Construction Methods and Equipment Management
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Lecture-9
Engineering Fundamentals of Moving Earth

Hello everyone, I welcome you all to the lecture 9 of this course construction methods and equipment management. In this lecture we are going to discuss about the fundamental of earthmoving operations. So, what are all the different fundamental terms related to earthmoving operations and we will be exposed to in this particular lecture.

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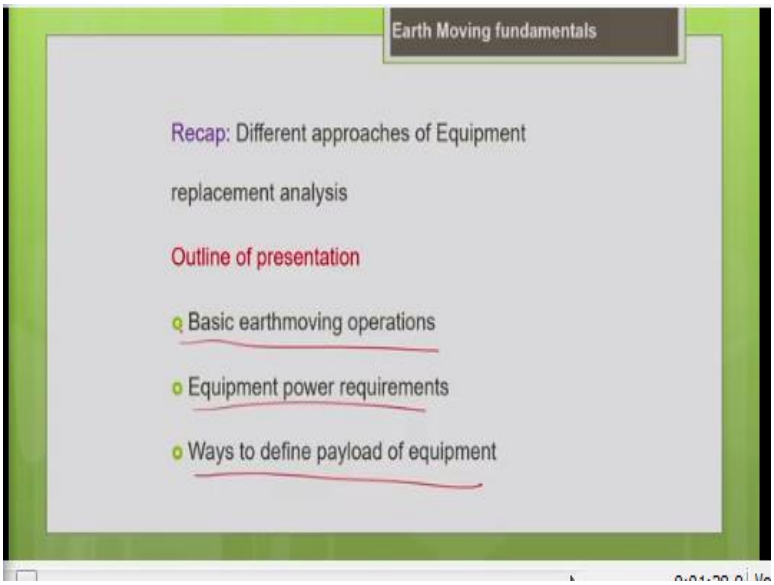

And the let us have a recap of what we learnt in the last lecture. In the lecture 8, we have discussed about the different approaches of the equipment replacement analysis. So, let us look into the outline of today's presentation. In today's presentation I will introduce to you the basic earthmoving operations. So, what are all the basic earthmoving operations and followed by the discussion on what are all the power requirements of the equipment for a particular project condition.

What are all the power requirements, how to estimate the required power? So, these things we will be discussing. And we will also see what are the different ways to define the payload of particular equipment, say how to express it volumetrically or gravimetrically. So, what are the different ways to express the payload on what volumetric basis. So, we are going to learn in this particular lecture.

Basically, this particular lecture is to introduce to you the fundamental terms related to the earthmoving operation. Because followed by this particular lecture, we will be discussing on different earthmoving equipments and the productivity estimation of the earthmoving equipments. So, this particular lecture will help you to understand some fundamental terms related to the earthmoving operation, so that you can have a better understanding of the equipment.

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So, what is the need of earthmoving? So, basically this earthmoving is a very, very broad spectrum. It refers to a broad spectrum of construction activities, it may be simple levelling of ground or a grading of ground or just stripping of the top soil, or it may be some deep excavation for the purpose of making the foundation or excavating trenches for pipeline and or it may be embankment construction. So, all these things involve the earthmoving operation. So, you can see that this earthmoving is a very common activity which can be seen in the most of the construction projects.

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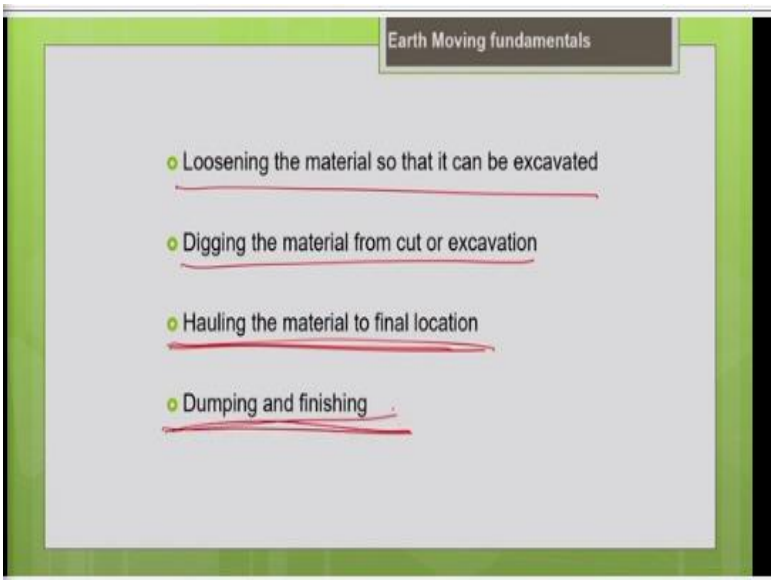

Now let us see what are all the basic steps in the earthmoving operation? To start with we have to first loosen the material which we are trying to move. So, loosening the; material, so that it can be excavated. So, if you loosen it before digging it, it will be more easier to dig, so it will enhance the productivity of the job. So, the first step is loosen the material you can use a tractor with the reaper and then loosen the earth followed by digging the material from the cut of the excavation.

So, after digging, you are going to haul the material to the location where you need to dump it. So, how much distance you need to haul, that depends upon your project requirement. Say for example, for dam construction or for a highway construction, the haul distance maybe longer. So, depending upon your dumping site, depending upon your project requirement the haul distance will vary.

The last step is dumping and finishing. So, you have to dump the hauled earth. So, in some cases, we just dump it in a haphazard manner, so because you may not use that particular material again. So, on organized manner you can just dump it or if you are going to use a dumped material as a fill material, then you have to dump it in an organized manner or uniformly spread it then compacted with the rollers to the required thickness.

So, depends how we are going to dump, depends upon your project requirement. So, these are basic operations involved in most of the earthmoving projects.

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So, let us look into what all are the earthmoving equipment which are commonly used for the earthmoving operations. So, you can see this bulldozer, this is a scraper, this is the loader, front end loader and this is a backhoe, we call this an excavator. So, basically which equipment we need to select depends upon your project requirements. We have discussed about the factors influencing the selection of the equipment in the lecture 1, hope you remember.

So, let us try to have a small recap of what we discussed with from earthmoving perspective. So, basically for the earthmoving operation which equipment I need to select. First you need to think about the haul distance needed. So, what is the haul distance needed for a project because every equipment has it is own economic haul distance. Say for example, bulldozer, it has economic haul distance of 100 meter.

Scraper, you can have economic haul distance of up to 1000 meter. Here loader if it is wheel mounted, you can even go up to 200 meters, this one you cannot go beyond 20 meters. So, it is mobility is very much limited, the backhoe. So, depending upon your haul distance requirement, you have to make the choice. So, another important thing is your project requirement.

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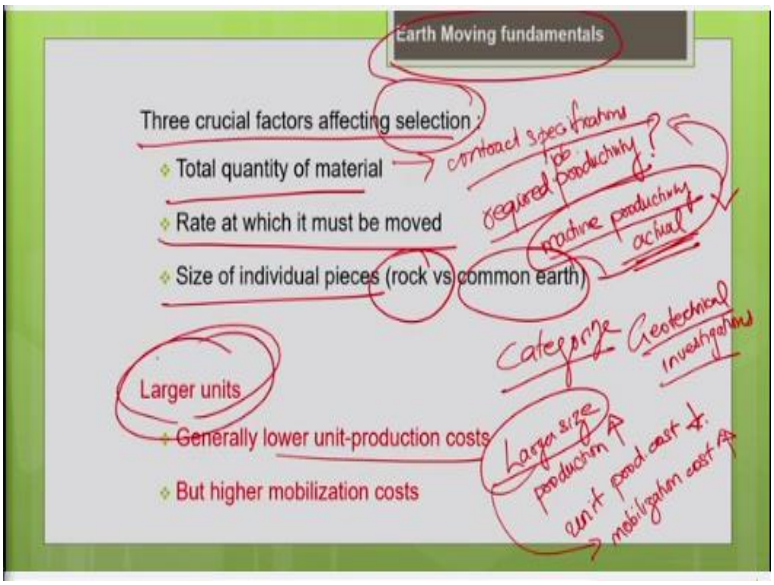

So, basically what are the project requirements, you need to know what is the quantity of material to be excavated? So, that I can know it, from your contract specifications and the drawings, so I can get to know what is the total quantity of material which has to be excavated? And how much is a duration allocated for this particular activity. So, that also you can get it from the specifications from the project schedule or the work breakdown schedule, you can get the duration allocated for the particular activity.

So, now you know what is the; required productivity for that particular job. So, from the contract specifications you can get to know what is the required productivity? So, from the equipment manufacturer, you can know what is the machine capability or the machine actual productivity. So, you can get to know from the manufacturer then you can make the selection accordingly. You know what is the required productivity for that particular job and what is the machine actual productivity you can get it from the manufacturer, so, based upon that you have to make the selection.

So, 3 crucial factors which affect a equipment selection are the total quantity of the material to be moved and the rate at which it must be moved, that you need to know from the contract specifications. And another important thing with respect to earthmoving operation is you need to categorize the material. You need to categorize what type of material you are going to handle. Because the equipment you need to handle common earth and the equipment you need to handle

the rock, they are totally different. So, if you need to excavate the rock, you need to go for different method, drilling, blasting. If it is a weaker rock you can go for a ripper.

So, it depends upon what material you are going to handle, whether it is a common earth or consolidated clay. So, depending upon the size of the individual pieces, you have to make the selection of the equipment. Basically you need to do some geotechnical test or the investigations to categorize the material or you maybe even supply with the information by the contractor.

Or you may have to carry out some tests to know what is the type of material which are going to handle, according to that you have to make the selection. So, basically your economic haul distance of the particular machine, what is the haul distance needed at the project site? What is the underfoot conditions in your project? That will decide the mounting of your machine. And what is the required productivity of your project? And what is the actual productivity of your machine?

All these things you need to know before selecting the earthmoving machine. Another important thing you need to have in mind is, if you go for a larger units, larger equipment, you will have a better reduction in the unit production cost. Because you know that bigger the size of the machine, it is production will be more. So, larger the size of the machine it is production is going to be higher; the volume of production is going to be higher. So, the unit production cost will also be lower**.**

But one thing you have to keep in mind is when you go for larger size machines; your mobilization cost will increase, that you should always keep in mind. Mobilization cost, of mobilizing the machine to the particular project site that will increase when you go for larger size machines. So, you have to achieve a trade off and you have to work out the economics and then justify the selection of your machine.

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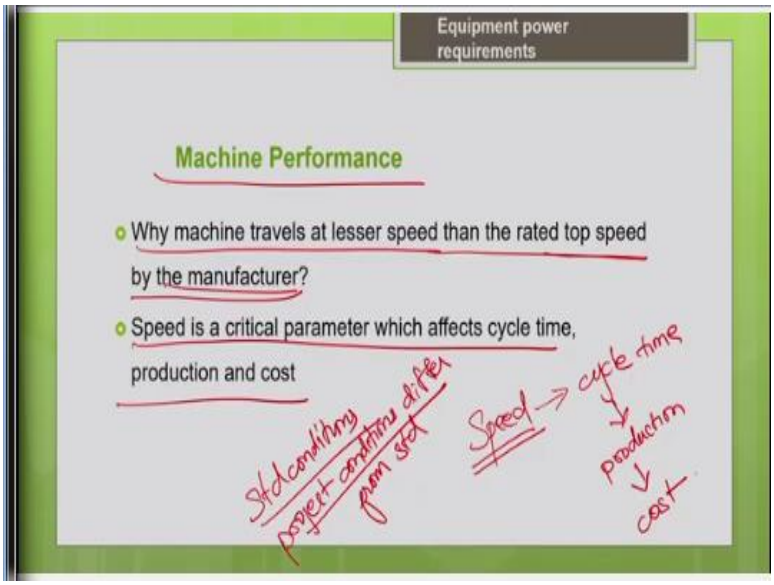
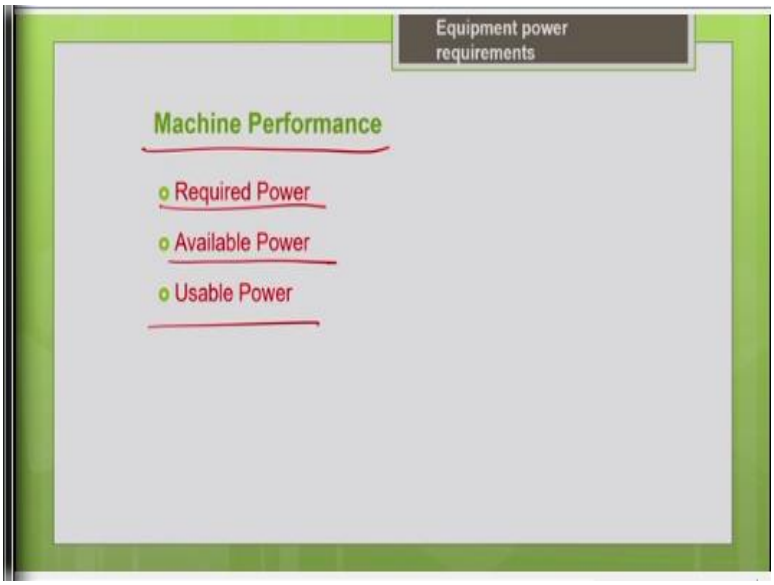


So, there are some more important terms you need to learn with respect to the machine performance. Basically, speed is a very important parameter used to quantify the machine performance. Most of the contractors are interested in the speed of the particular equipment. Because speed will affect your cycle time of the machine that is going to affect your production of the machine, that is going to in turn affect the cost associated with the machine.

So, speed is a critical parameter which affects the cycle time production and the cost. That is why we are very much interested in the speed of construction equipment. So, there is one common question always, why the machine travels at a lesser speed than the rated top speed by the manufacturer. So, most of the times we see that the manufacturer speed rating will be different. But what we realize in your project site will be lesser than the manufacturer rated maximum speed, why is it?

It is because the machine speed rating by the manufacturer is done under some standard conditions, but your project conditions may differ from the standard conditions. So, that is the reason we are not able to realize in many cases the maximum speed or the maximum efficiency prescribed by the manufacturer. So, that is why we need to know what is the expected performance of this particular machine for your project condition, you should be able to analyze that. So, we are going to learn how to analyze the particular performance in the upcoming slides. **(Refer Slide Time: 10:33)**



So, there were some important terminologies, which you need to learn related to machine performance. So, required power, available power, usable power, so these are the 3 important terms related to power requirements of the machine, we are going to learn what are these terms one by one in the upcoming slides.

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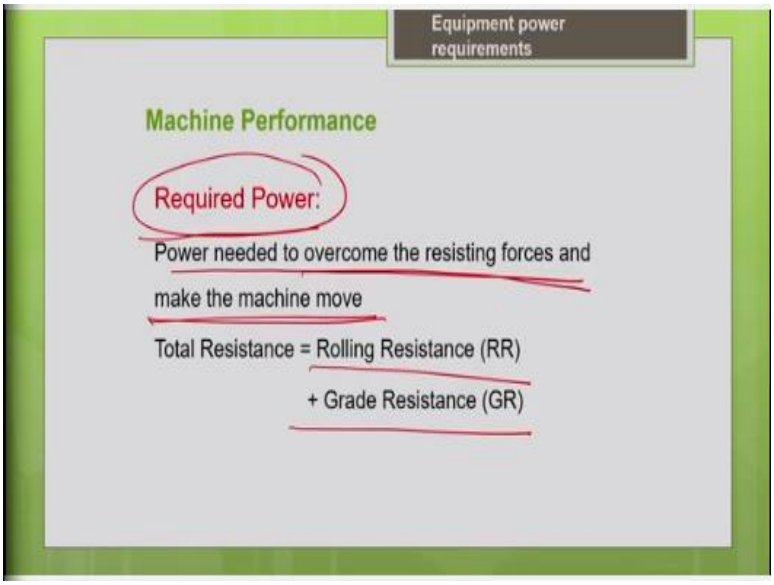

So, what is this required power? So, generally, what is the power needed by the machine to overcome the resisting forces in the project site and keep the machine moving, that is what is a required power. So, you know that every project site is unique, the underfoot conditions of the project site differs from site to site. So, the equipment which are going to use in a particular construction project site has to overcome all the resisting forces in the particular project site.

And then it should keep the machine moving. So, you should select the machine with the sufficient power, so that it can overcome the resisting forces in the underfoot conditions. So, that is what we are going to see, how to determine the required power of this particular machine? So, it is basically the power needed to overcome the resisting forces at the project site and make the machine move**.**

So, what are all the different types of resistances the machine is going to encounter? That is what we are going to see, one is rolling resistance, other one is a grade resistance. We will see what are these rolling resistance and grade resistance one by one in the upcoming slides.

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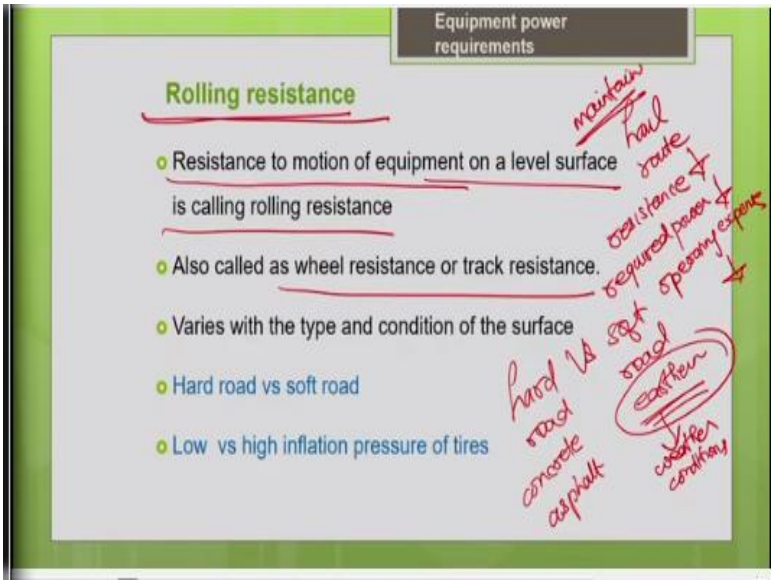

The first thing we will discuss about the rolling resistance. Rolling resistance is nothing but what is the resistance offered by the hauled route to the wheel which is rolling over the particular surface. So, what is the resistance offered by the hauled route to the wheel which is rolling over the particular surface, so that is what is your rolling resistance. So, resistance to the motion of equipment on a level surface is called as rolling resistance.

So, what is the resistance encountered by the wheel, when it is moving on a particular hauled route. That depends upon the type of the hauled route; it may be different for different haul route surfaces. Say for example, for a concrete road the rolling resistance maybe different, for an asphalt road, it

may be different, for the earthen roads it may be different. So, similarly for different types of haul routes the rolling resistances are different.

Basically, we can compare the rolling resistance between hard road and a soft road. So, hard road, you can say a concrete road, your asphalt all these are examples of hard road, your earthen roads are soft road. So, earthen roads, it varies a lot, it depends upon how you maintain it and prepare the earthen roads. If you are properly compacting the earthen roads maintaining the optimum moisture content in the earthen roads, it can even give you a better performance equivalent to hard roads.

So, and this will vary a lot depending upon the weather conditions. So, depending upon what type of drainage you are provided for the earthen roads, so according to that the rolling resistance of the earthen roads will vary a lot with respect to weather conditions and with respect to your maintenance. So, that is why we need to maintain the hauled route, we should spend lot of efforts to maintain the hauled route.

Because if you maintain your hauled route, the resistance encountered by your machine will be less. If the resistance is less, your required power to overcome the resistance will be less, if the required power is less your operating expense will be less. That is why it is always economical to maintain the hauled route**.** So, if you maintain the hauled route well, your resistances encountered by your machine will be less.

So, the required power to overcome this resistance and keep the machine moving will be less and so associated operating expenses and the cost associated with the machine will be less. So, basically this rolling resistance you can even call it as wheel resistance or track resistance depending upon what type of mounting your machine is going to have. So, it maybe a wheel mounted machine or it can be a crawler or track-mounted machine. So, according to this you can call it as wheel resistance or track resistance.

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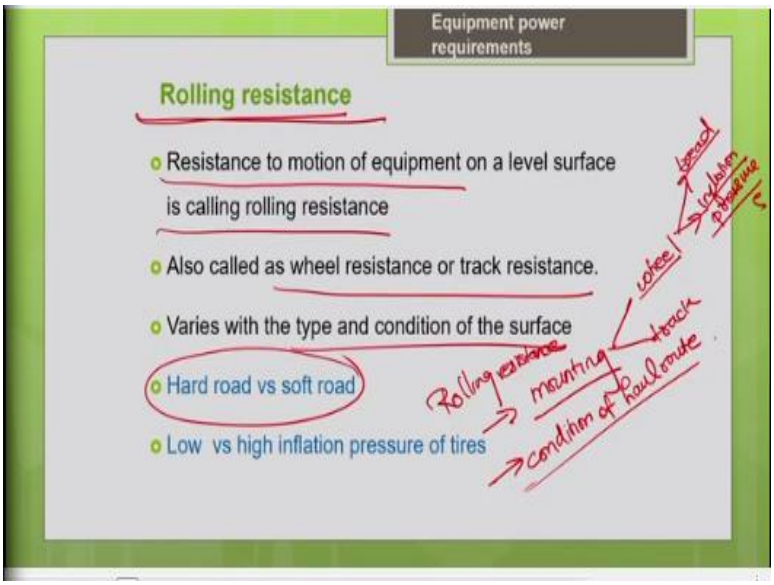

As I told you, it varies a lot with the type and the condition of the surface. And also, it depends upon the mountin, it depends upon the condition of your surface, condition of your hauled route. So, mounting in the sense, it can be either a wheel mounted or it can be a track mounted. If it is wheel mounted, even your dimension of your tyre, the tread dimension of your tyre and the inflation pressure of your tyre, all these things are going to affect your rolling resistance.

Your rolling resistance is going to depend upon so many factors; one is on your mounting. If it is going to be a wheel mounting, it depends upon the dimension of your tread, it depends upon inflation pressure in your tyre. Apart from that, it also depends upon your condition of the surface on which the wheel is moving. So, we were comparing the rolling resistance of the hard road and the soft road. So, I gave you the examples for hard road this soft road. So, your concrete and asphalt roads are hard roads and earthen roads, you can take it as an example for this soft road.

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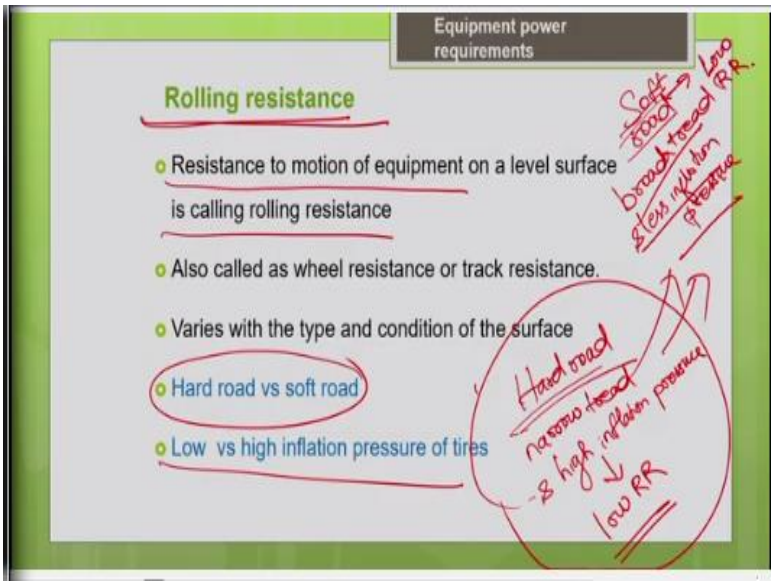

Say in a hard road, if you consider the rolling resistance, your wheel with a narrow tread, say a wheel with a smaller dimension that this narrow tread and high inflation pressure in the tyre, so that will give you low rolling resistance. So, if you see in the hard road to have a low resistance I need tyre with narrow tread smaller dimension and high inflation pressure. So, that the contact area of the surface will be the minimum, so that the resistance will be minimum, so this is for the hard road, but the same thing will not apply for the soft road.

If you look into the soft road, that is an earthen road. In the earthen road, if you go for narrow tread and high inflation pressure in the earthen road or the soft road, what will happen? The tyre will sink into the road, so it can easily sink into the road if it has high inflation pressure and narrow tread. Because generally in the softer surfaces the tyre tends to sink, it seems to a depth till it attains a contact area, so that the load can be distributed.

So, till it reaches a particular depth it will sink till it attains a particular contact area. So, that is why in the soft road, you should have a broader tread. Broader tread I mean, wider tires and you should go for less inflation pressure. So, this will give you low rolling resistance in the soft road. So, the things which are favourable for the hard road are not favourable for the soft road, so you should note that**.**

For the soft road, I need a tyre with a broader contact area, so that it will not sink much into the softer road. And also I need a tyre with lesser inflation pressure, so that it will not sink much into the softer road. So, accordingly you have to make the selection of your mounting, so that you can have a lesser rolling resistance. So, now we have discussed what are all the factors which affect the rolling resistance?

Basically, you have to maintain a hauled route, so that the rolling resistance is minimum, so that your amount of power needed by the machine to overcome the rolling resistance will be less that will make it more economical.

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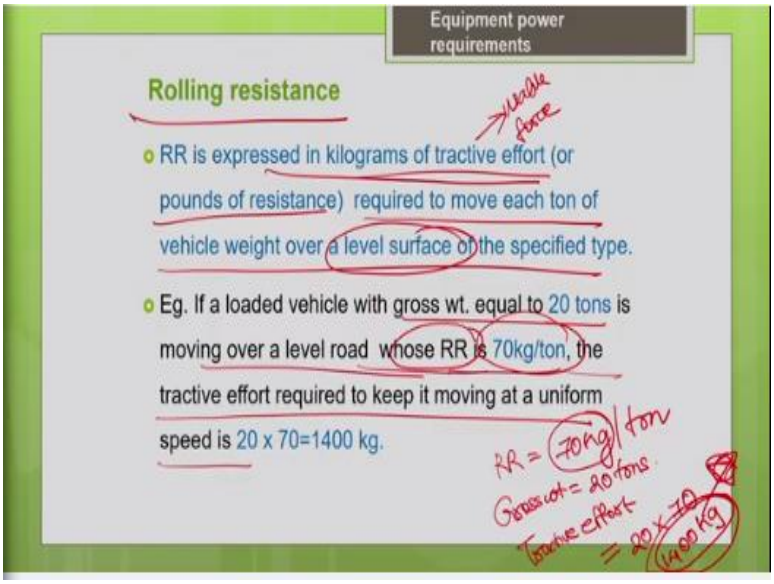

So, this rolling resistance is expressed in kilograms of tractive effort. So, tractive effort is nothing but your usable force, usable force at the point of contact between your wheel and the ground. So, rolling resistance is expressed in kilograms of tractive effort or pounds of resistance, these are just different types of units. So, either you can express it in kilograms of tractive efforts or pounds of resistance required to move each ton of the vehicle weight over a level surface of the specified type.

So, basically it is the amount of force needed to move unit weight of the machine on a level surface, why we consider level surface? Because the effect of grade, on the effect of slope will be considered separately under grade resistance, that we are not considering here under rolling

resistance. So, basically, rolling resistance you can see that it is expressed in kg of your tractive effort needed to move a unit weight of your machine over the particular surface.

Say for example, you have a loaded vehicle, it is gross weight is equal to 20 tons, it is moving over a level road. So, whose rolling resistance is given as 70 kg per ton. So, this rolling resistance value, you can get it from the literature for different types of haul routes, earthen roads, properly maintained earthen roads, poorly maintained earthen roads, for concrete roads, for asphalt roads for different types of roads, for different types of mounting of machines.

If it is rubber tyre mounted, for different inflation pressures, what is the rolling resistance value? You can get it from the literature. So, I have given you directly here for this particular problem. Say the rolling resistance for this haul route is given as 70 kg per ton, that means you need 70 kg of force, 70 kg of tractive efforts to move unit ton of your machine. Now you need to find what is that tractive effort required to, keep it moving at a uniform speed.

So, for this particular road, the rolling resistance is given as 70 kg per ton. That means, to move a unique kind of machine on the particular surface, I need 70 kg of force. Now you know what is the gross weight of your machine? What is the gross weight of your machine? It is nothing but 20 tons. Now we can calculate what is the tractive effort needed to overcome this rolling resistance and keep the machine moving. So, what is the tractive effort needed?

Let us multiply this weight of the machine 20 times into 70 kg that gives you 1400 kg. So, this is a tractive effort needed to move the machine over this particular surface. So, why do we calculate all these things? So, that you can make a selection of a machine accordingly. So, the required power to overcome this resistance is 1400 kg. So, you have to make a selection of the machine accordingly, so that this much amount of power is available with a particular machine to overcome this resistance in this project site.

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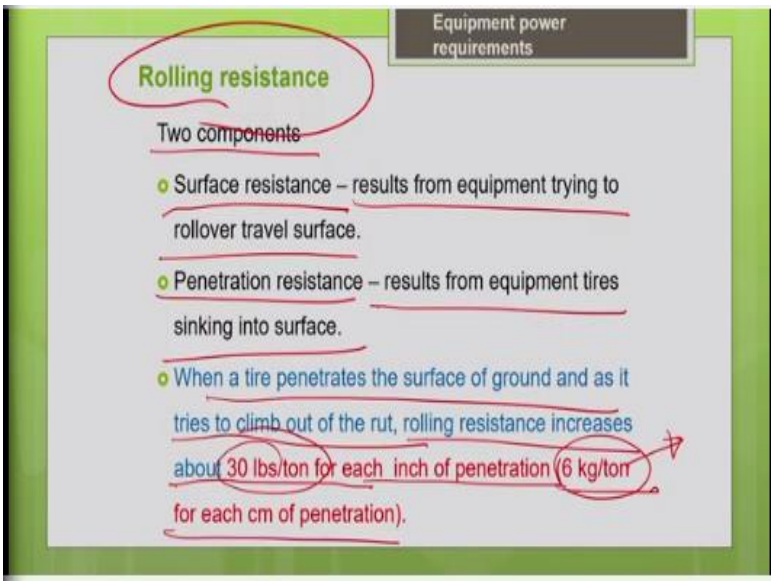

So, what are all the 2 important components of the rolling resistance? Let us see, one is the surface resistance other one is your penetration resistance. So, you can break this rolling resistance into 2 components, one is at the surface. So, the resistance which is encountered at the surface when the; wheel is moving over or rolling over the surface that is surface resistance.

Penetration resistance is nothing but the resistance encountered when the tire is sinking into the surface that is your penetration surface, this will happen for soft roads. Surface resistance results from the equipment trying to roll over the travel surface. Penetration resistance results from the equipment tires sinking into the surface. So, both these things we have to estimate and add it to find the total rolling resistance.

Now let us see how to estimate the penetration resistance. Say when a tire penetrates into a surface, so the resistance, the rolling resistance increases. So, say for example when the tire is sinking into the particular surface, you need some additional efforts to come out of the particular rut and keeps the machine moving. So, you need some additional efforts to bring the machine out of that rut and keep it moving.

So, what is the additional effort? That is what we are going to find now. So, when a tire penetrates into the surface of the ground and as it tries to climb out of the rut, the rolling resistance increases

about 30 pounds per ton for each inch of penetration. So, for 1 inch of penetration into the surface, how much efforts we need? 30 pounds per unit weight of the machine.

In SI units you need 6 kg per ton, 6 kg per unit weight of the machine, for each centimeter of penetration of the tyre into the surface. So, basically your rolling resistance increases by 6 kg per ton for each centimeter of penetration of the tyre into the surface. So, using this you can calculate your penetration resistance.

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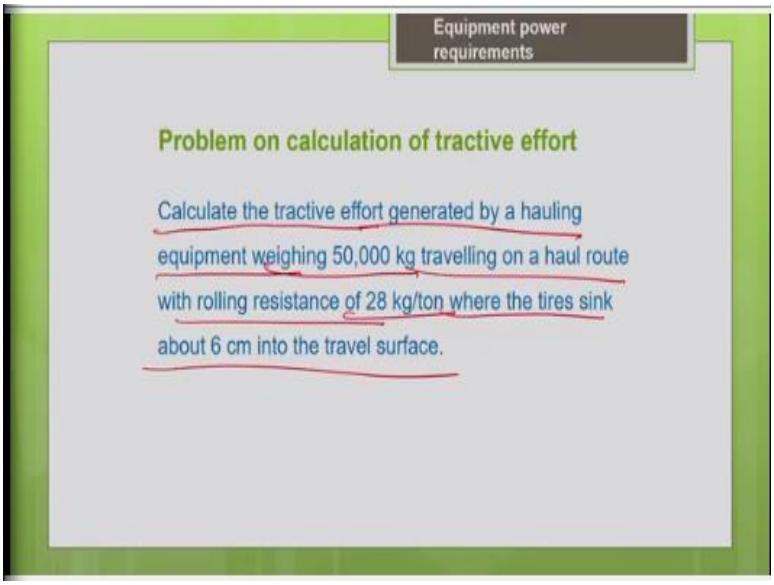

Now, for better understanding, let us work out a problem on calculation of the tractive effort. So, calculate the tractive effort generated by a hauling equipment, it is gross weight is given as 50,000 kg, it is traveling on a haul route. It is rolling resistance is given to you directly you can take it from the literature for that particular haul route; it is given as 28 kg per ton. And another important thing to be noted is your tire is sinking about 6 centimeters into the travel surface.

That means you have to take into account the penetration resistance also. Now we are going to find what is the total tractive effort needed to overcome this resistance is in the underfoot conditions in your project site.

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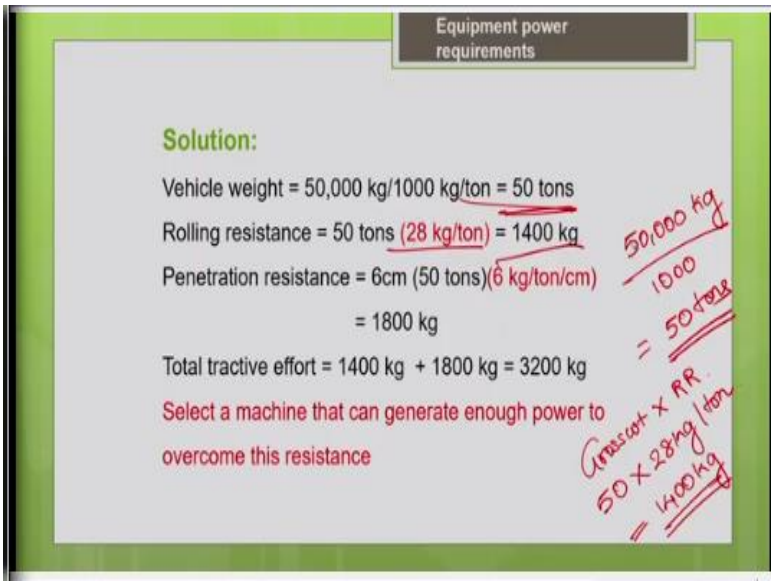

So, let us convert the vehicle weight into tons, because your rolling resistance is commonly expressed as kg per ton. So, let us convert the weight of the machine into tons you know that the gross weight of the machine is given as 50,000 kg. So, 1000 kg = 1 ton, so divided you will get the gross weight of the machine as 50 tons. Now the rolling resistance you need to calculate for this particular haul route it is given as 28 kg per ton.

So, you multiply the gross weight of the machine by the rolling resistance value. So, gross weight is 50 tons multiplied by the rolling resistance is 28 kg per ton for that particular haul route. So, now we are going to calculate for your particular vehicle what is the total rolling resistance? That is nothing but 1400 kg, so 1400 kg is your rolling resistance. Now we need to find the penetration resistance.

It is given to you in the problem that the tyre is sinking to the depth of 6 centimeters into the surface. So, you know that for each centimeter of penetration the amount of effort needed is 6 kg per ton per centimeter you know that**.**

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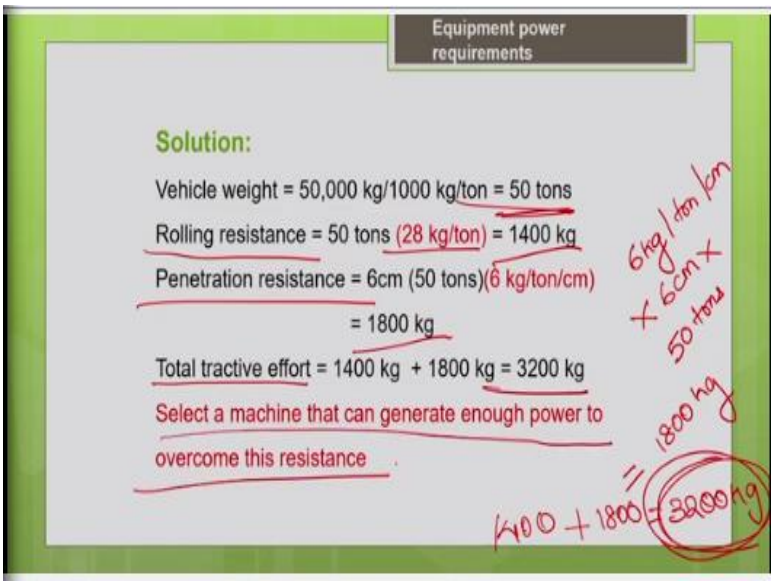

So, you multiply that by how much is the depth of penetration? It is nothing but 6 centimeter, and what is the gross weight of the machine? It is nothing but 50 tons. So, that gives you the penetration resistance as 1800 kg. Now we can find the total resistance, that is nothing but add your rolling resistance and the penetration resistance. It is nothing but your 1400 kg + 1800 kg, so that gives me the answer as 3200 kg is the total resistance.

So, I need tractive effort of at least 3200 kg to overcome this resistance in a project site. So, the total tractive effort needed to overcome this resistance is 3200 kg. So, select the machine accordingly, that is the purpose of estimating all this resistance, so that we can know what is the required power for your machine? Select a machine that can generate enough power to overcome this resistance**.**

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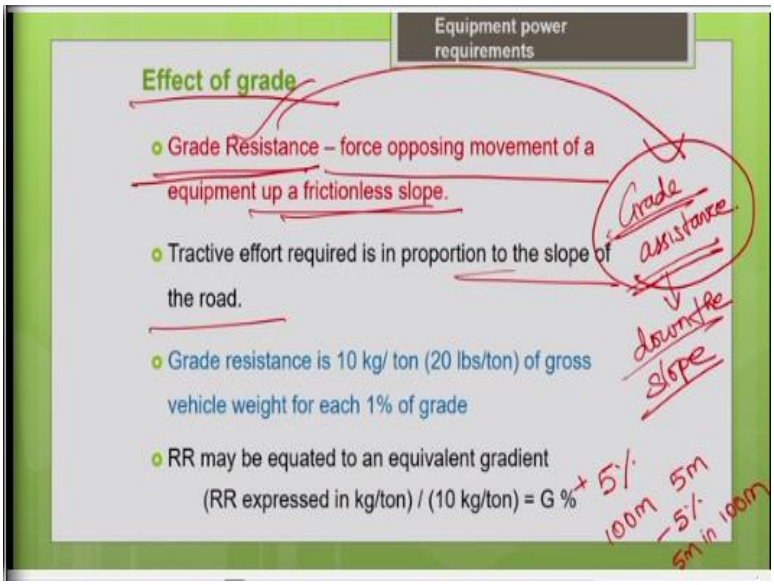

Now so far, we have discussed about the rolling resistance, let us look into the other part of the resistance in your project site that is your grade resistance. Most often you can see that equipment has to climb up a slope. So, when the machine is climbing up the slope, obviously you need some additional efforts to make it move up the slope because it is pulling against the gravity.

So, there is a force opposing the movement of the machine when it is moving up the slope that is causing grade resistance. So, when the machine is moving up the slope, so the machine is encountering grade resistance, that is a force opposing the motion of the machine movement of the machine up a frictionless slope. So, the friction part is considered separately. So, here we are going to consider what is the effect of grade, so grade resistance alone?

So, how much tractive effort we need? So, to overcome this grade resistance that depends upon the percentage of the slope how steep is your slope? According to the tractive force requirement will vary. Now similar to this, we should also know about what is grade assistance? So, we discussed about what is grade resistance, there is something called as grade assistance that means what?

When your machine is moving down the slope, you can see that the amount of power needed gets reduced because it can easily move down by the gravity, so the gravitational force will help you to easily move the machine. So, in that case the amount of power needed gets reduced, so that is

called as grade assistance. So, your grade resistance and the grade assistance are opposite to each other.

So, now let us look into the grade resistance. So, grade resistance as I told you the amount of tractive effort needed to overcome this grade resistance will depend upon the percentage of your gradient or the slope percentage or the steepness of the slope. Say for example, if your slope percentage is say 5%, it means what? In a horizontal distance of 100 meter you will have a surface rise of vertical surfaces rise of 5 meter that is 5%.

So, this is +5 that means upslope. If you say -5% it means down the slope that means you will have a fall of 5-meter vertical fall of 5 meters in a horizontal distance of 100 meter. So, that is what you mean by a -5%. So, basically greater the percentage of your slope the amount of tractive effort needed will be more. So, when you select your haul route, so we have to be very careful in the selection of your haul route.

So, if there is a option that you can use the down slope, it is always preferable to use down slopes, because your power required gets reduced. So, that way your operating cost gets reduced. So, you have to select the haul route accordingly, so that the total resistance in that particular haul route, your rolling resistance as well as the grade resistance will be minimum. Otherwise you have to prepare or maintain the haul route, so that the resistance gets reduced, so that the operating expenses will get reduced. Now let us see how to calculate the grade resistance.

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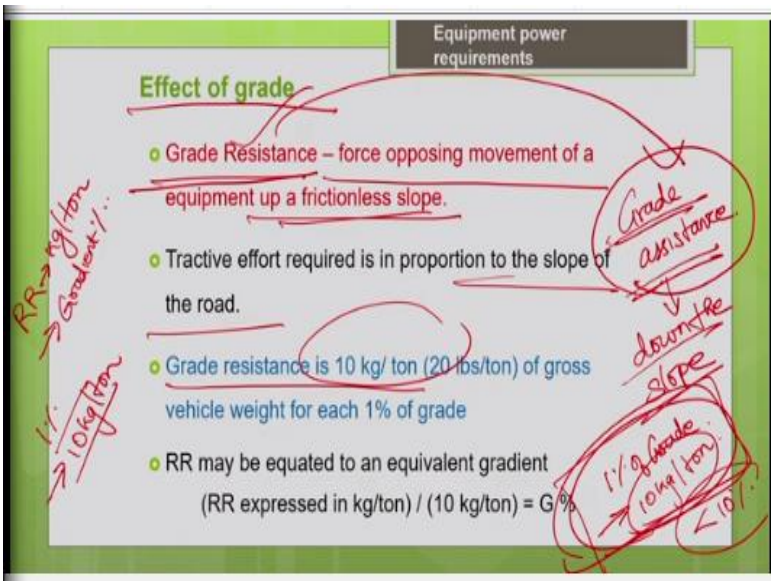

Grade resistance is nothing but by simple elementary I mean a mechanics people have worked out this the relations. Say for example, for 1% of grade so the amount of tractive effort needed to overcome this 1% of grade it is 10 kg per ton. So, this is simple guideline which they are worked out which is worked out in the literature you can easily find it. So, for 1% of grade, so the grade resistance is 10 kg per ton.

So, these guidelines will be valid for smaller slopes, say less than a 10% you can go by this guideline. So, there are sufficient information's in different literature which I have cited in the references towards the end of the lecture, you can go through. So, you can find the tables, which provide you the grade resistance for different percentage of gradient. For different slope percentage, what is a grade resistance?

You can directly take it from the literature. There are tables provided in the literature or you can go with a simple guideline also, but this valid for smaller slopes till 10%. So, for every 1% of grade, so your grade resistance is 10 kg per ton. So, now you can convert a rolling resistance also into equivalent gradient. The rolling resistance which you have expressed in kg per ton, that you can converted into gradient percentage equivalent gradient I can convert it, so how to convert it? So, you know the rolling resistance in kg per ton.

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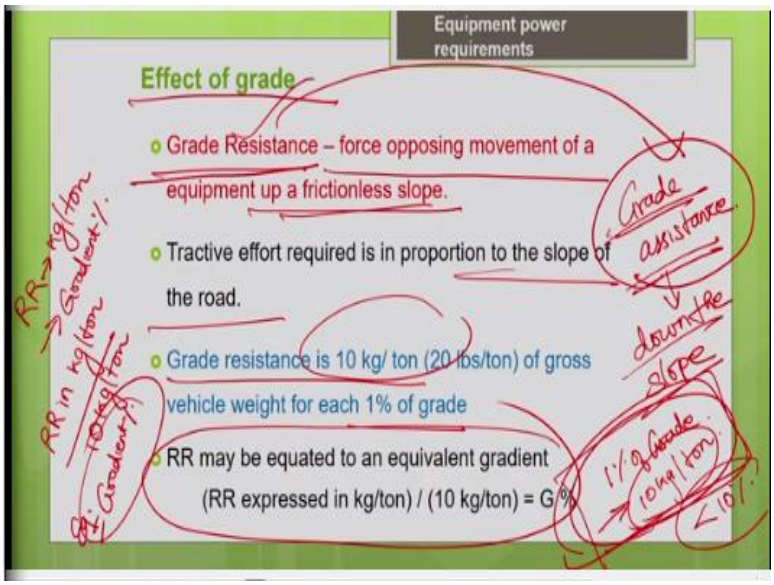

Rolling resistance you know in kg per ton, so you know that 1% of grade equal to 10 kg per ton. So, you divide it by 10 kg per ton, you will get the equivalent gradient percentage, so you can get the equivalent gradient. So, the rolling resistance for your convenience, you can have both the rolling resistance as well as the grade resistance both in terms of gradient percentage. So, with the simple relationship we can just convert the rolling resistance also into equivalent gradient. So, when you work out the problems you will understand this better, what is the significance of converting it?

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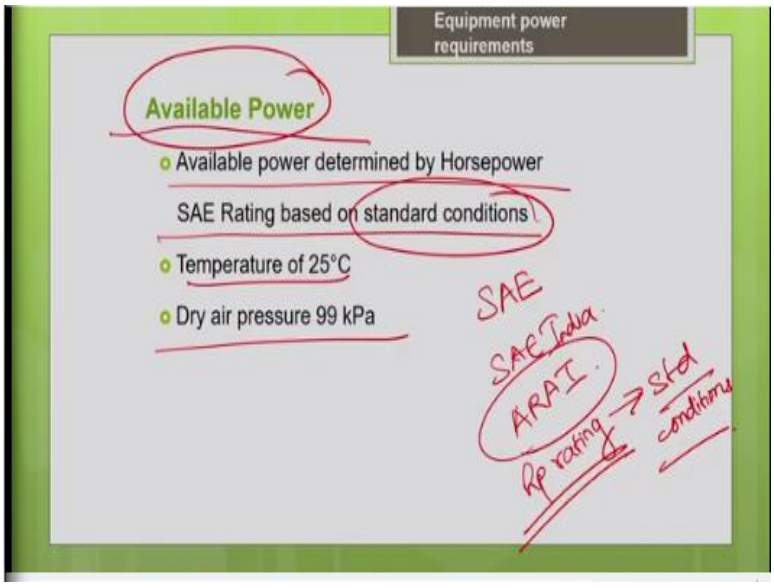

So, so far what we have discussed is about the required power. So, what is the total power required by the machine to overcome the different resistances in the project site, in the underfoot conditions.

Say your surface resistance or penetration resistance or a grade resistance, all these resisting forces which are opposing the motion of the machine, your machine should overcome it, for that it should have some sufficient power.

So, what is the power requirement that is what we have estimated so far. Now we are going to look into the estimation of the available power. So, the available power you can get the data easily, because the manufacturer would have done the horsepower rating of the machine. So, the available power is determined by the SAE rating. So, there is an organization called as SAE Society of Automotive Engineers, it is a US based organization.

So, in India also we have an organization SAE India. There are other organizations like automotive research association of India. So, there are different organizations which are doing the testing and the horsepower rating of the machines. So, horsepower rating is done by these organizations when they do this horsepower rating. They do the horsepower rating of the machine at standard condition that is to be noted.

The standard conditions are also defined by them. So, you can say for example, it is done at temperature of 25 degrees Celsius and at a particular atmospheric pressure, say 99 kilo Pascal. So, the efficiency of the machine, prescribed by them or the horsepower rating of the machine prescribed by the manufacturer, you can realize only at this particular standard conditions. But when your project conditions are going to deviate from these standard conditions, obviously your efficiency of the machine is going to be lesser, it will be different, and it will be lesser mostly.

Say for example, if you are working at a very high altitude, my project site is at a very high altitude, my equipment is at a higher altitude the atmospheric pressure will be lesser there. So, obviously you may not be able to realize the same efficiency as prescribed by the manufacturer, that we have to always keep it in mind. So, the available power as prescribed by the manufacturer, there is no guarantee that we will be able to completely realize it in your project site because, your project conditions only decides how much of the available power is going to be usable to you or not.

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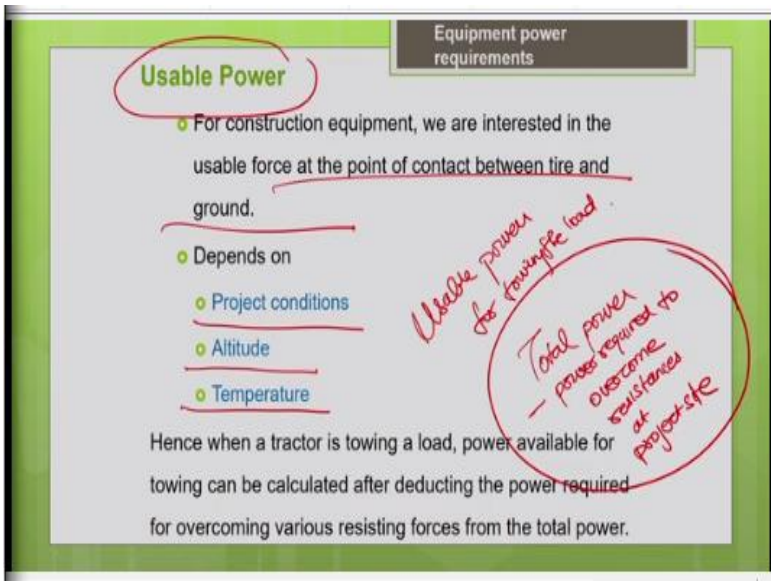

So, now let us see what is this usable power? So, out of the available power prescribed by the manufacturer, how much amount of power becomes usable to you? That depends upon your project condition that depends upon the altitude of your project site and the temperature at your place. Because as I told you the horsepower rating is done at a particular atmospheric pressure and it is done at a particular temperature.

So, when your project conditions are going to differ from that particular condition the usable power will be obviously different. But what we are interested is in mainly the usable power only. So, what is the usable force which can be realized at the point of contact between the tire and the ground, this is what is of our major interest? So, we need to estimate this usable power of this particular machine.

We are going to see how to estimate the usable power? Say for example, when we are using a tractor for towing the load. So, how much power is actually available for the towing the load? That we need to calculate, so you know what is the total power available for the tractor, you know from the manufacturer what is the maximum power possible you know that for the particular tractor. Where the tractors working?

In your project site, what are the underfoot conditions that you know? What are all the resistances it has overcome that you know? So, what is the rolling resistance? What is the grade resistance?

Everything we need to calculate. So, now from the total power you detect the power needed to overcome the power required to overcome the resistances at the project site. So, this will give me what is the actual usable power for towing my load.

So, from the total power you have to detect the power what is needed for overcoming the resistances in your projects site condition. After overcoming the resistance of the project site condition, only the remaining power is available for you to do the actual job of towing the load.

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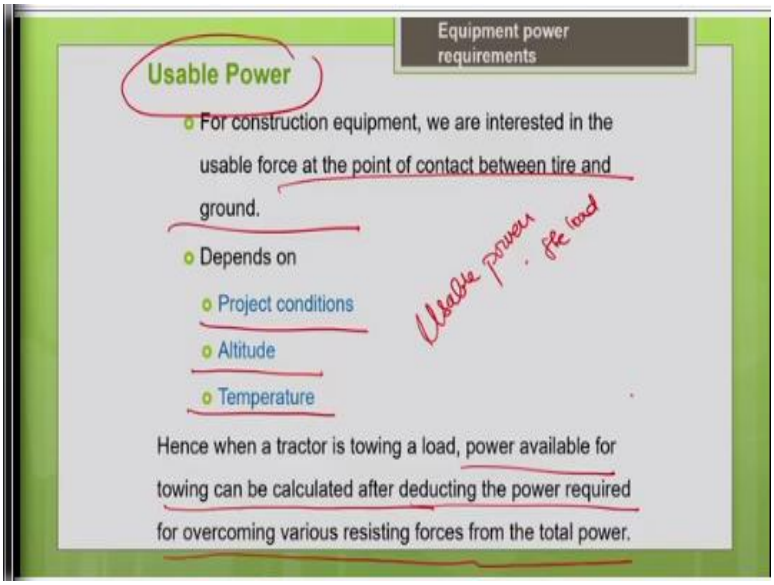

So, where a tractor is towing to load, the power available for towing can be calculated after detecting the power required for overcoming the various resistance forces from the total power. So, this we have to keep in mind, so this is nothing but your usable power.

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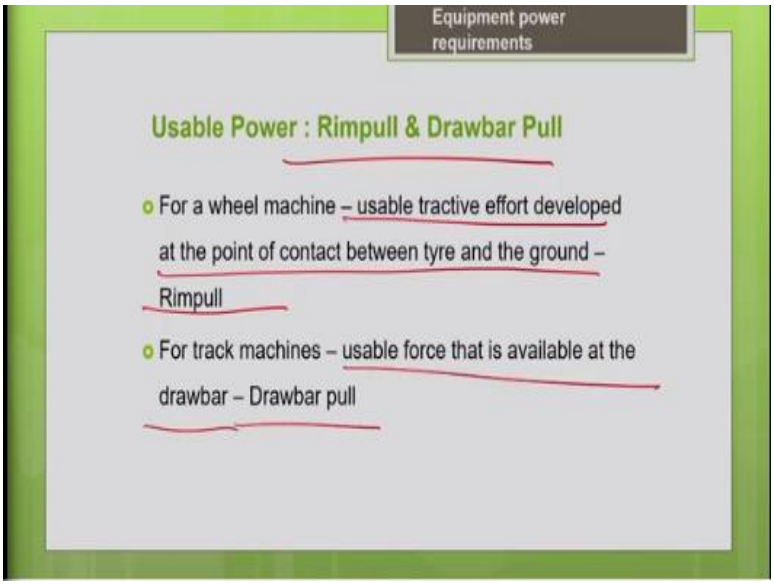

The usable power you can express in terms of rimpull or drawbar pull. So, depending upon the mounting of your machine. So, if it is going to be wheel or tyre mounted machine, we call it as rimpull. The usable tractive force developed at the point of contact between the tyre and the ground is called as a rimpull. Similarly, for the track mounted machines, track machines or the crawler mounted machines, it is called drawbar pull, the usable force that is available like a drawbar. So, the terminology varies with respect to the mounting of a machine.

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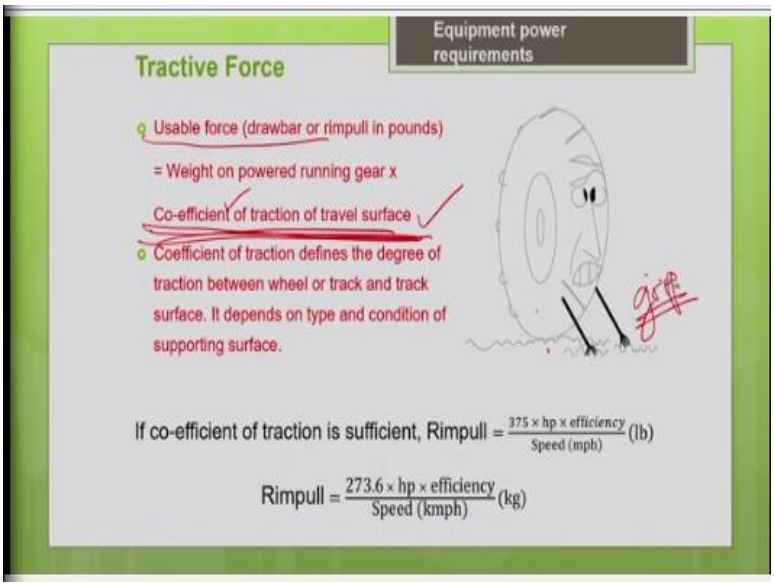

So, how to calculate this usable force? So, this usable force is going to depend upon the traction of your travel surface. So, as I told you how much amount of the total power becomes usable, it depends upon the degree of traction between your wheel and the ground. Traction is nothing but

your grip, the grip between the tyre and the ground. If you have sufficient grip sufficient traction between the tire and the ground, then total power will be converted into usable power.

But if the traction is poor, in that case you can see that only some portion of the total power can be converted into usable power. Then how much portion is going to be converted into usable power depends upon the coefficient of traction of the travel surface. So, that depends, that varies from surface to surface, this value also I can get it from the literature. Say for example, for a slippery surface obviously a coefficient of traction will be less.

For a concrete surface or asphalt surface, or a snow-covered surface, so for different surfaces, for a muddy surface. So, what are all the coefficients of traction? I can get it from the literature. So, depending upon the traction, the usable force is going to vary. So, the total usable force which is available depends upon the traction. If you have a better traction and more power will be converted into usable force.

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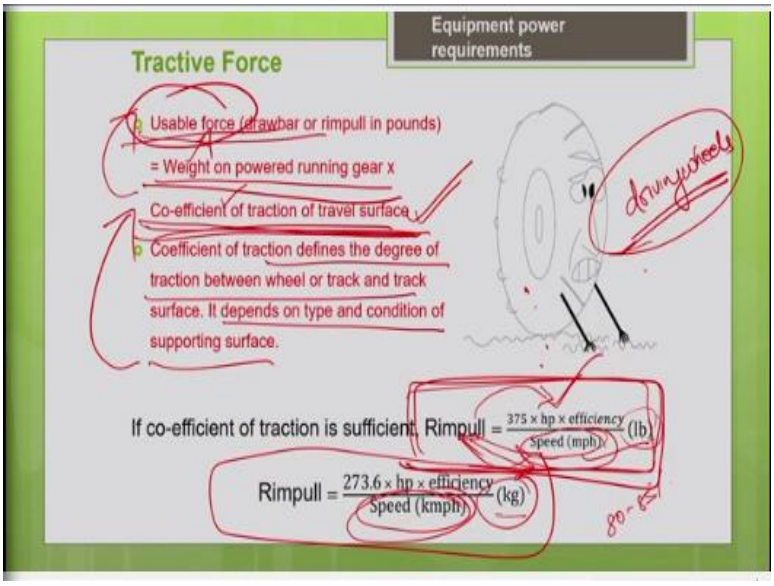

So, another important thing to be noted is weight on the power running gear of the machine. So, in common equipment or the common wheels of the cars whatever we are using, you can see that all the wheels of the car are not driving wheels. Common machines you can see that all the axles are not powered and all the wheels are not driving wheels. So, only some of the axles will be powered and the other axels will be just acting like a steering component.

So, you need to know that there is something called as driving wheels. So, certain equipments which are used for very tough conditions, say for example the construction equipments which are used for very tough conditions we prefer to go for all driving wheel. That means all the axels are powered and all the wheels will be driving. But some equipment which are used for just average conditions or moderate conditions, I need not go for all driving wheel equipments.

In that equipment, only some of the axles are powered and the remaining wheels are not driving, they are not powered. So, when you calculate the usable powers, we have to estimate what is the weight on the power driving gear that is only important to us. So, that is only playing role in the usable for generation. So, what is the weight of the vehicle, which is transmitted on the driving wheels, that is only important to us, that is used in the estimation of the usable force.

So, usable force is nothing but weight on the paver running gear multiplied by the coefficient of traction of the travel surface. So, greater the coefficient of traction of a travel surface, obviously the usable force generated is going to be greater. The coefficient of traction defines the degree of traction between your wheel or the track and the surface. It is going to depend upon a type and the condition of the supporting surface, how you maintain your surface?

All these things are going to affect your coefficient of traction. Say assumes your coefficient of traction is sufficient, if there is proper traction, sufficient traction between your wheel and the ground. In that case your rimpull can be taken as a function of your horsepower of the machine. Using this simple relationship, you can directly estimate the rimpull if you know the horsepower of the machine given by the manufacturer, equipment manufacturer.

And you should know that it is a function of speed; inverse function rimpull and the speed of the machine are inversely related. So, you can see the greater the speed of the machine the rimpull possible is lesser, the pull is lesser, they both are inversely related to each other. So, if the traction is sufficient, you can take the rimpull as a direct function of the horsepower of the machine, you can easily estimate the rimpull.

If you know the horsepower from the manufacturer, from the speed of the machine you can estimate the rimpull, so this is a relationship to estimate in pounds. In SI units you can use this relationship 273.6 into horsepower into efficiency. So, efficiency it will vary from 80 to 85%, you can assume the value. So, for the SI units you take this speed in kilometer per hour. So, here we are taking the speed is miles per hour and you get the answer of a rimpull in the pounds. Here you get the rimpull in kg. So, you are substituting the speed in kilometers per hour, so like that.

$$\textbf{Rimpull} = \frac{375 \times hp \times efficiency}{speed\ (mph)}\ \textbf{(lb)} = \frac{273.6 \times hp \times efficiency}{speed\ (kmph)}\ \textbf{(kg)}$$

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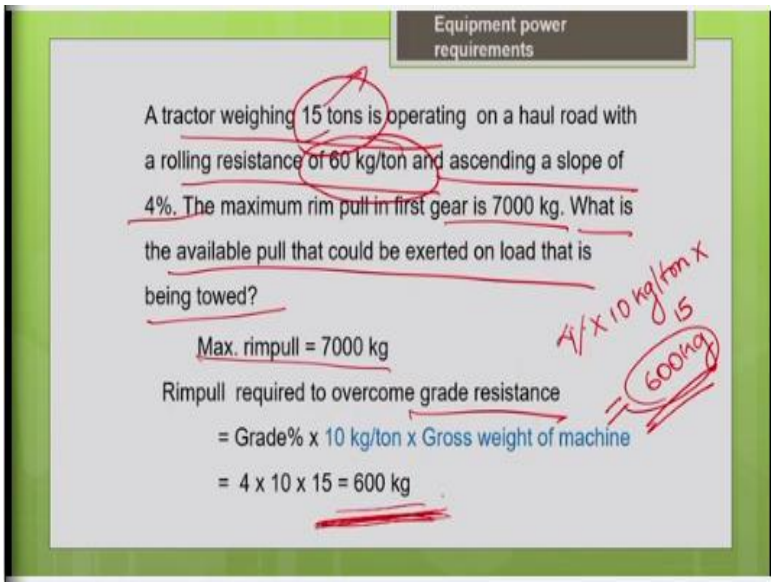

Now let us workout the problem on how to estimate the power requirements of the machine. So, a tractor weighing 15 tons is operating on a haul road, the gross weight of the machine is given as 15 tons. It means it includes it is empty weight as well as the load it is carrying, with the rolling resistance of 60 kg per ton, it is given you can take it from the literature also for this particular haul route.

For this particular mounting, what is the rolling resistance? The tables are available you can take it. And this machine is climbing a slope of 4% the gradient is given, the maximum rimpull in the first gear is 7000 kg. So, that is given by the manufacturer, what is the maximum rimpull possible for this machine in the first gear, it is given as 7000 kg. Now you are supposed to calculate what is the available pull that could be exerted on the load that is being told?

That is what we are interested, what is the usable power? So, that is available to pull your load or tow your load that is what we are going to estimate now. So, you know that the rimpull maximum rimpull available is 7000 kg for this particular machine is given by the manufacturer. Now you need to know what is a grade resistance on the rolling resistance? So, that you can find what is the tractive effort needed to overcome the grade resistance and the rolling resistance?

First let us see what is the tractive effort needed to overcome the grade resistance? Grade resistance, you know the grade percentage it is nothing but 4 %. As I told you for 1% of grade, the grade resistance is 10 kg per ton. So, 4% multiplied by 10 kg per ton, multiplied by the gross weight of the machine, what is the gross weight of machine? Nothing but 15 tons, it is given to you as 15 tons.

Rimpull required to overcome grade resistance = 4×10×15 = 600kg

So, this gives me the total tractive effort required to overcome the grade resistance. So, if you multiply this you will get the answer of 600 kg. So, this much rimpull is needed, this is the required power to overcome the grade resistance.

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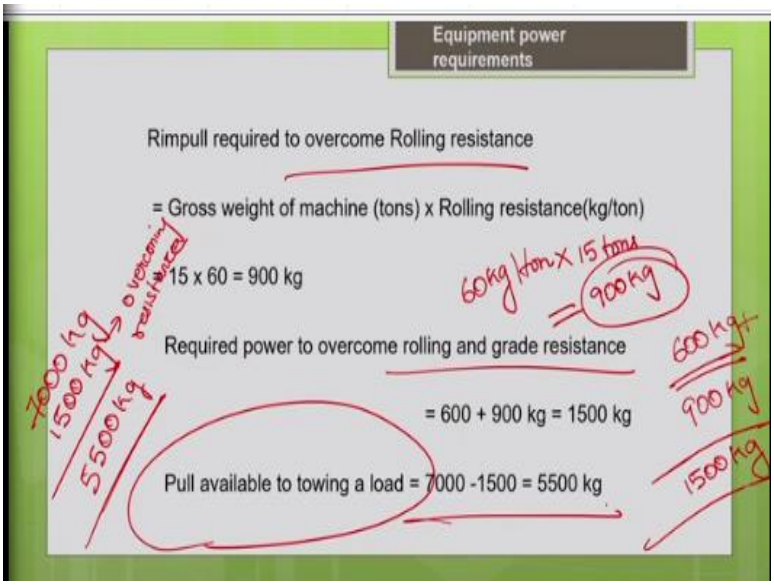

Now let us calculate how to estimate a tractive effort to overcome the rolling resistance? So, it is nothing but for this particular haul route the rolling resistance value is given us 60 kg per ton. So, what is the gross weight of your machine? It is nothing but 15 tons. So, that gives me the total

rolling resistance as 900 kg. So, you need this much amount of tractive effort to overcome this rolling resistance.

Rimpull required to overcome rolling resistance = 60×15 = 900kg

Now the total power required to overcome all the resistances are given here as 600 kg. So, 600 kg is nothing but your grade resistance, the power needed to overcome this grade resistance plus 900 kg is your the rolling resistance. You add both; you will get this total power needed to overcome the total resistance, 1500 kg. Now you know that the maximum rimpull available for this machine as given by the manufacturer is 7000 kg.

Required power to overcome rolling and grade resistance = 600 + 900 = 1500 kg

So, out of this 7000 kg, 1500 kg will be used for overcoming the resistances. So, for overcoming the different resistances in the project site, you are going to spend 1500 kg. Only the remaining power is available for you to for towing the load. So, this is the pull available for towing the load, 5500 kg. So, we were discussing about the usable power estimation. So, we found that the usable power depends upon the project conditions like the underfoot conditions prevailing in the project site.

Pull available at towing a load = 7000-1500 = 5500 kg

So, we found that the, so out of the total power available for the machine. So, some portion of the power is used for overcoming all the resistance forces in the project site and to make the machine move. So, after overcoming the resistance forces, only the remaining power is available for towing the load or doing the actual job. So, that is what is a usable power. We just now discussed how to estimate the usable power.

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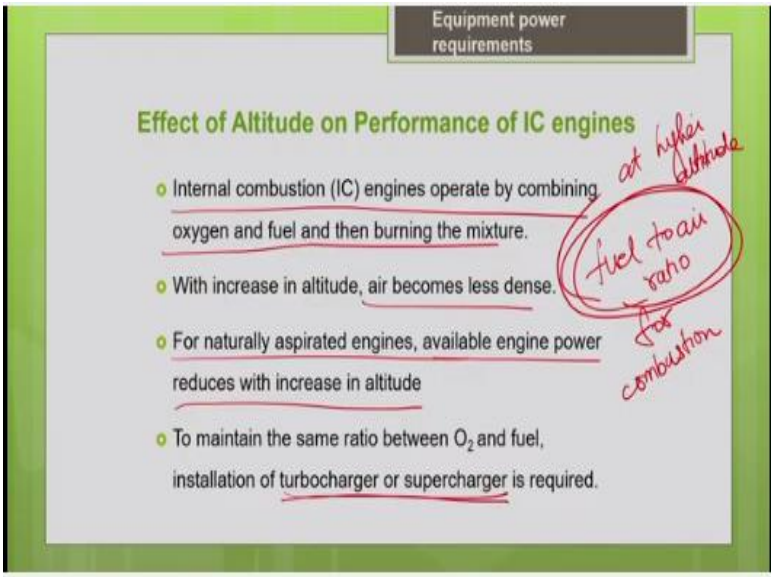

Now let us see what is the effect of altitude on the performance of the engine? So, as we discussed earlier, the usable power depends upon the underfoot conditions, altitude and temperature. So, you know that the horsepower rating of the machine is done with the standard conditions by the manufacturer. So, they might have done the horsepower rating at standard temperature and the standard atmospheric pressure.

So, if your project site is going to have a temperature or the atmospheric pressure different from the standard conditions, then obviously the efficiency of the machine is going to be different. So, what is the effect of altitude on the performance of the internal combustion-based engines? We are going to see now. So, generally most of the construction equipments, what we are using at the project site or IC engines or internal combustion-based engines.

So, for the combustion mechanism, the fuel air ratio is very important. So, you know that as the altitude increases, so if your project site is located at a higher altitude. In that case you can see that the atmospheric pressure will be lesser, your density of air will be less. So, if you are not able to maintain the fuel to air issue, then the combustion process will not be efficient.

In that case in your project site, if the altitude is going to be higher the efficiency of the machine will be affected. So, we have to take into account how much the efficiency is going to be affected? So, basically the internal combustion engines you know that they operate by combining oxygen

and fuel in and then burning the mixture. So, that is why I told you, you have to maintain the fuel to air ratio is very important for the combustion process.

So, with increasing the altitude, your atmospheric pressure will reduce so your air is becoming less dense, so this ratio gets affected. So, that is why your efficiency of the machine will get affected. So, the efficiency what we realized with the machine at the new sea level will be higher. The same efficiency we cannot realize in a project set at a higher altitude, so that we should understand.

So, for naturally aspirated engines the available engine power reduces with increase in altitude that is why to compensate the loss in efficiency you should go for some special attachments like your turbochargers or supercharges. There are certain devices which I discussed even in the first lecture. So, these devices will help you to maintain the fuel to air ratio even at higher altitude. So, even at higher altitude you can maintain the fuel to air ratio using this particular turbocharger or supercharger.

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So, I have shown you this picture in the lecture 1, hope you remember, like you can see this blue color indicates the air movement, there will be a compressor arrangement, which will compress the air and supply the air and maintain the air to fuel ratio in the chamber. So, that is how the combustion process is not effective, if you provide this the turbocharger. So, at higher elevations either you should go for these kinds of special turbochargers.

Or you should go for more number of machines to compensate the loss in efficiency or should go for a bigger equipment to compensate for the loss in efficiency. So, you should know that with the increase in altitude your efficiency is going to be affected and you have to take care. So, now we understood that the altitude will affect the usable power available.

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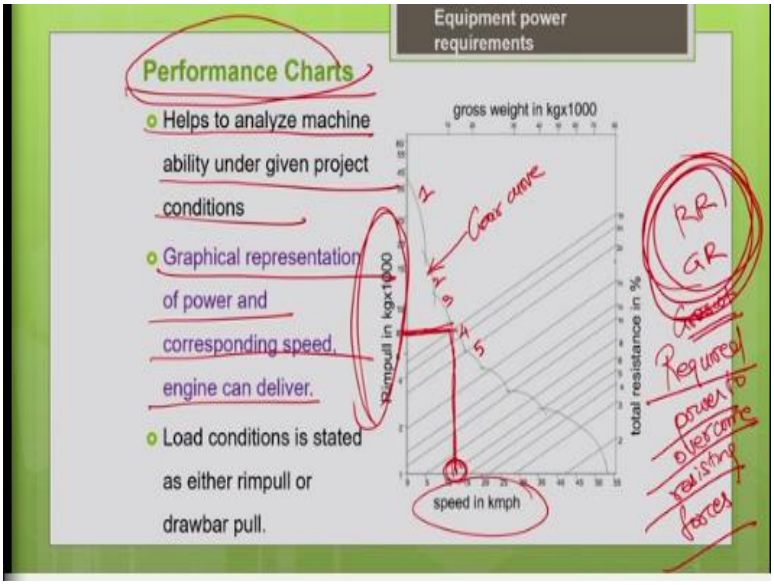

So far, we discussed on what are all the factors the usable power depends of? The usable power depends upon the underfoot conditions, that means the resisting forces in your project site, your altitude as well as the temperature, everything is going to affect your usable power. Now let us see what is the significance of this performance charts? So, generally the equipment manufacturer they supply the performance charts for the models which are manufactured by them.

So, in an equipment handbook, you can see the performance charts of various models manufactured by the manufacturer. So, with the help of the performance chart, we can know what is the actual performance of the machine in a particular project condition? So, that is what is the significance of this chart, it helps you to analyze what is the performance of a particular machine in a particular project condition.

So, it helps to analyze the machine ability under the given project condition, it is basically a graphical representation of power and the corresponding speed an engine can deliver. So, this is a

sample of your performance chart. So, you can see that you have speed in the x axis and in the rimpull in the y axis. Using this performance chart, you can find what is the actual performance of machines in terms of speed for the given project condition.

Say for your project site, you know what is your rolling resistance and penetration resistance? So, penetration resistance you may be, knowing what is the grade resistance for the particular haul route. So, you know the gross weight of the machine, so with that you can find what is the required power? So, what is the required power to overcome the resistance forces, you can know. To overcome the resistance forces in your project site, that you can calculate**.**

For your haul route, if you know what is your rolling resistance and the grade resistance you can. And if you know the gross weight of your machine, you can calculate. So, you can calculate the required power or the rimpull. So, once you calculate that, say for example, if this is going to be say 8000 kg, 8 into 1000 8000 kg. So, you draw a horizontal line intersecting this gear curve, this is nothing but gear curve for different gears, say first gear, second gear, third gear, fourth gear, so different gear curves are there.

Now you draw the horizontal line from the actual rimpull in your project site, so intersecting the gear curve. From that intersection point draw a vertical line, so where the vertical line intersects the horizontal axis that gives you the actual speed possible for this particular project condition, for these particular resisting forces in a project site and the gross weight of a machine.

So, you can find what is the speed possible, what is the machine speed you can realize in your project site that machine performance you can analyzes in this performance chart. So, other way there is also another y axis you can see here. See you can express your resistance in your underfoot conditions using total resistance percentage.

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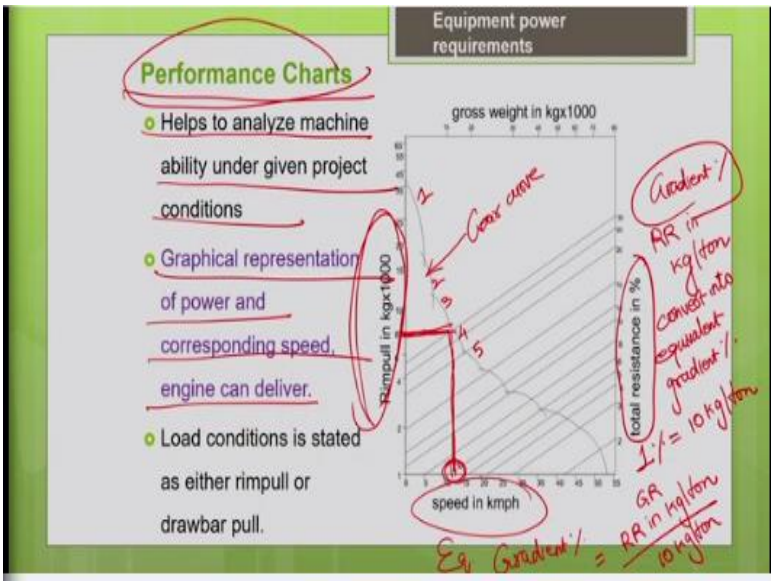

So, already you know the gradient, you know the gradient percent that is the slope percent you know it, the rolling resistance you know in kg per ton. So, this you can convert it into equivalent gradient percent as we discussed earlier. So, you know that 1% is of grade assistance equal to 10 kg per ton, so this we discussed earlier. So, now you can convert your rolling resistance in kg per ton into gradient divides it by 10 kg per ton.

So, this gives you the equivalent gradient percent, so you can get your gradient percent, equivalent gradient. So, you can convert the rolling resistance into equivalent gradient and add it to the actual the gradient percent you will get the total resistance percentage of your project site. So, once you know the total resistance of the haul route in your project site, so you can note that these inclined lines are representing your resistance.

Now you know the gross weight of your machine. So, it depends upon the trip whether it is an onward journey or return journey. In a return journey maybe, your truck maybe in an empty condition, so accordingly you have to note down the weight. In the onward journey it will be in fully loaded accordingly the gross weight will vary. So, note down the actual weight of the machine, so say your weight of the machine is this is your weight of the machine, say your resistance is 8%.

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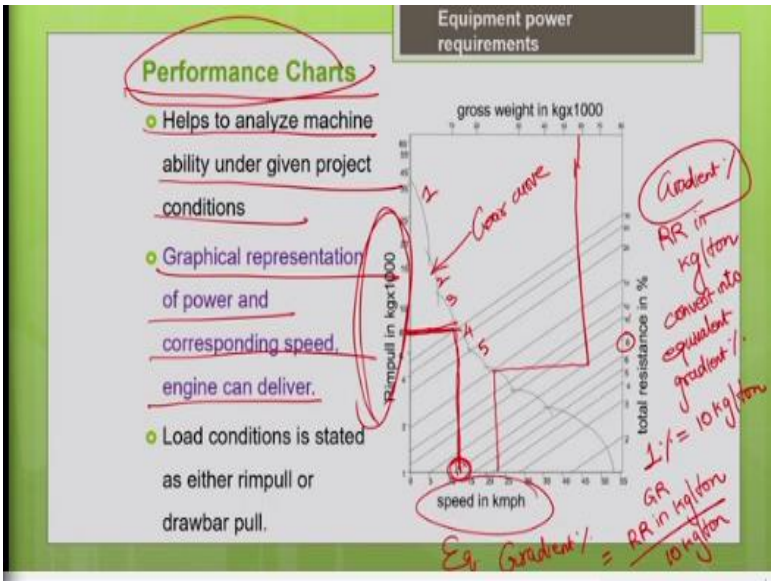

So, you have to draw a vertical line intersecting your total resistance percentage line. Once it intersects your; the total resistance percentage line, then draw a horizontal line to the left intersecting your gear curve. Now drop a vertical line intersecting your speed, so this is how you can find the speed of the machine if you know the total resistance percentage.

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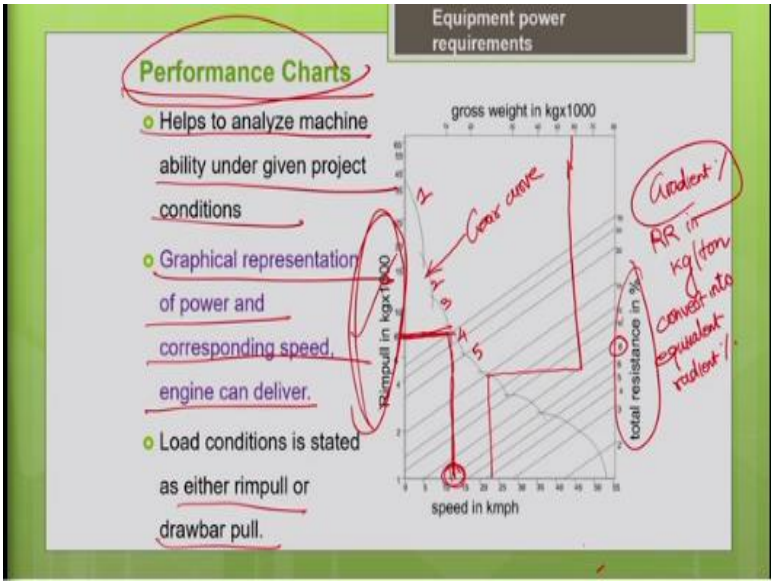

So, either you can use this rimpull in kg and find the speed or you can use the total resistance in percentage and you can use the gross weight and find the actual speed of the machine possible for this particular project condition. So, depending upon the mounting your low condition can be stated either in the rimpull or in the draw pull. So, depending upon the whether it is tyre mounted machine or track mounted machine accordingly.

So, these performance charts are provided by the manufacturer for all the models which are manufactured by them. So, you have to choose the corresponding performance chart and for your particular project conditions you have to find the speed which is possible. So, this data you can use it later in the estimation of the productivity of your machine.

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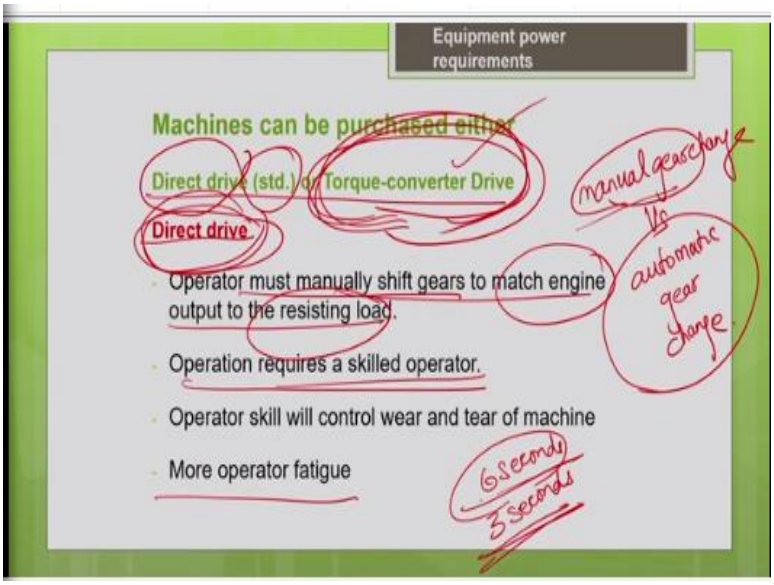

So, another important thing to be noted is the machines when you purchase depending upon the mode of transmission, you can call it as direct drive base machine or torque converted drive-based machine. In a simple way to say it is nothing but your manual gear change versus automatic gear change. So, basically your direct drive is nothing but your manual gear change**.**

A torque-converter drive is called as automatic gear change. So, nowadays if you know that we have a lot of vehicles or cars in the market, with automatic drive option, automatic gear change option. So, the same thing when we are discussing here. So, the technical term which you are supposed to use is for manual gear change which is nothing but direct drive transmission we call it as standard machines.

So, in this direct drive transmission, so the operator has to manually change the gear, he has to manually shift the gear, so according to the load conditions in your haul route. So, you have to manually shift the gears to match the engine output to the resistant load. If the load conditions are

highly variable in the particular case, you can see that it will be really tedious for the operator to change the gear appropriately.

So, if he is a skilled operator, then he can handle it very well. So, this operation requires a skilled operator because he has to manually change the gear according to the load conditions. Particularly for constantly changing load conditions, the operator has to be very skilled, so that he can match the engine output to the resistance load. If there is a mismatch between the engine output to the resisting load, you can see that it will result in wear and tear, it will affect the it will damage your machine.

Your vehicle will come to a stall it will come to a halt if you apply a wrong gear. So, if there is a mismatch between engine outputs to the resisting load or there will be a loss in momentum of your machine. So, this mismatch can affect the life of your machine, it will result in wear and tear of your machine. That is why we need more skilled operator for this direct drive transmission.

So, as I told you operator skill controls the wear and tear and this also results in more operator fatigue, if you look into the cycle time, so if you are going to use an equipment with manual gear change or direct drive transmission, you are supposed to use a technical term, you should say direct drive transmission. So, if you are going to use machines based on direct drive transmission, it will affect the cycle time of a machine.

Because your maneuver time will get affected. Say, for example for manual gear change, if the maneuver time is 6 seconds, for automatic gear change vehicle it maybe lesser it is 3 seconds. So, I am just giving you some examples it may not be the right thing for all the machines, but some approximate numbers I am giving you. So, basically you should know that when you go for this torque converter drive, you can see that the maneuver time is getting reduced, so the cycle time gets reduced.

So, that will affect your productivity and the production cost. So, but your automatic gear changer torque converter drive the initial cost will be more that you should note it, when compared to direct drive transmission the initial cost of torque converter drive will be more. But you can get the

benefits of increase in productivity when you go for this machine. So, when you estimate the productivity of the machine, you should appropriately adjust the influence of the transmission of the machine on the cycle time.

If it is mentioned it is direct drive then accordingly you should know that the cycle time will be slightly more because the maneuver time is more for the direct drive, so extra time is needed for changing the gears, so that time should be taken into account.

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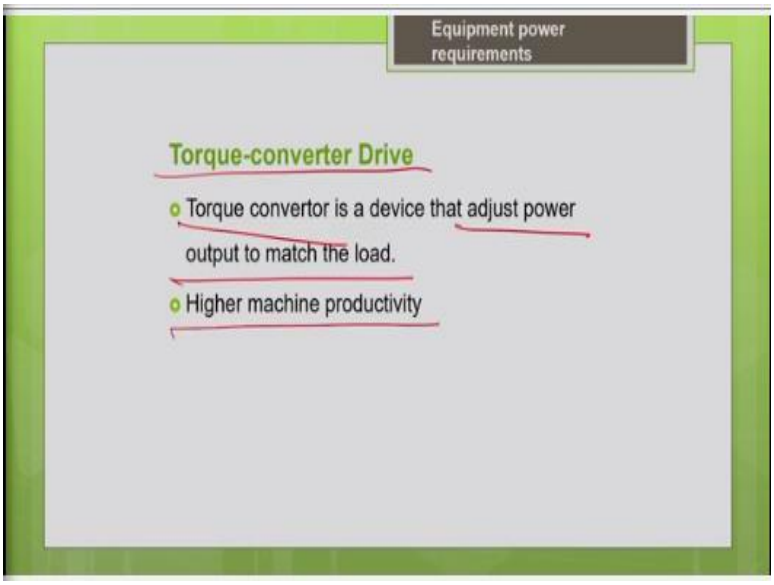

So, other one as we discuss just now is torque converter drive, it is initial cost is high. So, you have a torque converter device here which can automatically match your adjust your power output to match the load conditions, so it results in higher productivity. So, you know why higher productivity because your maneuver time is going to be lesser here, your cycle time will be reduced, so the productivity will increase**.**

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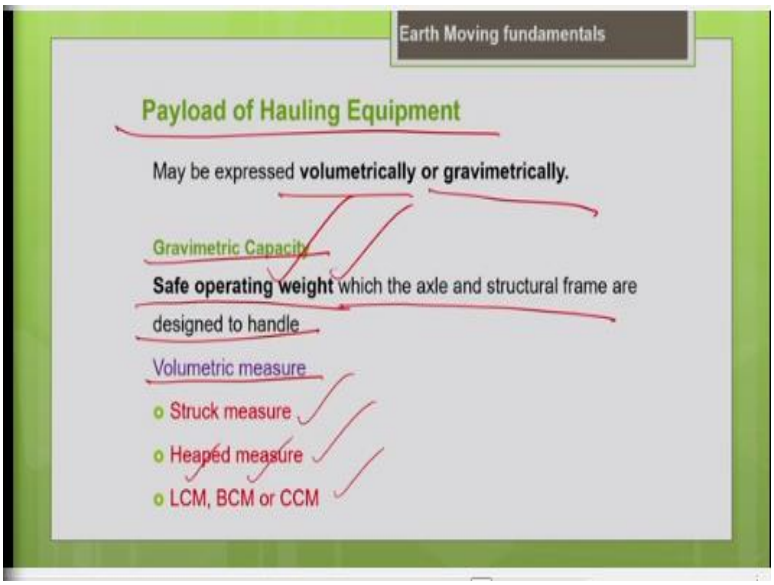

Now let us see what are the different ways to quantify or measure or express the payload of the hauling equipment. You can express the payload either on the weight basis gravimetrically or on volumetric basis. So, basically most of the equipment manufacturers, they give you the data on what is the safe operating weight of the vehicle. So, that is the gravimetric capacity, the safe operating weightness.

That is the weight which the axle and structural frame of the particular vehicle can handle without much wear and tear. So, you have to be very cautious that you should not overload the machine beyond the safe operating weight as prescribed by the manufacturer. So, many circumstances you can see the trucks are often overloaded, they put some sideboards and try to increase the capacity of the truck.

Obviously by putting the side boards, you can increase the volume of the truck, you can increase the productivity of your truck and you can reduce the cost you can reduce the production cost. But this will be only for short run. So, look into from a longer time perspective, you can see that in the longer run, you are actually abusing your machine, when you overload the machine beyond the safe operating weight, what will happen is?

Your tyre's will be abused all the other components of the machine it will be abused, it will result in more wear and tear and it will result in premature aging of your machine. So, this will result in

additional cost, huge cost of replacement of your machine at a earlier age itself. So, that is why we will not say much by just loading the machine or overloading the machine beyond its safe operating weight that you should understand. It will result in premature aging of the machine and it will result a huge loss to you by driving you for earlier replacement of a machine with a new machine.

So, next is volumetric measure, so, to express the capacity of the machine on volumetric basis. So, there are certain terminologies which I am going to expose you the struck measure, heaped measure, loose cubic meter, bank cubic meter, compacted cubic meter. So, these are the different terminologies we use related to volumetric measure, we will see what are these one by one in the upcoming slides.

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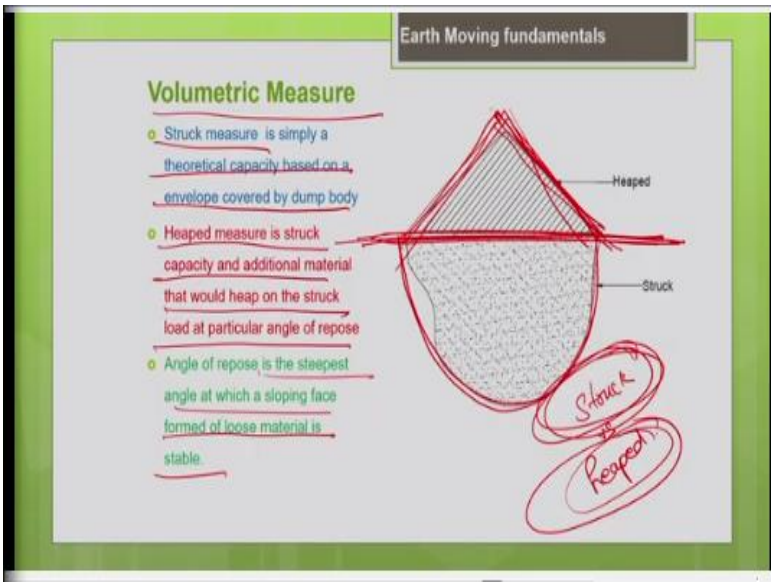

So, first is the struck measure. See, basically say for example, you have the bucket of your excavator, so you are going to excavate the load, you are going to load the bucket of your excavator, how do you express the volume of the bucket? See basically, there are different ways to express the volume; either you can express it on the basis of struck capacity or heaped capacity.

So, struck means, so you are going to strike off and measure what is the actual volume occupied by the bucket, so that is, your struck capacity. You strike it level the surface and measure the capacity that is struck capacity. So, it is nothing but the theoretical capacity based on the envelope covered by any structure, any dump body or anything. So, it is a theoretical capacity.

So, basically in the practical scenario, so when we load any bucket or any load the truck we never struck it level and then measure. So, we are not interested in struck capacity, what we are interested in is heaped capacity only. Normally when we load a bucket or load the truck, we heap the material at a particular angle of repose depending upon the material type, so we are interested in this heaped volume only.

So, heap measure is nothing but struck capacity as well as the additional material that would heap on this struck load at a particular angle of repose. So, angle of repose is the steepest angle at which the sloping face formed of loose material is stable; it will vary from material to material. So, this is what is the; difference between the struck capacity and the heap capacity. So, struck means we are going to struck off level and measure that is struck capacity. Heap means, you heap the material at a particular angle of repose and measure the volume. So, very commonly we use only the heaped volumetric measure.

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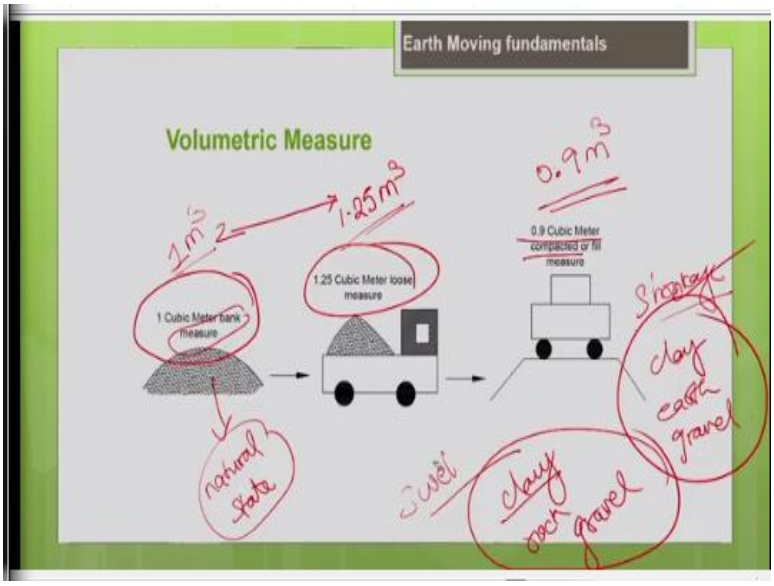

So, what are the other different ways of expressing the volume of the material? So, you know that the same quantity of material can occupy different volumes based on how you handle the material, say this is 1 cubic meter of material volume in the natural state of the material. Natural state in the sense, see before you excavate the earth with any earthmoving equipment the earth is in the natural

state. So, that is called as a bank state or natural state, before it is excavated it is called as bank measure or it refers to natural state of the material.

So, let us say it is 1 cubic meter; it occupies 1 cubic meter, now to excavate the material with excavating equipment and load it. So, once you excavate it what happens, the material gets loosened, so the more voids will be created, now it will expand and occupy more volume. So, you can see that the loosened volume is 1.25-meter cube, you can compare in natural state is 1-meter cube, in loosened state it is 1.25-meter cube.

It depends upon a type of material; this volume will vary depending upon the swell factor of the material. So, the swelling ability of the materials will vary. Say for example, your clay will have different swell factor, rock will have a different swell factor, gravel will have the different swell factor, and it will vary from material to material. So, how much is the swell factor you can get it from the literature for the particular material type.

Similarly, now you compact the material, say for example, when you prepare the subgrade for the roads, you compact it. So, when we prepare the earthen embankments you compact the material with the rollers. So, when you compact it properly, now you can see the volume will be 0.9-meter cube, so now the volume has reduced. So, the shrinkage has happened because of compaction, the voids are eliminated.

So, how much it will shrink, that depends upon the material. Clay has it is own shrinkage as I told you the earth, the gravel everything has it is own shrinking ability. So, you have to do some geotechnical investigations to study what is a swell factor or I mean shrinkage factor or you can take it from the literature. There are lot of information's available for different types of materials related to swell factor and the shrinkage factor of the material, you can make use of those values for your estimations.

So, one thing you have to keep in mind is when you do the volumetric estimations, so when you do your productivity estimation, when you are using the when you are expressing the volume of the particular materials, you should maintain some consistency.

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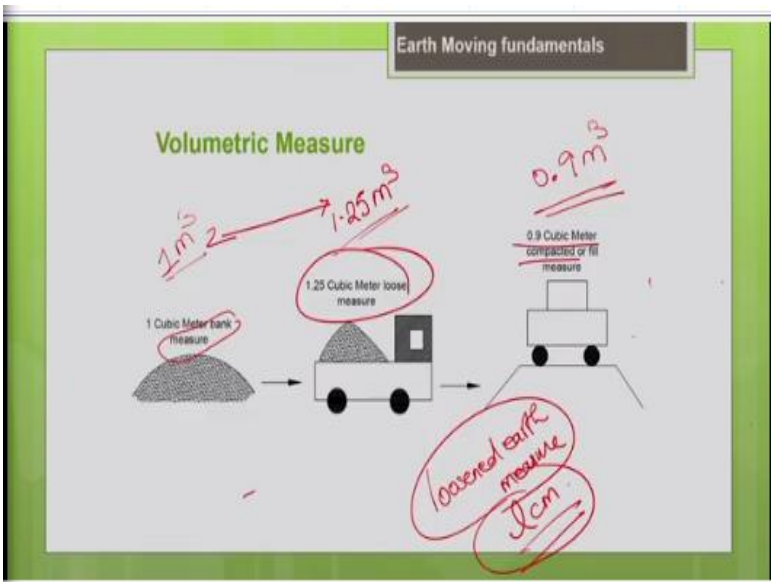

Say for example, you are going to estimate the productivity in terms of loosened earth measure. So, we want loosen the cubic meter. So, in that case, what you have to do consistently you have to use this particular volumetric measure. So, when you do the estimations of your productivity, you have to consistently use the volumetric measure. So, you should not mix up the terminologies. And there are certain factors which will help you to do these consistent calculations, let us see that.

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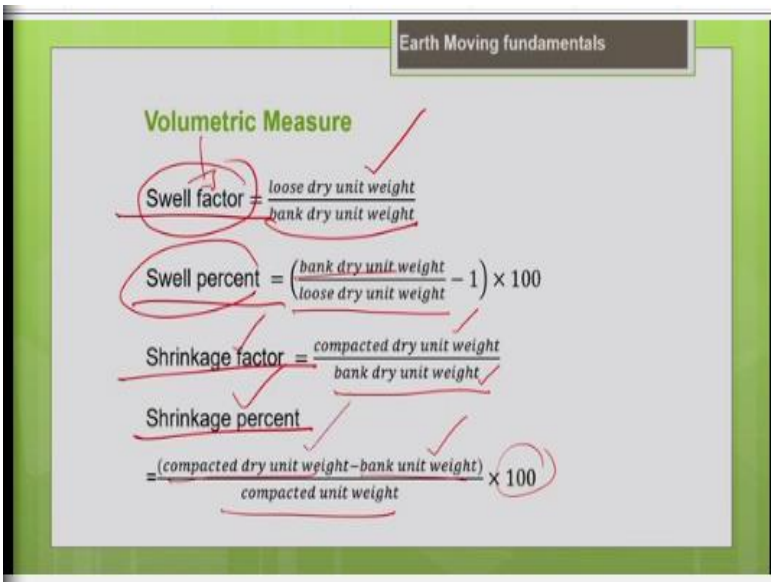

See as I told you swell factors, shrinkage factors, so all these things helps you to make some conversions, let us see what are those conversions? So, swell factor is nothing but it is the ratio of loose dry unit weight to the bank dry unit weight of the material. So, how much the material

expands or swells from it is natural state that is a swell factor. So; ratio of loose dry unit weight to the bank dry unit weight.

So, you can also express it in percentage, it is nothing but bank dry unit weight minus loose dry unit weight divided by loose dry unit weight into 100, so this is how you calculate the swell percent. Say for example, if you know the natural or the bank unit weight of the material. So, once it is disturbed excavator, in the loosened state you do not know what is the unit weight of the material?

So, from the literature, there are some tables which provide you the swell factor of different types of material. So, from the literature, you can take the swell factor for the particular material when using this swell factor you can calculate what is the it is loosened unit weight. So, that is the significance of these factors, these factors can see in the conversions, so that you can use it for the consistent calculations of your volume or the productivity when you make the estimations.

Similarly, shrinkage factor, so from the bank dry unit weight how much it has reduced in volume. That is what you are trying to find by the measuring the shrinkage factor. Shrinkage factor is nothing but compacted dry unit weight divided by bank dry unit weight. So, you can also express it in percentage, it is nothing but compacted dry unit weight minus bank dry unit weight divided by compacted unit weight into 100.

So, this gives you the shrinkage percentage. So, if you know the bank unit weight, if you do not know it is weight after compaction. So, depending upon the material type, if you know the shrinkage percentage, so from that you can calculate the compacted unit weight of the material. So, this helps you in simple conversions for your estimations of volume and the productivity.

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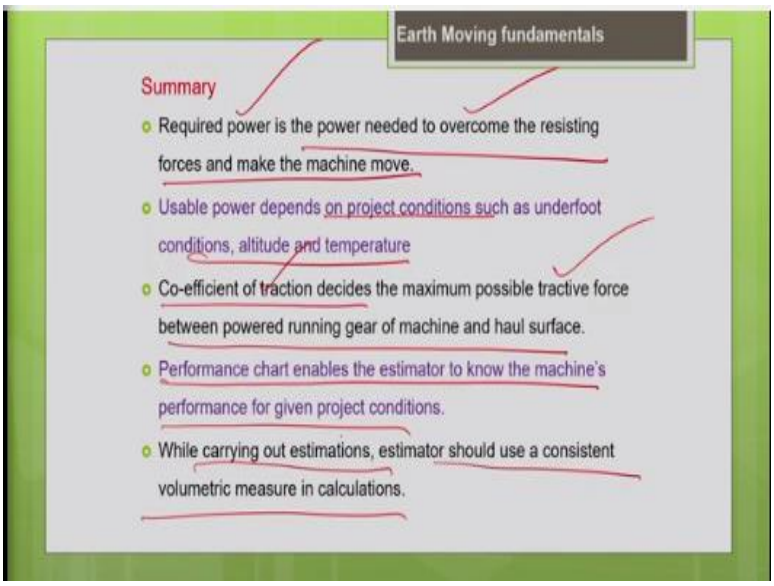

So, now we have come to the end of this lecture. So, let me try to summarize what we have discussed so far. So, you should know that the required power is nothing but it is the power needed to overcome the resisting forces in your project site and make the machine move. So, depends upon what are all the resistant forces in your haul route. So, what is the surface resistance, penetration resistance, grade resistance all these things you have to take into account.

So, then you have to find what is the tractive effort needed or the power needed to overcome these resisting forces. Then usable power, usable power it depends upon the underfoot conditions in a project site and the altitude and the temperature. So, it varies depending upon your project site. Then coefficient of traction it decides the maximum possible tractive force between your powered running gear of the machine and the haul surface.

So, out of the total power of the machine, how much power is going to be usable for doing your work it depends upon the coefficient of traction of that particular haul route. It depends upon the grip between the machine and your the haul route, so that is going to decide the usable tractive effort. Then performance chart help you to know the machine performance. So, for your given project conditions, I can know what is the speed of the machine from with the help of the performance chart.

So, as I told you when you do the estimations of your productivity, and the volumetric estimations, you should use a estimator should use a consistent volumetric measure in the calculation. So, there are different ways to express the volume you know that, loosened cubic meter, bank cubic meter, compacted cubic meter. So, whatever measure you are going to do, use, you have to use it consistently throughout your calculations.

So, you can make use of the swell factors, shrinkage factors of the particular soil type to know the corresponding values, you can use it for the conversions, which will facilitate you to do the estimations.

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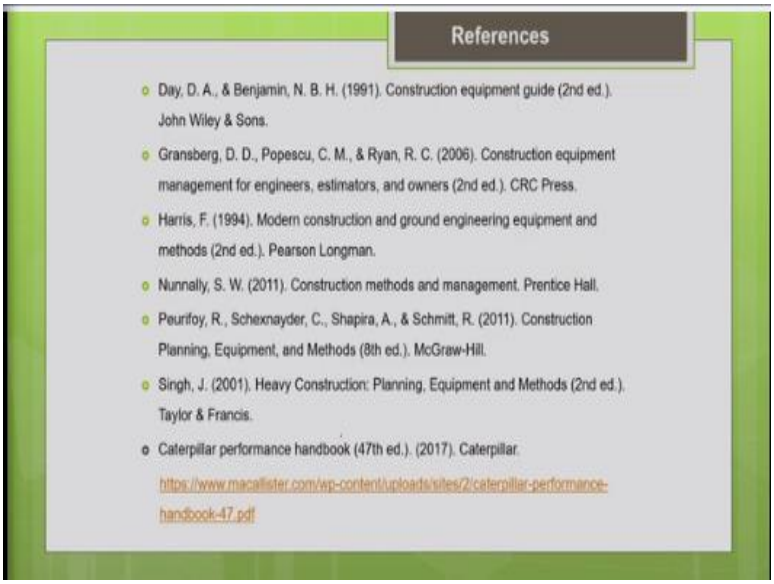

So, these are the references which I have used for this particular lecture. So, in the next lecture we shall discuss about the earthmoving equipment**.** So, firstly we will discuss about the bulldozers. So, what are the applications of bulldozers? How to estimate the productivity of bulldozers? What are the factors which affects the productivity bulldozers? All those things will be discussed in the upcoming lecture, thank you.