it is loose soil, so when it moves, it compacts the layer below. These projected ends go down, compact the lower part, and when the roller moves ahead, as each pad exists, it fluffs the surface. So, it makes the top surface loose again, or it makes it fluffy. Now, leaving a loose top layer, it has compacted as it has gone down; this projected part of the lower section is getting compacted. So, with this particular one, we are starting the compaction of the soil from the bottom up, in this case. When a new fill is added and when you put a new layer over it again, you go with this sheep's foot roller; then what will happen is that the fluffed part will be compacted.

So, when new fill is added, the underlying layer is further compacted while the top is fluffed. So, this is how it processes: we start the compaction from the bottom up; in that case, we continue the bottom-up compaction process. So, this is a typical process that is achieved through compaction with a sheep-foot roller. Now, another one that is a slight deviation is specifically called a pad foot or tamping roller, which is present. Similar to a sheep's foot, the important thing is that the lugs of larger areas or the projected areas are larger and tapered.

So, here you can see that these particular ones are comparatively bigger and tapered. Now, when we have these tapered projections or pads, since these pads are tapered, there is no fluffing that occurs during the compaction when the pads come out of the lift. So, it comes out smoothly because they are tapered. So that helps us achieve good compaction here because there is no fluffing happening, or you could say that less fluffing is happening in the top portion. When we use the pad foot rollers, or as we call them, stamping rollers, we achieve better compaction.

So, as per IRC SP 97, if we compare some of the salient features of the sheep foot roller and the pad foot roller, we can see that the roller pad and pad face are specifically mentioned; in the case of the sheep foot, it is cylindrical or circular, resembling more closely a sheep's foot. Here we have a tapered one and a rectangular one. So, these projected ends you can see in this particular one are tapered and rectangular, whereas in this particular case, you can see that these are rounded; these are the sheep foot rollers, and you can see that these are the rounded ones. So, this is the pad face

and the type of pads that are there, and another is specifically here, where you need to move at a slower speed; you can also go for higher speeds while doing the compaction.

Compacted soil can have a thickness of up to 30 centimeters. Normally, we have seen that when we are compacting subgrade soil, the normally recommended compacted thickness is 25 centimeters, and here it can go for compaction up to 30 centimeters. Even in the case of pad foot rollers, it certainly reaches a higher thickness compared to your sheep's foot roller. Best suited for clayey and cohesive soils, they are difficult to compact in large projects. So, especially with sheep's foot or padfoot rollers, they are quite helpful when cohesive soils need to be compacted. Now, vibratory rollers are also known as soil compactors because they are very popular for compacting soil mass.

So, we have a self-propelled, single-drum vibratory roller. This is a common one. You can see there are pneumatic tires at both ends, and this is the single drum at the front, and it is a vibrating one. So that is why it is known as a vibratory roller. So, you have a vibration, and in addition to this vibration, you will experience an impact and pressure. So, pressure will also be applied, and impact will also be implied when vibrations are present; thus, these three actions are combined when using a vibratory roller, which is widely used in soil compaction and typically has one steel drum in front and two pneumatic tires in the rear.

And you can see again that these pneumatic tires have these pad foot-tired rollers; this one specifically in these pneumatic tires, and the purpose is to have a smaller contact area with this particular one. And this will help us further compact the soil mass because it generates more pressure due to the smaller contact area. A greater static linear load, along with a higher amplitude on the steel drum, will result in better soil compaction, and, as I mentioned, these are often known as soil compactors. The vibratory roller forms an improved version of an ordinary smooth steel roller. We have seen earlier where the steel rollers, three-wheel rollers, static three-wheel rollers, static two-wheel rollers, and smooth wheel rollers were located.

And they form attachments, and this vibration—how this vibration is attained—is through attaching rotating weights to the axle. So that helps you to give the vibratory actions here. The vibration is generated by one or more eccentric weights rotating on a shaft, specifically the front shaft centered in the drum. Self-propelled vibratory rollers may have single or tandem vibratory drums.

I will show you a picture. Yes, this is a tandem. So, this is also used, but for soil, you will find that most of the time, this smooth drum single-vibratory roller is used. Now, this has a dead weight usually varying in the range of 8 to 12 tons. So, you might see in many of the specifications that they say if you go, you need to use compaction with 8 to 10 tons, 8 to 12 tons, or 10 to 12 tons of vibratory rollers in that case. So, the drum drive is equipped with a hydraulic motor that provides the attractive forces.

When you have tandem vibratory rollers, they vibrate and drive on both drums. So that is there because vibrations have to be produced from both drums, and that is when you have tandem vibratory rollers. Now, the important part is that when you have these vibrations, there are two components that come into the picture: one is the frequency, and the other is the amplitude. So,

both of them are very important: specifically, how much amplitude there is and what the frequency of the vibration is. So, in general, it is said that there is a high amplitude and a low frequency.

It is specifically required when a soft soil mass is present. So, when you are compacting soft soil masses and the thickness is greater, you should apply higher amplitudes and lower frequencies so that they become compacted. So, this is what you are doing for the soft soil masses with greater thickness. On the other hand, if you have stiff soils and shallow depths, you will prefer to opt for lower amplitudes and higher frequencies. So, this is how you can control the amplitude and the frequency of these vibratory rollers. So, this is a very important part of these vibratory rollers when you do the compaction; you do this compaction, as I mentioned earlier.

Also, we need to construct trial stretches, and then we work out how many vibratory passes will correspond to how many plain passes, without any vibration. So, a combination of these passes needs to be understood, and in this combination, what level of vibrations will be given. There will be levels of vibrations; also, as I mentioned, both the amplitude and the frequency can be varied. So, it similarly states that thick layers require higher amplitude and lower frequency compared to thin layers, where you require low amplitude and high frequency. So, this is an additional advantage that helps us to compact to a greater depth and to a uniform density in a shorter period of time.

For instance, a roller may operate at a high amplitude and a low frequency. So, initially, when I start, for example, if I begin with a soil mass that is loose. So, I would prefer to go with a high amplitude and a low frequency. Thank you.