Rock Engineering

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Lecture - 56
Foundations on Weak Rocks

Hello, everyone. In the previous class, we finished our discussion on the stability analysis of rock slopes. Let us try to understand another application area of rock engineering, which is related to foundations on weak rocks. So, in this chapter, we are going to learn how to determine the bearing capacity of the foundations. As far as soils are concern, you are aware of various theories related to the determination of bearing capacity.

But, you will know by now that this material rock and rock mass is quite different than that of the soil and therefore, the treatment of this material is going to be altogether different. So, before we go to the determination of bearing capacity of the foundations on weak rocks, let us first try to understand that what are going to be the different problems as far as foundations on weak rocks are concerned. How the stress distribution going to take place in case of the foundations on weak rocks?

So, let us start with that often the foundations of multi storey buildings, bridges and dams. They are constructed on rock mass. These rock masses are non-homogeneous and discontinuous due to the presence of fissures, joints, faults or bedding planes with varying strength or there can be the combination of any of these 2 discontinuities. Greater degree of conservation is exercised in the estimation of load carrying capacity and resulting deformation of rock mass.

If you recall, you always apply a factor of safety of 2.5 to 3 in case of determining the safe bearing capacity of the foundations on soils. But in case of rocks, we have to be extra careful because of the non-homogeneity and discontinuous nature of this material.

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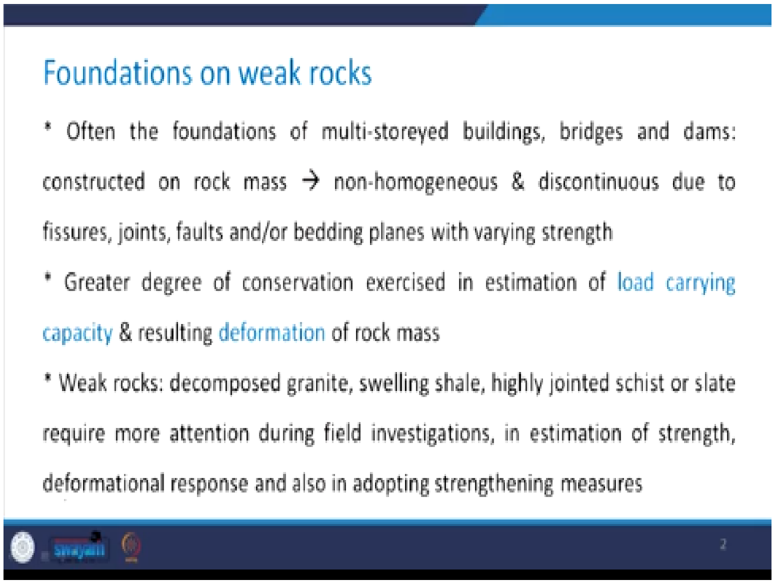

Weak rocks can include decomposed granites, swelling shale, highly jointed schist or slate and such type of weak rocks, they require more attention during the field investigations in the estimation of their strength and deformational response and also in adopting the strengthening measures.

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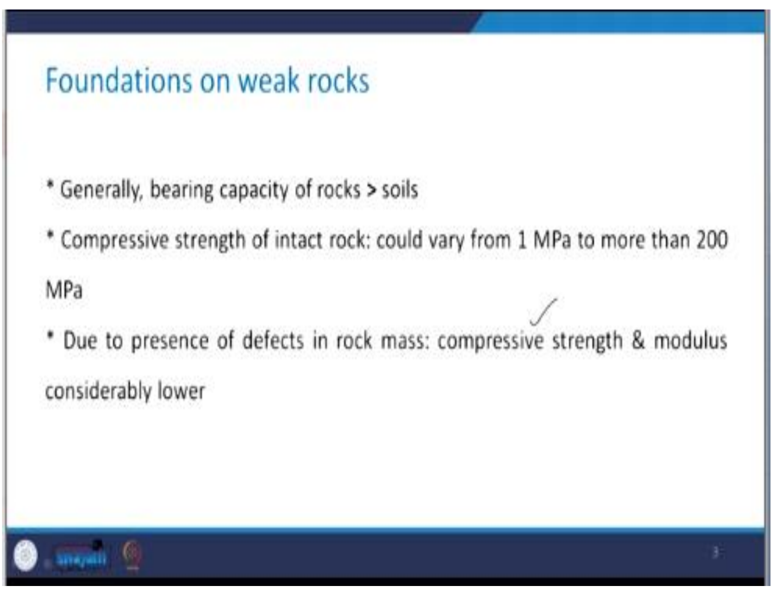

Generally, bearing capacity of rocks, they are more than those of the soils. So, when I write here that bearing capacity of rocks more than that of the soil, that means I am talking about the bearing capacity of the foundations on rocks, they are more than the bearing capacity of the foundations on soils. Compressive strength of this intact rock, it varies from 1 MPa to more than 200 MPa. And we have seen such things in detail in some of the earlier chapters of this course.

You all know that due to presence of defects in rock mass, the compressive strength and the modulus of the rock mass is much less as compared to that of the intact rock.

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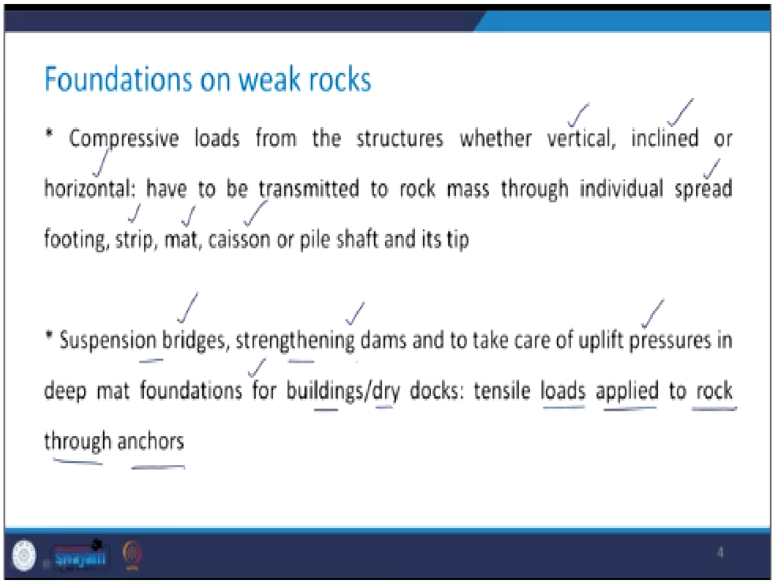

Compressive loads from these structures, whether these are vertical or inclined or horizontal. These have to be transmitted to the rock mass through individual spread footing or strip footing or mat foundation or it can be caisson or pile shaft and its tip. Suspension bridges, strengthening of dams and in order to take care of uplift pressures in deep mat foundations for buildings in dry docks, these tensile loads, these are applied to the rock through anchors.

So, you see that all the compressive loads are to be transmitted to the rock mass through these individual footings. These can be shallow footings or the footings however, such cases where you have to take care of the uplift pressures and these strengthening the dams or the suspension bridges. In these cases, tensile loads are applied to the rock through anchors.

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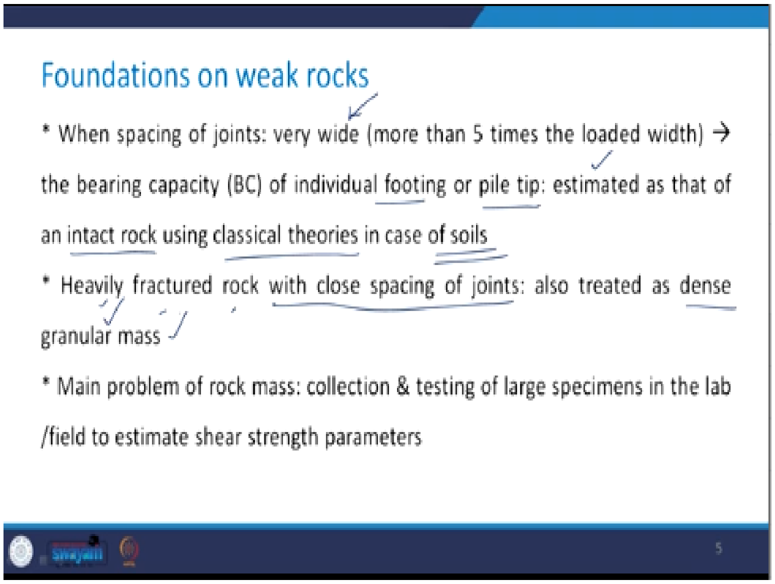

Now, when the spacing of the joints, they are very wide. So, which spacing that we will call as very wide that is the spacing which is more than 5 times the loaded weight. In such cases, the bearing capacity of the individual footing or the pile tip can be estimated as that of an intact rock using the classical theories, which we have in case of soils. However, in case of the heavily fractured rock with close spacing of joints, so, you see in the previous case when you had very wide spacing and in the second case, you are dealing with very close spacing of joints.

Now, this case can also be treated as dense, granular mass and all the theories which are relevant in case of soils, they will be applicable in this case as well. The main problem of the rock mass is the collection and testing of the largest specimen in the lab or field in order to estimate their shear strength parameters. And we have seen all these problems when we were discussing about the laboratory testing of the rocks.

It is really not possible to carry out some of these tests on the specimen of the rock mass. And you saw that how we obtained the Mohr-Coulomb parameters under effective stress condition using or taking the help of Hoek-Brown parameters.

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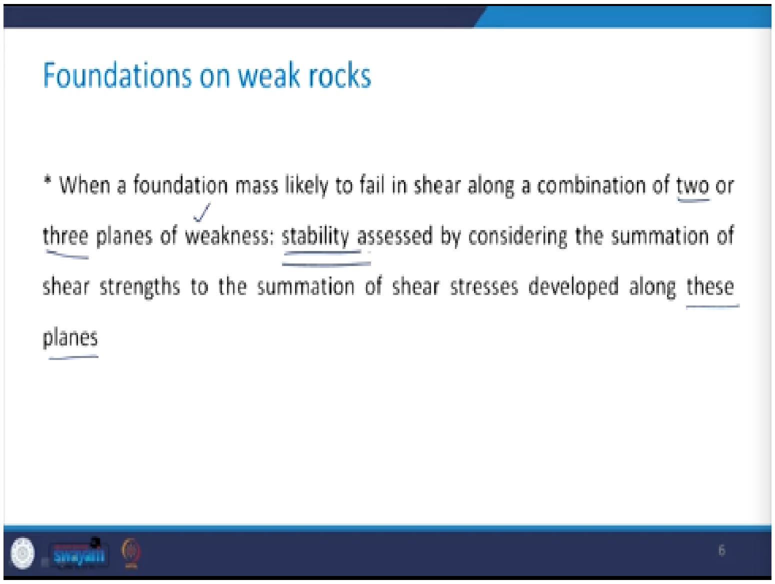

Now, when the foundation mass is likely to fail in shear along a combination of 2 or 3 planes of weakness, the stability is assessed by considering the summation of shear restraints to the summation of shear stresses developed along all these planes. Why we say that the stability is assessed by this? You are aware now that when we talk about the stability, we try to get the factor of safety.

And how do we obtain the factor of safety that is the basic definition of this is the ratio of strength to the cause, which is responsible for inducing that kind of failure. So, that is why here if the failure is going to take place along more than one plane of weakness, then we have to consider the shear strength and the shear stresses, which are developed along all these planes when we try to assess the stability.

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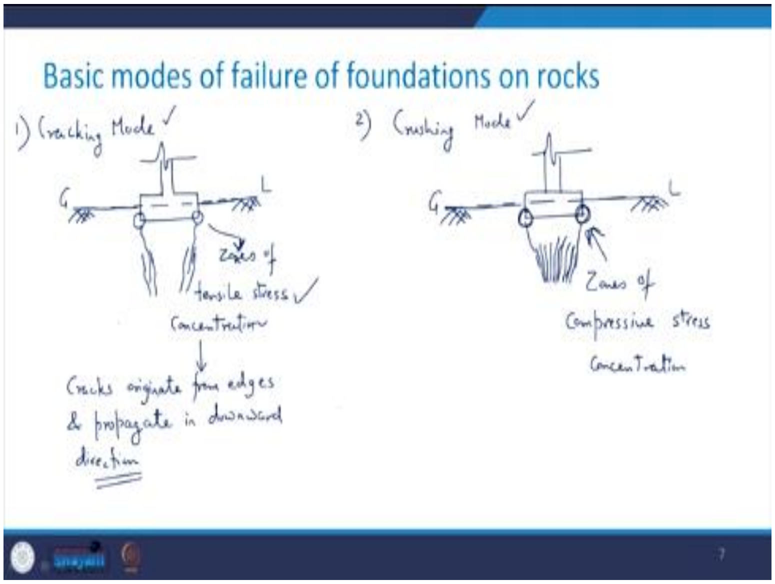

So, let me draw the basic modes of failure. So, the first mode of failure is the cracking mode. Let me draw that. So, here this is what that we will have as a ground level and this is what is going to represent the footing say and this is your ground level. So, in this mode, what happens is at these 2 points, the cracks start propagating like this in this particular manner and therefore, the cracking takes place.

So, these are basically, the zones of tensile stress concentration. In this case, what happens is that crack originates from edges and they propagate in the downward direction as I showed in this figure. So, this is what is called as the cracking mode. Then the second mode is the crushing mode. So, let us again draw a foundation and this is again in the similar way, this is what your ground level is.

And in this case, these 2 zones are going to be the zones of compressive stress concentration. So, these are zones of compressive stress concentration. So, what is the difference between cracking mode and crushing mode? In case of the cracking mode, there occurs these zones of tensile stress concentration and the cracks propagate. In case of the crushing mode, these are these zones of the compressive stress concentration and the failure takes place accordingly.

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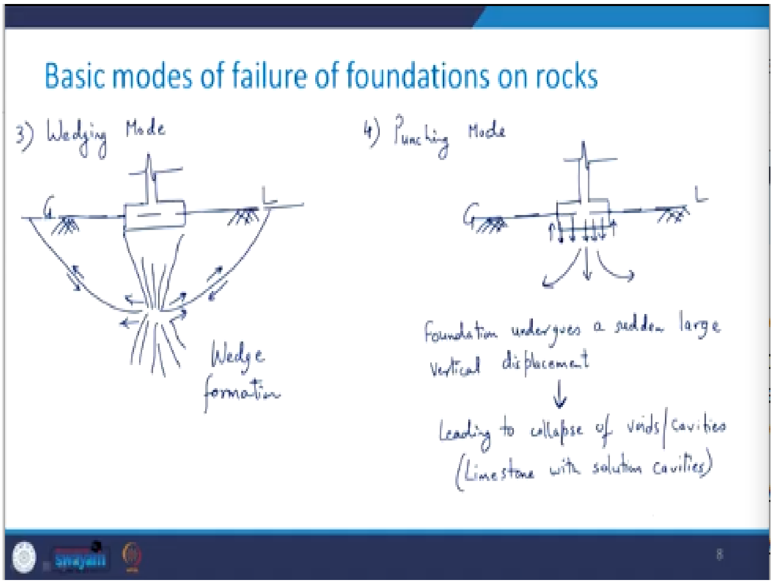

Then, the third mode is the wedging mode. As the name suggests, in this case, there is the formation of a wedge below the footing. So, say this is your footing and this level is ground level. There is going to be the formation of this kind of wedge, which will be extended in either side. And this is how we are the center, it is going to be and here on this side, it is going to be this kind of shear which is develop. So, in this case, there is going to be the formation of wedge.

The fourth one is the punching mode. Let us draw the footing once again, ground level and in this case, you will have be punching and here, it will be this manner and you will have the deformations like this. So, in this case, what happens is that the foundation undergoes a sudden large vertical displacement and this leads to collapse of voids or the cavities. This is quite relevant. In case, you have the limestone with the solution cavities. So, such type of failure mode is the punching mode.

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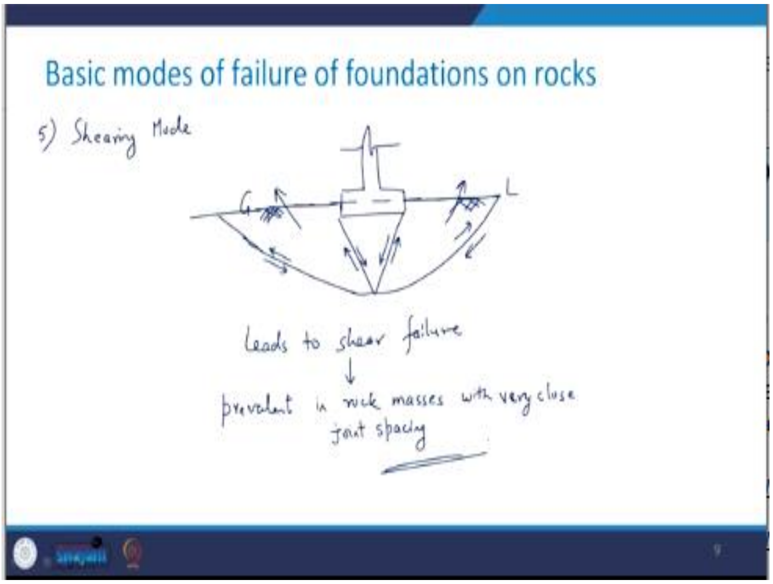

Then the last in this category is the shearing mode. Let us have the footing once again. So, this is your ground level and you are going to have this kind of situation in this case, so, this leads to the shear failure. This is prevalent in the rock masses with very close joint spacing. So, these are the 5 basic modes of the failure of foundations on rocks cracking, crushing, wedging, punching and the shearing mode.

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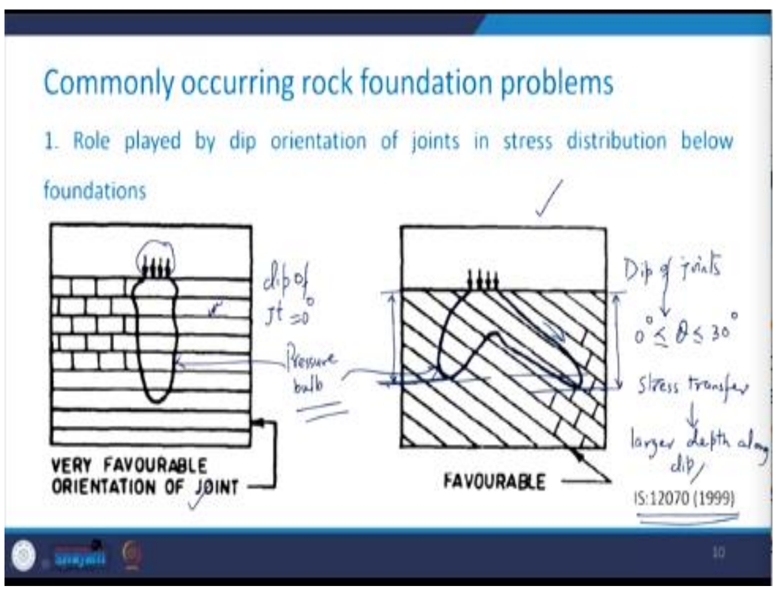

Now, let us learn about some of the commonly occurring rock foundation problems. So, the first factor which plays an important role towards these rock foundation problems is the dip orientation of the joints in stress distribution below the foundation. So, these figures, I have taken from the relevant IS code which deals with the bearing capacity of the foundations on the rock masses.

So, the first figure, you can see that here that see, load which is coming from the footing and the depth of the joint in this case is 0 degree and this is what the pressure bulb is. So, this is very favorable orientation of the joint as far as the footings to be placed on such type of rock masses concern. Now, the next one is this favorable condition where the dip of the joints, they are between 0 and the 30 degree and in this case, this is what is the pressure bulb as has been shown by this.

So, this is what your pressure bulb is in this case. Now, you can see that the stress transfer, it extends to a larger depth along the dip. So, see here, this is the direction along the dip and you can see that the stress transfer has taken up to this depth as compared to on the other side which is smaller than this particular depth. You can see that there is a difference. So, a stress transfer extends to; the stress transfer, it extends to larger depth along the dip.

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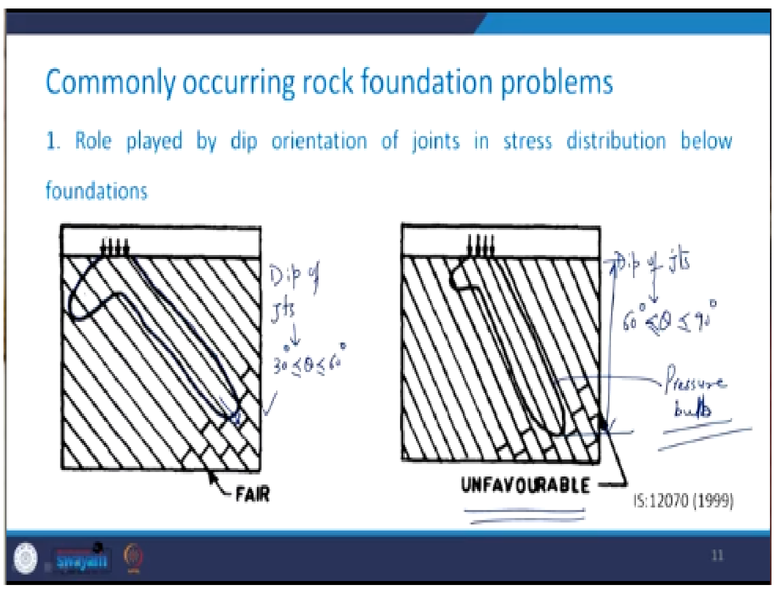

Coming to the next category, which is here that is the shear condition where the dip of the joins, they are between 30 degree to 60 degree and this is what is the pressure bulb and here you can see that the depth of this pressure bulb goes to much larger depth in the direction of the dip which is this okay. So, in this case, it is the dip of the joints is between 60 degree to 90 degree and you can see here that this is quite unfavorable condition and this is what the pressure bulb in this situation is.

So, as the dip of the joint is increasing the depth up to which the pressure bulb is getting developed below the foundation is also increasing. So, this is unfavorable condition.

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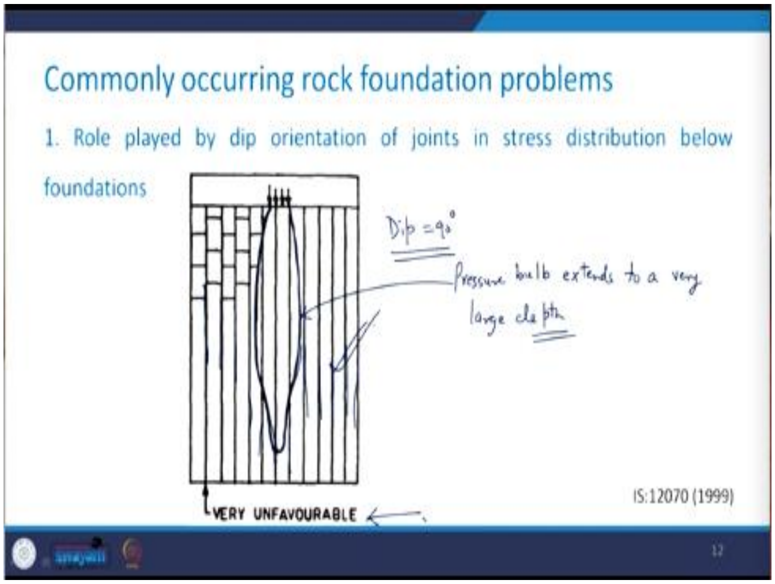

Now, the next one in which case you have dip as 90 degree and in this case, this pressure bulb extends too much larger depth as you can see here in this figure that this is what is your pressure bulb which extends to a very large depth and in this case, because the dip is 90 degrees. So, you can see that there are columnar joints this particular manner. So, this is the most unfavorable condition for the foundation to be resting on such type of the rock mass.

So, this is how the dip orientation of joint plays an important role in these stress distribution. You have seen that as the dip of the joint increases, the pressure bulb extends to the larger depth.

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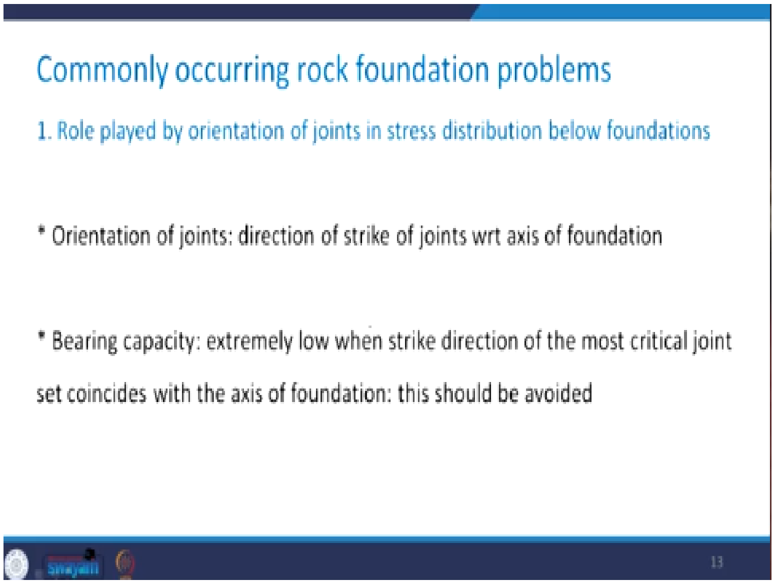

Orientation of the joints is the direction of the strike of the joint with respect to the axis of foundation. Bearing capacity is extremely low when the strike direction of the most critical joint set coincides with the axis of the foundation that we have seen as very unfavorable condition and this should be avoided. The second common occurring rock foundation problem includes the presence of thin clay seams below the foundations.

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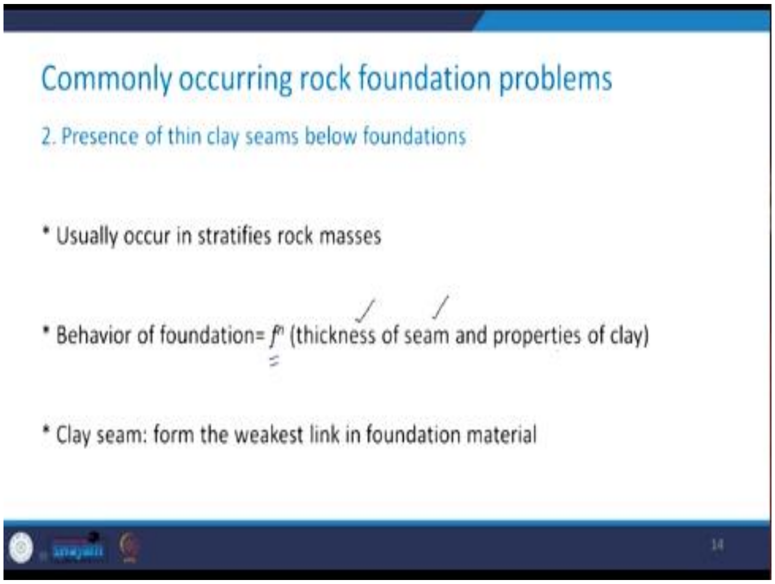

These usually occur in stratified rock masses in which case the behavior of the foundation is a function of thickness of seam and the properties of the clay. This clay seam form the weakest link in the foundation material.

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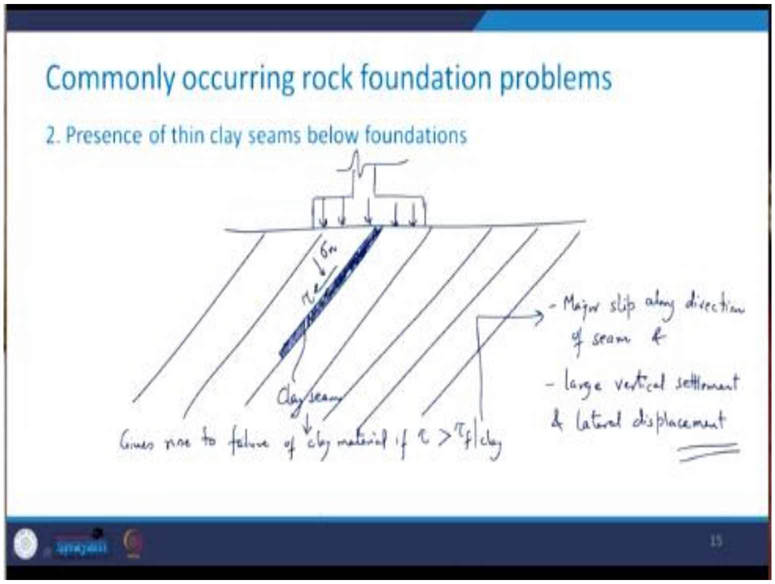

Let me draw a figure and try to explain you that what do we mean by this presence of thin clay seam below the foundation level. Let us draw this foundation first. So, see, it is surface footing for example. Now, the load is transferred like this and see here, you have the joint sets and on this portion, here, this is what your play seam which is present is. So, this is clay seam and along this, you will have a shear stress that is tau and normal to this, you will have sigma n.

Now, what happens when this clay seam is there? This gives rise to the failure of this clay material which is there in the seam. If the tau is more than tau f for the clay. Now, what happens if such situation is there? First of all, the major slip along the direction of seam takes place and be large vertical settlement along with the lateral displacement takes place and this causes significant problem in case if this clay seam is present below the foundations.

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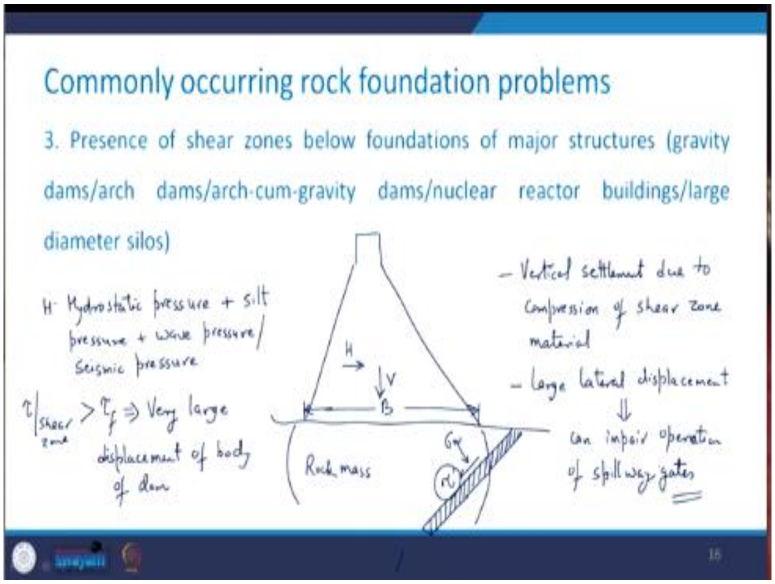

The another common occurring rock foundation problem includes the presence of shear zones below the foundations of major structures like gravity dams, arch dams, arch cum gravity dams or nuclear reactor buildings and large diameter silos. Let me try to show you with the help of a figure in case of a gravity dam where there is a presence of the shear zone. Say, the width here is at the base is say, *B*. Obviously, that the pressure bulb is going to be there and say that there is the occurrence of this shear zone like this.

So, again, here you will have the shear stress and the normal stress in this case that is σ_n. This is what your rock is mass. Now, there is going to be the presence of the vertical as well as the horizontal force and say that the horizontal forces *H* and the vertical one is *V*. So, this H would include the hydrostatic pressure plus the silt pressure plus the, you can have wave pressure or they can be the presence of seismic pressure because of that also this horizontal force can be caused if the τ in the shear zone which has been shown here is more than τ_f.

What is going to happen? There is going to be very large displacement of the body of the dam. Now, this displacement would include the vertical settlement due to the compression of the material which is there in the shear zone. Then there can be large lateral displacement and this can impair the operation of spillway gated which are an important feature of any dam structure. So, this is how the presence of shear zone is going to create the problem for the dam foundation case.

Coming to the fourth one in case if you have the presence of the geological faults or fault zones, then also it creates problem related to the foundations which are to be founded, where such geological structures are present.

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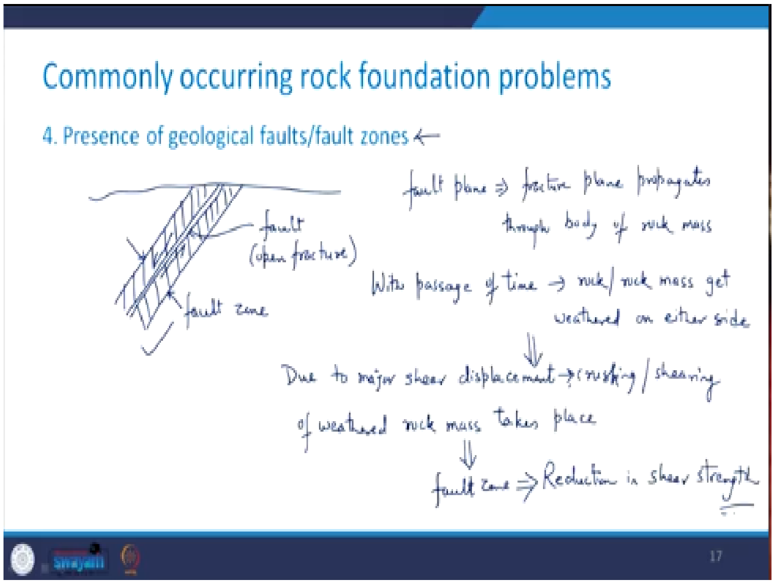

Let us try to have a look that how this influences. So, say, this is your ground surface and here you have the fault. And in the neighboring region, I have fault zone. So, this is what the fault which is the open fracture is and this one is the fault zone. So, what happens in case of the fault plane? It is the fracture plane which propagates through body of rock mass. Like it has been shown here.

Now, what happens with the passage of time? This rock or the rock mass which is present on either side of this fault get weathered. And because of this, there is going to be major shear displacement. Crushing are the shearing of the weathered rock mass takes place because of this major shear displacement and this causes deformation of fault zone which has been shown by the shaded portion in this figure.

And when this fault zone gets formed, there is a drastic reduction in the shear strength and therefore, presence of the fault zone or the faults create problem for the foundations which are to be founded on such rocks.

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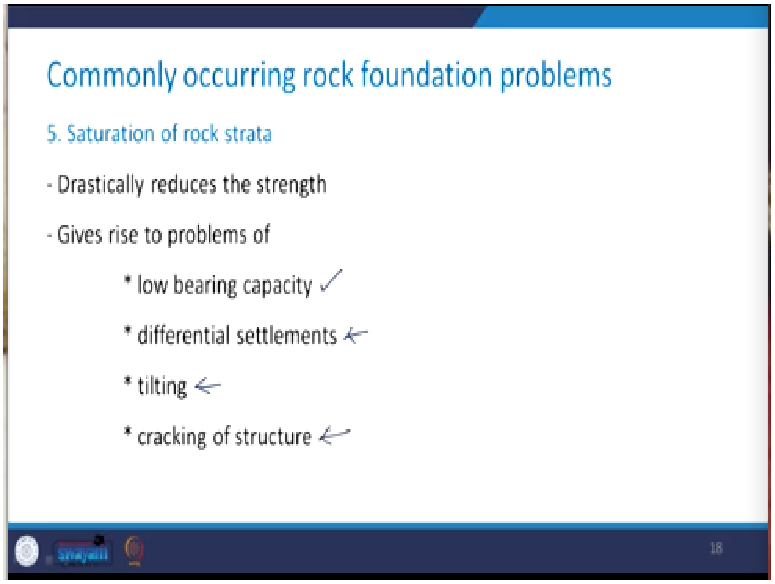

Then the saturation of the rock strata again creates problem because it drastically reduces the strength and it gives rise to the problems of low bearing capacity, differential settlements, tilting or the cracking of the structure.

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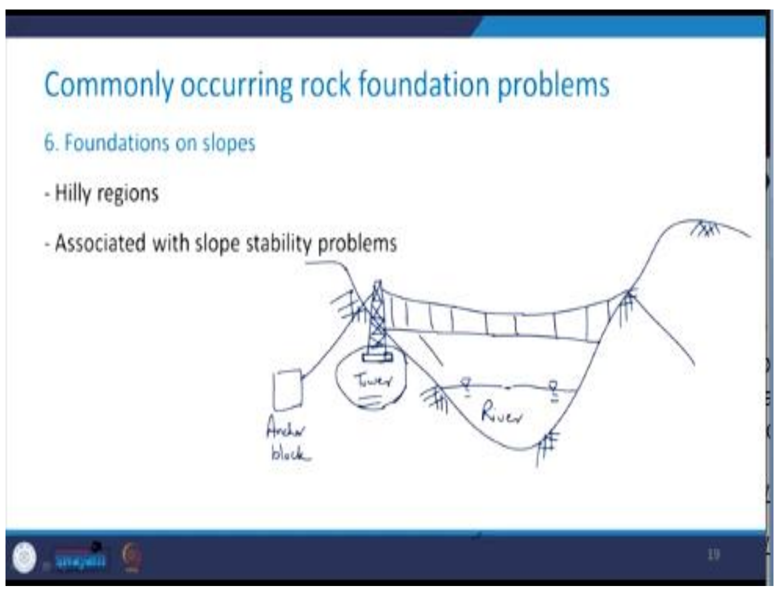

Then in case if you have the foundations on slopes or foundation in the hilly terrain, these are associated with the slope stability problems. So, these also create the problems for the foundations. So, in case let us say that this is how they say, the situation is. Here, this is what is your ground surfaces and say, here you have some kind of a structure that is going to come up and for that structure, and here is the foundation system.

So, say, this is what the tower is and then you will have here as the anchor block and say here, you have the river. Some superstructure is there. So, you see that whatever the foundation for this tower are. They will be treated as foundations on slopes. So, there, we need to be careful that this slope itself should be stable and all those problems which are associated with the slope stability issues, they are going to be the problems here in case of the foundations for, let us say, this tower is structure.

So, in case if the foundations on slopes are there, they also create these problems for the foundations on the rocks. So, these are some of the common occurring type of the problems that may occur. So, having this background of the effect of the joint orientation and the other associated problems related to foundations on rocks. Now, we are ready to learn that how to determine the bearing capacity of the foundations which are to be constructed on the rocks or rock masses. So, that we will take up in the next class. Thank you very much.