Geoenvironmental Engineering (Environmental Geotechnology): Landfills, Slurry Ponds & Contaminated Sites

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Lecture - 38
Remedial Measures for Slope Failures in Embankments / Dykes of Slurry Ponds

So, today we are going to look at some cases of failures in embankments of slurry ponds and as I told you in India most of the raisings are done by the upstream method. So, let us look at why these failures take place and how can we take remedial action a; that means, you have either seen a sign of distress or actually some failure has taken place how quickly can we make the pond operational again. So, today's topic is remedial measures for slope failures in embankments Dykes of slurry ponds.

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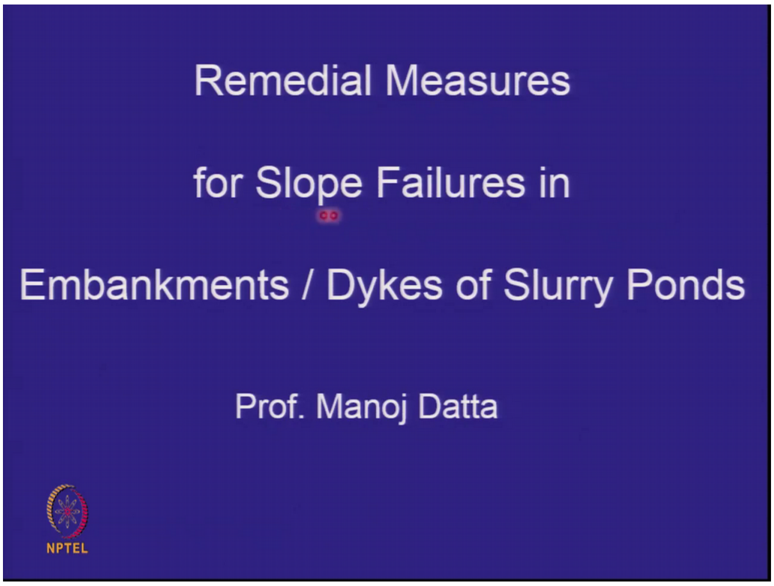

So, normally such failures are not reported in downstream method of construction, but there are very few cases of downstream method of construction in the country so most of the failures that we are going to do are by the upstream method. So, just you recall this is an ash pond and where the ashes breached and has come out.

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This is another tailings impoundment in which there is been a failure of the slope.

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Here there has not been any failures, but you can see vertical erosion and seepage paths you can see wet can you see the wet downstream face quite clearly the phreatic line is not being captured. If the phreatic line was captured you will have a dry slope and this also shows small movements in not small large movements in on the downstream face of an upstream raised embankment.

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So, what are the causes of failure? What we normally seen are two causes absence of an internal drain and clogging of an internal drain. Now why should they why should an internal drain be absent.

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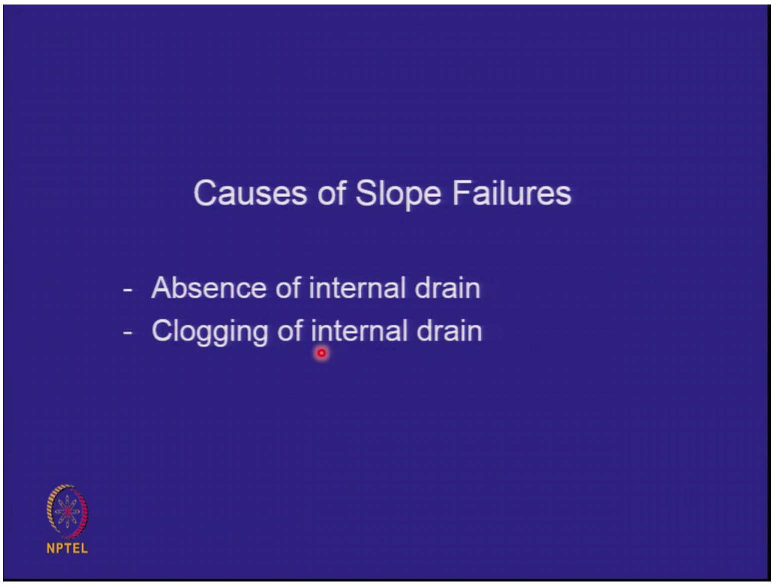

So, if you look back at the tailings ponds or ash ponds which you have constructed 10 15 twenty years ago at that time one had not anticipated such immense pressure that you will not get land for disposal of tailings and ash and you have thought that these ash ponds would be 5 to 10 meters high right. And at that time for a 5 to 10 meters high embankment it look like a road embankment and typically you are not putting chimney drains or horizontal drains in a road embankment. So, what was done was you would take local soil make an embankment and start pumping the slurry behind in that pond and after the first 5 years if the pond became full you take either the ash or the tailings and put another upstream embankment and cover it with soils so that there was not much of dust which would flow.

So, if you look at the very old ponds there is a very high probability that the original dyke did not have an internal drain and normally construction records may or may not exist. Also remember that constructing a chimney drain is not a simple task, it is a thin vertical element right and if you do not do it properly you may make the drain, but it may get clogged with time either the width is not sufficient or if the width is sufficient then the gradation has not been mapped using the filter criteria between the ash between the embankment material and the drain. You all know the filter criteria, you remember filter criteria.

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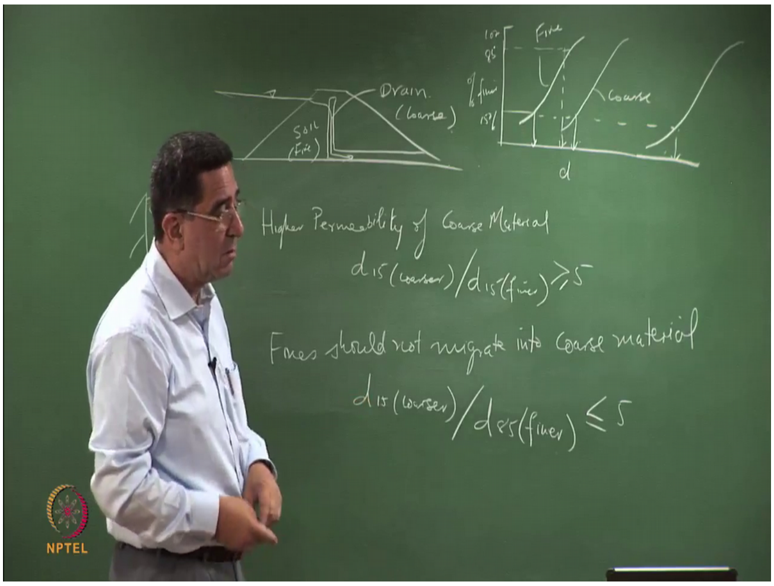

There are two issues when you make a chimney drain or a blanket drain, between the soil and the drain or when we said between the fine material and the coarse material we have to have a criteria what is the criteria the coarse material should have a higher permeability than the fine material so that it catches the water and does not allow it to go forward. Suppose I make a drain with the same permeability as soil what will happen water will come into the drain since it cannot take it out at a faster rate it will go across the drain.

So, water will not go across a drain only if the permeability of this is much much higher than the permeability of the soil because water is coming from this side. So, when we say it is a drain we say the water falls like this and goes like this for that the permeability has to be higher agreed. However, the other issue is while the permeability may be higher the material should not be so coarse that the fine particles of the soil can go into the drain. So, there is a restriction of how coarse the material that of the drain can be. So, there are two criteria one is higher permeability second is fines should not migrate, of the coarse material and the second is fines should not migrate into coarse material. Now you will do this if you have not done it already in your slope stability coarse but quite clearly if I make a grain size distribution on a log scale let us say this is this is the fine soil and this is the coarse soil.

So, for the permeability do we hire the criteria requires that d 15 you might take this 15 percent let us say this is 100 percent. So, this is d 15 of the finer material and this is d 15 of the coarser material. So, the requirement is d 15 of the coarser material to d 15 of the finer material should be greater than 5 or greater than equal to 5. You remember permeability of sands there is some empirical formula, permeability of sands has this formula, what is the formula?

Student: (Refer Time: 08:07) d tan to the power.

d tan square. So, what it says is the permeability is governed by the fines d tan is the size bellow which 10 percent of the particle lie. So, permeability is dependent on the square of d tan, in that sense it could also be the square of d 15. So, if the d 15 of the coarser material s greater than d 15 of the finer by 5s likely that your permeability will be in the ratio of square 25 times. So, your permeability is that much more higher this is what it does. But the other criteria is if you make it very coarse then the fine materials will start to pass through right.

So, suppose I have a clay soil and on in front of that I have gravel now fine he the gravel has a permeability more than 100 times or 1000 times of clay, but the problem is the fine particles of clay will migrate through it. So, we try and now make it smaller so that the fine particles cannot migrate. So, what is that criteria? That criteria is that d 15 of coarser to d 85 of the finer should be less than equal to fine. So, if I take d 85 of the finer and this is d 85 of the finer and this is d 85 of the finer what is this trying to say the d 15 of the coarser to d 85 of the finer should be less than 5. If by chance the coarser material was here then what would happen? d 15 of the coarser material would be very large in compared to the d 85 of the finer material sorry this should be here and that would mean that the fine particles could pass through the voids. So, this criteria prevents the migration of the fines, this criteria prevents the migration of the fines.

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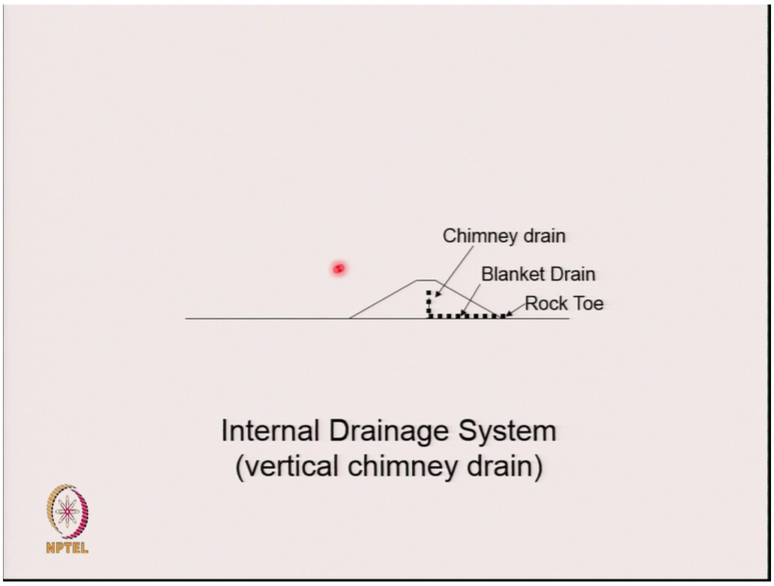

You have a chimney drain; you have a blanket drain you have a rock toe and the idea is that when the water is high it should be caught by this and similarly when you are raising then the phreatic line passes through this.

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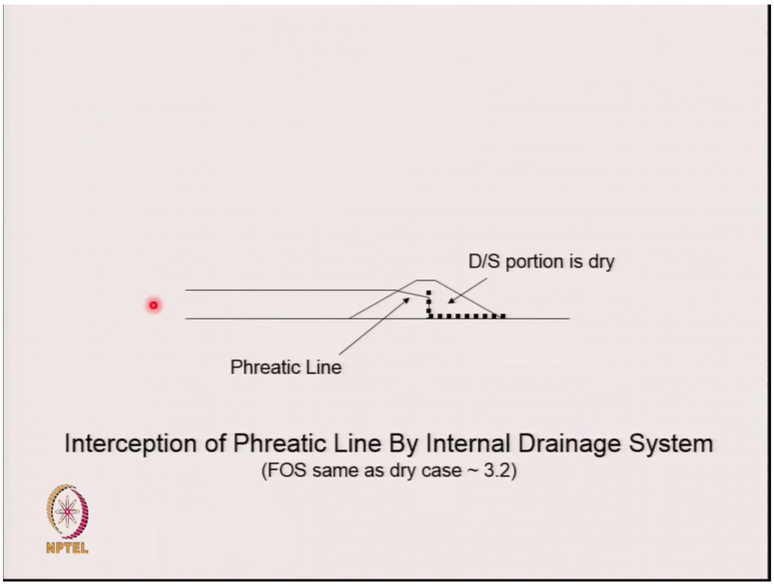

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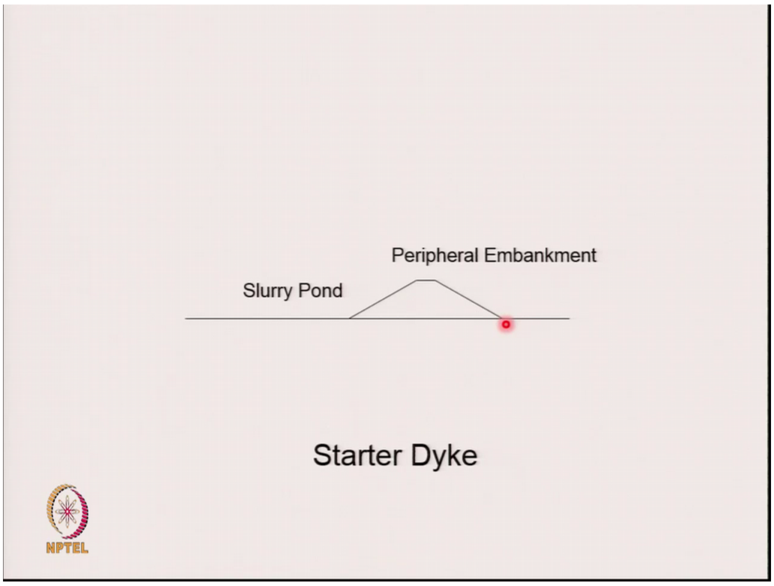

Now let me take a peripheral embankment and a slurry pond, this may be low phreatic line this may be high phreatic line, it is missing the vertical chimney drain and the horizontal blanket drain is missing.

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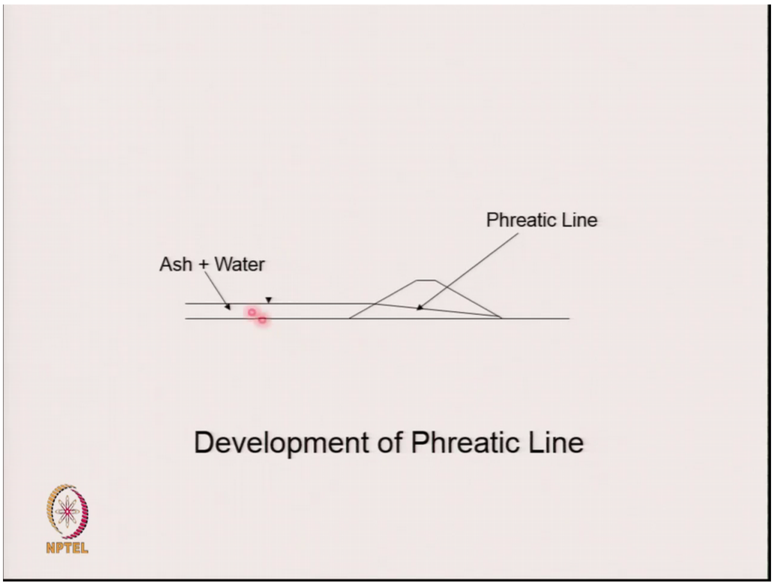

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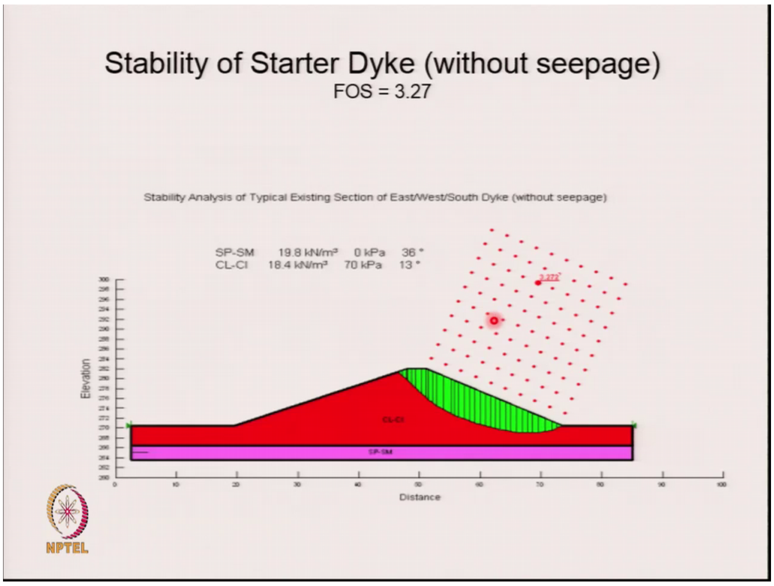

Let me do some stability analysis this is a real life problem. Here is the dyke made of the local soil some properties are given to you, you cannot probably read this, but this value is 3.27. So, when you make a starter dyke of a local soil without seepage you may have a factor of safety of 3.7; 3.27 sorry.

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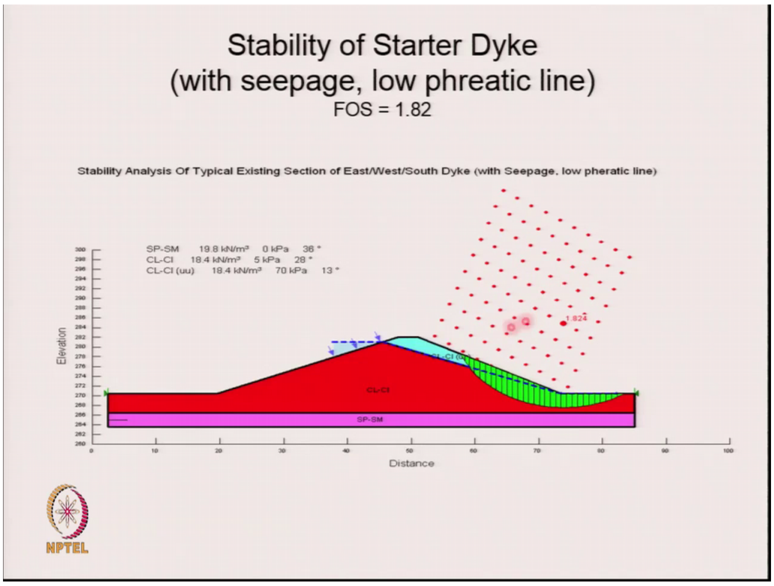

Now when the phreatic line is low, this is the phreatic line, and please see it does not meet the downstream phase phreatic line is high means that this dotted line will meet the downstream phase. So, the factor of safety falls to 1.82 from 3.27. Still no failure is more than 1.5; however, now let me make the phreatic line higher, my phreatic line is high and it meets the downstream slope; that means, now I am going to get a wet phase when I get a wet phase I know that flow is occurring parallel to the outer slope on the downstream phase factor of safety is down to 1.1. This is less than 1.5 this is not acceptable in a long term case. So, this embankment does not have acceptable factor of safety. So, the absence of a internal drain will always cause a problem when the phreatic line is high.

Now, let us go forward.

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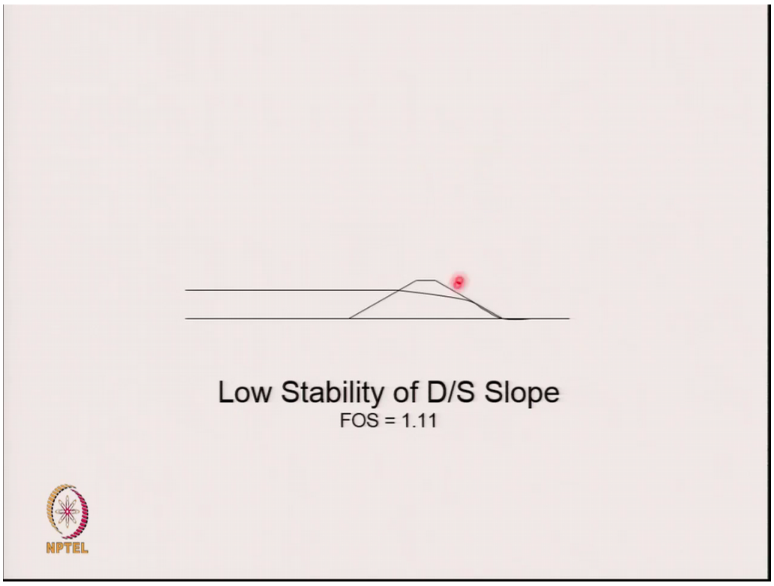

So, during the high phreatic line I have a low stability of the slope how are you going to remediate I know it, it is 1.1 it has not it has not failed so far because it is above 1, but tomorrow if an earthquake comes with it will fail. So, now, you are the designer and you have captured the problem the Professor Datta told you phreatic line must always be controlled and not towards the downstream toe. So, how are you going to solve, this how are you going to remediate this?

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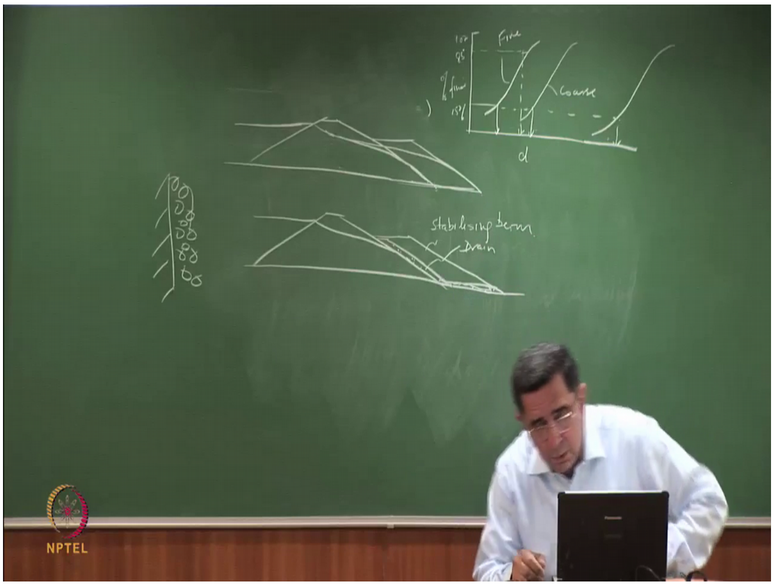

If I have a starter dyke and I do not have a chimney drain and my phreatic line is coming like this how can I remediate this. Well if I have a phreatic line and if I want to remediate this I need to do some stabilization, I need to do some stabilization.

So, if I have a phreatic line which is coming out here now I know that I have a problem what kind of remedial measures would you take, how do you stabilize this embankment. Well one thought is let me go and make a chimney drain inside now the pond is working this water behind it how do you make a chimney drain, how do you make a blanket drain, can I make this? Not possible, maybe I can make a vertical trench and make this, but this is just definitely not possible, maybe I can drill some horizontal holes to make the drainage. So, it is difficult. So, normally what we do philosophically is if I have space on the downstream side not too much see the requirement is the phreatic line should not reach the downstream surface I can make a berm here, if I have 5 to 10 meters space which normally is available there may be a road or something then I put a berm, have I caught the phreatic line.

Please answer my question, if I put a berm here have I caught the phreatic line? No, if you put the berm here the phreatic line is going to go and become this. Before you put the berm you must put an interceptor drain what was not there earlier. How do you make the interceptor drain? In the same place you have the downstream phase before you put the berm you put a sand drain, now you put the berm I am using the word sand drain what I mean is a ore permeable drain. Now what happens now you are able to intercept the phreatic line; that means, you have your phreatic line will come here and go out from here.

Now, your downstream slope is this one now your downstream slope is this one now this slope has no wetness no water flowing parallel to the outer slope. So, this is now a remidiated slope a stabilizing berm with an internal drain is the solution for an embankment which was originally poorly designed the only requirement is that you need some space on the downstream side typically 3 to 5 meters. typically 3 to 5 meters to keep your phreatic line away. So, this is the stabilizing berm.

So, let us see what we do n the case that we was studying where the factor of safety had fallen to 1.1, in this case the factor of safety had fallen to 1.1 and A stabilizing berm is made and in internal drain is provided therefore, the phreatic line does not reach the downstream phase

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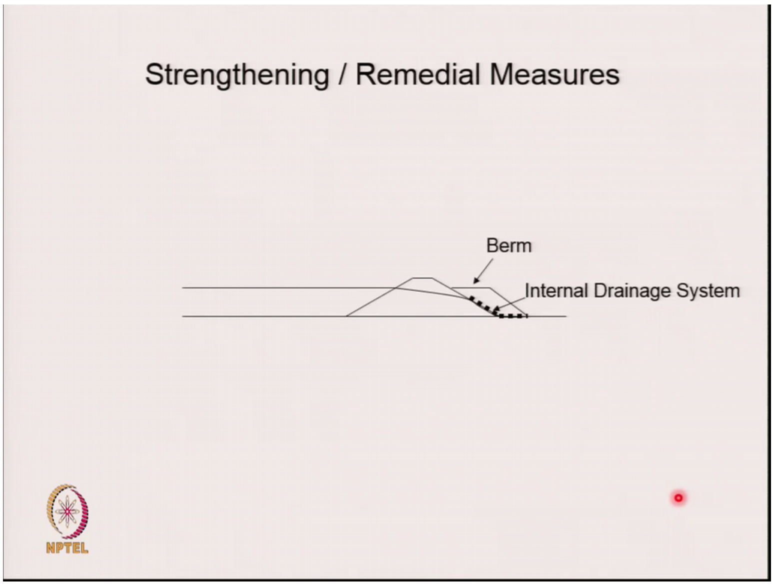

Let me do the stability analysis. Same problem has before the phreatic line is high please see its coming and meeting this, but you have got stabilizing berm therefore, the phreatic line is going down here and coming like this.

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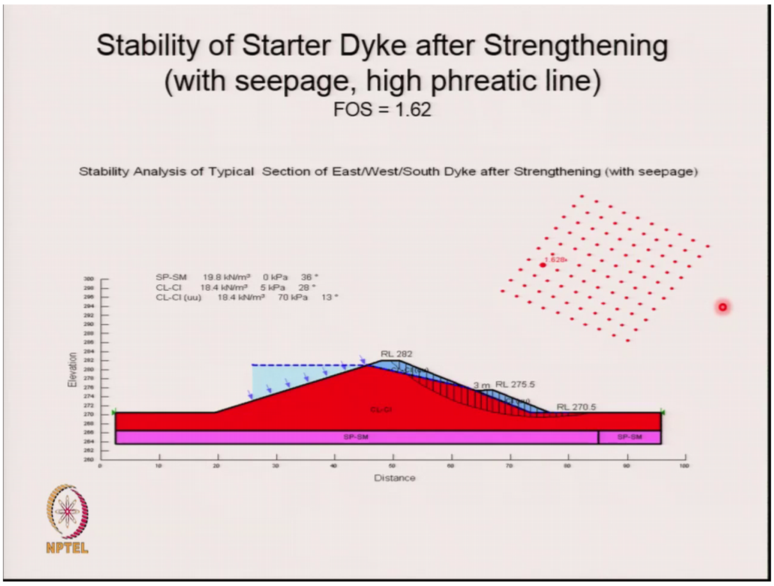

Factor of safety increases from 1.11 to 1.62, you are not going to have a wet downstream phase, you are not going to have low factor of safety.

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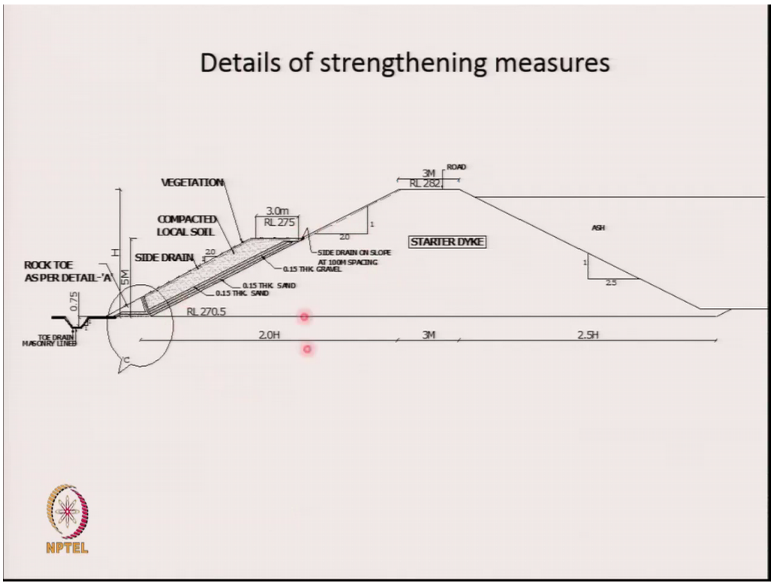

This diagram is actually a mirror image of the how what does the stabilizing germ look like, the stabilizing berm will be nothing, but some additional soil or ash or tailings along with a drain and along with the rock toe and a toe drain.

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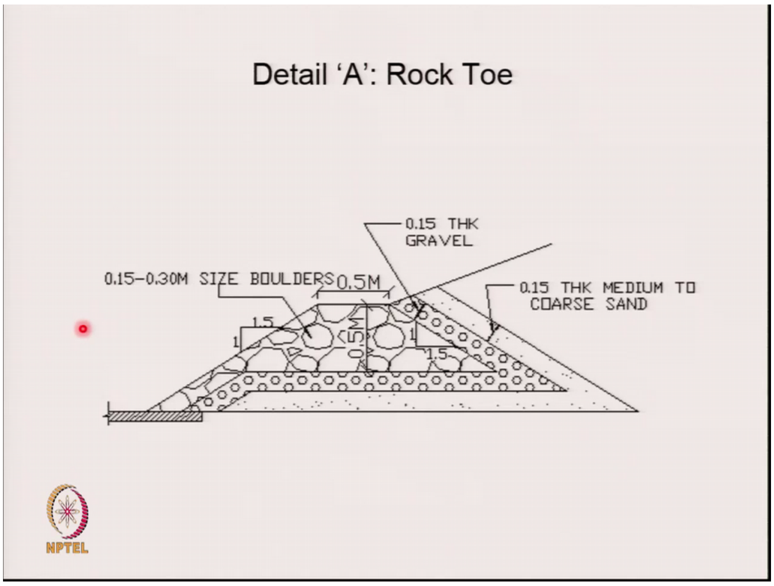

So, typically a rock toe will look like this, this is your ash or tailings or soil this is sand this is gravel this is cobbles and boulders.

Let me go back I am looking at this, now you can always make the stabilizing berm of rock rock cobbles and boulders, but cobbles and boulders are not easily available they are very expensive. So, you have to make use of the local soil or the material in the pond which you can do for the stabilizing berm. So, the stabilizing berm is made of the same material and this is the rock toe. Any questions?

Student: Will the factor of safety depend on the width of the berm?

Will the factor of safety depend on the width of the berm? The question being asked is instead of 3 meters I had made it 4 5 meters the stabilizing berm please see the critical fact critical failure surface here, the stabilizing berm is more towards the resisting soil this side is a resisting soil. So, wider the berm the better the factor of safety because it stabilizes it adds against the driving forces which are bringing the soil down. So, the wider the berm the better it is. So, you have to optimize it what is the width of the berm which gives you a minimum factor of safety of 1.5 because this will be more earthwork and require more land area on the downstream side, but definitely a wider berm is a more stable. I mean I can also do a mid height berm here that will even give me see because when once you increase this width all that will do is increase the resistance on the downstream side. So, this is another form of a berm.

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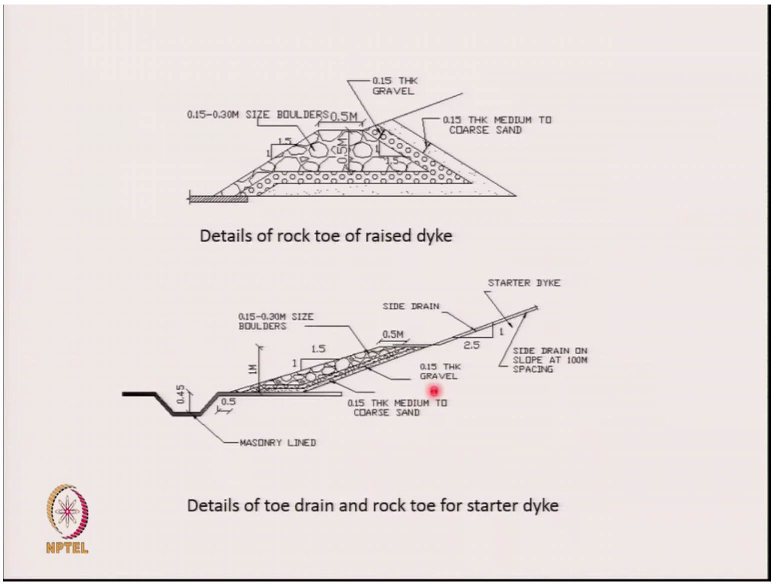

Here of course, the entire rock fill or boulders or cobbles have been used instead of the local soil, but this is more expensive; however, the width has been reduced.

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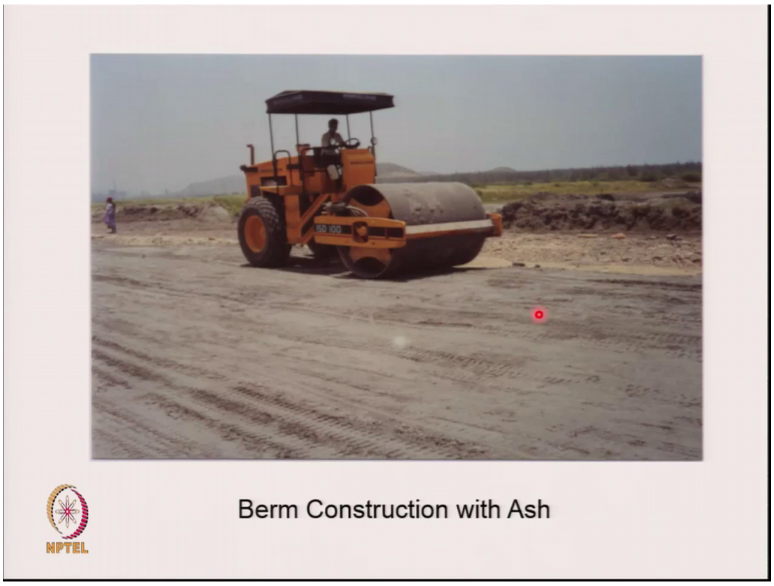

So, I am just showing you that this is a berm which is being constructed with the ash itself and I want to show you the rock toe which is critical.

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This is the toe drain, this the cobbles and boulders can you see that, this is the gravel, that is the sand coarse sand that is the fine sand and that is the ash. So, so many layers of transition filter why? Water should come through this, but no fine should come. So, ash is silty sand sandy silt ash will not go into fine sand, fine sand will not go into coarse sand, coarse sand will not go into gravel, gravel will not go into cobbles and boulders and only clear water will come through. So, this has to be designed and constructed with great precision.

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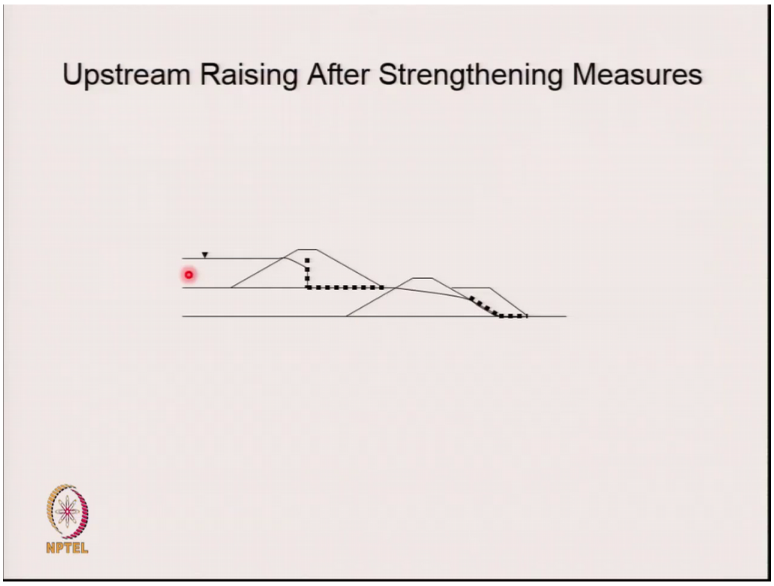

So, if you are able to make this berm then you can also do the upstream raising. We are just showing you the same thing.

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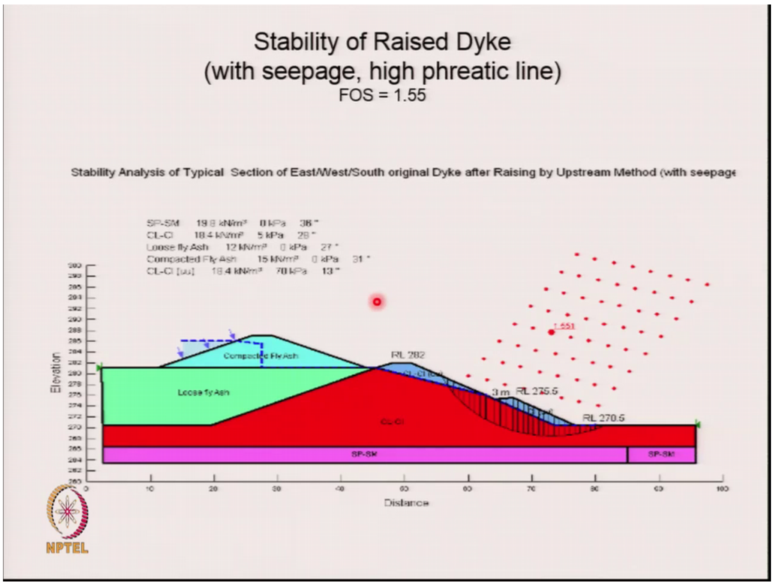

We had made this berm and it had gone to 1.6 now we do the upstream raising also the water is coming from here been caught by the chimney drains coming through here, coming through here still the factor of safety is more than 1.55. So, you can do the upstream raising after remidial action on the original dyke.

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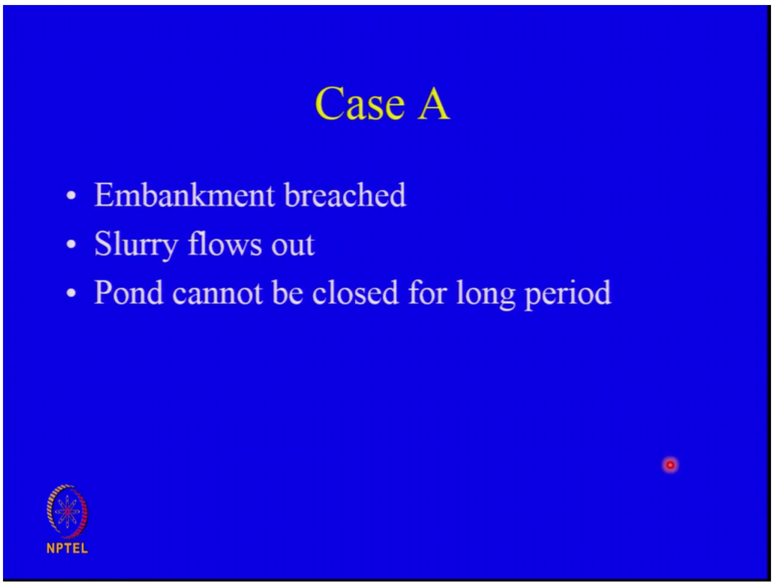

So, I will take up two case studies very quickly in one case the embankment was breached slurry had flown out, but the thermal power station was operating, so you cannot keep this you know I will take 6 months to make the embankments I the field engineers want the embankment to be rectified the next day.

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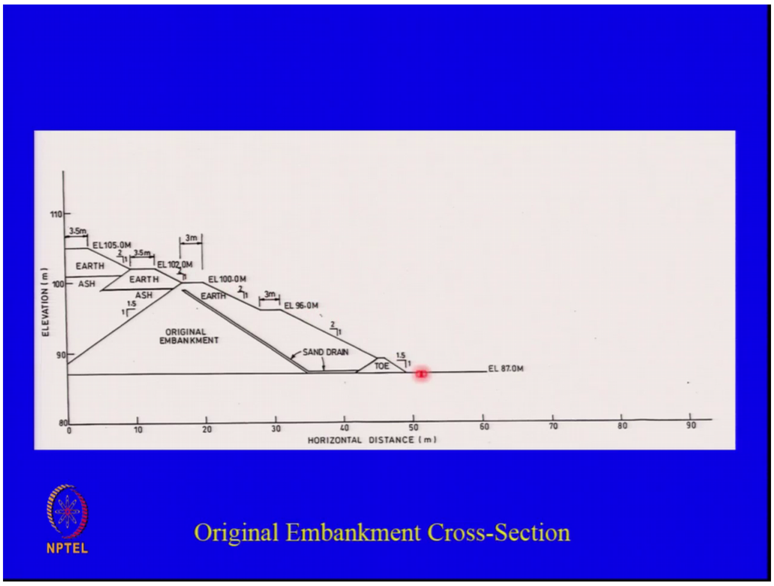

So, this was the original dyke design which was given to us, soil sand drain toe. If this sand drain is not made properly it is a very this sand drain it can malfunction very easily sometimes you are not able to establish the design does show sand drain, but you are not able to establish whether that sand drain is actually operating or is it clogged unless you go and see this downstream side of the phase. So, this one had failed and this is the profile of the failed soil like that; and this is pob probable failure surface this is the probable failure surface.

So, what do we do? This is the ash pond there are two ash ponds. So, temporarily they have closed this ash pond because it has failed there is been some over topping now you have to repair it. If you want to take up a brand new problem of stabilizing it by completely excavating the failed portion you see one option one option is excavate the whole area are compact because the other pond is working right, but before you can excavate you have to dry out the ash the ash is full of slurry water see the crest has only come fallen from here to here. So, here the issue is what you do.

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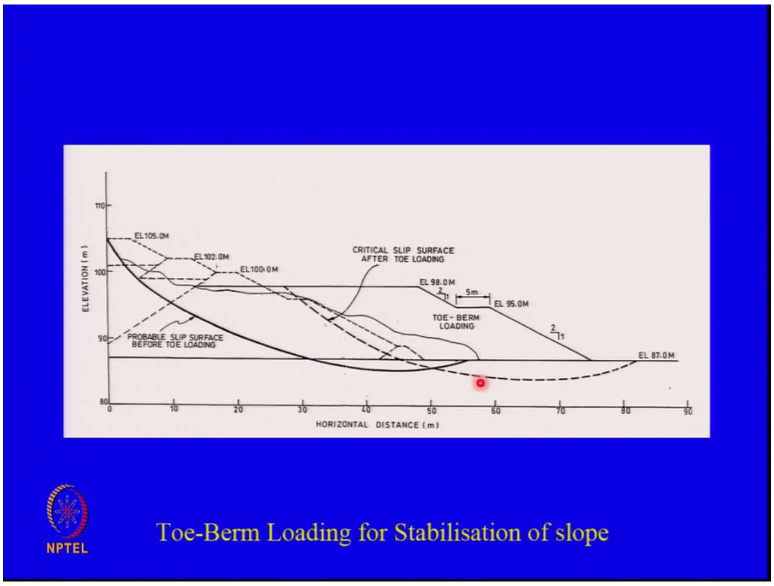

In this case we put a stabilizing berm, this was able to give us a solution this is the critical slip surface now. But there was a problem the crest had come down they also wanted us to rebuild the crest and the thing is this is now all loose material I am not excavating this material I am putting the stabilizing berm in front of the material because excavating it and re compacting it will take months. So, we have to work with what it was. So, the other options that we looked at was to create this crest here.

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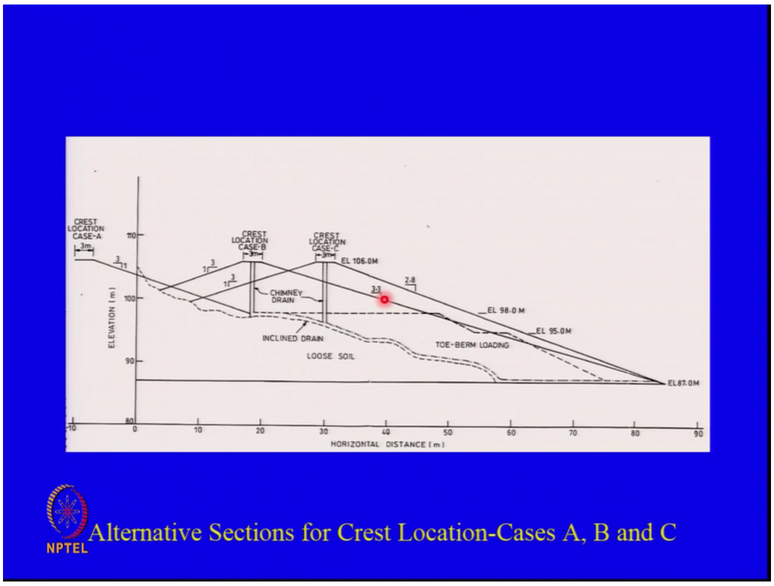

This is your stabilizing berm, so there was two options which would examined one here and one like that and these are the slopes 3.3 is to 1, 2.8 is to 1 and we had to put a drain on this please remember. We have to intercept the phreatic line and it should come it should not reach the downstream phase and they have a vertical chimney drains and the drains put on this.

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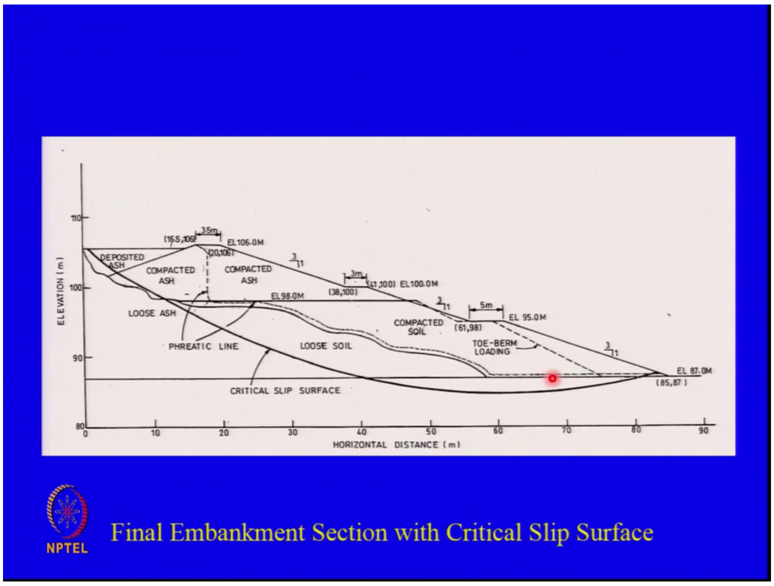

So, finally the section which was adopted was this downstream slope 3 is to 1 with some berms on this, there was a chimney drain and then the balance drain was on the original loose soil and these are thick drains because you it may be the original loose soil will settle a little. So, you took that settlement to into account and give thick drains, if you look at the details it looks like this.

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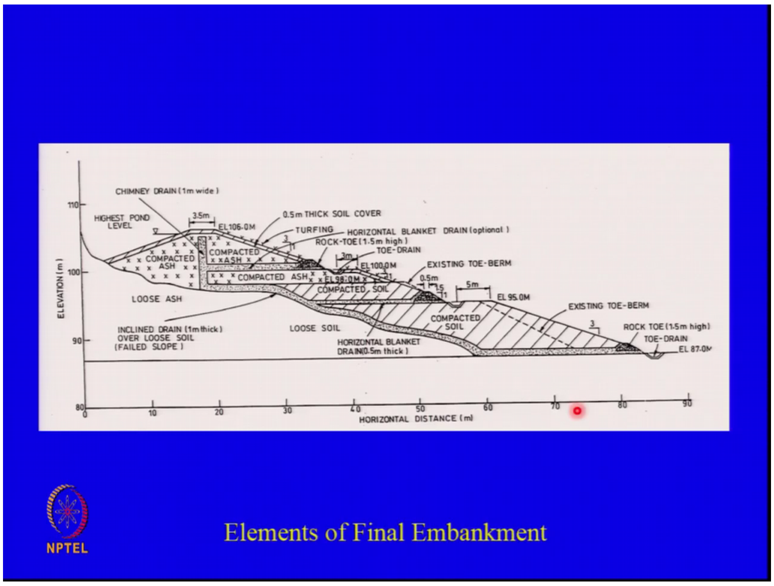

That is the fail material - first put a blanket drain then make this then put compacted soil then put another drain. So, drain at as often as possible. So, one chimney drain one and two horizontal drains and three bottom horizontal drain and that is the new crest. So, on the original field material the stabilization was done. Now if you do the stability analysis the water would come here the phreatic line would come like this for this loose soil take the phi dash for loose material and see what is the factor of safety. And this was the solution for stabilizing this embankment luckily we had this entire distance available to us.

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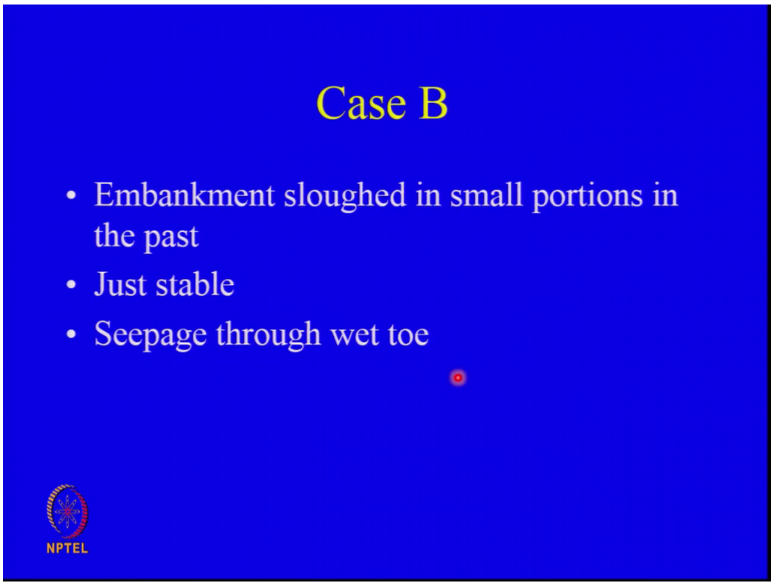

The second case which I am going to discuss with you is tailings dam in which complete failure had not taken place, but the embankment was beginning to move you could see sloughing, sloughing means material wanting to move forward, but no slurry had come out. So, the embankment was just stable, but you could see the seepage on the downstream side showing that the internal drain was not working.

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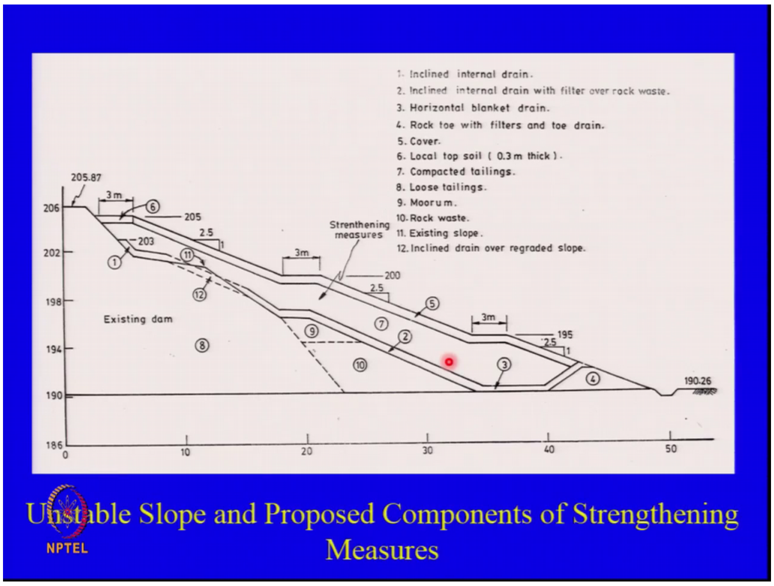

So, this is the original slope here very steep and you can see this is 190 this is 206. So, this is 16 meters high this was the starter dyke probably and there was some upstream dykes as well, but made in a very casual manner. So, we said that look we would like to put a drain on this first you wanted to stabilize the lower portion then you wanted to put a drain then we wanted to put the stabilizing berm and then cover it up again.

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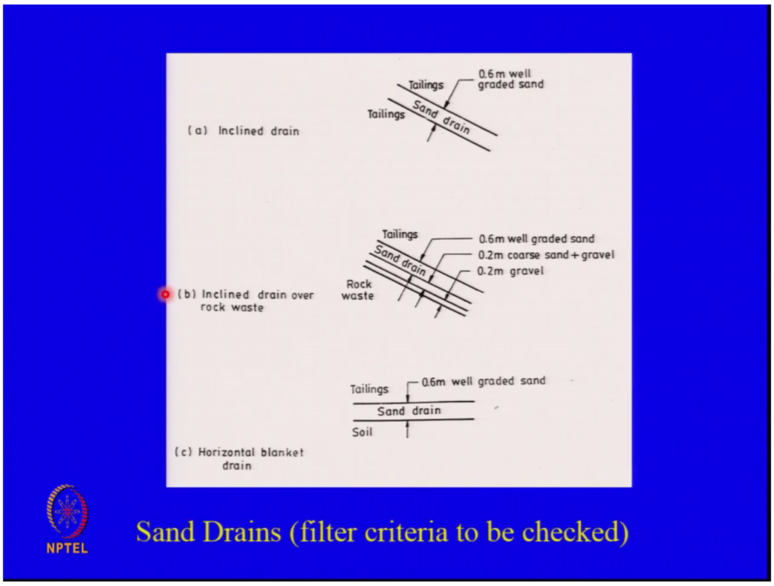

Soil, in fact, when they had started noting some wetness on this side they had started noting some wetness on this side right, then they had put a rock waste (Refer Time: 27:05) you typically what a field engineer will do when he sees anything becoming wet or sloughing he will say all right please put coarse material on it because fine material can come through coarse. But you what he did not do see this dam was made of tailings material there was another tailings pond nearby they had used that. So, 8 is loose tailings. What has he done 10 is rock waste, so to stabilize this he has put rock waste in front he has not put a filter between the two.

So, now he has put the rock waste behind that is the tailing, the tailings are gradually coming out through the large voids of the rock waste. So, the whole thing is the mess you go to the side and he will say sir [FL] I put so many tons of waste rock and still it is not stabilizing the milky water is coming out, we have to now re-engineer the whole problem and see what was done. You wanted to put a drain on it, so that is any seepage take place it is intercepted. So, on this you can put a sand drain on the tailings material you can put a sand drain. On this rock toe can you put a sand drain? No, the rock you put sand it goes into the voids right and you say all right do not know this is free draining. So, ill not put any sand you put a sand drain here, but the tailings will still come out from here because there is an interface between the tailimngs and the rock how do you prevent this tailings material from coming out by putting a drain at the top it does not work. So, you have to re-engineer this thing. So, that you can put a sand you can prevent the tailings from coming out and then you can put the stabilizing berm.

So, here are some of the interesting things, where there was an inclined plane we just put the sand on top of the tailings because tailings on silty sand and you can put sand on it no problems. Where there was rock waste can you put sand on it no on the rock waste first you put gravel, gravel will not go into the rock waste is bigger, on top of the gravel you put coarse sand and gravel and on top of that put sand, so three layer system was used. And remember importantly is this entire stabilizing berm was made with tailings it was made with tailings.

So, therefore, if I go back I had the rock waste then the gravel then the coarse sand plus gravel then the sand and then the tailings on top. So, that is the way in which we constructed that intercepted drain on the downstream phase.

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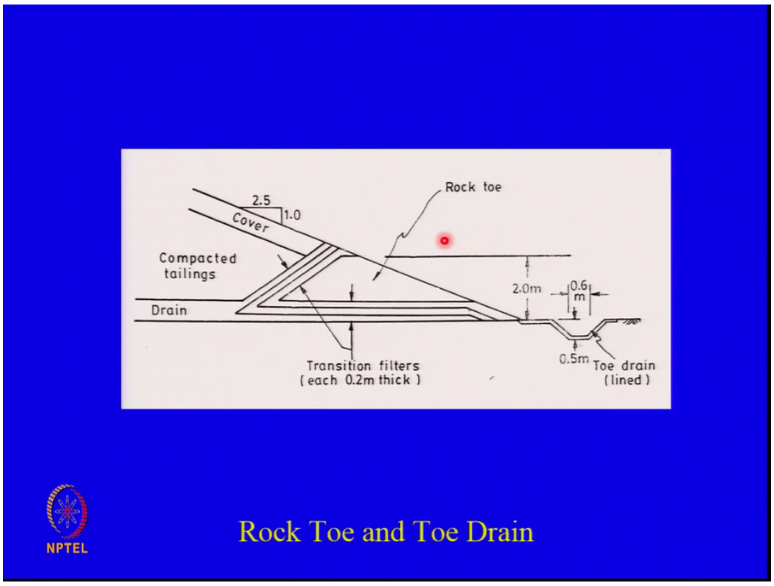

And then we had the rock toe sand drain and this is the rock toe cobbles and boulders and they here you have from the sand to the coarse sand to the gravels to the cobbles and boulders.

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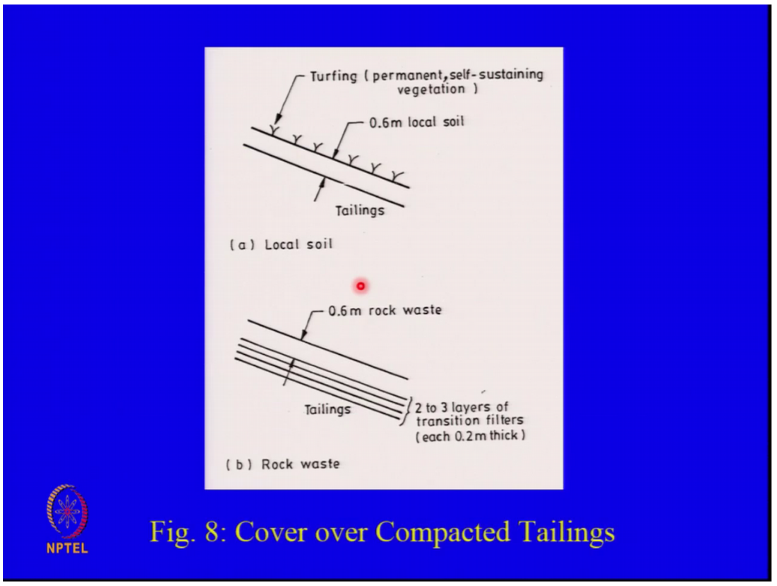

Fig. 8: Cover over Compacted Tailings

On the top of the tailings you have to put a soil cover no problems the tailings are silty sand sandy silt local soil could be put right, but it was a dry climate area. So, the operator could not assure us that he will be able to irrigate this top soil cover and have grass on it. If there is no grass on the soil the soil will erode with time and the tailings will become exposed. So, we said no he said I have a lot of rock waste lying around. So, we said all right if you cannot assure us irrigation and green grass all the time, then I go from tailings to rock waste again. So, my front (Refer Time: 30:50) would now become gray instead of green because of the rock waste; however, on the tailings we will go to sand gravel, gravel, coarse gravel, cobbles and rock. So, we have to put three layers before I can put the rock waste. If I put the rock waste directly on the tailings the rain water will come it will go into the rock waste it will come out and bring out the tailings. So, this is extremely extremely important.

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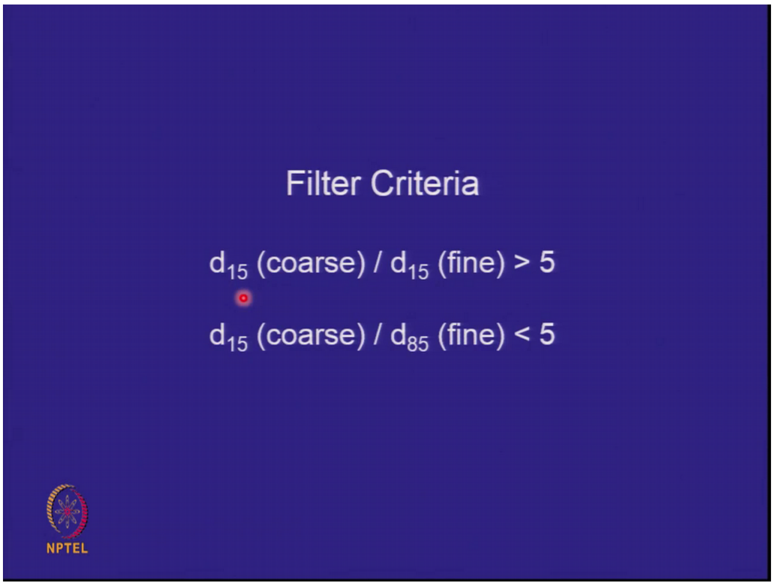

In the end I would like to say filter criteria, filter criteria, filter criteria whether there is flow or no flow fines should not be able to migrate into the coarse voids of the next material now here was the case where there was a rock on top of that we had to put a sand drain and to that we had to put so many layers of filter criteria. So, if you design your filters well if you design your stabilizing berm well you are able to intercept the incoming phreatic line.

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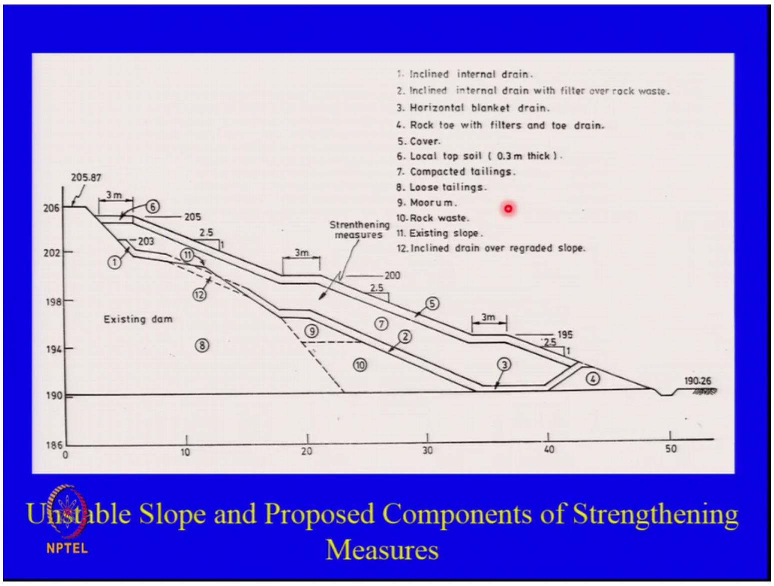

For example in this solution now what will happen when the reservoir is full the phreatic line will be developed, but it will caught by this drain and it will come like this and this is the stabilizing berm all this will remain dry even though it is made of tailings and a cover and a drain and this will stabilize the whole embankment which otherwise is sloughing and is very close to failure.

So, with this we come to the end of this lecture where all that I have introduced to you is the concept of remediation of failed embankments without having to dig up the embankment. The ideal solution is empty the reservoir bring down the slurry levels dig up the embankment make the embankment again this time with the proper chimney drain and a blanket drain, that you have to compare with the cost of remediation with the stabilizing berm and the fact whether you have got place on the downstream side or not.

If you cannot close say you say no I have only 15 days then I have to bring back my slurry into this pond then the only way to do it is build up the stabilizing berm with the downstream behind it and build it to the top because the earth work is of lesser than re doing the entire embankment. So, this is a new, this is a good concept about how to re mediate failed slopes and have a stabilizing berm, but if you do not put a drain behind it then the stabilizing berm is not going to work because the phreatic line will again reach the downstream phase of the dam. Any clarifications or any thoughts come to your mind?

Student: Terzaghi's filter criteria we have (Refer Time: 33:34).

This is the Terzaghi's filter criteria which was given several several decades ago they have better filter criteria now but.

Student: Now we carry out the (Refer Time: 33:45).

Question asked is how do you carry out the grain size distribution of cobblers and boulders. Well you have large size sieves, it is still a sieve analysis. So if you are dealing with what are your maximum sieve size for sand 2 mm or 4.75 mm that is the difference between gravel and sand. So, from 4.7 mm to 300 mm you can get sieves of any size. If you do not get them please manufacture them take strips of steel and make suppose you want to make a sieve of 100 mm how will you make it you need the mesh size of 100 mm [FL]. So, take strips weld them together so the mesh is 100 mm by 100 mm. So, what is above it? So, you can make sieves of various sizes, but in the market also they are available definitely up to 100 mm plus they are available. So, you have to do the grain size distribution, but the quantity of soil that you will need or the rock fill that you need is very large. How much soil do you need for doing a grain size distribution of sand silt and clay?

Student: 200.

200 grams, but if you want to do grain size distribution of cobble size material one cobble may weigh a kg or more. So, you should be using a 1000 kg of soil if not a 1000 at least 100 to 200 kg of soil. So, the representative sample must be large enough for getting a grain size distribution of soil.

Student: (Refer Time: 35:18).

Question asked is there any maximum permissible settlement for upstream method. So, the embankments that we are constructing by the upstream method are all flexible embankments and they work on the principle that if any embankment settles the crest will be raised these see this slurry deposited material will settle with time luckily for us it is not like clay that it settles over 2 years or 4 years these are all silty sands and sandy silts. So, the settlement takes place over a period of few weeks or a few months. So, when you are making your raisings by the time you finish constructing your embankment and rolling them the settlements have already occurred.

So, your final crest weights are pretty stable. If there are incremental settlements which occur later then you are already expected to raise the height of the crest. So, these are flexible elements there are no limits on the settlement due to cracking or due to any other factors in this. Intuitively one feels that in slurry deposited waste there will be lot of settlements, if it is time dependent settlements suppose you are very high fines then you are in trouble why because you have made the embankment if you get 10 20 30 centimeters of settlement then if there is gradually sinking, but both in a ash ponds and in mine tailings ponds drainage is pretty quick and you do not get time dependent settlements which are that significant most of the settlement takes place while the embankment have been constructed.

Student: Sir, when we are putting the stabilizing berm (Refer Time: 37:16), but we are also increasing the weight of the (Refer Time: 37:25) weight of the soil or whatever stream soil so not (Refer Time: 37:31).

Question being asked is stabilizing berm is put on the downstream side not on the upstream side. The stabilizing berm is put here and next raising will be here. So, what is bothering you?

(Refer Slide Time: 37:48)

Student: Sir, (Refer Time: 38:00) which was considered earlier without that stabilizing berm.

Earlier slip surface may be like that.

Student: Now weight of the soil.

Yeah, but now if you look at it, it is like this. So, please understand this is the weight of the soil which is pushing it downwards and this is the weight of the soil which is resisting. So, the weight of this soil is adding to the resistance. Are you appreciating this, this was the original failure surface, this was the downward force now I have put this stabilizing berm, if I extend the original surface then this force is acting this way because the slope is on this side. So, the stabilizing berm is acting against the driving force of the earlier mass of the embankment. So, this stabilizes this increases the factor of safety the new after the stabilizing berm is put the new failure surface will be here this will give you lower factor of safety this, but still there is no phreatic line here it will give you a factor of safety which is above 1.5. So, this is the original failure surface critical this failure surface the factor of safety will rise hugely this is the new critical failure surface which will still be within acceptable limits all right.

We will stop here have a good day all the best.