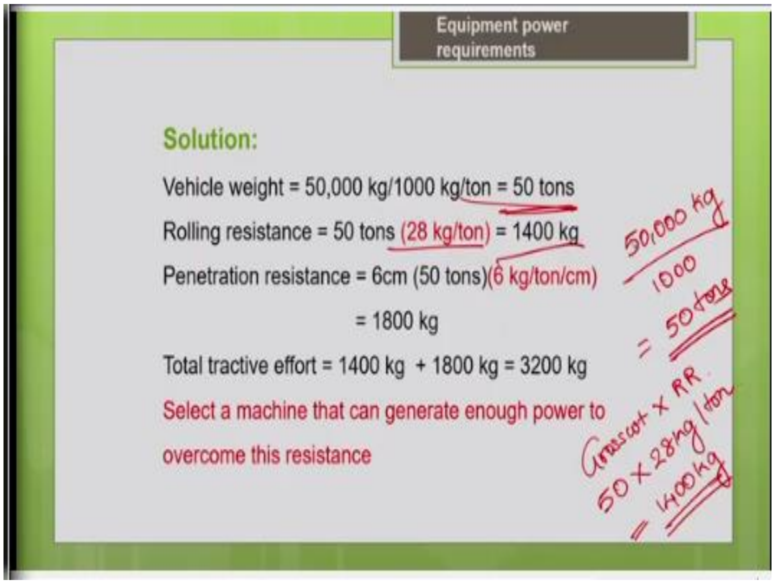

So, let us convert the vehicle weight into tons, because your rolling resistance is commonly expressed as kg per ton. So, let us convert the weight of the machine into tons you know that the gross weight of the machine is given as 50,000 kg. So, 1000 kg = 1 ton, so divided you will get the gross weight 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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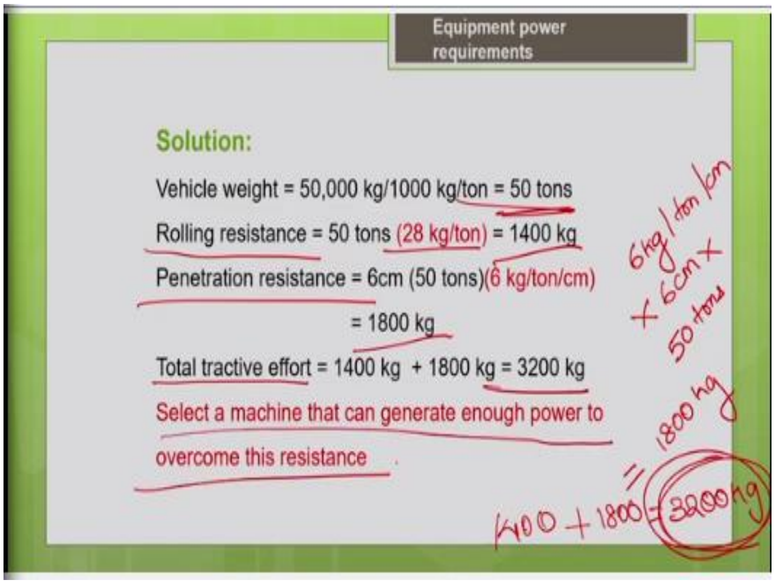

So, you multiply that by how much is the depth of penetration? It is nothing but 6 centimeter, and what is the gross weight of the machine? It is nothing but 50 tons. So, that gives you the penetration resistance as 1800 kg. Now we can find the total resistance, that is nothing but add your rolling resistance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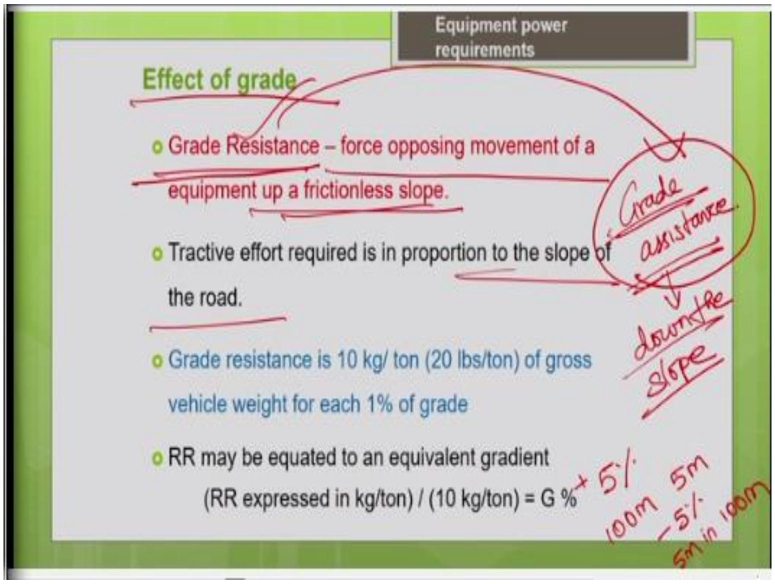

Now so far, we have discussed about the rolling resistance, let us look into the other part of the resistance in your project site that is your grade resistance. Most often you can see that equipment has to climb up a slope. So, when the machine is climbing up the slope, obviously you need some additional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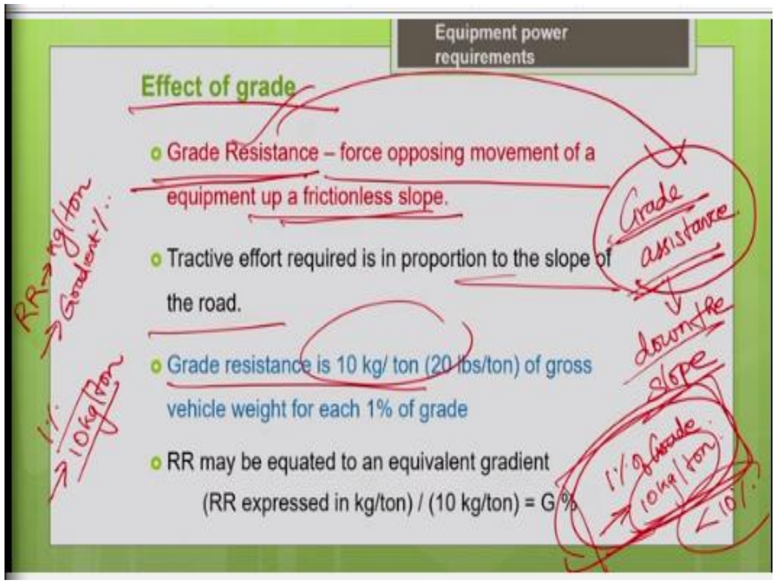

Grade resistance is nothing but by simple elementary I mean a mechanics people have worked out this the relations. Say for example, for 1% of grade so the amount of tractive effort needed to overcome this 1% of grade it is 10 kg per ton. So, this is simple guideline which they are worked out which is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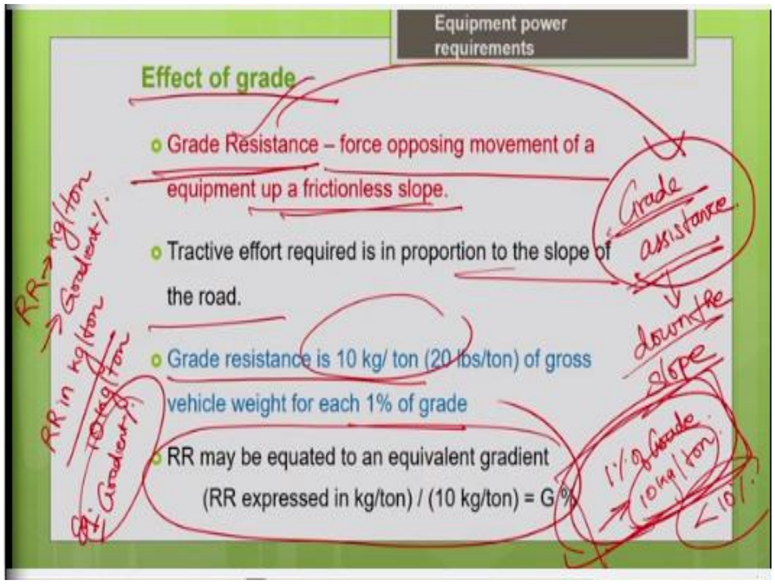

Rolling resistance you know in kg per ton, so you know that 1% of grade equal to 10 kg per ton. So, you divide it by 10 kg per ton, you will get the equivalent gradient percentage, so you can get the equivalent gradient. So, the rolling resistance for your convenience, you can have both the rolling resistance 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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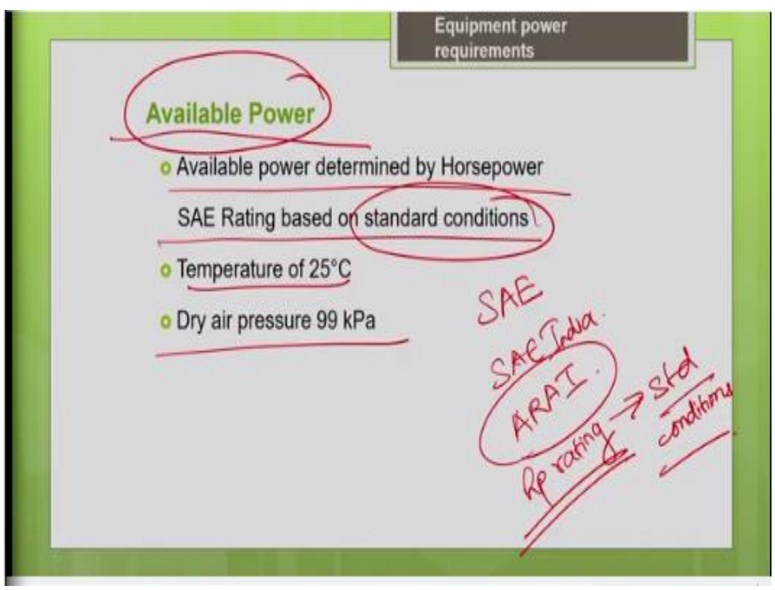

So, so far what we have discussed is about the required power. So, what is the total power required by the machine to overcome the different resistances in the project site, in the underfoot conditions.

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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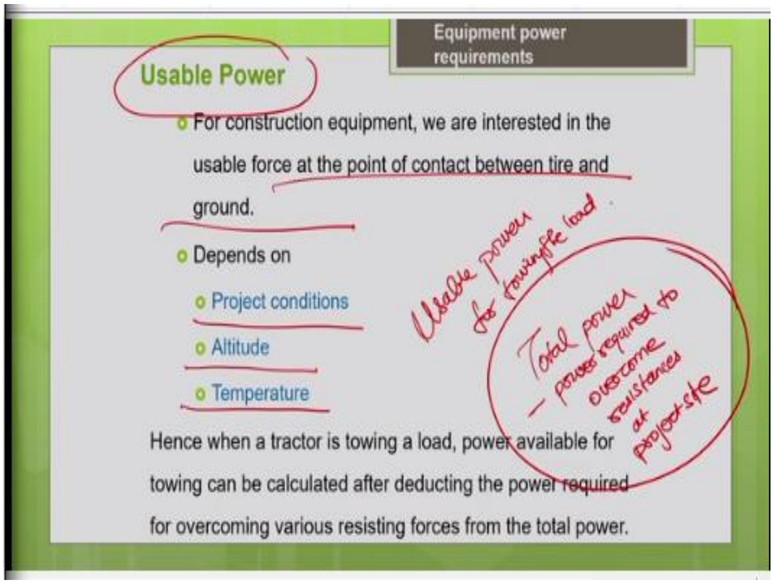

So, now let us see what is this usable power? So, out of the available power prescribed by the manufacturer, how much amount of power becomes usable to you? That depends upon your project condition that depends upon the altitude of your project site and the temperature at your place. Because as I told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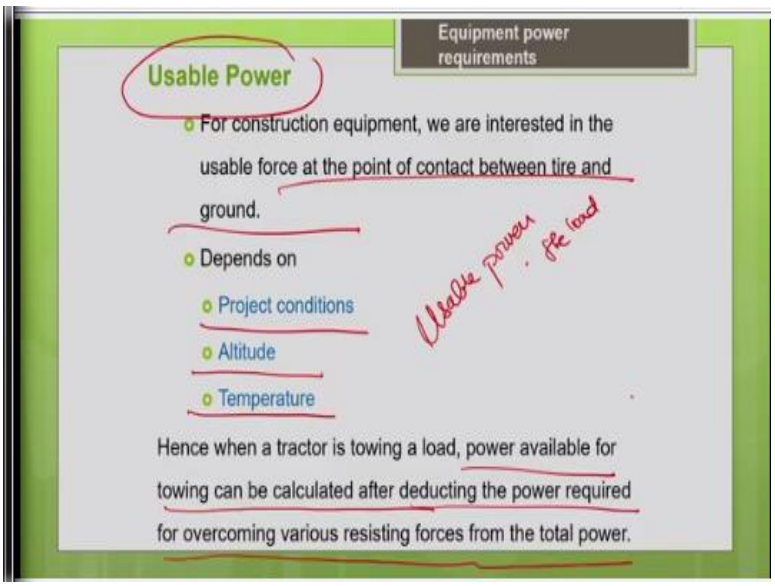

So, where a tractor is towing to load, the power available for towing can be calculated after detecting the power required for overcoming the various resistance forces from the total power. So, this we have to keep in mind, so this is nothing but your usable power.

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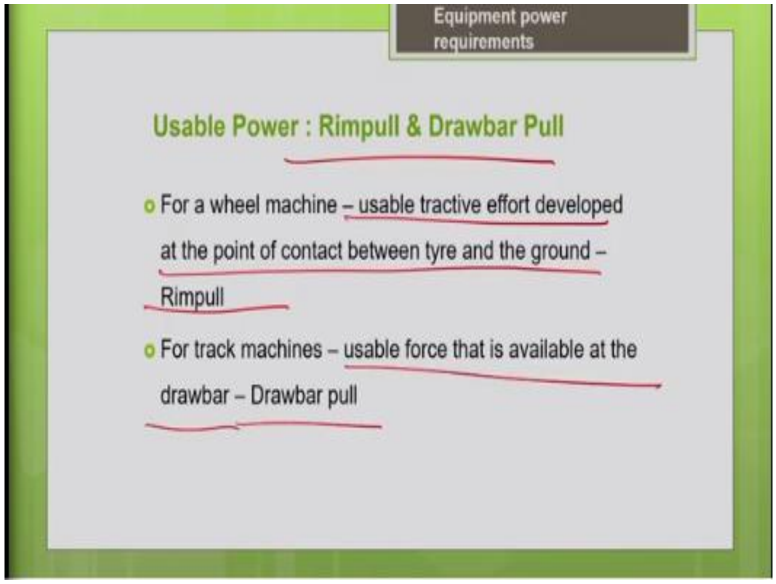

The usable power you can express in terms of rimpull or drawbar pull. So, depending upon the mounting of your machine. So, if it is going to be wheel or tyre mounted machine, we call it as rimpull. The usable tractive force developed at the point of contact between the tyre and the ground is called as 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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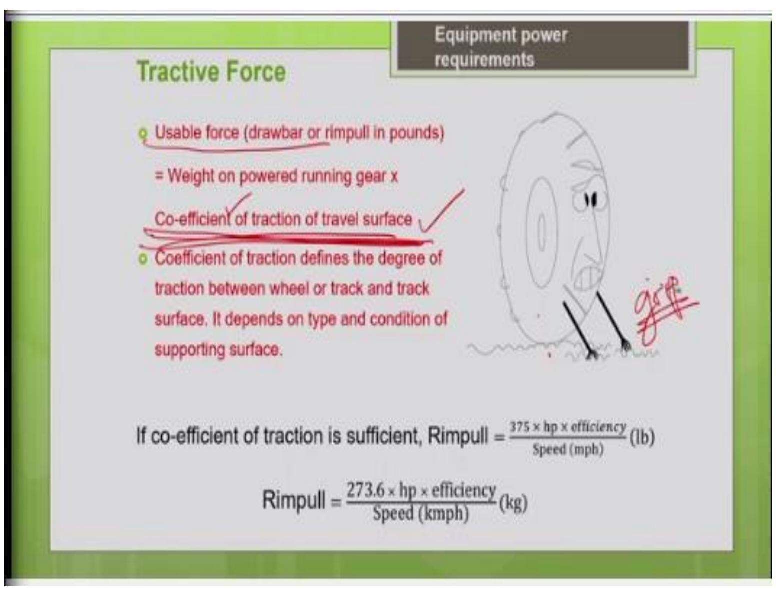

So, how to calculate this usable force? So, this usable force is going to depend upon the traction of your travel surface. So, as I told you how much amount of the total power becomes usable, it depends upon the degree of traction between your wheel and the ground. Traction is nothing but your grip,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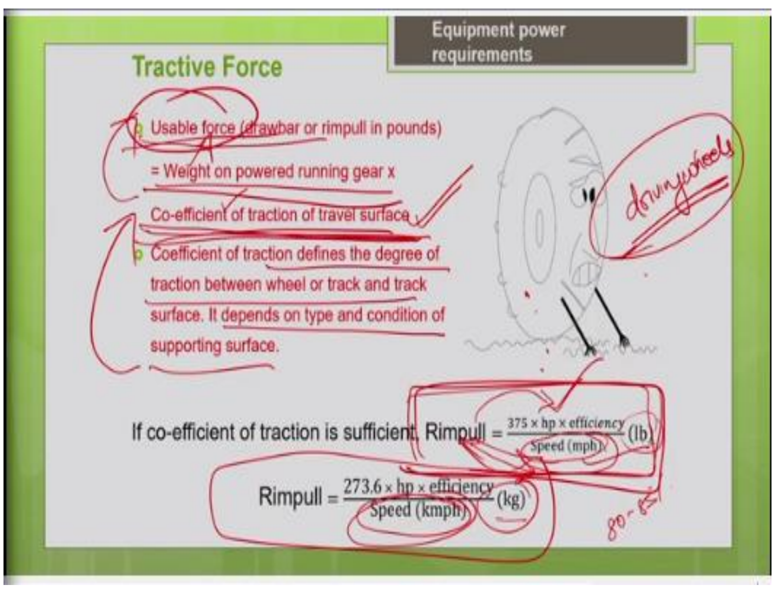

So, another important thing to be noted is weight on the power running gear of the machine. So, in common equipment or the common wheels of the cars whatever we are using, you can see that all the wheels of the car are not driving wheels. Common machines you can see that all the axles are not powered 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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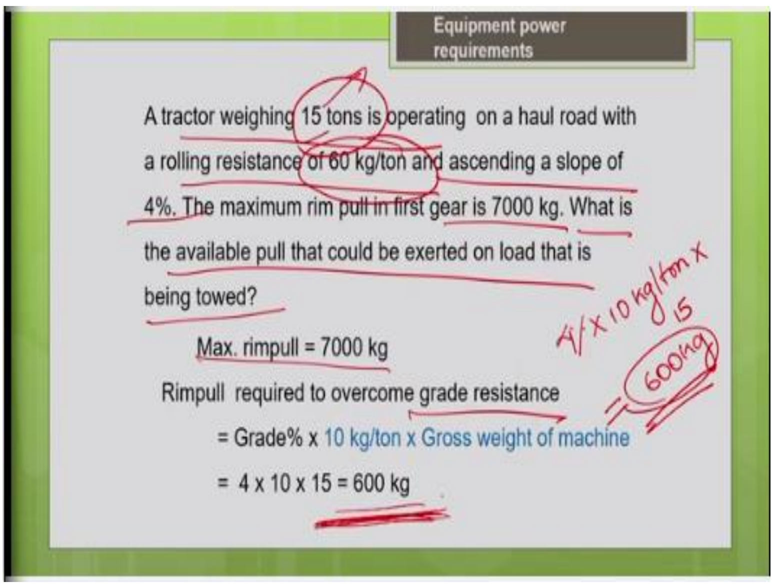

Now let us workout the problem on how to estimate the power requirements of the machine. So, a tractor weighing 15 tons is operating on a haul road, the gross weight of the machine is given as 15 tons. It means it includes it is empty weight as well as the load it is carrying, with the rolling resistance 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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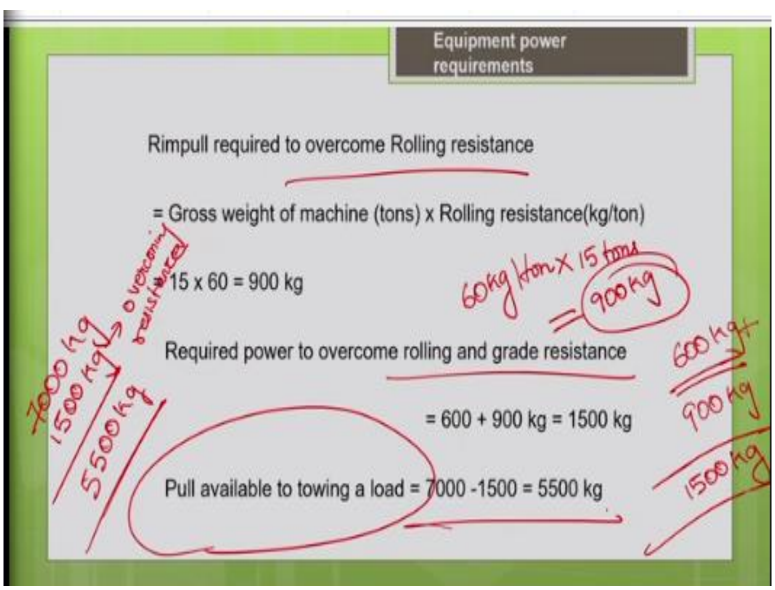

Now let us calculate how to estimate a tractive effort to overcome the rolling resistance? So, it is nothing but for this particular haul route the rolling resistance value is given us 60 kg per ton. So, what is the gross weight of your machine? It is nothing but 15 tons. So, that gives me the total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