Rock Mechanics and Tunnelling
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Lecture 42
Foundations

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Hello, everyone. I welcome all of you to the 1st lecture of Module 9. So, in Module 9, we will discuss about the foundations and the rock support systems. So, today we will begin with the foundations.

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So, first we will discuss about the types of foundations on rock. Then we will focus on the shallow foundations then, estimation of safe bearing pressure from rock mass classification, from core strength, from pressure meter test these things we will learn today.

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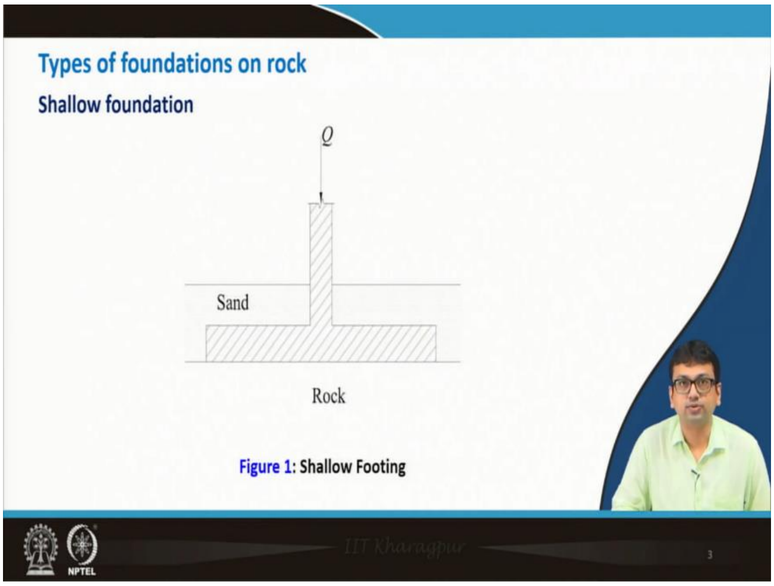

As we have learnt in soil mechanics that there are two types of foundations which are shallow foundation and deep foundation. So, shallow foundation is something like this here as shown in the figure.

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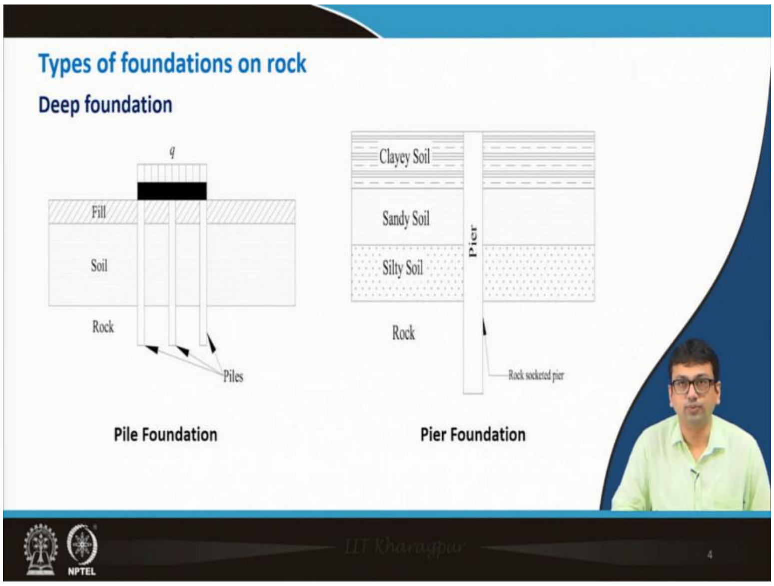

And deep foundation is like pile foundation, then pier foundation.

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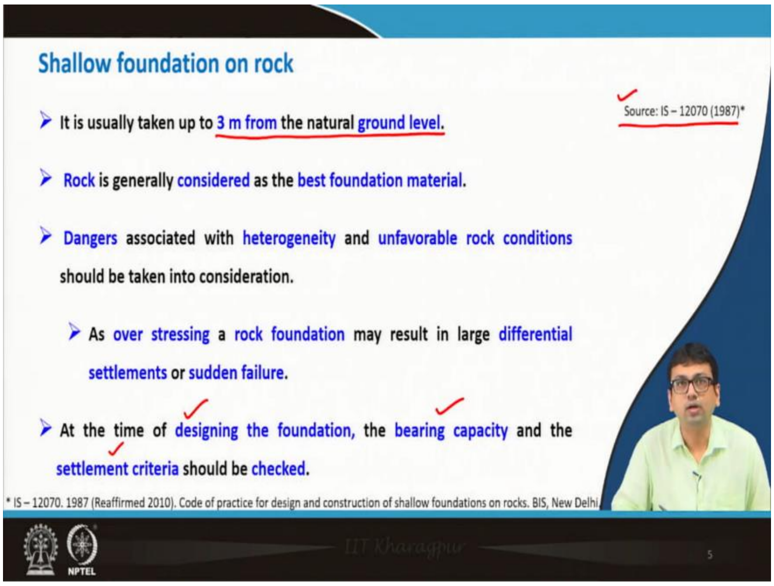

So, as per IS- 12070, the depth of the shallow foundation is usually taken up to 3 meter from the natural ground level. In general, if the depth of foundation is less than equal to the width of the foundation, then we call the foundation as the shallow foundation.

As per IS-12070, the foundation up to 3 meter depth from the ground level can be considered as shallow foundation.

Now, rock is generally considered as the best foundation material. Generally, as compared to soil, rock is having more compressive strength. That is why, rock is generally considered as the best foundation material.

Now, dangers associated with heterogeneity and unfavourable rock conditions should be taken into consideration as over stressing a rock foundation may result in large differential settlements or sudden failure.

That is why, at the time of designing a foundation, the bearing capacity and the settlement criteria should be checked. So, both bearing capacity as well as the settlement criteria should be checked.

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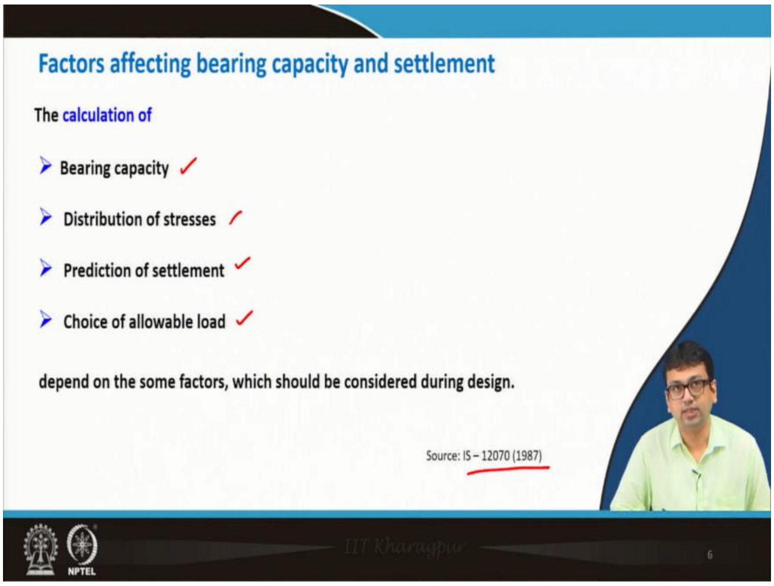

T IS code has given some guidelines regarding this. So, the calculation of bearing capacity. Then distribution of stresses. Then prediction of settlement and choice of allowable load depend on some factors which should be considered during design. So, as per IS-12070 we will see now, some of the factors which we should consider at the time of designing the foundation.

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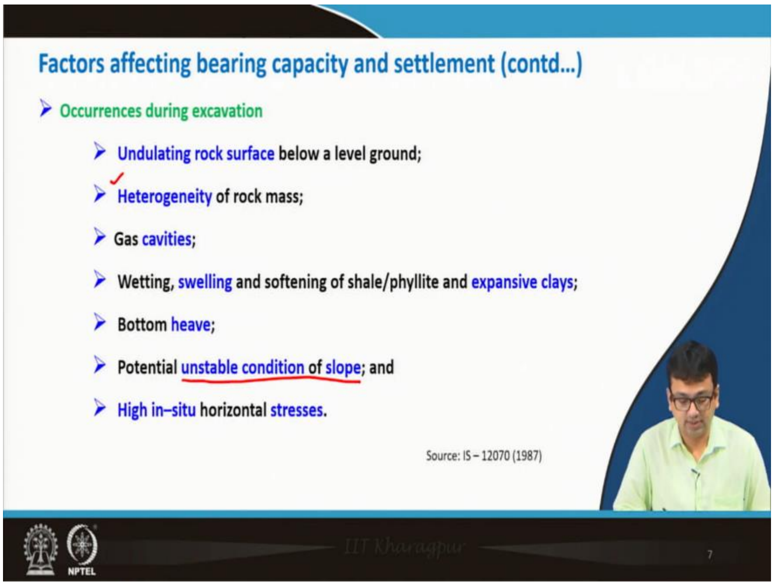

So, the first one is the occurrences during excavation like undulating rock surface below a level ground. Heterogeneity of rock mass which is very much important as we know that the rock mass is highly heterogeneous, anisotropic. So, the heterogeneity of rock mass can play an important role.

So, at a particular location, the strength is very high but within a very near vicinity, you may find a weaker rock mass because of the presence of different discontinuities that may cause the rock mass to become weaker. Hence, the heterogeneity of rock mass should be considered because depending on that, the overall strength of the rock mass can be obtained very precisely. Now, the presence of gas cavities and wetting, swelling and softening of shale or phyllite and expansive clays.

So, expansive clays swell when it comes to the contact of water, so, those things we need to consider. Then bottom heave that also we should consider. Potential unstable condition of slope, that is also important. Unstable condition of slope that also we should consider, i.e., these factors are needed to be considered at the time of designing the foundation and high in-situ horizontal stresses. So, these are all the factors taken from IS-12070.

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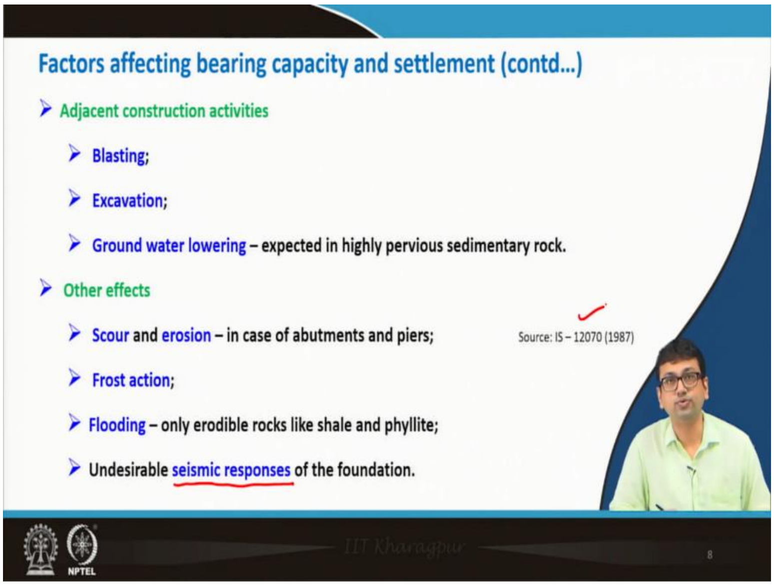

Likewise, few other conditions like adjacent construction activities like blasting, it is one of the very important thing whether blasting is happening or not that we need to consider because of blasting is a sudden impact load (dynamic). It may come suddenly so, that is what we should consider at the time of designing. An excavation, if some adjacent construction activity where excavation is going on, that may affect the bearing capacity or the settlement of the foundation.

Also, the groundwater lowering because of adjacent construction activities, i.e., the ground water may get lower. So, that also we should take into account. So, groundwater lowering expected in highly pervious sedimentary rock.

Apart from that IS code recommends few other effects like scour and erosion in case of abutments and piers. Frost action, then flooding (only erodible rocks like shale and phyllite) for that flooding can be one of the important condition which we should consider at the time of designing. Also, undesirable seismic responses of the foundation. So, that is also we should consider as per IS-12070 (1987).

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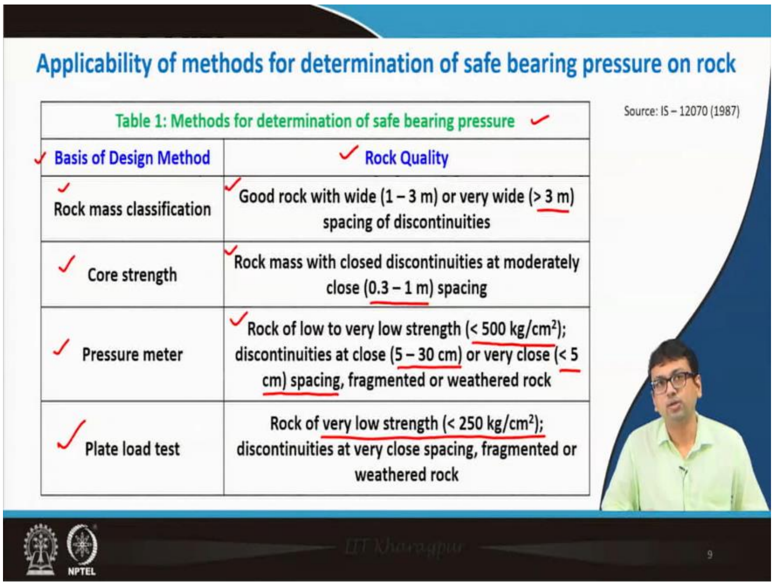

Now, applicability of methods for determination of safe bearing pressure on rock as per IS code. So, IS code provides some guideline for the determination of safe bearing pressure. So, we have to check the rock quality and based on that we have to decide the basis of design method. So, let us look at the first one. It says good rock with wide 1 to 3 m or very wide > 3 m spacing of discontinuities. In that case, rock mass classification can be used. I will explain what IS code says regarding that.

Then for the second one that rock mass with close discontinuities at moderately close, i.e., 0.3 to 1 m spacing. So, in that case core strength that should the basis of design. Then rock is of low to very low strength means < 500 kg/cm^2. Discontinuities at close (5 to 30 cm) or very close (< 5 cm spacing), fragmented or weathered rock; in that case pressure meter test should be the basis of design method. Again, the IS code has given some guidelines for that also.

Other than that, another thing is the plate load test. So, rock is of very low strength which indicates < 250 kg/cm^2. Discontinuities at very close spacing, fragmented or weathered rock. So, in that case, we go for plate load test, i.e., the basis of design should be plate load test and for that also IS code has given some guidelines. So, we will learn the plate load test in the next lecture, but today we will discuss up to the pressure meter.

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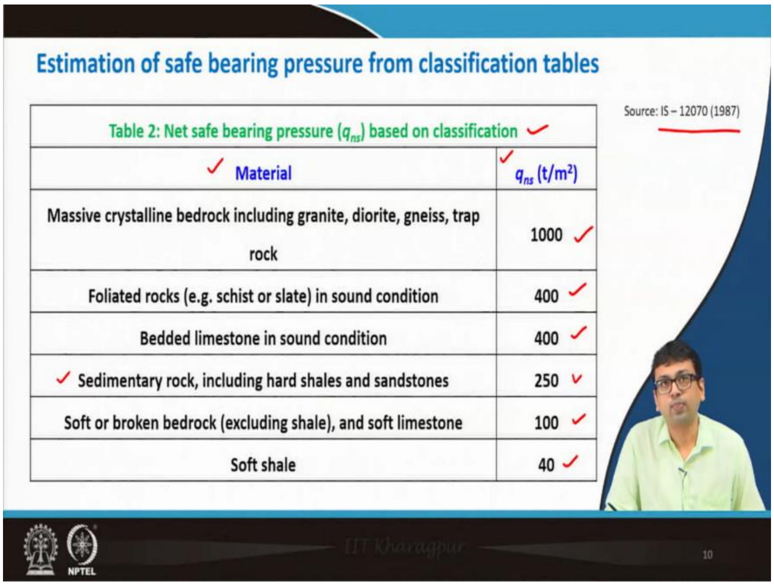

So, the first one is the estimation of safe bearing pressure from the classification table. So, net safe bearing pressure (q_{ns}) is based on classification. As per IS-12070 so, what it says? So, material and q_{ns}, in t/m2. For massive crystalline bedrock including granite, diorite, gneiss, trap rock, the q_{ns} value is 1000 t/m^2. Likewise, for foliated rocks in sound condition, the q_{ns} value is 400 t/m^2. Similarly, for the bedded limestone in sound foundation, the q_{ns} value is 400 t/m^2.

Likewise, for soft shale, the q_{ns} value is 40 t/m^2. Thus, for the sedimentary rock including hard shales and sandstones, the q_{ns} value is 250 t/m^2. Then, for soft or broken bedrock, they are 100 t/m^2. So, this guideline may be followed when rock quality is satisfying this criteria.

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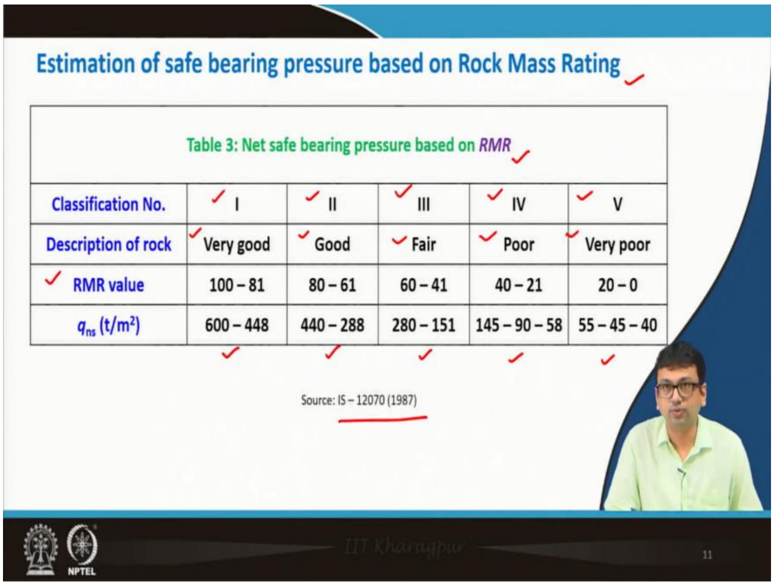

Now, again based on rock mass rating, you know RMR system as you have learnt it in the earlier module (we have discussed about it in detail). Now, from the rock mass rating also, the IS -12070 has given some guidelines. So, estimation of safe bearing pressure based on rock mass rating. So, net safe bearing pressure based on RMR. So, we are familiar with these classification numbers, i.e., I, II, III, IV, V and then description of rock is very good, good, fair, poor, very poor, respectively.

And corresponding RMR values are also provided here. Now corresponding to these RMR values, what should be the q_{ns} value in t/m^2 regarding that also IS code provides some guidelines. So, for a very good rock when the RMR value is between 81 and 100. So, we can consider the net safe bearing pressure (q_{ns}) as 448 to 600 t/m^2. Likewise, for good rock, it is 288 to 440 t/m^2. Then, for fair rock, the q_{ns} value is 151 to 280 t/m2.

Then, for poor rock, three values are given which are 58 to 90 to 145 and for very poor rock, 40 to 45 to 55. These ranges are provided by IS code. So, these are the readily available values which can be quickly identified if we refer to IS code.

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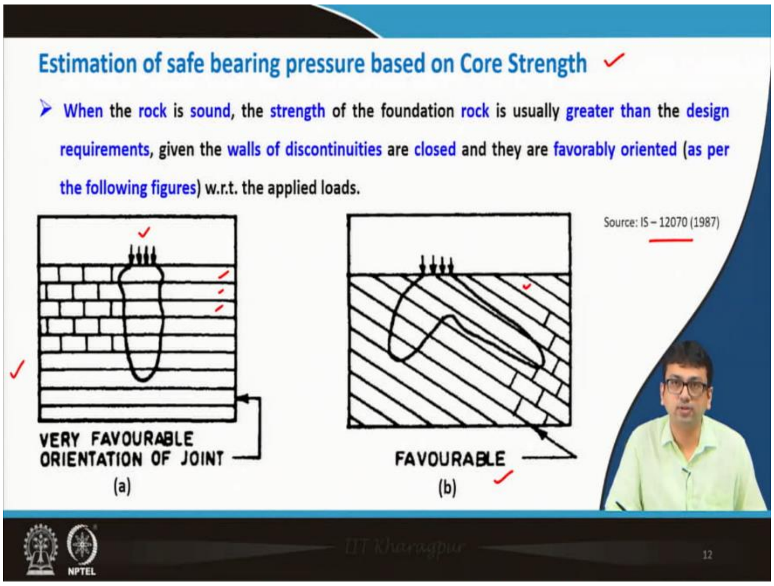

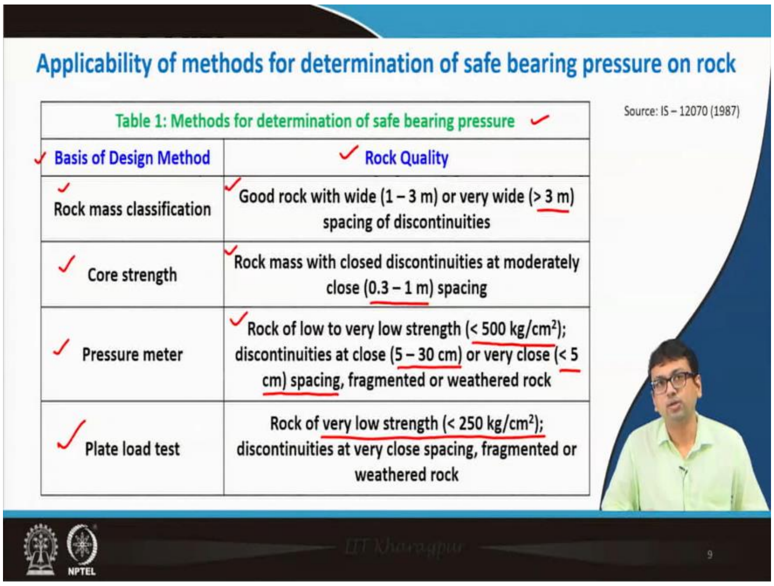

Now, another condition as I have discussed earlier is the estimation of safe bearing pressure based on core strength. So, when rock mass with close discontinuities at moderately close 0.3 to 1 m spacing in this case, we have to use core strength.

So, when the rock is sound, the strength of the foundation rock is usually greater than the design requirements. In general, given the walls of discontinuities are close and they are favourably oriented. This is as per the following figures with respect to applied loads. So, this condition will be considered as very favourable orientation of joints. These joints are parallel and perpendicular to the loading and it is considered to be the very favourable condition. Then, if the joint orientation is like this, then it is favourable. So, all these things are as per IS-12070.

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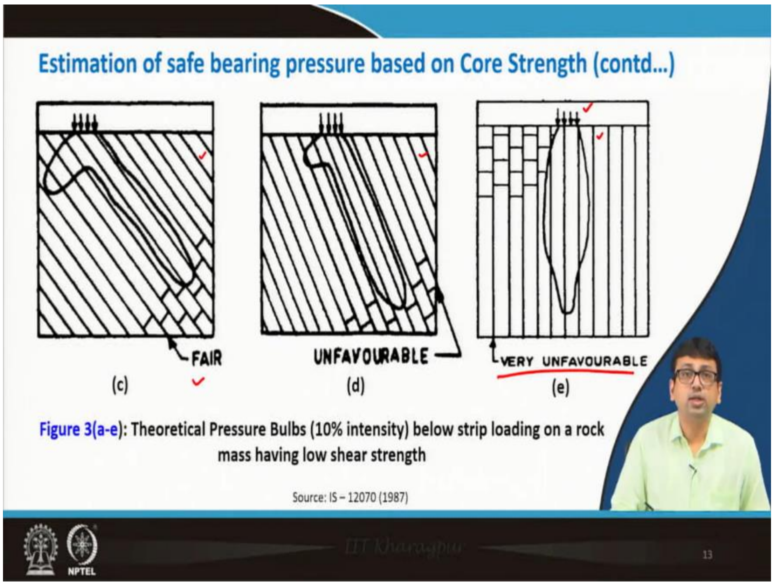

So, likewise it is the fair condition and it is unfavourable condition. What is the difference between fair and unfavourable conditions? The angle is steeper. So, it is unfavourable and then very unfavourable because here you can see, these angles are vertical, i.e., the angle between loading and the joints are zero (means they are in the same line). That is why, it is very an unfavourable condition. So, this is the theoretical pressure bulbs 10% intensity below strip loading on a rock mass having low shear strength.

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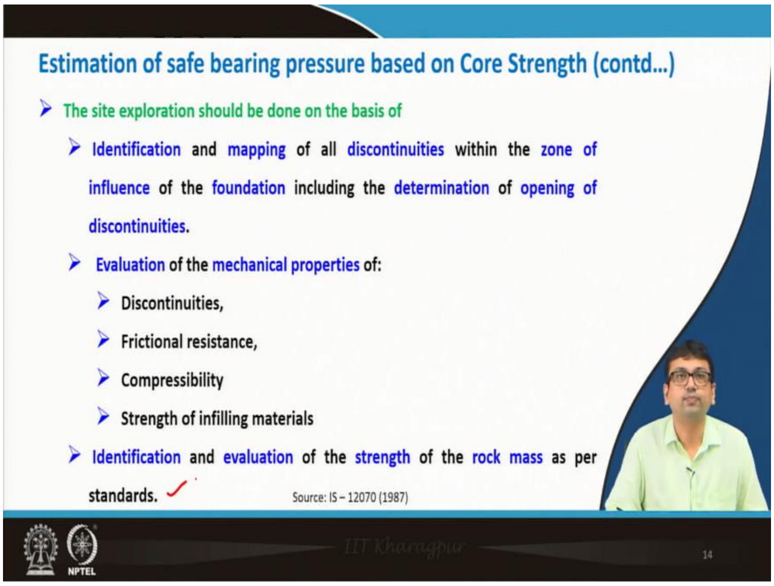

Now, the site exploration should be done on the basis of the identification and mapping of all discontinuities within the zone of influence of the foundation including the determination of opening of discontinuities. Also, evaluation of the mechanical properties of discontinuities, frictional resistance, compressibility, strength of infilling materials and also identification and evaluation of the strength of rock mass as per standards. So, again this is as per IS-12070.

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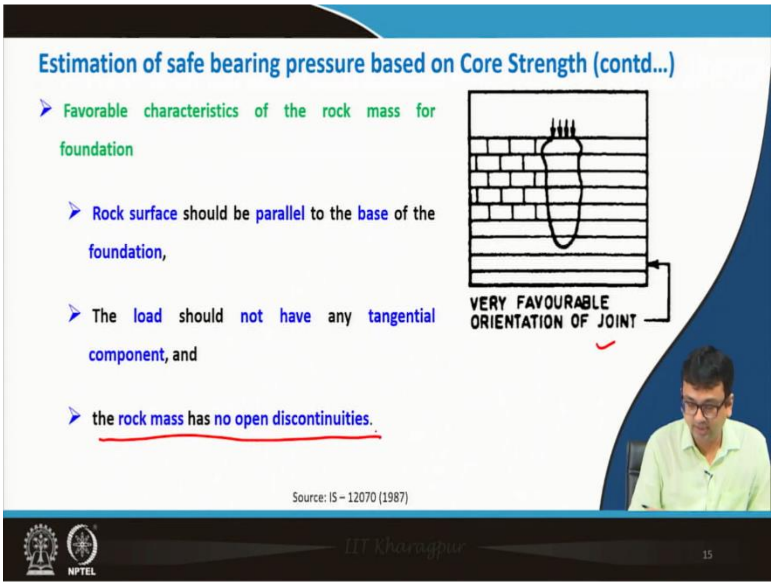

Now, the favourable characteristics of the rock mass for foundation. As per the illustration, the rock surface should be parallel to the base of the foundation. The load should not have any tangential component and the rock mass has no open discontinuities.

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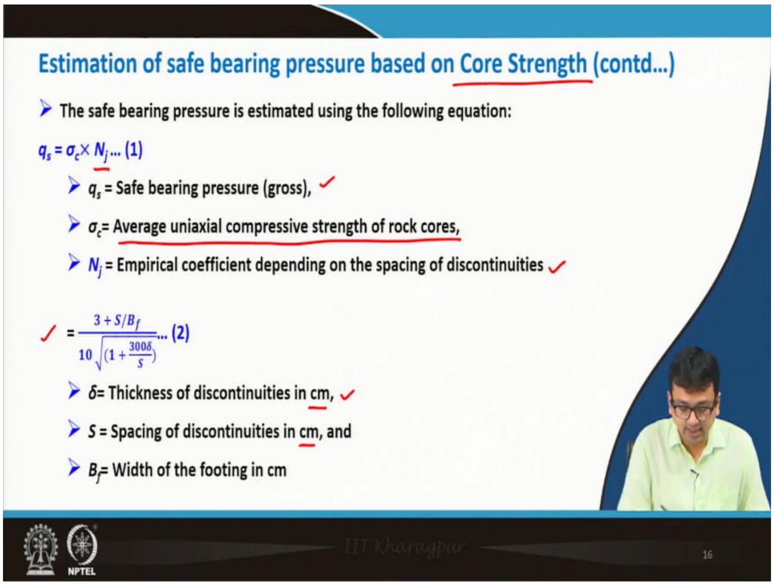

Now, the safe bearing pressure is estimated using following equation. So, we are discussing about the estimation of safe bearing pressure based on a core strength. The safe bearing pressure is estimated using the following equation. $q_s = \sigma_c \times N_j$. q_s is the safe bearing pressure, i.e., the gross safe bearing pressure; σ_c is the average uniaxial compressive strength of rock core.

N_j is an empirical coefficient depending on the spacing of discontinuities. So, as we know that the spacing of discontinuities plays an important role. So, the N_j actually is an empirical coefficient depending on the spacing of discontinuities.

So, $N_j = \dfrac{3 + \dfrac{S}{B_f}}{10 \times \sqrt{\left(1 + \dfrac{300\delta}{S}\right)}}$. So, δ is equal to thickness of discontinuities in cm. S is equal to spacing of discontinuities in cm. Here, the units are very important and B_f is the width of the footing in cm.

So, for this empirical equation, units are very important. So, using this equation we can easily find out the N_j which is an empirical coefficient depending on the spacing of discontinuities. So, we can see, the S is the spacing of discontinuities and B_f is the width of the footing. So, the (S / B_f) is a non-dimensional parameter which is the ratio of spacing to the width of footing.

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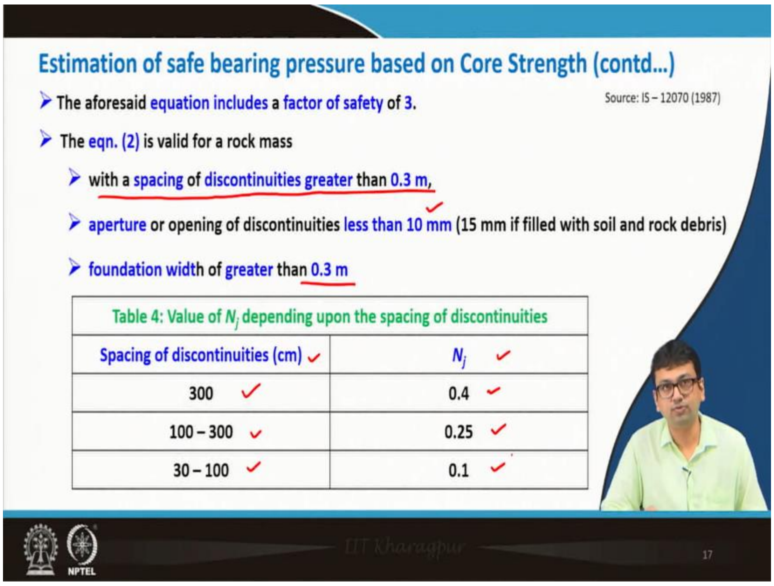

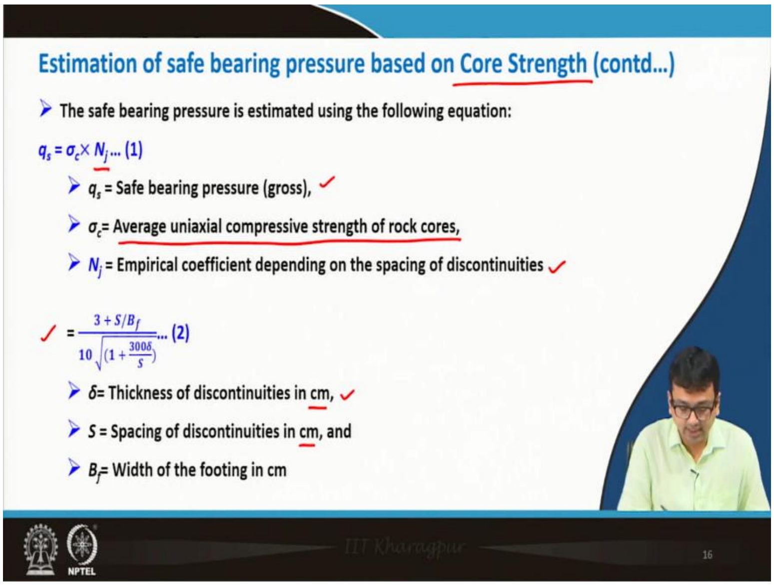

The equation what I have mentioned over here, includes a factor of safety 3. Now, the Eq. 2, $N_j = \dfrac{3+\dfrac{S}{B_f}}{10\times\sqrt{\left(1+\dfrac{300\delta}{S}\right)}}$. The equation is valid for a rock mass with spacing of discontinuities > 0.3 m.

There are some guidelines when we are using this equation. So, with the spacing valid for a rock mass with a spacing of discontinuities > 0.3 meter. Aperture opening of discontinuities is < 10 mm and 15 mm if filled with soil and rock debris. So, again these all are as per the IS code guidelines. So, the foundation width should be > 0.3 meter.

Now, the IS code also provides a table where the N_j value depends on the spacing of discontinuities (in cm). Thus, when the spacing of discontinuities is 300 cm, the N_j value is 0.4, likewise when the spacing of discontinuities is in between 100 cm to 300 cm, the N_j value is 0.25, and when the spacing of discontinuities is in between 30 cm to 100 cm, the N_j value is 0.1. Anyway, we have the equation which can also be used.

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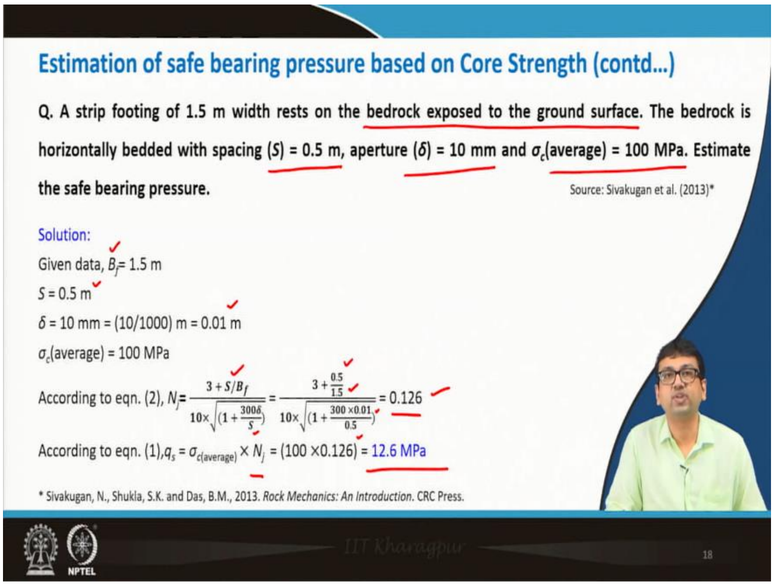

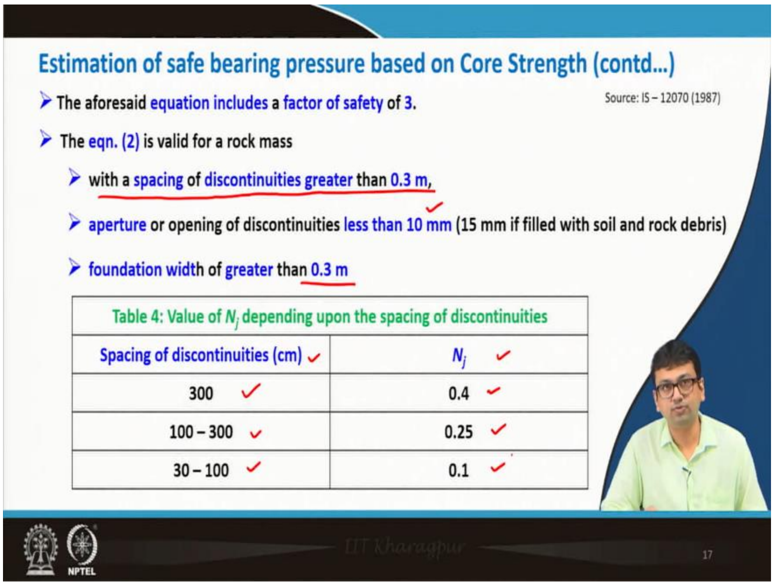

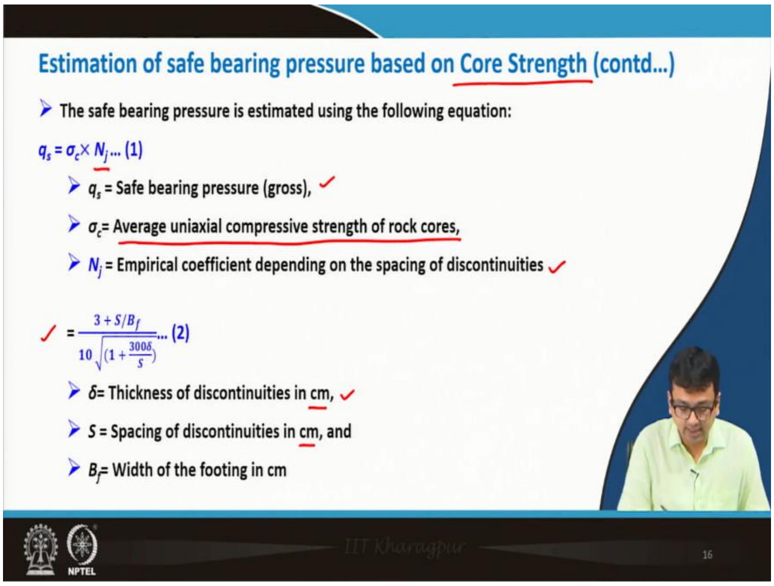

Now, let us solve a problem. So, the problem says a strip footing of 1.5 m width rests on bedrock exposed to the ground surface. So, the bedrock is exposed to the ground surface. The bedrock is horizontally bedded with spacing S is equal to 0.5 m, aperture is 10 mm and σ_c average is 100 MPa. So, estimate the safe bearing pressure.

So, what are the given data and what are the things we need? Let us look at the equation. So, we need S, we need B_f, we need δ. So, in this equation so, let us see what are the given data. So, B_f is given 1.5 m, then S is given as 0.5 m, then δ is given as 10 mm. So, 10 mm means it is 0.01 meter and σ_c (average) is 100 MPa.

So, we have converted all these things into m and now, you see since here it is like (S / B_f), so, meter-meter means it will become a non-dimensional parameter. Also, (300 × δ / S) also becomes a non-dimensional parameter.

So, basically if we take all the units in meter, then also it is fine otherwise as we have, we can see in this equation yeah, as I have shown you this is all the units were in cm but no problem because anyway these (S / B_f) and (300 × δ / S) are the non-dimensional parameter.

So, if you convert all these length units in to same units, so, then also no problem otherwise, you can make everything in cm and you can solve it. So, I hope you understand what I mean to say, both are same, but you cannot have B_f in meter and then S in cm and δ is in mm as it is not possible. Then, the empirical equation will not give the correct results. So, these are the given data. Now, according to equation 2 or as we know you can write, $N_j = \dfrac{3 + \dfrac{S}{B_f}}{10 \times \sqrt{\left(1 + \dfrac{300\delta}{S}\right)}}$. So, S is 0.5 m and B_f is 1.5 m. Likewise, δ is 0.01 m.

So, if all these values are replaced, we will get the coefficient, N_j as 0.126. Now, the gross safe bearing pressure (q_s) is $\sigma_c \times N_j$. So, according to Eq. (1), σ_c (average) is given as 100 MPa and N_j is 0.126. So, the safe bearing pressure (q_s) is 12.6 MPa.

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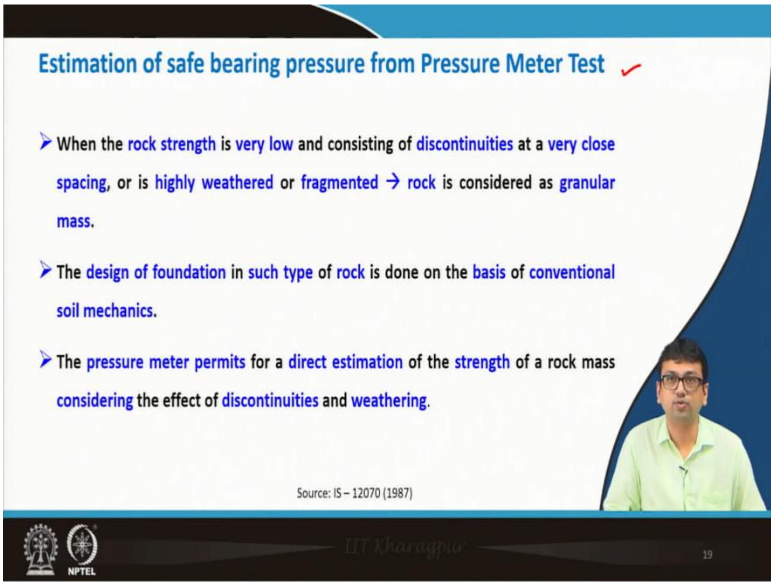

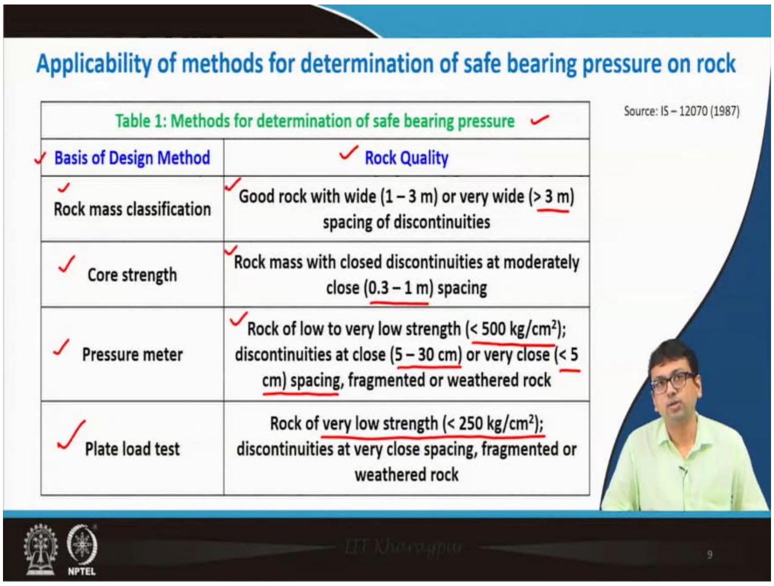

Now, the third one is related to the estimation of safe bearing pressure from pressure meter test. So, what was the corresponding condition? So, the pressure meter test is related to the rock of low to very low strength less than 500 kg/cm^2, discontinuities at close 5 to 30 cm or very close < 5 cm spacing, fragmented or weathered rock.

So, this is for pressure meter. For the rock of very low strength, i.e., less than 250 kg/cm^2. For that, the basis of design should be plate load test. Anyway, in this lecture, we will discuss up to the pressure meter test related guidelines. So, the estimation of safe bearing pressure from pressure meter test. When the rock strength is very low and consisting of discontinuities at a very close spacing or is highly weathered or fragmented, the rock is considered as granular mass.

The design of foundation in such type of rock is done on the basis of conventional soil mechanics. The pressure meter permits for a direct estimation of the strength of a rock mass considering the effect of discontinuities and weathering.

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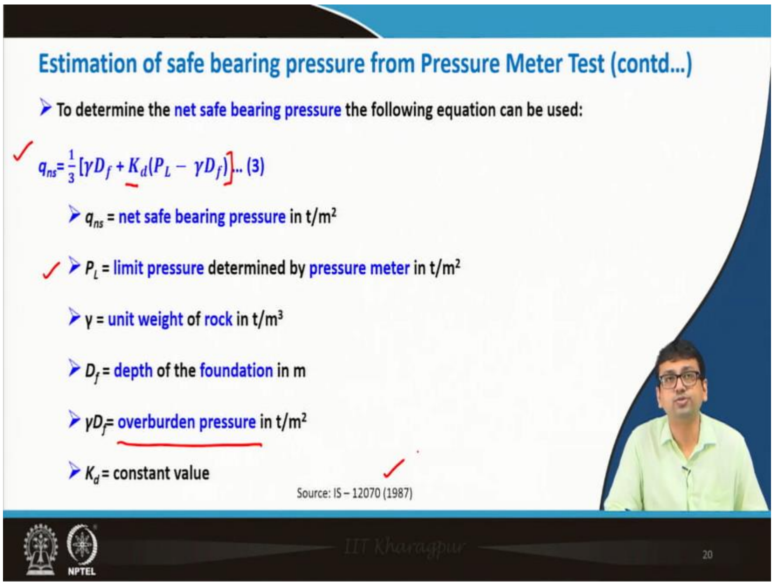

Now, to determine the net safe bearing pressure, the following equation can be used. So, this is again as per IS-12070 guidelines. So, this is the equation for net safe bearing pressure $q_{ns} = \frac{1}{3}[\gamma D_f + K_d(P_L - \gamma D_f)]$. So, the q_{ns} is the net safe bearing pressure in t/m^2. P_L is the limit pressure determined by pressure meter in t/m^2.

Now, γ is the unit weight of rock in t/m^3 and D_f is the depth on the foundation in m. So, obviously γD_f is the overburden pressure in t/m^2. Now, K_d is the constant value. Now for that IS code has given some guidelines what should be the K_d value. So, let us see that.

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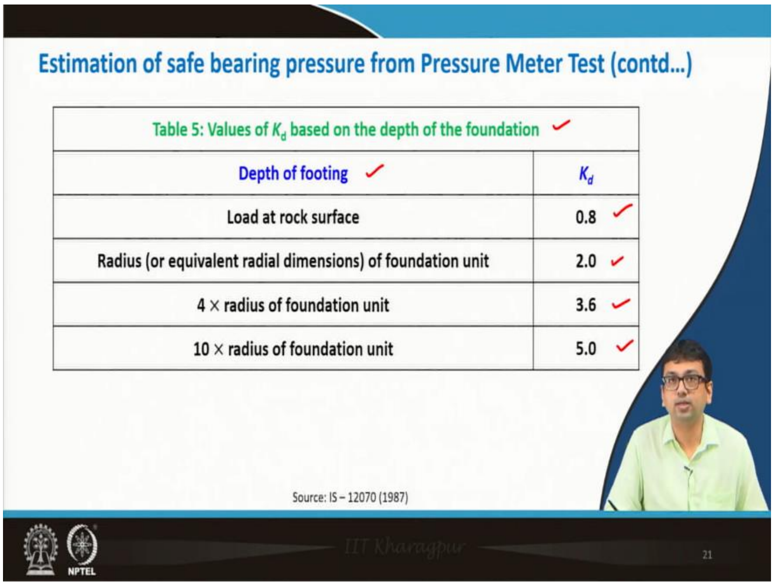

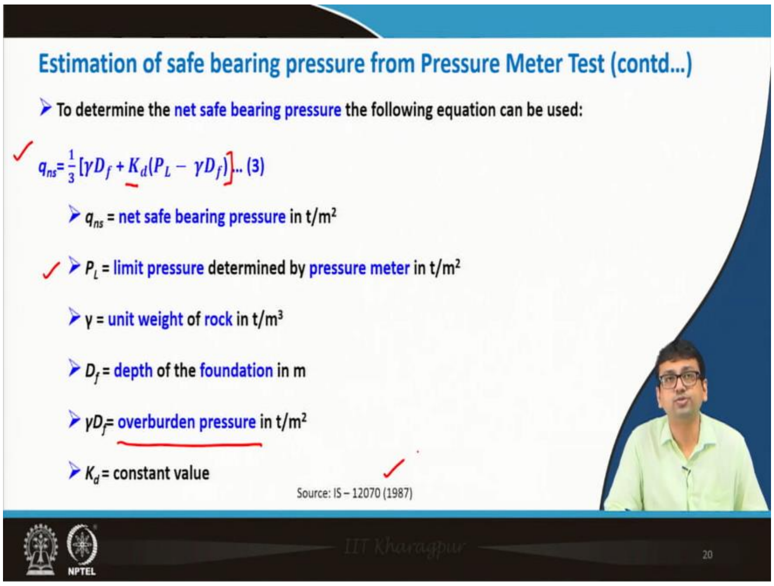

So, the values of K_d are based on the depth of the foundation. When the loading is applied at the surface of rock, i.e., the depth of footing = 0. In that case, K_d is 0.8. If the depth of footing is equal to the radius (or equivalent radius) of the foundation unit, then the K_d value is 2.

So, radius of foundation means what is the radius that is the depth of foundation. So, in that case, the K_d should be 2. If the depth of the footing is 4 times radius of foundation unit, the K_d value is 3.6, and for the depth = 10 times radius of foundation, it is 5. So, in this way K_d values can be obtained from this table provided in Is code. So, we can simply use this Eq. (3) to determine the net safe bearing pressure.

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So, okay so, with this let us conclude our today's class. So, in our next class we will continue with the guidelines for estimating the net safe bearing capacityss based on the plate load test. Thank you.