Rock Engineering

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Lecture - 60
Dam Foundation Problems

Hello, everyone. In the previous class, we discussed about the determination of bearing pressure from the plate load test data and then we saw that how some of the factors should be considered when you go for the construction of these shallow foundations on the rocks or rock masses and then some treatment of these foundation also be discussed. So, today, we are going to discuss few problems which are associated with dam foundations.

This is very, very important as far as the application of the rock engineering to the foundations on weak rocks is concerned because many times, these dam foundations are founded on the rocks or rock masses. So, it is very important. There is not going to be much mathematics behind this. I will try to give you the idea about these dam foundation problems from the conceptual point of view.

And then we will see that how some of the problems which are associated with such foundations can be overcome by adopting various stabilization techniques. Let us try to see first that what we mean by the dam foundations. Here, I have put 2 pictures.

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This picture gives you the idea that how the gravity dam looks like and this one is corresponding to arch dams. You can see here that the foundation is there on the abutments of the dam here. This case, it is this side. Obvious, the foundation of the dam is in contact with the rock plus the abutments. So, this abutments, they are also integral part of the dam foundations. So, here we can have different types of dams. It can be gravity dam; can be arch dams or arch cum gravity dams.

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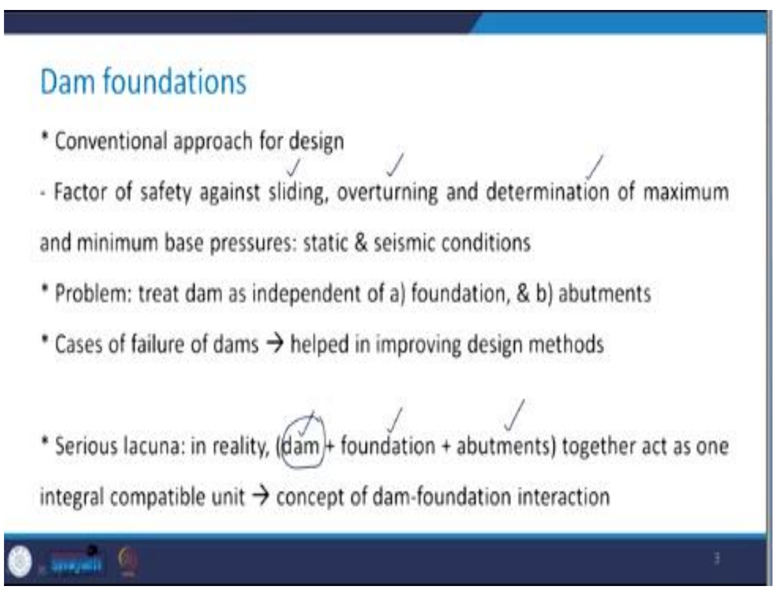

As far as the analysis and design of these dam foundations are concerned, most of the time, one goes for the conventional approach, where we find out the factor of safety against sliding, overturning, and then we determine the maximum and minimum base pressures under static as well as the seismic conditions. Now, the problem which is associated with these conventional approaches is that these approaches treat the dam as independent of foundation and the abutment that means that they only analyze the superstructure part of the dam.

Now, when we study the cases of the failure of the dams, these studies helped us in improving the design methods and what came out from these studies is that there is a serious lacuna in the conventional approach for the design of dams. In reality, what happens is, dam, foundation and the abutments, all three components, they act together as one integral compatible unit and you cannot analyze only the dam body separately without considering the effect of foundation and the abutments.

So, in order to do away with this lacuna of the conventional approach, there comes the concept of dam foundation interaction. Let us understand, what we mean by this term dam foundation interaction.

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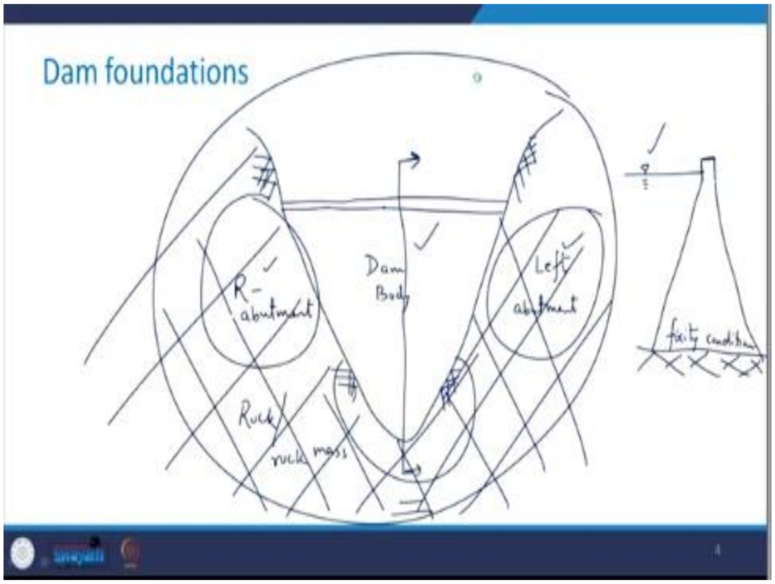

So, here you see that let me draw a picture in order to show you that how these structures, they look like. So, say, this is what your ground surface is and you have here as a dam body. So, this is what your dam body is and I take a section. I will draw the cross section little later and then here, we have the rock mass. This is what is the right abutment and here on this side, you have the left abutment and this whole portion is rock or the rock mass. These are all the bedrock.

So, you see that this dam body is always in contact with this bedrock as well as these abutments that are right and the left abutment and if we tried to draw the cross section along this section, see this is how it will look like. If we try to draw the cross section, see this is how it is going to look like. You may have here as a fixity condition and on this side, the water level is there. So, you see that it is not that the only dam body which can be analyzed separately from these abutments and the foundation. This whole thing needs to be analyzed because they act as one together.

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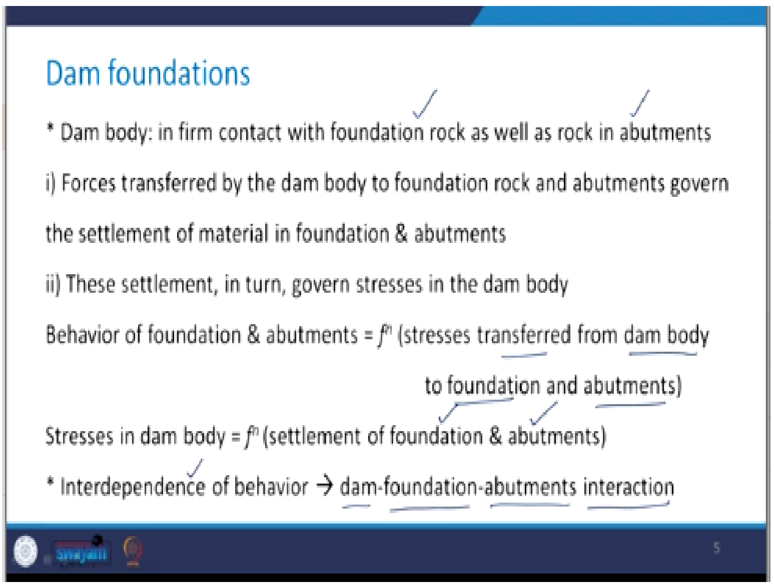

Now, this dam body, I showed you, is in firm contact with the foundation rock as well as the rock which is there in the abutments. The forces which are transferred by the dam body to the foundation rock and the abutments, they govern the settlement of material which is there in foundation and the abutments. Now, what happens? These settlements in turn, they govern the stresses in the dam body.

See, the load is coming from the dam body to the foundation rock and the abutments and the settlement is going to take place. The moment, there is a settlement; this results into the redistribution of stresses in the dam body. And therefore, the behavior of the foundation and abutment, they become the function of stresses, which is transferred from the dam body to foundation and the abutments. And the stresses in the dam body, they become the functions of the settlement of foundation and the abutment.

So, you can see here that there is going to be the interdependence of the behavior. So, this is what is called as dam foundation abutments interaction that is the behavior of one aspect is influencing the behavior of another part and vice versa. So, there is the interdependence of behavior and this is called as dam foundation abutments interaction.

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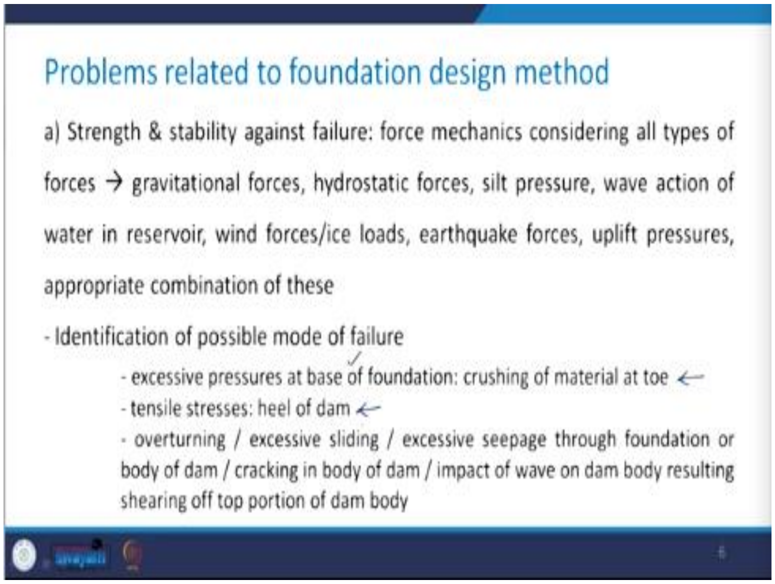

Now, different problems which are related to the foundation design method. The first one relates to the strength and stability against failure. So, force mechanics considering all types of forces, now, these can be gravitational forces, hydrostatic forces; can be silt pressure, wave action of the water which is there in the reservoir. It can be wind forces or ice loads or earthquake forces and uplift pressures plus they can be the appropriate combination of these forces which can act on the dam foundation and abutment system.

The identification of possible mode of failure becomes very, very important. Now, how these can be there? There can be excessive pressure at the base of foundation and that can result into the crushing of material at the toe. There can be the occurrence of the tensile stresses at the heel of dam or there can be overturning, excessive sliding, and excessive seepage through the foundation or the body of dam.

There can be cracking in the body of dam and obviously, the impact of the wave on the dam body would be there and that can result shearing of the top portion of the dam body. So, it is very important for us to identify these possible modes of failure while going for the foundation design of these dams. The second aspect includes the deformation characteristic.

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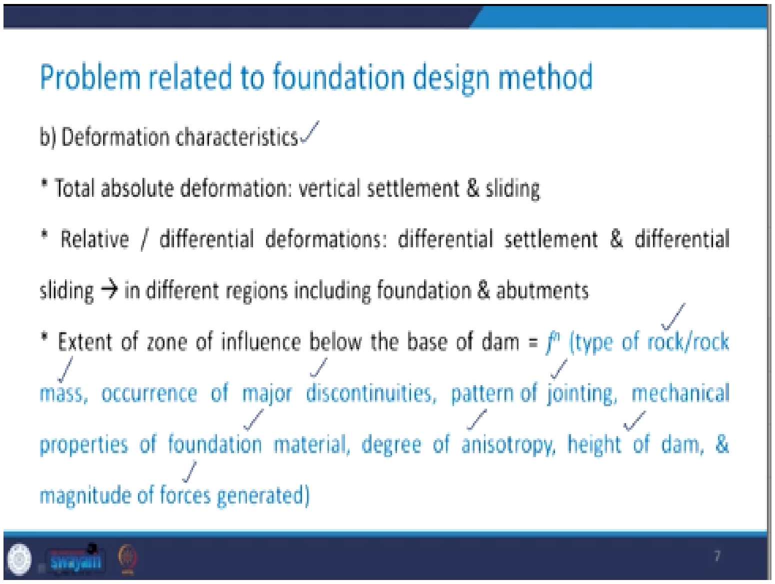

As far as the total absolute deformation is concerned, there can be vertical settlement as well as the sliding for relative and differential deformations. Again in this case, you can have the differential settlement and differential sliding. It will depend on that what are the different regions including the foundation and the abutments. And hence, the extent of the zone of influence below the base of the dam becomes the function of type of the rock or rock mass.

What are the occurrences of the major discontinuities, pattern of jointing, mechanical properties of the foundation material? What is the degree of an isotropy? What is the height of the dam? And what are the magnitudes of various forces that are being generated? These forces, I listed just little before here. So, all these factors, they influence the extent of zone of influence below the base of the dam.

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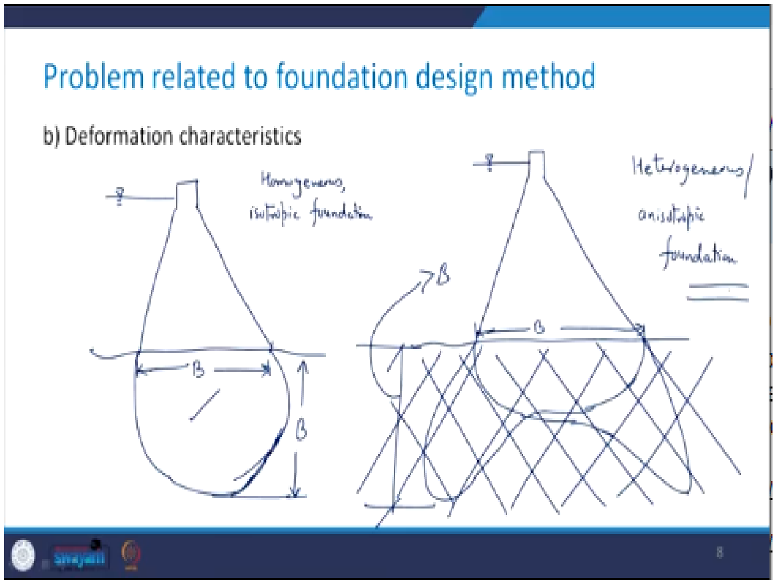

Now, let us try to have a look at what can be this extent of these zones, influence zone. So, in case if you have the homogeneous or isotropy kind of foundation and let us say that is the base on which the dam is resting, see, it looks like this. And here, this is the cedar base width. Then in case of the homogeneous and isotropic foundation, this influence zone can be like this where the extent of this can be say, equal to the width of the footing or weight of this base of the dam.

So, this is how in case of the homogeneous situation, it will be. Now, let us try to see that in case if you have heterogeneous or anisotropic kind of foundation. Then what will happen? So, again I will try to draw a cross section. So, again here, the base is say, B and in this case, you have this type of situation. So, it can be the pressure bulb; can be something like this or it can be something like this and its extent can be much larger than its width B.

So, this is what the situation in case if you have heterogeneous or the anisotropic foundation. The moment, these pressure bulbs, they extend to the larger depth; your deformation characteristic will depend on these things.

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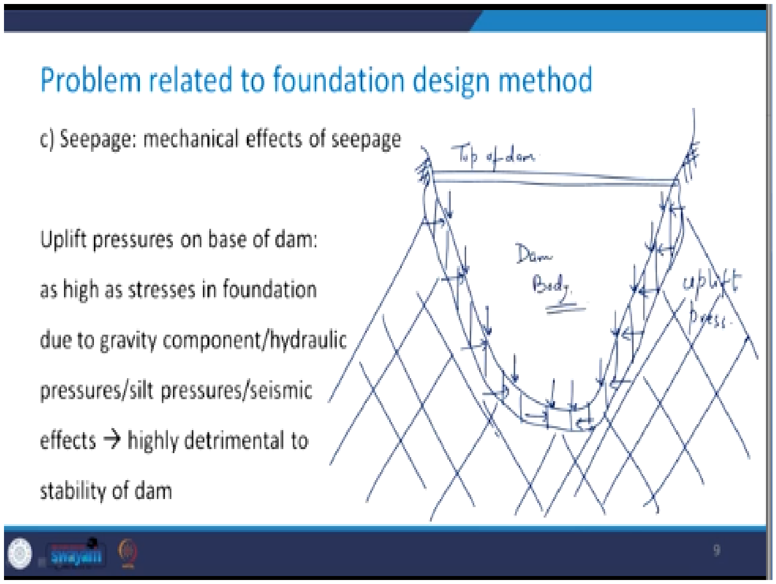

Then the seepage is another problem which is associated with the foundation design method. There are some mechanical effects of the seepage. Let us see. Let me draw a typical figure. So, say, this is, you have the rock surface and here is say, the top of the dam and then there can be here, you have all rock mass. There is going to be the presence of the uplift pressure. So, it will be having these components like this. This is your dam body.

So, there is going to be the occurrence of uplift pressures on the base of the dam and these can be as high as stresses in the foundation due to gravity component or hydraulic pressures or silt pressures or seismic effects and therefore, these are highly detrimental to the stability of the dam. So, these create lot of problem while designing the foundation. Now, how to come over some of these problems? So, we can go for some kind of foundation treatment.

So, the first method which is mostly adopted in case of the dam foundation includes the grouting. You all must be aware of this particular fact that in this case, the slurry is injected under pressure. This process is called as grouting. So, this reduces the aperture of joints, it fills cracks and the voids and results into the reduction in the conductivity of rock mass for the flow of water. Plus, it improves the strength by improving the elastic properties and the compressibility characteristics.

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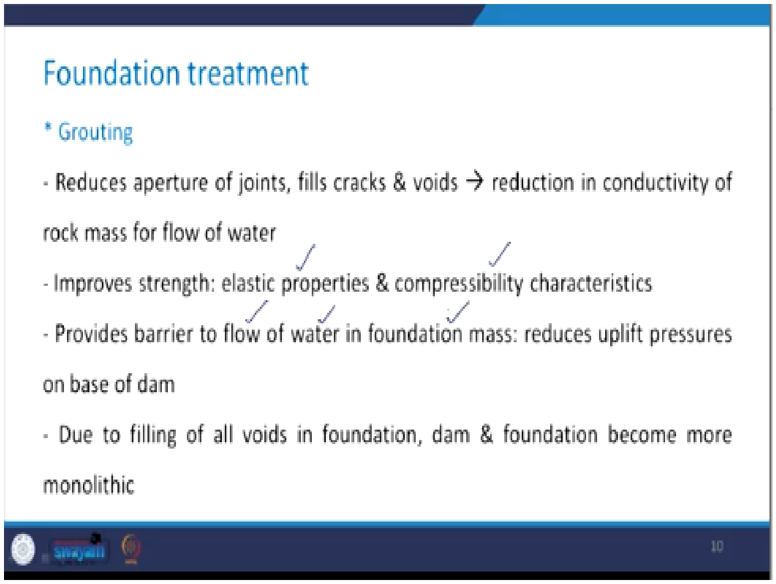

It also provides a barrier to flow of water in the foundation mass, thereby reducing the uplift pressures on the base of the dam. Now, due to filling of all the voids in the foundation, dam and the foundation become more monolithic. So, these are the advantages of the grouting. The next one is the concrete shear key. We discussed this that what exactly is the functioning of this shear key, when we were discussing about the slope stabilization measures. So, the concept is the same. However, here it is provided below the dam foundation.

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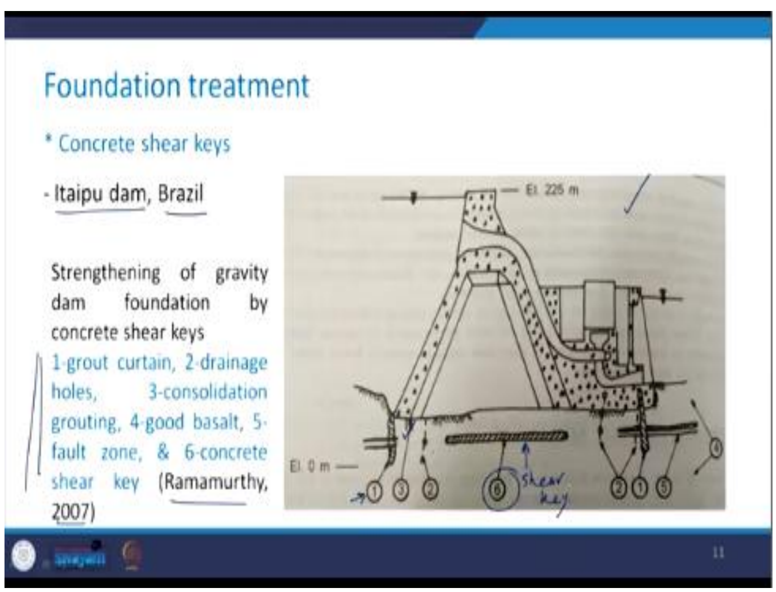

Here, this picture has been taken from this reference and this is from the Itaipu dam which is there in Brazil. And in this dam, the strengthening of the gravity dam foundation was done by concrete shear keys along with the other measures, which have been listed here. You can see here that the first one is the grout curtain that is being provided, and then the drainage holes are there. So, that whatever is the excess pore water pressure that is getting generated, it can be dissipated.

Then you have the consolidation grouting here. Then in this case, this sixth portion, this is what is showing you the shear key. So, what this does is that it increases the factor of safety in sliding. So, this is one way that the foundation for the dam can be treated. The second one is the provision of board concrete piles.

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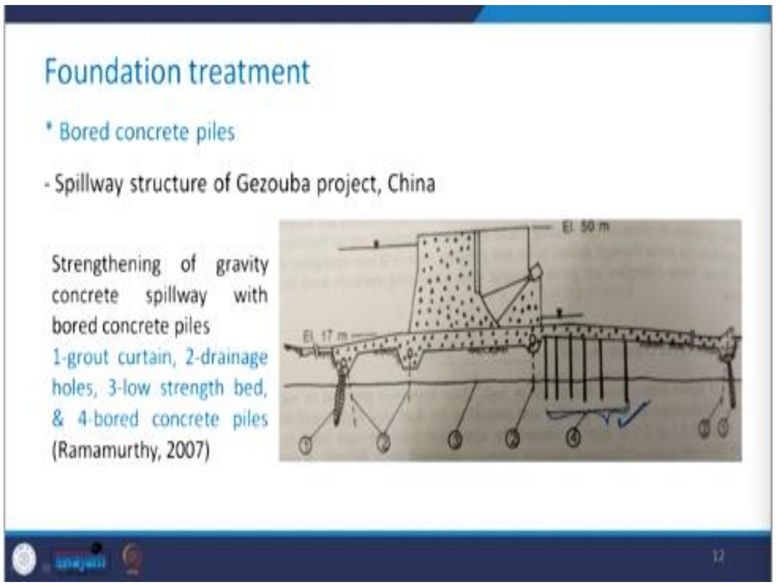

You can see here that along with the other measure, here these board concrete piles, they have been provided. These were done for the strengthening of gravity concrete spillway of the Gezouba project in China.

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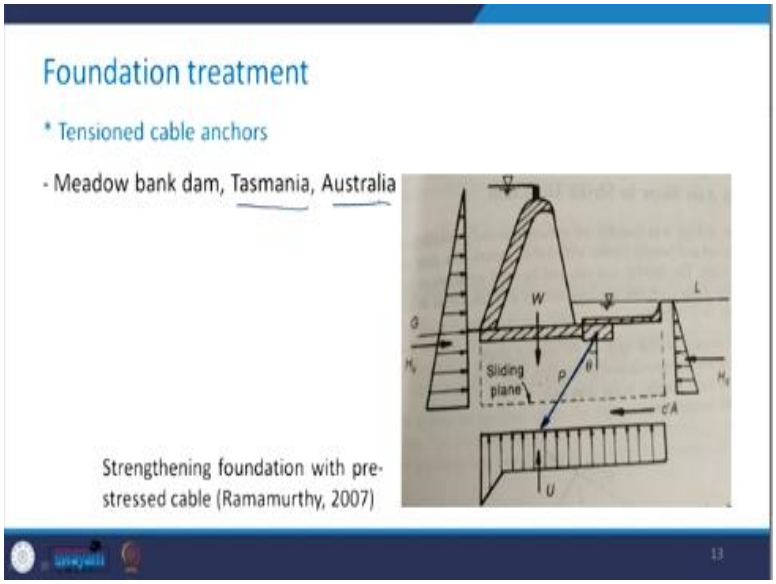

Then one can go for the provision of tensioned cable anchors. So, you can see here that this is what the anchor and there is a tension which is going to be mobilized and this has been used in the case of Meadow bank dam in Tasmania, Australia. So, these are some of the foundation treatment measures that I am trying to discuss with you. We are not going into the detailed design methodology of these, but then, this is for you information that how the foundation can be treated in order to overcome the foundation related problems that we discussed just now.

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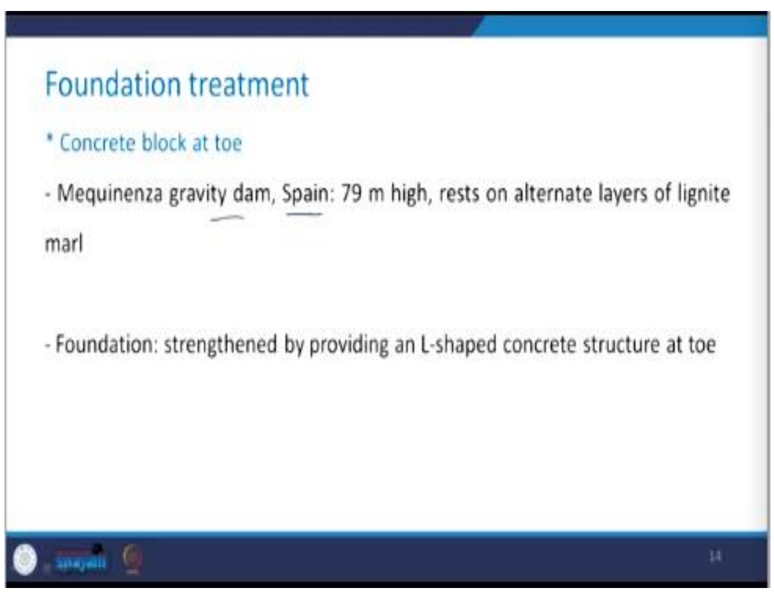

The next one is you can provide the concrete block at toe and this has been done in this gravity dam which is there in the Spain, this is 79m high and it rests on alternate layers of lignite marl.

So, the foundation in this case was strengthened by providing an L shaped concrete structure at its toe.

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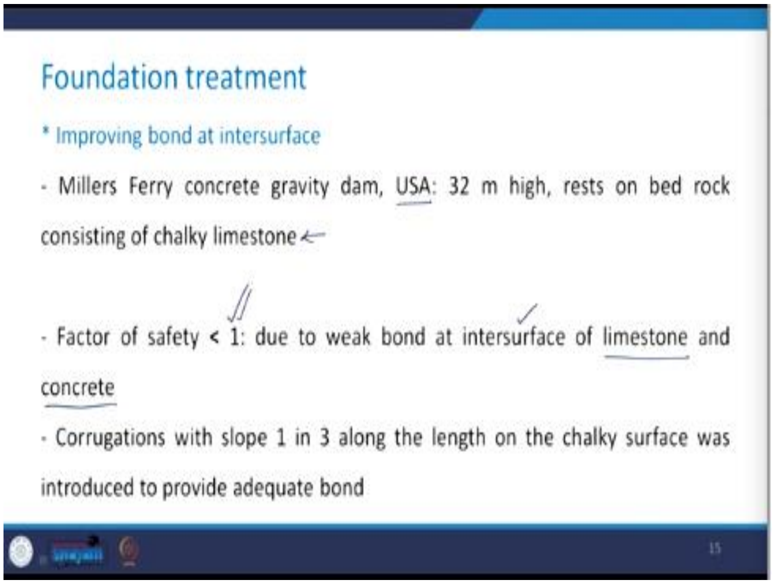

The next one is say the situation is like that, there is not a proper bond at the interface or inter surface. So, such type of measure was adopted in Millers Ferry concrete gravity dam in USA, which is 32m high and it rests on bed rock which is consisting of chalky limestone. And the factor of safety was obtained to be less than 1 because of the weak bond at the inter surface of the limestone and concrete. So, what was done in this case is that the corrugations with the slope of 1 in 3 along the length on the chalky surface were introduced.

And this provided the adequate bond at the inter surface of limestone and concrete and thereby, it enhances the factor of safety, which was earlier less than 1 and later on, it was improved.

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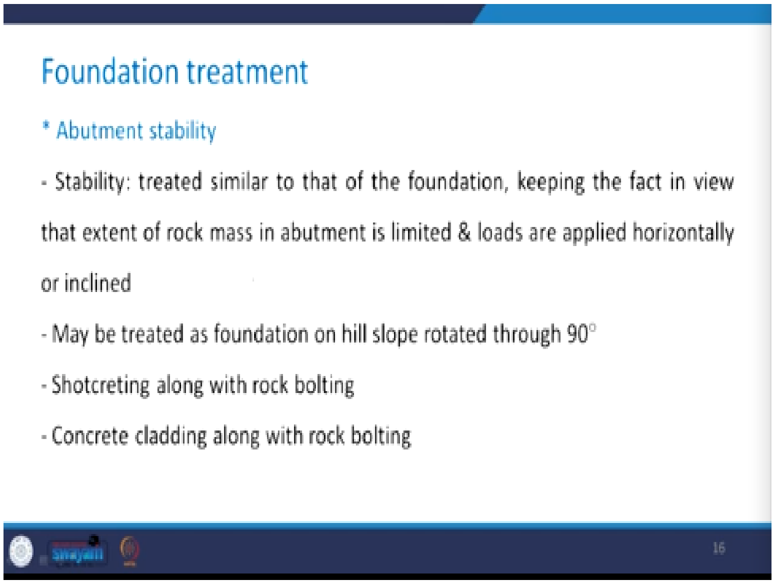

Then till now, we discussed about the foundation treatment. It is not only the safety of the foundation is important, but the abutment stability is equally important. So, the stability of the abutments can be treated as similar to that of the foundation, which we discussed in the previous class. Keeping the fact in view that the extent of the rock mass in the abutment is limited and loads are applied either horizontally or inclined.

So, these may be treated as foundations on hills slope rotated through 90 degree. So, whatever are the measures that you have learned for the slope stability analysis that can be applicable in case of the abutment stabilization. So, this can include the shotcreting along with the rock bolting, and sometimes, when this does not work, one can go for the concrete cladding along with the rock bolting.

So, this is what is all about the dam foundation problems and how that treatment for such foundations can be carried out. So, this was all about that I wanted to discuss with you as far as this 30 hours course is concerned. So, in order to summarize, just let us start from the very first lecture, where we discussed about the rock formation, rock forming minerals, their identification, then we learned about the geological classification of rock various geological structures like faults, bolts, joints, bedding planes, etc.

Then we saw that how these geological data can be projected stereo graphically, because all these geological data, they are in the 3 dimensional planes in the field, but how to represent them. And we have seen subsequently in some of these application areas like tunneling, then slope stability and foundations on weak rocks that how these stereographic projections can be useful.

So, in this chapter, we learned about the principle of equal area net, representation of a line or plane, and then we saw that how the intersection of the 2 planes can be determined. And then we learned about some of the applications related to slope stability. Then we started our discussion on the laboratory testing of rocks. There, we learned about the determination of various physical properties, unconfined compressive strength, tensile strength, then shear strength along with some other tests like slake durability test and Schmidt Hammer test.

And we also learned about the stress strain response of the rocks, various factors which were influencing these stress strain response that also we discussed. Then subsequently, we talked about the engineering classification of rocks and rock masses and there, we discussed about the classification system for the intact rock which was Dheere-Miller classification system. I introduced you to the concept of rock mass.

We learnt about the rock quality designation, rock mass rating, rock mass quality which was q system, then geological strength index and then we saw that how these systems are applicable in various civil engineering projects. Then we studied some aspects related to the strength criteria for rocks and rock masses. We started with Mohr's failure theory, went to Mohr-Coulomb criterion and then Coulomb-Navier criterion and then we learnt few aspects related to the empirical criterion. And one of the most important empirical criteria was Hoek-Brown criteria.

We also learned about the Batten’s theory, where we could find the strength characteristic of the joints. From these basics of the rock engineering, then we shifted to be some of the application areas and the first application area was the analysis of the tunnels. And in that case, first, we learned about various ground conditions in case of the tunneling, then how can we analyze these tunnels using elastic and elasto plastic analysis. In case of the elasto plastic analysis, we considered the Tresca yield criteria.

We also took the elastic analysis of a tunnel with the concrete lining. Then we saw the application of the stereographic projections in case of the tunneling. We discussed about the structurally controlled failure where the wedges were formed either in the roof or in the wedge. And we saw that how we can determine the shape and the size of these wedges. And then we learned few aspects related to various support systems.

And we also discussed about new concept which was the rock mass tunnel support interaction analysis. And there, we discussed about the support reaction curve and the ground response curve. Then we went on to the next application area, which was related to rock slope stability analysis. We learned that there can be 4 modes of the rock slope stability, which can be plane, wedge, circular and the toppling failure mode.

And we saw that how using the limit equilibrium approaches. We can analyze rock slopes under these 4 failure modes. We also learn about the application of the stereographic projections and followed by the discussion on the slope stabilization measures. Then finally, we started our discussion on foundations on weak rocks. So, we discussed that what all are the problems which are associated with the foundations when we lay on rocks or rock masses.

We discussed about the Bell's approach. Then how can we find out the bearing capacity of the shallow foundation based upon the various classification approaches. Then unconfined compressive strength, test result in plate load test results and there were few special consideration and the foundation treatment that was followed by the discussion on the problems related to the dam foundations.

So, I hope that you have got an overall idea about this branch of engineering which is rock engineering and as a geotechnical engineer or as a civil engineer, it is very, very important for you to understand; not only the material called soil, but also rock. So, in this 30 hour course, I tried to give you the idea about the engineering aspects related to this material rock and rock masses. Hope, you must have found this beneficial and it will be helpful for your future endeavors. Thank you very much.