Traction Engineering
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Lecture 08
Measurement and Characterization of Terrain Response

Hi everyone. This is Professor H. Raheman from Agricultural and Food Engineering Department, IIT Kharagpur. I welcome you to this NPTEL online course on Traction Engineering. This is the lecture 8, where I will try to cover Measurement and Characterization of Terrain Response.

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The concepts which will be covered are terrain characterization, plate sinkage test, sinkage modulus of cohesion, then sinkage modulus of internal friction. So we will try to find out how to utilize this terrain characterization, which will help you in evaluating the performance of a vehicle.

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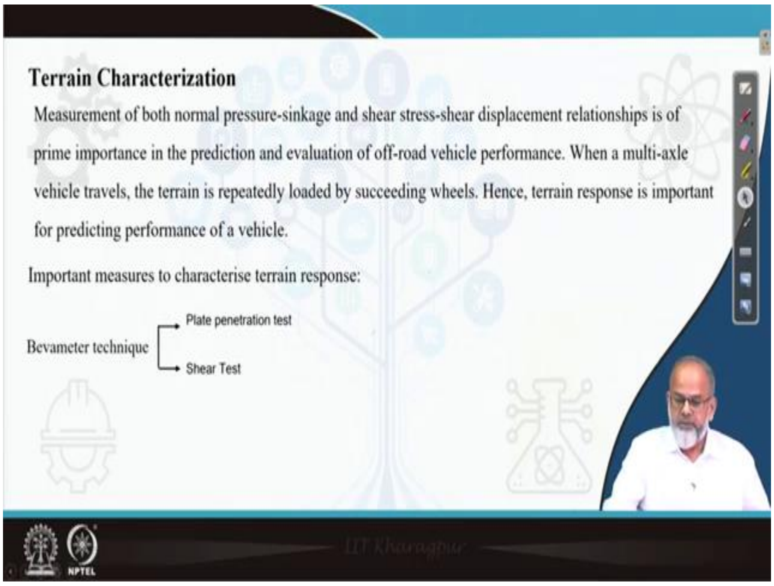

Measurement of both normal pressure-sinkage and shear stress-displacement relationship is of prime importance. Why we call it as of prime importance because the load is acting on the wheel and the wheel will cause certain soil compaction, and thereby, rolling resistance or the motion resistance is developed.

Now when a torque is applied to the wheel, a shearing force will be initiated or a shearing force will be developed at the tire or the wheel-soil interface. So we need to know what is the pressure, which is applied through the wheel. So, that there is sinkage in the soil, sinkage of the wheel in the soil, or we need to know what is the stress it is developed because of the torque which is supplied to the wheel and the corresponding shear displacement.

So these are the two parameters, which are to be studied and the most used technique to study these two tests are your Bevameter technique. It comprises of two sets of tests, one is your plate penetration test, the other one is shear test.

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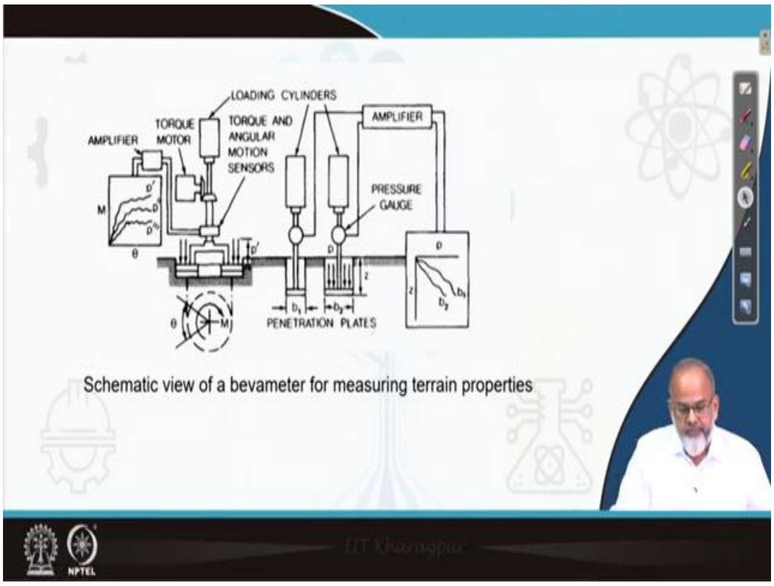

So let us now see, what is this plate penetration test and what is the shear stress, shear test? Plate penetration test, if you look at this figure, there are plates of different sizes that are to be forced into the soil and then we try to measure how much is the pressure, which is required to force this plate into the soil. Now question arises what sizes of plate are to be inserted into the soil? So size of the plate should simulate the contact area of tire.

So, and the aspect ratio can be maintained. Aspect ratio means the height to width ratio should be more than 5 to 7. And the minimum width can take as 5 centimeter, but nevertheless, it should be, should not be less than 10 centimeter; that is the minimum width of the plate we have to take. Now different sizes of plate, they are to be inserted into the soil with the help of a hydraulic cylinder and how much is the force, which is required to push that soil, that plate into the soil that force are to be recorded, continuously and what is the corresponding sinkage? So in this figure there are two plates indicated b1 and b2, and the pressure which is recorded that is indicated for different depths in this graph, D versus Z for two different plates.

The other test is your shear test. Shear test means in lecture 7 we tried to discuss about the shear annulus. So basically this is a shear annulus plate which has to be rotated for different normal loads and what is the corresponding torque, which is required to cause failure to the soil that is to be recorded.

So there should be a torque meter, there is a hydraulic loading cylinder and how much torque is required to cause rotation of this plate that has to be measured, either you can put a torque meter or you can put a sensors to measure that. Now knowing the torque and the outer diameter the expressions which we give in case of lecture 5, so you can find out what is the torque required to cause shear failure.

That means if you plot torque versus theta you can see after some time the nature of the curve will be almost static or it will try to go down. So this has to be done for 2, 3 different plates, minimum 3 plates. If you take 2 plates I will discuss what are the limitations, if you take 2 plate, so you have to take minimum 3 plates. So this is all about the bevameter technique, let us now see what is the pressure-sinkage test? How we can handle those data which is, which are obtained from this pressure sinkage test.

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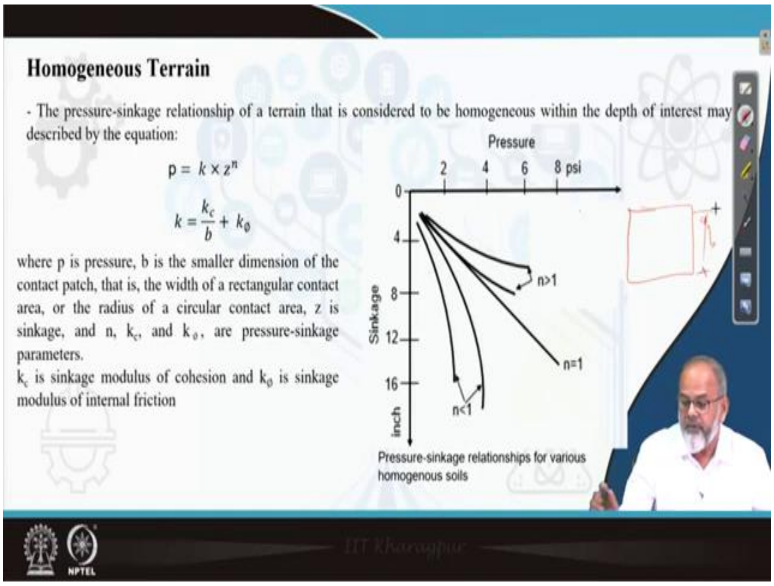

Now, the pressure-sinkage data if you plot it can take different shapes, which are shown in the right hand corner. If n is less than 1, then the tendency it is going down, if n is 1 it is a straight line at an angle of 45 degree, if n is greater than, sorry, if n is less than 1 this is going down, if n is greater than 1 it is going up and if n is 1 it is almost a straight line.

So the relationship can be described by an equation, which is given by Bakker's that is

$$p = k \times z^n$$

So k is the modulus of sinkage and z is the sinkage and n is the exponent of sinkage. So now, when you try to find out what is k? So, what we observed is

$$k = \frac{k_c}{b} + k_\emptyset$$

Where kc is the sinkage modulus of cohesion and k phi is the sinkage modulus of internal friction and b is the width of the plate. That means in a plate b is the smaller dimension, so this is b.

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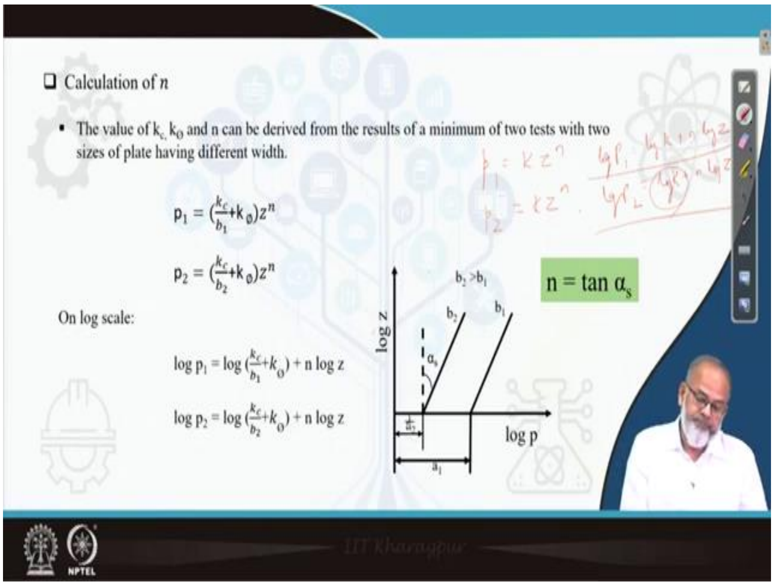

Now, for two plates if you try to collect data, then we try to relate; for plate 1, we will get a relationship

$$p_1 = (\frac{k_c}{b_1} + k_\emptyset) z^n$$

And for plate 2

$$p_2 = (\frac{k_c}{b_2} + k_\emptyset) z^n$$

So this if you look at, if I take log on both the sides then

$$\log p_1 = \log\left(\frac{k_c}{b_1} + k_\emptyset\right) + n \log z$$

$$\log p_2 = \log\left(\frac{k_c}{b_2} + k_\emptyset\right) + n \log z$$

Now log P1-log z, if you try to plot you will get a straight line plot like this which is shown here for a plate b1, for a plate b2, where b2 is dimension is greater than b1. Now, after getting these plots, the next thing is how to find out this kc, k phi and n. Now, slope of these two plots will give you the exponent of sinkage. But question is whether the two plots which you get for the two plates, are they parallel?

If they are not parallel then what value of slope you are going to take? So, if they are parallel, it is very simple. Any one slope you can take as the exponent of sinkage, but if it is not parallel, if these two lines are not parallel, then what you have to do is you have to take the slope of individual lines, then take the average of the slope and then find out what is the average slope that represents the exponent of sinkage.

Now after finding out the exponent of sinkage, then question is how to find out kc and k phi. So, in this plots what you can see there is an intercept, if you look at this equation or this equation, the intercept is nothing but your log k. So I have indicated for plate b1, the intercept as a1 and for b2, the intercept as a2. Now at z is equal to 1. So, what will happen? So this component will be 0, this component will be 0.

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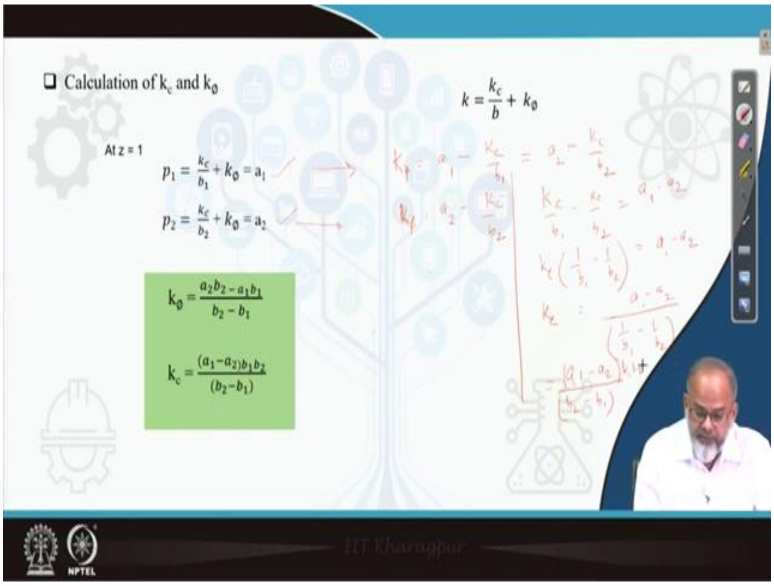

At z = 1

$$p_1 = \frac{k_c}{b_1} + k_\emptyset = \mathrm{a}_1$$

$$p_2 = \frac{k_c}{b_2} + k_\emptyset = \mathrm{a}_2$$

$$\mathrm{k}_\emptyset = \frac{a_2 b_2 - a_1 b_1}{b_2 - b_1}$$

$$\mathrm{k}_\mathrm{c} = \frac{(a_1 - a_2) b_1 b_2}{(b_2 - b_1)}$$

But the limitation of this kind of expression, which you derived is, it is only applicable when the sinkage is 1, z is equal to 1, then only you can derive this. But all the time you may not get sinkage as 1. So in that case how to find out kc and k phi.

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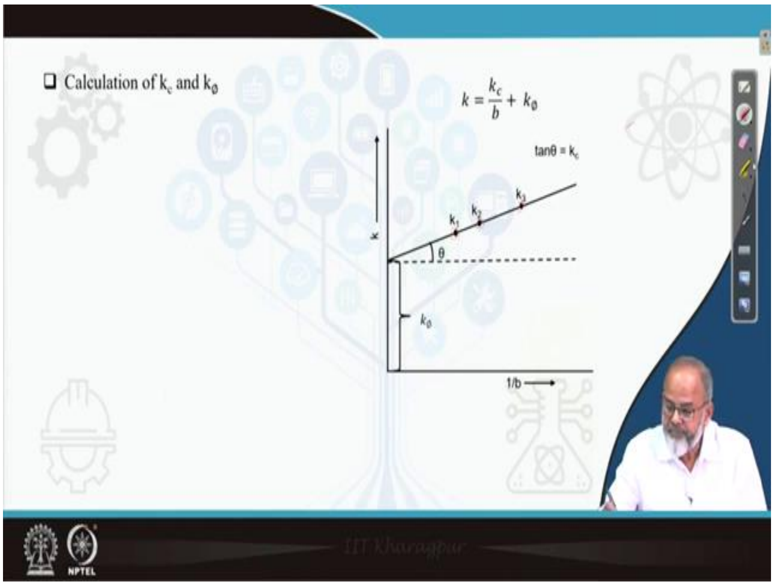

So that’s why, in the beginning I said at least you have to take 3 plates and the plate-sinkage test has to be carried out for 3 sizes of plates, whether it is a rectangular plate, whether it is a circular plate, does not matter, but if you are taking a circular plate, then the radius should be equal to the width of the rectangular plate. So now if you are taking 3 plates then you will be getting three k values,

$$p = k \times z^n$$
.

So in that case, for three plates you will get three k values. Now if you try to plot these k values versus 1 upon b, so then you will land up with, these are the points which you get and then you best fit a line passing through these points and extend it to touch the y axis. So now the intercept will give you directly k phi, and the slope will give you kc. So this is a little simpler and free from error in the sense, for any depth you can find out the kc and k phi value by using three plates.

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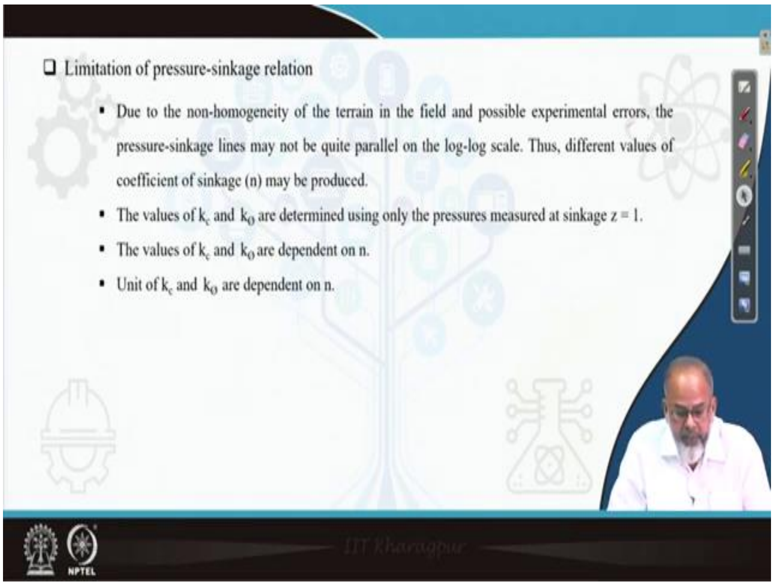

So, now this has been proposed by Bakker's, so let us now see, what is the limitation of this Bakker's pressure-sinkage equation? P is equal to kz to the power n. The value of kc and k phi, they are dependent on n. If we vary n that dimension, the unit will change, and this is applicable to soil, which is to be homogeneous. If it is a non-homogenous soil then applicability of this equation is not known.

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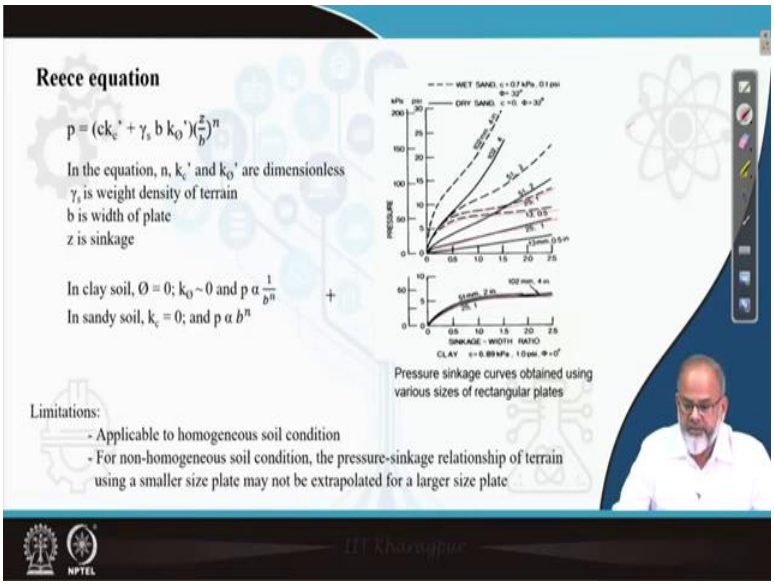

So another scientist, named Reece, he tried to modify that equation. So he developed an equation

$$p = (ck_c' + \gamma_s \, b \, k_\varnothing')\left(\frac{z}{b}\right)^n$$

Where n, kc dash and k phi dash they are all dimensionless and gamma is the wet density of the terrain and b is the width of the plate and z is the sinkage. Now he tried to prove the principle parameters which are used, the principle features of this equation here he tried to verify.

And what he has done is, he has carried out different plate-sinkage tests by taking plates of different sizes, starting from 1 inch to 4 inch and with the aspect ratio of 4.5, then what he has done is, initially he tried in a clayey soil. So if it is a clayey soil means, the equations simply implies that k phi is 0, so that means p versus z by b, if we will plot, irrespective of which size of plate you take, the curve will be similar. Similar means, they will merge into one curve, so which is indicated in this figure.

Now he has taken a sandy soil, where c is equal to 0. So if that is so that means the pressure required to cause penetration depends on the size of the plate. When you increase the plate size then pressure will increase. So, this pressure versus z by b ratio, when it is plotted you can see for different sizes of plates, these solid lines, these are the plots which you obtained.

So that means whatever equations he has developed that is fitting to the experimental findings. Now what he has done is in dry sand, he calculated, he measured and verified these are the solid lines are the plots for the dry sand, and in that dry sand he tried to add certain water. So by adding water what happens, the c value is not changed rather, some cohesive force will come into picture and the pressure which will be required that will be increased.

And that is what he has obtained. You can see 13 millimeter plate and 13 millimeter plate, when water is added. So there is a difference, so this is the pressure versus z by b plot, when moisture is added. So that is reflected in this equation. Similarly for 25 millimeter, you can see, when it is a dry sand you are getting this line, when moisture is added, you are getting a line this.

So the features which are observed experimentally, those features are reflected very nicely in the equations, which are developed by Reece. But again this equation is suffering from, the limitation is that it has to be applied in a homogeneous soil. And for non-homogeneous soil the pressure-sinkage relationship of terrain using a smaller size plate may not be extrapolated for a larger size plate. So these are the limitations.

So we discuss about the two equations which are available for finding out the pressure-sinkage relationship; one is Bekker's equation, the other one is Reece equation and those are applicable to homogeneous soil. Now if the soil is non-homogeneous like organic muskage, so in that case what will happen to this pressure-sinkage relationship? So let us now see that.

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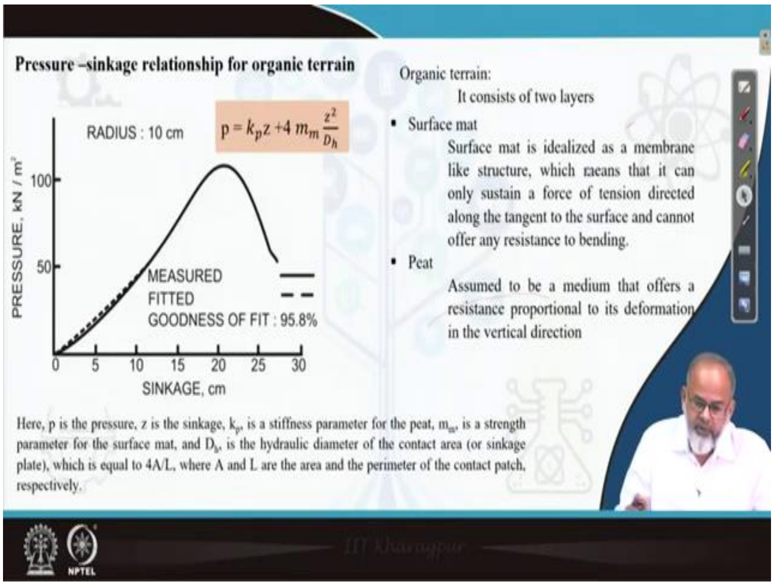

So organic muskage means there will be vegetative cover on the top surface and on the bottom surface there will be peat, a saturated peat. So if, that is the soil condition, then the pressure-sinkage test with a plate of radius 10 centimeter, shows this kind of curve. Initially, there will be resistance which will be offered by the vegetative cover, then after the vegetative cover is about to fail, then what will happen?

The lower saturated peat or clay that does not offer that much of resistance, so it will start decreasing. Okay. So here the relationship is indicated by

$$p = k_p z + 4\ m_m \frac{z^2}{D_h}$$

For z is the sinkage, kp is the stiffness parameter for the peat and mm is the strength parameter for the surface mat and Dh is the hydraulic diameter of the contact area. So, which is equal to 4A/L, where A is the area and L is the perimeter of the contact patch.

So utilizing this equation we can find out the pressure-sinkage relationship for organic terrain. What we have considered here is, the organic terrain has two layers, as I said, the one is the surface mat or the vegetative cover, this is idealized as a membrane like structure, which means that it can only sustain a force of tension directed along the tangent to the surface and it cannot offer any resistance to bending.

And the peat is assumed to be a medium that offers a resistance proportional to its deformation in the vertical direction. So we discussed, the two equations which are used for finding out the pressure-sinkage relationship for homogeneous soil. Then the other relationship is for the muskage or the vegetative cover with peat below.

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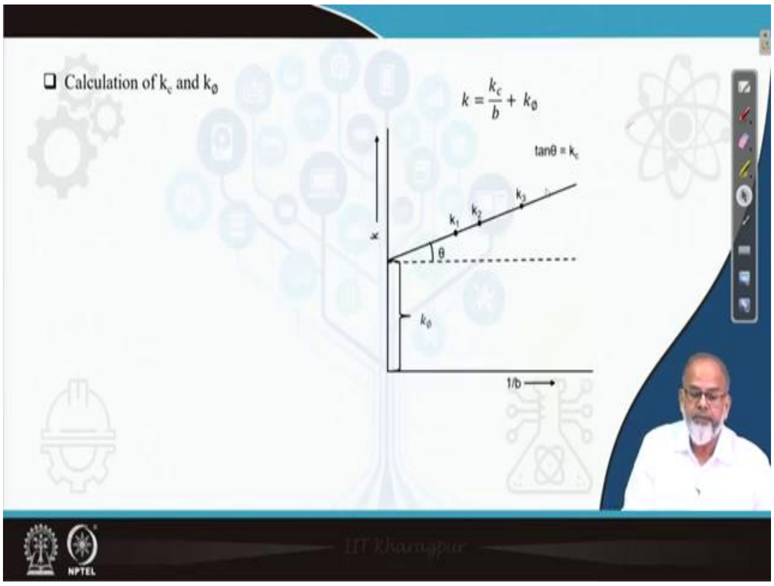

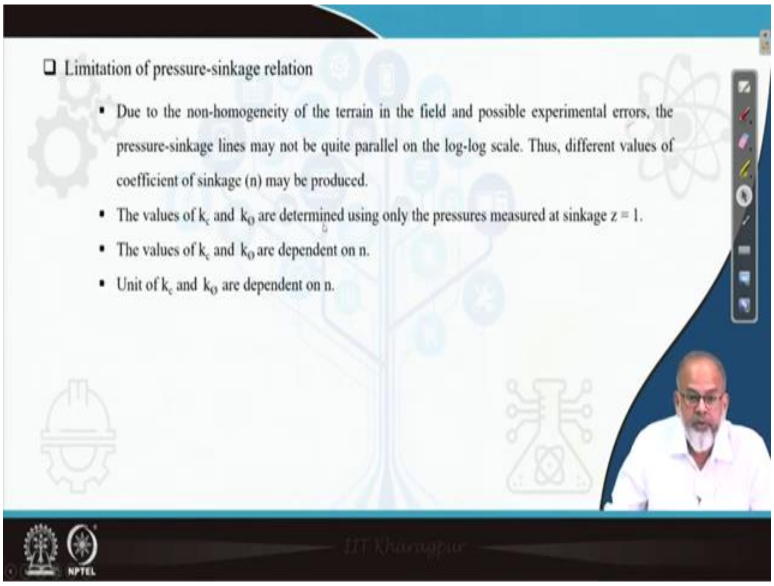

Now one thing I like to say here is the plot in case of k versus 1/b, here the k value is the, 1 by k is equal to. This is for finding out kc and k phi and that means the cohesive modulus of sinkage and the frictional modulus of sinkage and exponent of sinkage. So this is all about the Terrain response.

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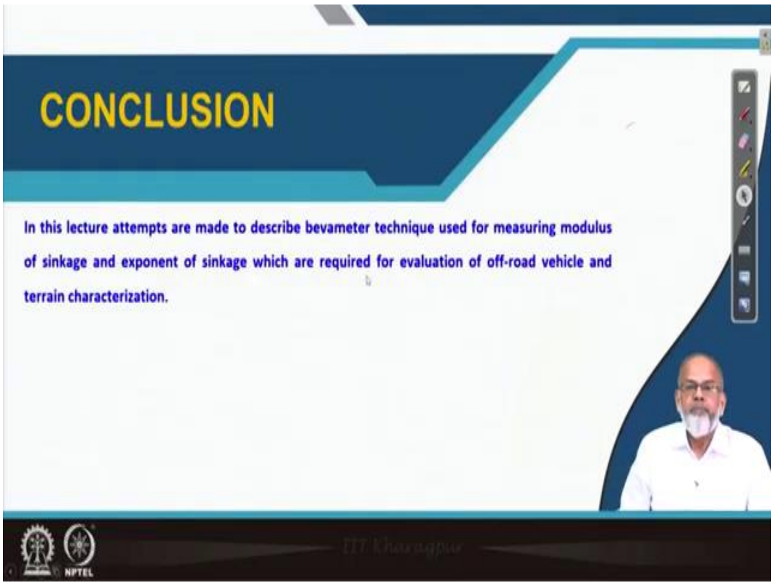

So in brief I can conclude that attempts are made to describe the bevameter technique, which is used for measuring modulus of sinkage and exponent of sinkage and these are required for evaluation of off-road vehicle and terrain characterization.

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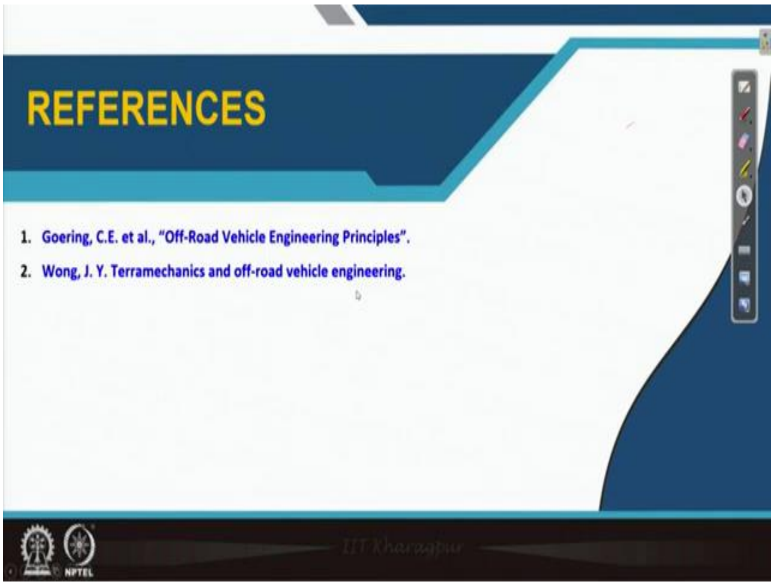

So you can refer the books like 'Terramechanics and Off-Road Vehicle Engineering,' then 'Off-Road Vehicle Engineering Principles' for further clarification. Thank you.