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

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Lecture – 35
Planning & Design of Slurry Ponds

Good day to all of you, we continue our discussion on disposal of tailings and coal ash in slurry ponds. So, today we will be focusing on the planning and design of slurry ponds; that means, how do we decide the layout, how do we decide the drainage and the decanting arrangements, how do we decide the stability of the site slopes, what heights we can reach. So, these are some of the factors that we will cover. So, mostly we will cover the geotechnical aspects of the design and we will also touch briefly on the other aspects. So, I am going to use the word slurry ponds mostly what is presented here relates to ash coal ash disposal, but it is equally applicable to mine tailing disposal. And when we are discussing slurry ponds, we are basically looking at lean concentration slurry disposal that is what is prevalent in most of the ponds today in India.

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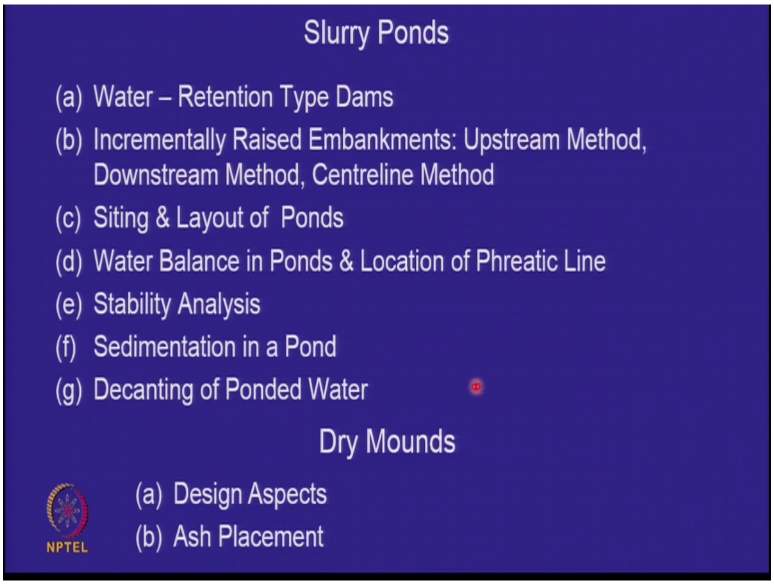

So, slurry ponds can have two types of retaining structures, water retention type dams or incrementally raised embankments. We will discuss both of these and compare these, when you incrementally raise the embankments they can be by the upstream method downstream method or the centerline method. We look at the layout of these ponds the water balance the most important thing how much water is there in ash pond or a tailing pond, because the higher the water the higher the free anticline and that does effect the stability of the embankments. We look at how we handle stability, we will also look at how sedimentation occurs and how we decide the size of a pond and finally, how do we take out the water from which all the solids have settled down. Briefly we will look at dry mounds as well some design aspects and some ash placement aspects, and their relative advantages and disadvantages of slurry ponds and mounds.

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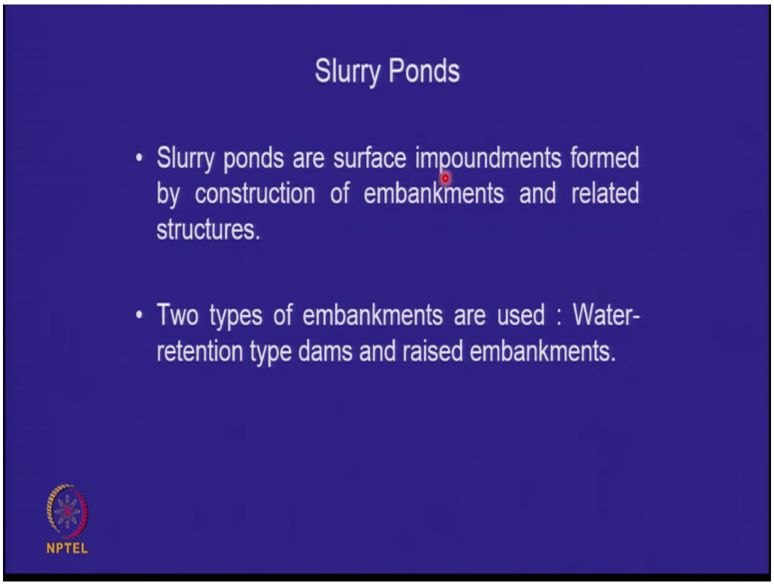

So, just to quickly recap slurry ponds are surface impoundments formed by construction of embankments and related structures, all around the area in which the tailing or ash has to be disposed, and we looked at the fact that embankments can be water retention type dams and raised embankments.

So, there is a tendency to think that you know slurry is not water and therefore, the design will be different, but because it is lean slurry because it is lean slurry predominantly 10 times water in comparison with the solids. So, it is like you know designing a lake, you may operate the ash pond such that water is less and the water is more, but the critical event occurs when water is more.

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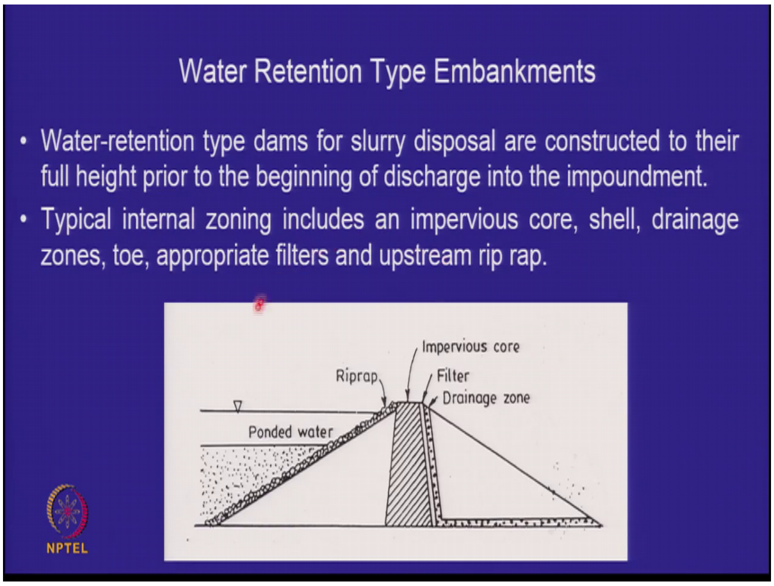

So, if you just recall our standard water retention type dams or what we call earth and rock fill dams there is a core in the middle and there is a shell and there is riprap, and there is a filter and there is a drain. So, in a slurry pond, the ponded water level will typically be higher than that deposited material. So, such a dam is what one could think that one can adopt. These if you have to construct water retention type dam you have to construct it to the full height prior to the start of discharge; that means, you have to make your complete investment in the full height of the dams if you want your slurry deposited slurry deposited material to be 20 meters thick, and you want to give a extra free board of 1.5 meters.

So, if you want to have a 21.5 meter high area in which you will be storing your ash or mine tailings, then you have to build this whole dam in one go. And as I said this is the typical internal zoning which we adopt.

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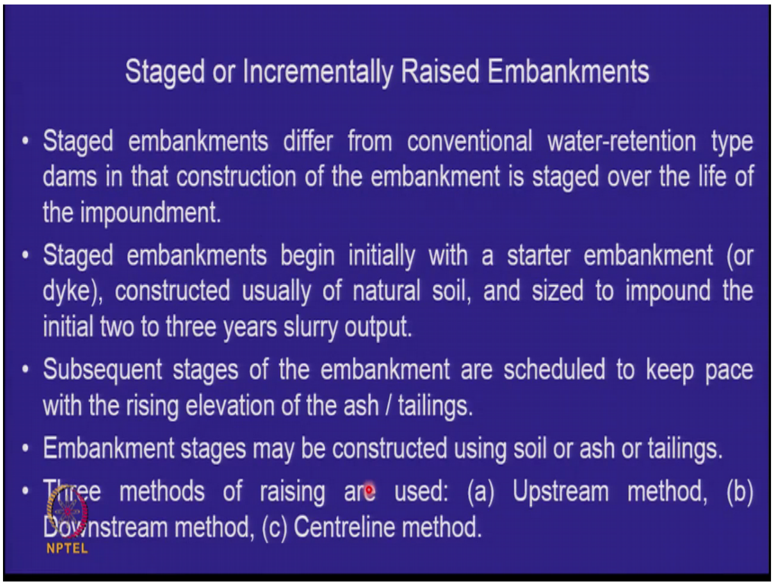

In contrast as I said it is most of the time one does not want to make the those kind of investments in one go. So, we use stage embankments or incremently raised embankments. So, they differ from the conventional water retention time dams in that construction of the embankment is done in stages, you start with the starter dyke or a starter embankment, which you construct with locally available material the local soil. So, you usually use the natural soil and basically the idea is that you should be able to collect two three years of ash or tailings in the empowerment. After that you raise the embankment and because you are collecting this ash or because you are collecting the tailings behind the started hike, that is the most abundant material which is available to you.

So, economics demands that now stopping getting more material from outside the started dyke is of the natural soil, but the other raisings that you do maximize the use of the material which is available to you in the pond, which is soil like and then design it so that you do not have to get more natural soil from outside. So, subsequent stages of the embankment are scheduled to keep pace with the rail raising elevation, you are getting more and more tailings or ash everyday and these stages may be constructed using soil or ash or tailings, but predominantly we want to maximize the use of this. Of course, if the tailings are as are rendered as hazardous, then you cannot use them in the making of the embankment, but as long as the a non hazardous you can use them, and already talked about that we have 3 methods.

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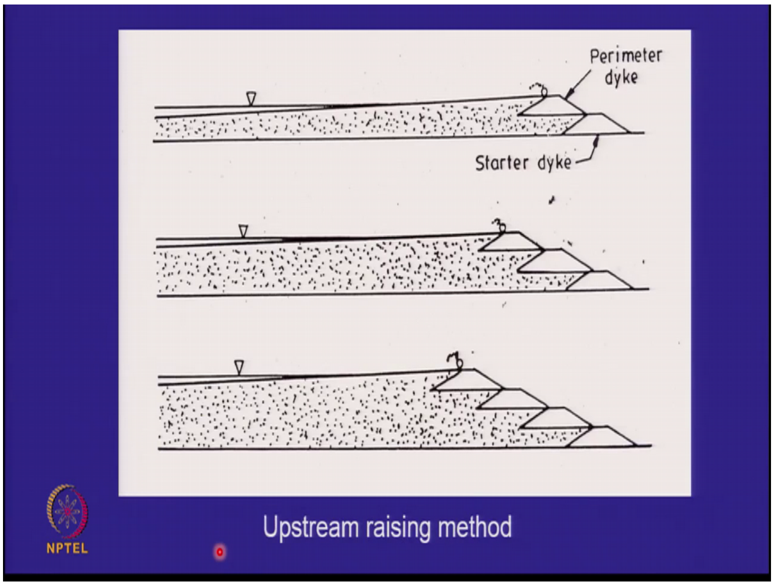

And the three methods look like this, this is your starter dyke which will typically be made of the natural soil and then you will stop depositing your material and once the material raises towards the stop you will put the second dyke this will be made primarily of this material, and like that when this is filled up then you will make this embankment using this material and then do the slurry deposition. So, every three years or so, may be more sometimes four years, you will raise your height and as you can see this is progressively moving upwards and inwards, and each embankment is resting on the loose deposit which has been hydraulically deposited. You can compact this, but can you compact this that is that is the question.

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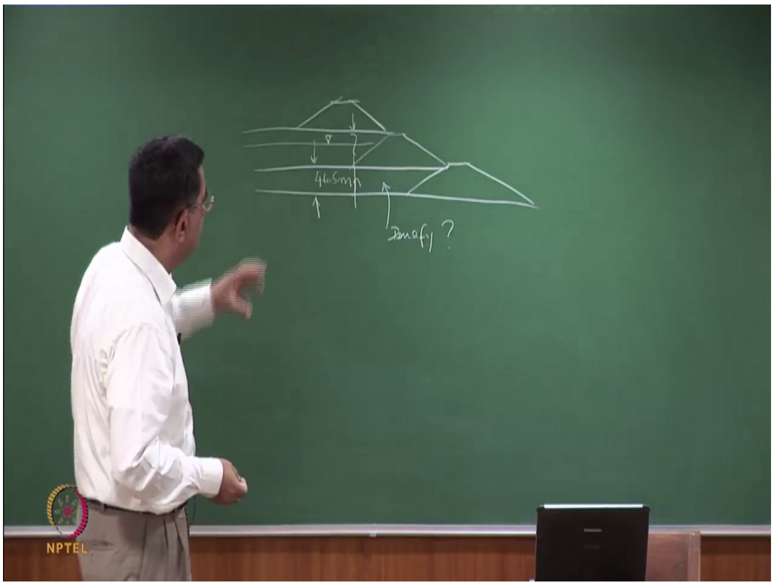

So, if I was to say alright this is my starter dyke, and I have filled up my material up to this level, I want to make my next dyke let me sand making it here, now can I compact this? This is let us say starter dyke was 4 to 5 meters high, I am placing this on you call later on you know as you fill up the slurry level will rise. So, you are on saturated loose hydraulically deposited material in the upstream. So, the question is can you compact this how do you densify? You can densify this as you put the embankment layers you can use rollers and you can do optimum moisture content gamma d max, that this material will be dense and strong the challenge is here, and as I go higher and higher you can see the challenge when I am going to put this then I have to compact this. And as I go higher and higher I am going backwards into the upstream into the pond and I am sitting on thicker and thicker deposit. So, now, if I am making my second stage how do I compact the soil beneath it, to what depth can a heavy roller compact soil beneath the surface. Take the heaviest roller and the maximum compaction energy that you can give with it know how thicker deposit you think it can compact, anybody would like to address the addition, now let me say I have a 20 ton roller.

I want to increase the compaction energy by giving 20 passes, how deep down you think you will compact any idea. So, rollers do not compact to great depths, please be clear about it you know your pressure bulb no might what the weight if the width of the footing is b, then the significant increase in pressure is up to 1.5 to 2 b we all know that. Now when you have the roller the area of contact is very small. When you have a roller the in a perfect rigid subsurface and a circle roller you will have a line contact, but here the roller does go into the loose soil a little bit. So, you will have a limited width contact. So, no roller is going to compact for you more than 50 centimeters or say, you are giving vibrations and if it is sand may be a 80 centimeters, you cannot compact using rollers anything which is3 or 5 or 5 meters thick, then you have to go for insitive densification as per all the other techniques which you may have done on the ground improvement like you know all those vibe of rotation dynamic compaction they very expensive techniques. So, they rarely adopt it.

So, in upstream method the staged embankments or the incrementally raised embankments are resting on soft soil loose soil, which is hydraulically depositive.

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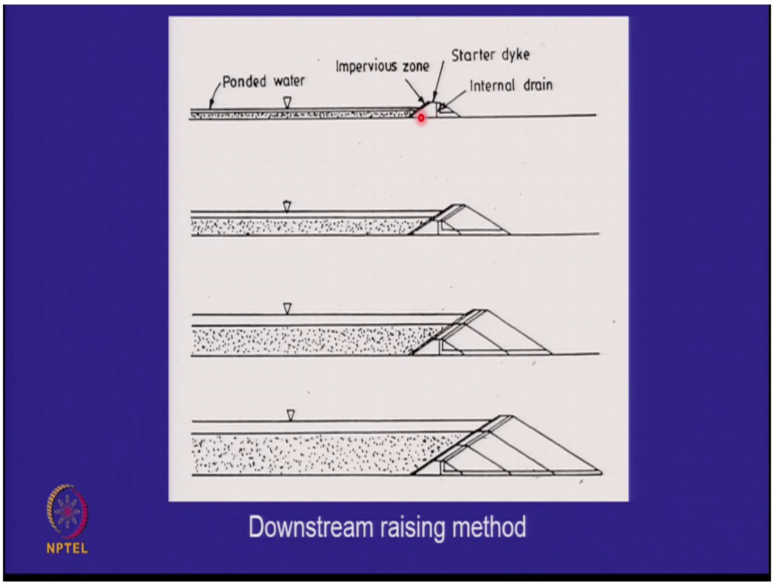

To get rid of this problem the other method is called the Downstream method of construction. Now the difference in the downstream method of the construction is that you are moving downstream, this is your first dyke made of soil, then the second one is made above it and towards downstream side, and then like that third and fourth the two important things. If your boundary of the ash pond was here, and you started your started dyke here you cant go downwards that is an error. So, when you want to do downstream raising you please be well inside the outer boundary of the area, which you are required for the tailings pond otherwise. So, this is one thing you will please see from that last figure, I start here and I go inwards. So, I have no problems, but here if I start here and my boundaries here I cannot construct it. The second is how much material are we using, how much earth work are we doing the cost of the dam or an embankment is the volume of earth work that is done one is how far is it coming from and secondly, how much compaction you have to do, but everything is per cubic meters.

So, see if I have one two three four stages of rising, this is the amount of earth work that I have to do that is the mod of compaction that I have to do. I go back here and in contrast I have to do only this much also this is much smaller amount of material. So, downstream method of construction is more expensive because it requires more earth work; however, it is everything is compact nothing is resting on the loose tailings or the loose ash. So, this is well compacted and it is stronger. The hybrid method is the center line method where part of the embankments sits on the loose deposit can you see, but most of the embankments sits on the density compacted material. This requires less earth work than this, and please remembers the vulnerable slope always is the downstream slope, the failure normally occurs with of downstream slope failure. So, if you have the downstream slope that is basically made of compacted material that is called the center line method of construction. It is intermediate in cost and advantages between downstream and upstream methods.

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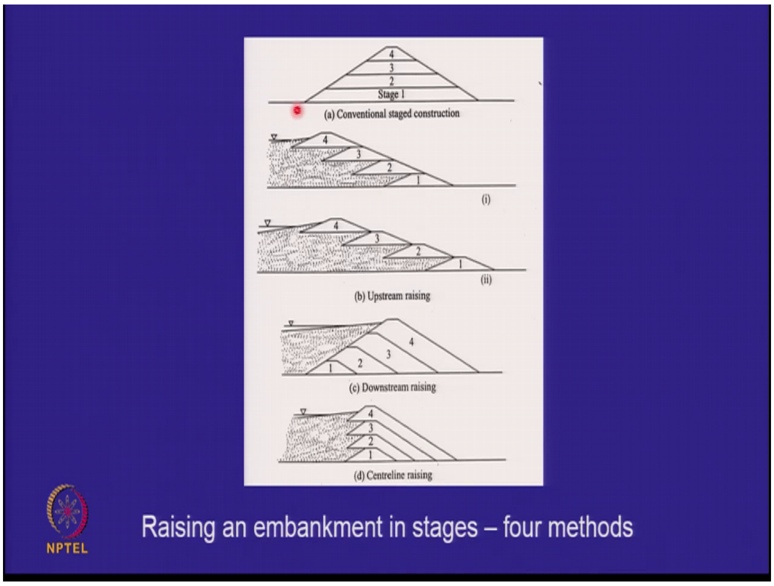

Just quick quick recap if I wanted to make the conventional dam in one go, and I said no no I will do it stage professor datta said I do not want to make the full investment in one go, conventional staging is like this, this is stage 1, then stage 2, then stage 3 and then stage 4.

So, the maximum earth work would anyways be in the first stage, that would still require a large investment and a very large surface area would remain exposed. So, we do not do staging like this, we do staging either like this upstream or downstream or center line. And there are two diagrams here what is the difference here it shows that the upstream, the toe of each stage is at the end of the crest. This is normally not adopted with each stage you move backwards; that means, you gave a little bum here this becomes like an inspection road for the raisings and we can have a track or a motor able small bum on which you can go and inspect the performance of your dykes.

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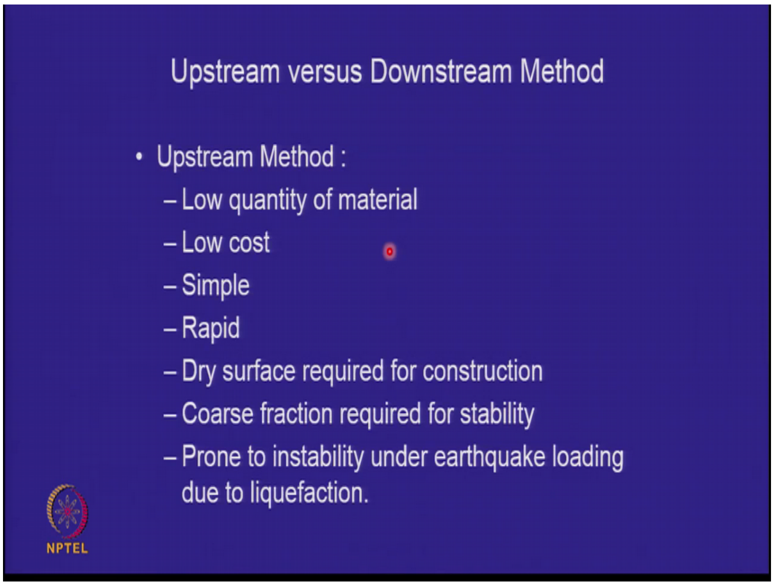

So, upstream verses downstream method, upstream requires low quantity of material I showed you therefore, it is of low cost, it is simple and it is rapid. It is faster because less quantity of material as to be placed, but you require dry surface for construction you cannot construct it when the pond is operational.

So, you must have two ponds available with you one pond, pond is operational the other is drying when it is dry you can construct on it, and you do want if you want your stability of the upstream method you do want at the coarse fraction of your tailing should be towards the peripheral embankment. So, that you have raising is on the coarse of fraction, why coarse of fraction though loose our in even when they are loose are stronger because they have larger particle size and they have free draining. So, they do not have pore water pressure build up. So, you want coarse fraction to be closer to the peripheral embankments on which the upstream raising has to be done; that means, you have to operate your ash pond well will address this issue towards the end. All these loose hydraulically deposited tailings or ash are prone to instability under earthquake, due to possibility of liquefaction. So, the grain size distribution of the material lies in the range of liquefiable materials unless of course, the coarse fraction s the which some lateral shorting does take place, but we cannot always assure you that lateral shorting would have taken place in the pond. So, there is an issue about liquefaction on the upstream. So, we are in a highly seize make prone area watch out for this problem.

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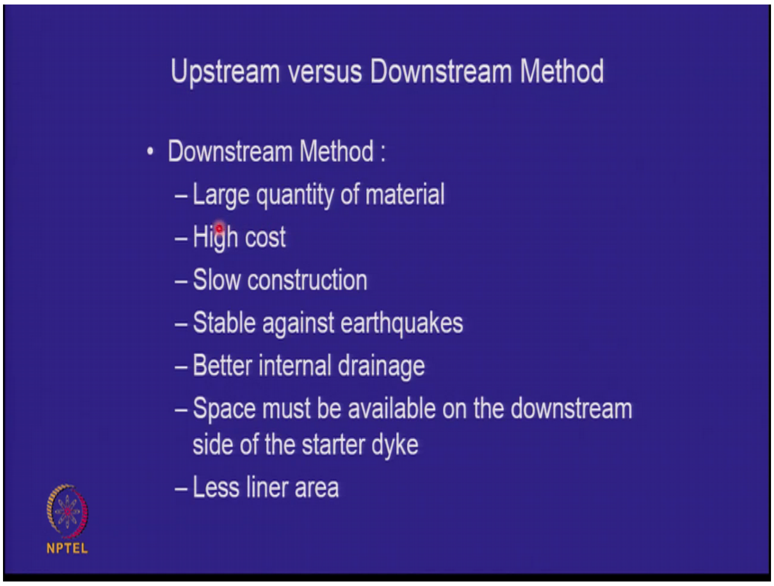

The downstream method of construction requires larger quantity of material therefore, it as higher cost it has slower construction in the sense it takes longer, one thing which has been (Refer Time: 16:50) is it can be done while the pond is still operational, because you are constructing basically on the downstream side which is available to you. So, construction can be done when the pond is operational, as stable against earthquakes it is nothing is resting on loose deposit, it has better internal drainage will see this in later stage. However, space must be available on the downstream side of the starter dyke; if you do not have the space you can expand on the downstream side it.

It requires less liner area we will address this later, but new guidelines of the ministry of the environment and forest and new standard emerging globally are requiring liners to be placed at the bottom of slurry ponds. So, you will find that the liner area is lower because you start the starter dyke on the inside and the liner has to be in a upstream method the starter dyke is at the outside. So, the liner area is larger. In inmost of our ponds we are using the upstream method of construction, but then failures are also reported from time to time and that makes it critical that makes the design critical.

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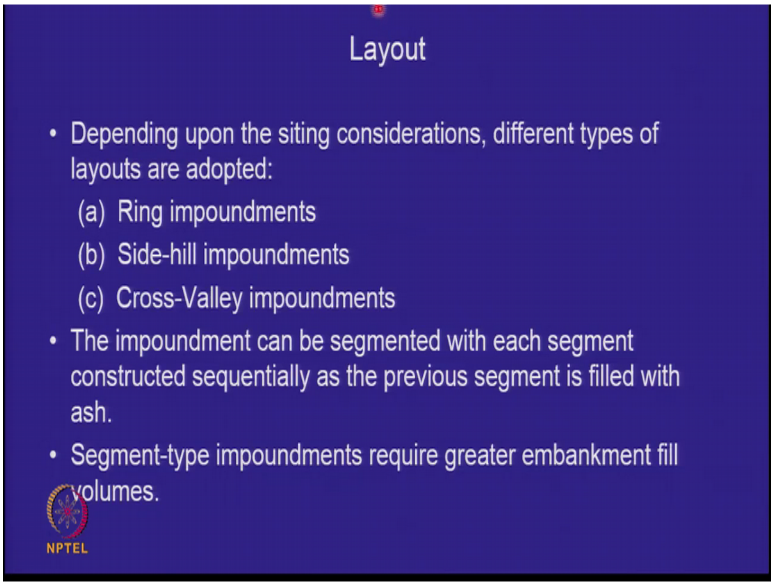

What does a slurry pond look like in plan, it can be ring impoundments or a side hill impoundment or a cross valley impoundment, much like when we talked about landfills. Depending on whether you are in flat ground or low lying area or you are on a hill slope or you are on a cross valley arrangement, and the impoundment can be segmented and of course, segmented impoundments require greater embankment fail.

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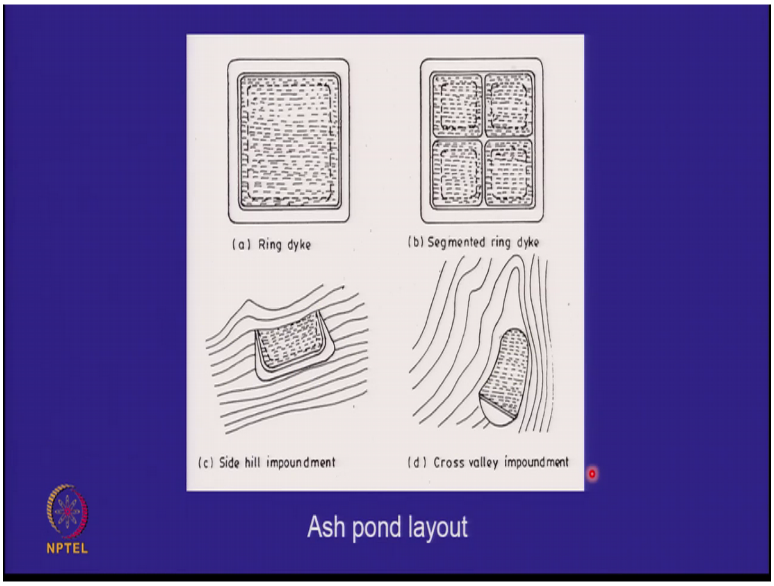

So, basically if you are in flat ground you will put an embankment all around, and as you will if you have to in increase this by the upstream method then the embankment should progressively move inwards in plan, if you are at the side of a hill your impoundment will look like this; that means, here the embankment height will be a maximum. If you have a valley type of arrangement then you will have a cross valley impoundment like a dam just like you create a reservoir and you have only one side on which there is an embankment, there are hills and the raise ground all around it. Typically we work with segmented ponds because if you have want to use upstream method of construction, you should be able to close one and move on to the other, they here we are showing four segments, but normally it is a two segment pond that is what we do in India; that means, slurry is deposited either in one or in the other.

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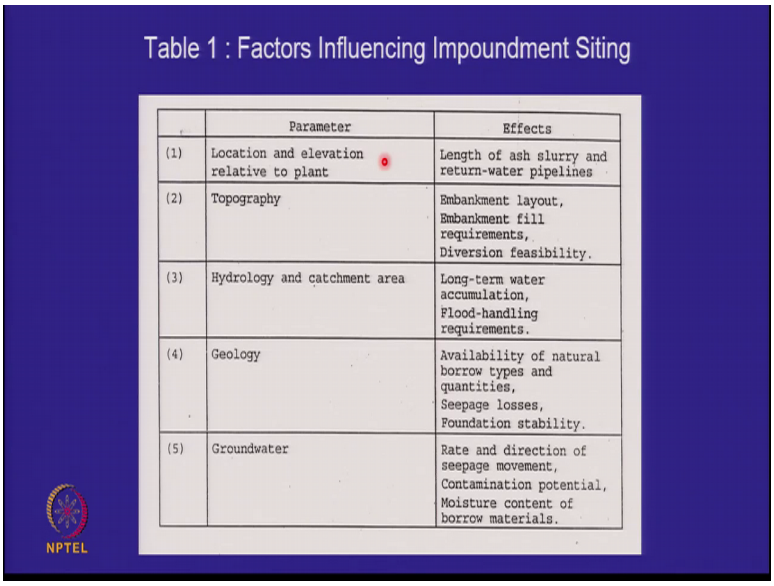
Table 1 : Factors Influencing Impoundment Siting

	Parameter	Effects
(1)	Location and elevation relative to plant	Length of ash slurry and return-water pipelines
(2)	Topography	Embankment layout, Embankment fill requirements, Diversion feasibility.
(3)	Hydrology and catchment area	Long-term water accumulation, Flood-handling requirements.
(4)	Geology	Availability of natural borrow types and quantities, Seepage losses, Foundation stability.
(5)	Groundwater	Rate and direction of seepage movement, Contamination potential, Moisture content of borrow materials.

And the factors which are of importance as for as the siting and the layouts are concerned, you have you know the tailings are coming from a processing area or the ash is coming from a thermal power station.

So, how far are you from the thermal power station or how far are you from the processing plant and what is the elevation; that means, how much do you have to pump up the slurry or pump down the slurry, what is the topography as I just talked about it, what is the hydrology and catchment area much water s going to come into the pond from outside areas. We look at that briefly, what is the geotechnical and geological features, what is the soil available where is the bed rock where is the ground water table, what are the kind of foundation issues are we going to have and of course, we are going to look at ground water quality, and seepage and contamination potential. These are the factors which influence the impoundment siting, but typically the issue is where do you get enough land where do you get enough land.

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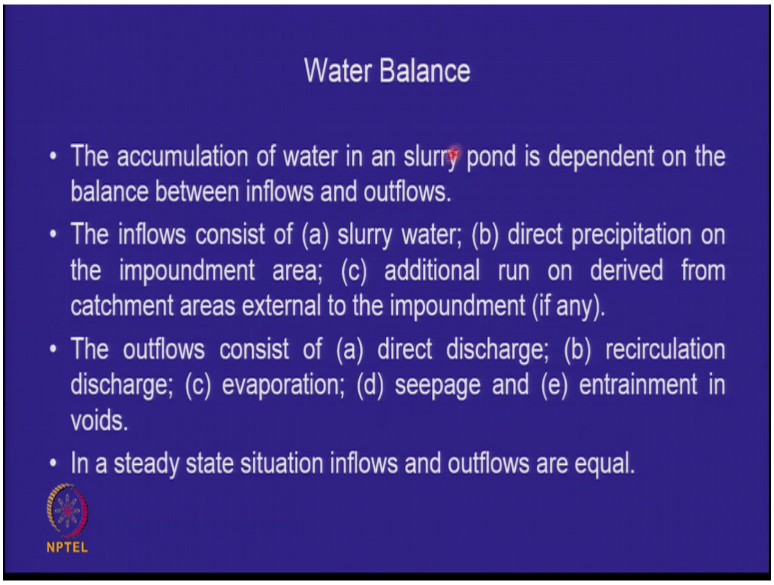

So, if you look at the water balance in a pond, the inflows consists of when this is important it is not a closed container system it is an open system. So, the inflows consists of slurry water which is coming in from the pipeline, more importantly also the direct precipitation which falls on that entire area. So, when it rains the rain water is collected that also adds to the surface water inside the impoundment, and if you are in a low lying area or if you are in a side hill impoundment or if you have an cross valley impoundment, and all the run on coming from the sides will also come into the pond. So, this is the inflow the outflow of course, is the discharge of the decant ratio, some of the decantation may also be treated like are circulation discharge. We may lose some water to evaporation, some will seep into the ground and some will remain entrapped in the soil voids or in the ash and tailings voids. So, those are the outflows for your water level to be constant inflow and outflow must be the same, otherwise if the inflows are more the water level will rise if the inflows are less the water will fall down.

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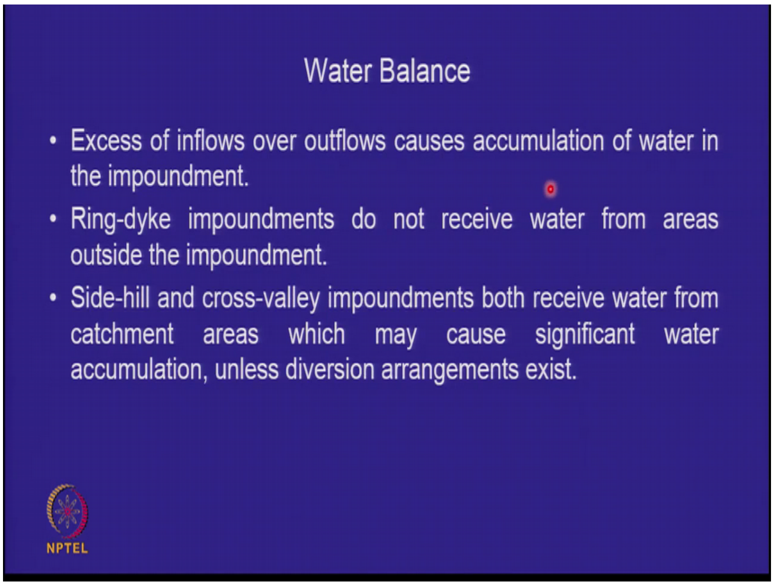

So, excess of inflows is sometimes a problem because it cause accumulation of water, this excess inflows is not a problem in ring dykes nothing comes into the into your impounded area from outside because there is a dyke all around it. Even if there is a little bit of flood water outside it would not come in, but in your side hill impoundment and cross valley impoundments there is this huge issue about receiving the surface run on, and though your embankment costs are low we have to make you know diversion channels.

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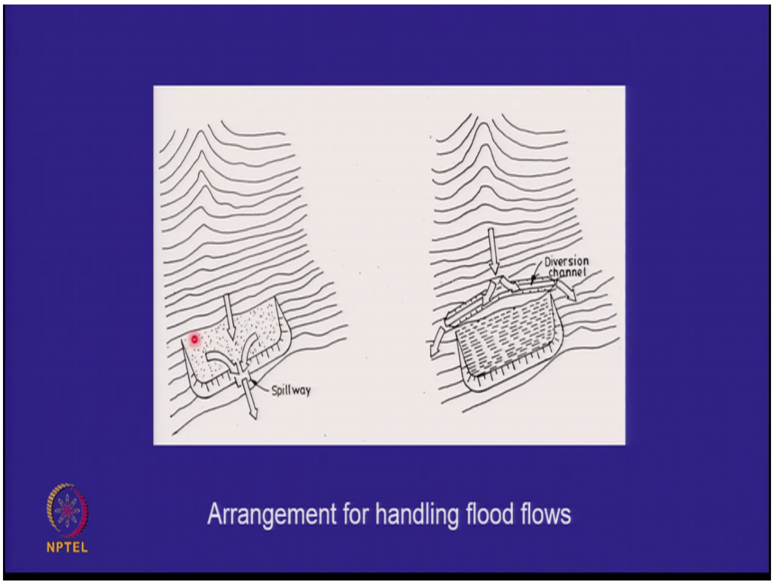

So, if this is a side hill impoundment water will tend to come in into this, this is already fully slurry water. So, this will increase and you will need a spill way to handle these flows alternatively you have to spend some money and make diversion channels.

So, that any water coming down this hill slope is diverted to the sides and does not enter your ash ponds this is important. Because if the water level rises, the phreatic line in the embankment raises and that case cause for stability issues are problem which come later. So, I talked about the phreatic line all of you are remembering the phreatic line yeah. So, just quickly to recall elementary slope stability of earth dams. So, dams can be zoned or homogeneous dams let us say I have a homogeneous dam.

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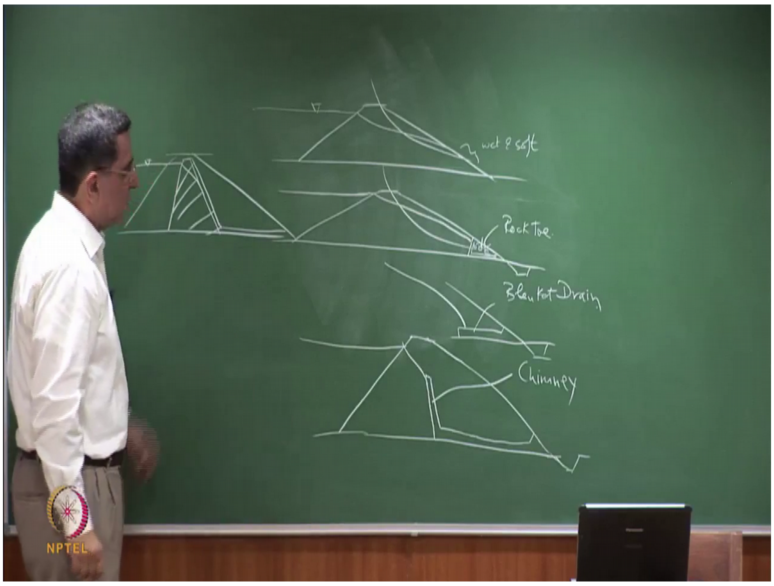

Typically I may have a homogeneous dam which are use for a lake embankment 5 meters high that is my lake. So, phreatic line is the top flow line which develops, let us assume it is sitting on impervious base and the phreatic line will tend to develop like this. You know all the ways of constructing this is a casa grande method you make a flow net, you can calculate the seepage. This is not a good way of designing an embankment because this will remain wet and soft and eventually you know you will have piping. So, you building some elements that this does not happen and that is your entire philosophy of design of a homogeneous embankment. So, what do you do? For the same problem anybody what will you do in the (Refer Time: 24:17) this does not happen.

Student: Perfect.

Make a.

Student: Toe filter.

Toe filter or a rock toe or they are different things somebody might want to do this, with adequate somebody else may want to put a horizontal drain and yet somebody else may want to do this is hope this is visible to you I the might want to put a chimney. So, if I put a rock toe here. So, what it does is the phreatic line gets captured something like that, it is very near the surface very near.

So, if you are looking at stability analysis you still get pour water pressures, but there is nothing soft at the downstream toe. If I bring this little inwards then my phreatic line comes and hit it here now I am further away, from the downstream side. And if I build a chimney drain let me complete this diagram then I am through the chimney drains. So, this is what a blanket drain this is a. So, in this arrangement you have a chimney drain horizontal blanket and a rock toe right here you have a horizontal blanket and a rock toe, all of them have a toe drain at the end toe drain is something which is here. A good design says that you carry catch this water and take it away. So, the further you keep the phreatic line from the downstream phase the most stable the dam the drier the material and this are the series of options for controlling the phreatic line in a normal embankment. So, this is I can I would like to complete this discussion this is a homogeneous dam, but if I have a core then really nothing comes to the downstream side; why is a earth come rock filler zone dam better if for the same case I have a zone dam and I have a core here.

So, how is the phreatic line this is shells. So, (Refer Time: 27:20) and material head losses is limited and the phreatic line is like this and there is a filter and a drain here. So, what happens there is a phreatic line is really far away from the downstream side. So, here also you can think of it as this. So, an earth come rock fill dam or a zone dam also keeps the phreatic line well away from the downstream side. So, the location of the ponded water with respect to the embankment crest is the most important factor influenting influencing the location of the phreatic line.

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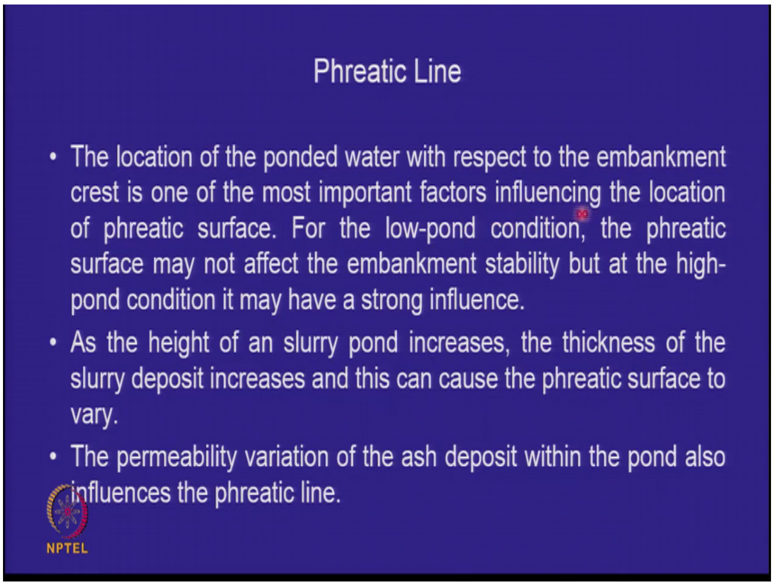

If you are operating the dam well, if you are operating the pond well you have you can keep your phreatic line low; however, if it rains then it will rise.

So, says it is a open system it is not that easy to control the phreatic line, if it is a closed system I could say (Refer Time: 28:00) I will close the valve of the inflow pipe, and I will reduce the inflow and outflow, but I cannot do in this system. So, therefore, critical design always is keeping the water level to the highest possible level and; that means, a phreatic line will develop. For the low point condition the phreatic line may not effect embankment stability and therefore, a pond is normally stable in most of the time, but at the high pond condition it has the strong influence. And the other thing is as the height of the slurry pond increases the thickness of the deposit increases and the phreatic surfaces also increases goes higher and higher the pressure is build up, and lastly the important aspect is the permeability of the ash deposit within the ash pond also influences the phreatic line, because ash is deposited in layers. So, which permeability is higher horizontal or vertical?

If a material is deposited in layers; that means, it gets fine coarse fine coarse fine core the horizontal permeability is given by the coarse material.

So, the horizontal permeability is more than the vertical permeability; that means, the water has a tendency to flow laterally rather than to flow, downwards in comparison to a homogeneous material that also has an implication on the phreatic line.

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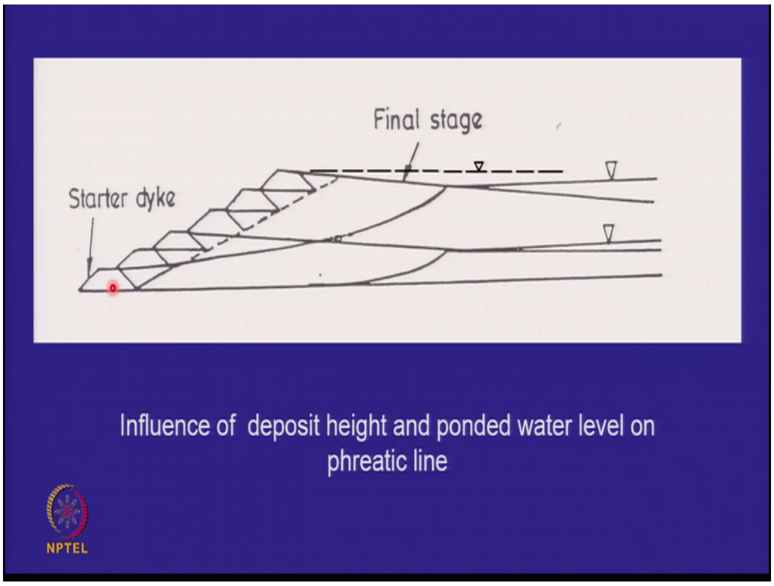

So, if I look at this, this is my starter dyke this is my first raising this is my second raising at the in the second raising if I am operating with a low pond right you have phreatic line is far away. That is say 1, 2, 3, 4, 5, 6 after 6 stages I am here I am still far away, but my pour pressures are now increasing because the water level is becoming higher. However, most of the dams do get operated where the water level reaches half a meter to the crest. When the high pond level occurs then the phreatic line is formed inside this and when that happens it becomes the critical stability issue. So, there is a two issues here if the water was high here, this still a small height dam, but if it is high here this is a 20 meter high dam, but if it is high here this is a 20 meter high dam with the water very close to the top and the phreatic line will give you a wet toe so that can cause issues.

So, height of the deposit and the ponded water level are the two critical conditions in many people will say no no I can operate it with low water it is not possible, it is an open system today it is low tomorrow you are sleeping there is a huge storm at night is a huge dam pour you cannot say I will not have water level which will raise.

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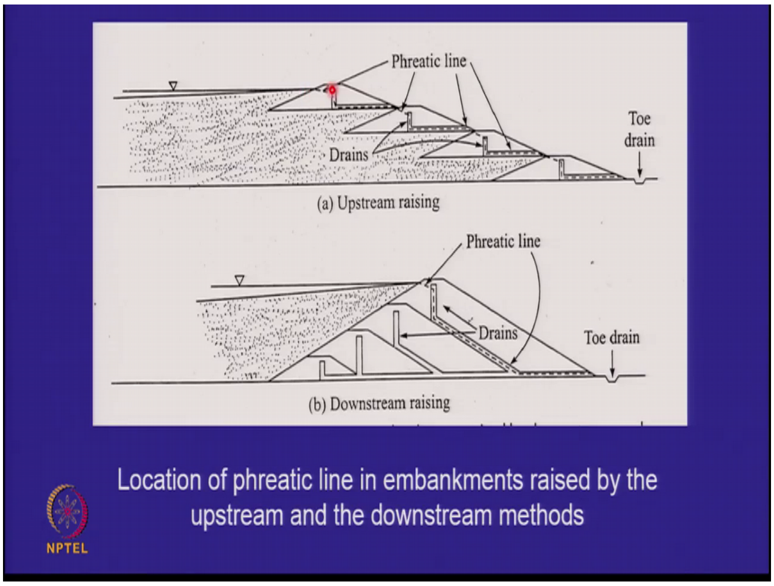

So, to take care of this we put the drains like a in a homogeneous embankments, which I just talked. But do see this that even if I put drain in the middle of the upstream side, if I am if my failures my failure surface will tend to go through the loosely deposited material, the critical failure surface will go like this, there is still be pour water pressure. Where as in this case in the downstream side the failure surface will go like this and the pour water pressure will not be a much issue. So, in the downstream method you are able to keep the phreatic line well away from the downstream phase whereas, in the upstream method there is always this issue when water is coming out here water is coming out here seepage water is coming out here. So, a downstream method of construction handles the phreatic line better.

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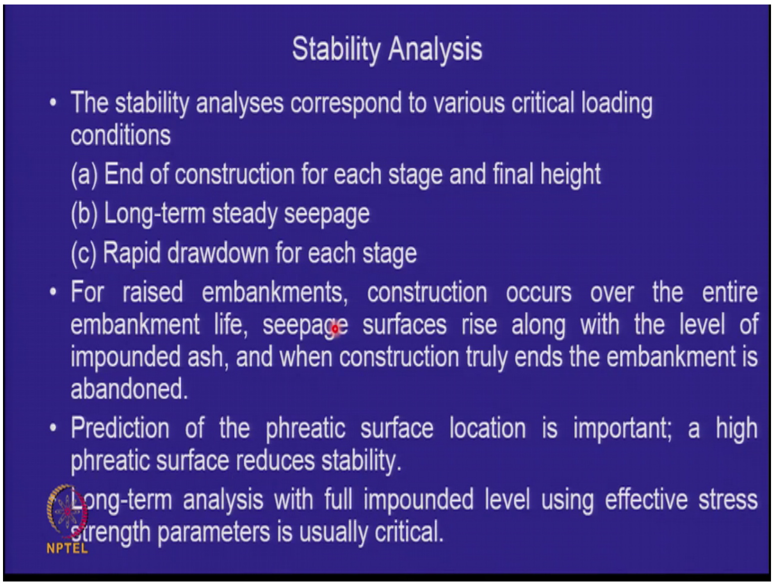

Now, we do the stability of these embankments. So, why because they have reported to fill every now and then, well designed and well operated ash ponds or tailings pond this does not happen, but in the others it does. So, you remember that for typically design of embankment dams water retaining type structures we have three conditions; end of construction, long term steady seepage and rapid draw down. So, which condition is important for stage construction, which condition is important for stage construction in stage construction? The rapid draw down is for the upstream slope you remember and the water is forced to fall from the highest reservoir full level to the rare depleted reservoir, or the minimum reservoir level. So, we have a 25 meter high embankment it could fall by 20 meters, but in our case every three or 4 meters the ash is getting deposited or the tailings are getting deposit.

So, the upstream slope is getting buried. So, rapid draw down can only for one or two meters it is not going to be there for 20 25 meters. So, rapid draw down is normally not a very critical parameter for stage construction. Because the deposited material is burying the upstream slope agreed? End of construction is only for the stage embankments; that means, staged embankment means each increment of raising 3 meters 5 meters 6 meters the height of the embankments is not very large, but long term steady state seepage I mean steady state seepage which slope do we analyze downstream or upstream downstream slope and suppose I have 6 raisings of 4 meters each, how high is my embankment now 6 raisings of 4 meter each 24 or 28 depending on the starter dyke.

Now, I have downstream slope which is 28 meters high it is not being buried by the material right. So, the steady state seepage with reservoir full or the phreatic line very close to the top is the main design critical case and this may occur once in a year or once in 5 years, you know it may not occur if there if the pond is dry or the pond has got low water level the embankment may look stable, but when it occurs then the design should be able to take care that there is no piping there is no excessive seepage, and there is no failure due to excess pour water pressure. So, as out of these three the long term steady state seepage is the most critical others have to be investigated for short heights, prediction of the phreatic surface location is important a high phreatic surface reduces stability long term analysis with full impoundment level using effective stress parameters is critical.

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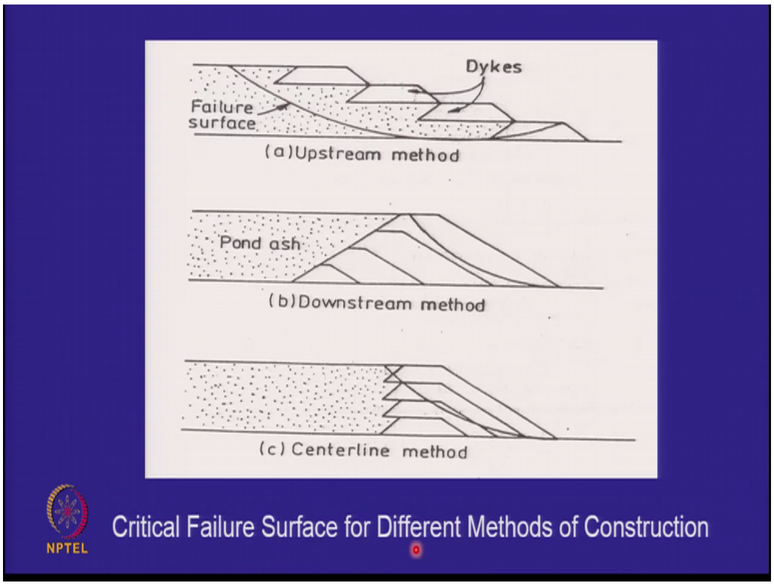

And as I said when you will do for the same height of the dam by the three methods, your critical failure surface in the upstream method because this strength is low than this strength, will something like this it will be flatter, but it will be something like this. But for the downstream method of construction the critical failure surface will be here, this is strong material well compacted. So, issues are not similarly in the center line method it will still be here.

So, in both the center line method in the downstream method, the issue is about stability of the compacted material. In the upstream method the issue is about the stability of the hydraulically deposited material and both form slope stability perspective and also looking at the liquefaction potential of this slurry deposited material. So, this design would only be good if anything has been investigated properly.

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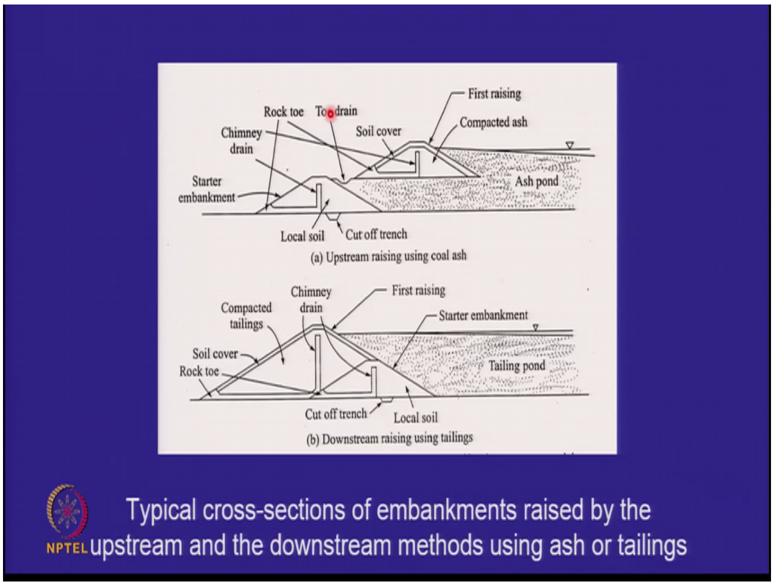

So, these are typical embankment sections which one adopts, suppose I have a tailings pond and I have an ash pond starter dyke will be of local soil, local soil means homogeneous embankment chimney to keep the phreatic line away this is a good design, then I will use most of the ash here when I use most of the ash here, I have to make soil cover. So, that there is no erosion no dust you know if you put flash in an embankment, when it is dry it tends to fly away it will start creating dust people will say that it is causing the problem. So, the tendency is to put a soil cover over the compacted ash. Similarly in a mine tailings pond if tailings are available first stage it may be made up of local soil this is stage one, in the second stage the tailings may be used here and tailings the fine tailings also tend to fly away, and so you will put a soil cover. There will be a chimney drain, there will be a blanket drain and there will be a rock toe as here chimney drain blanket drain rock toe, but remember the failure surface will pass like this.

So, it is basically through dry soil, here the failure surface will pass like that. So, though there is a phreatic lines still there is a pour water pressure beneath the phreatic line on the failure surface. So, these slopes will be flatter these slopes will be steeper. Typically these will be 3.5 to 4 is to 1 the average downstream slope, where as this will be 2.5 is to 1. So, this is a steeper for downstream method of construction.

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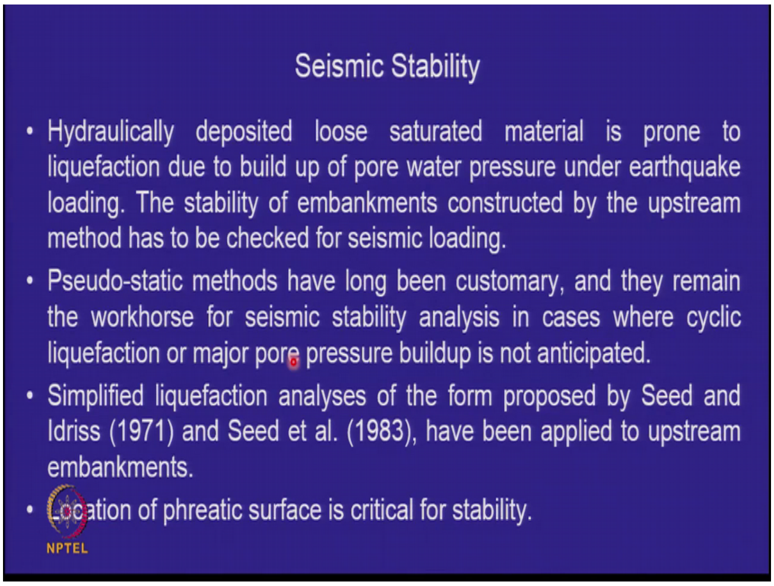

Seismic stability as I said there are two issues here, one is the horizontal alpha h component which you do for like a pseudo static analysis. So, we have to do the if you are in an earthquake prone area you have to do pseudo static analysis, and you have to get your stability values within the above the minimum acceptable factors of safety; that means, the factor of safety of your embankment should be above minimum acceptable and you remember what is the minimum acceptable factor of safety for a static case without earthquake, 1.5 is the normal acceptable factor of safety. We must have that and with earthquake if you are using the pseudo static method if factor of safety acceptable is lower, how much 1.05 1.1.

So, both these conditions should be met, but the third condition. So, the pseudo static method is fine, but the third thing that you have to analyze is the liquefaction analysis, you can use the seed and idriss approach of find whether your tailings will liquefy and if they will liquefy what depth will they liquefy because your embankment may be stable, but du during earthquakes you may have possibility of liquepe liquefaction. So, this has to be investigated in details we have to do a liquefaction analysis for (Refer Time: 39:02) stability in all these conditions phreatic surface, will remain the most critical how high is your highest water level in the pond, how high is your highest phreatic line in the embankment that will give on your stability.

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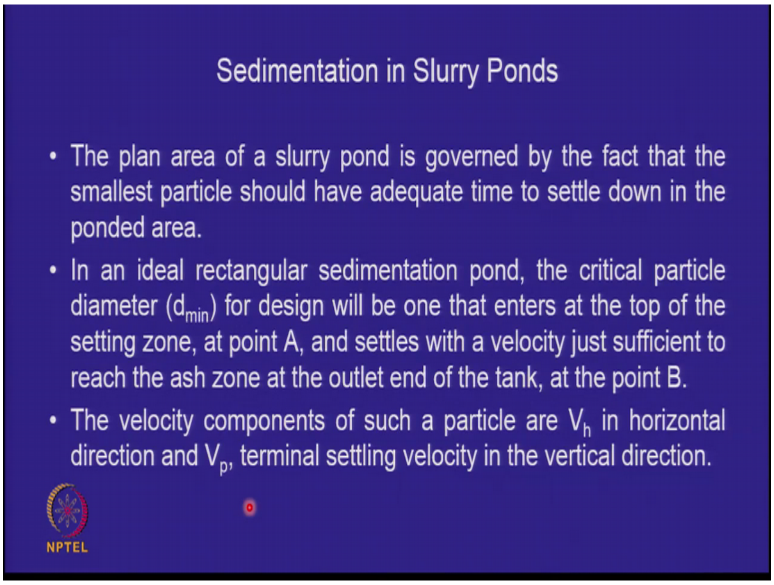

The other aspect is about sedimentation in slurry ponds. Now sedimentation in slurry ponds is hydraulic aspect we are really not bothered about it.

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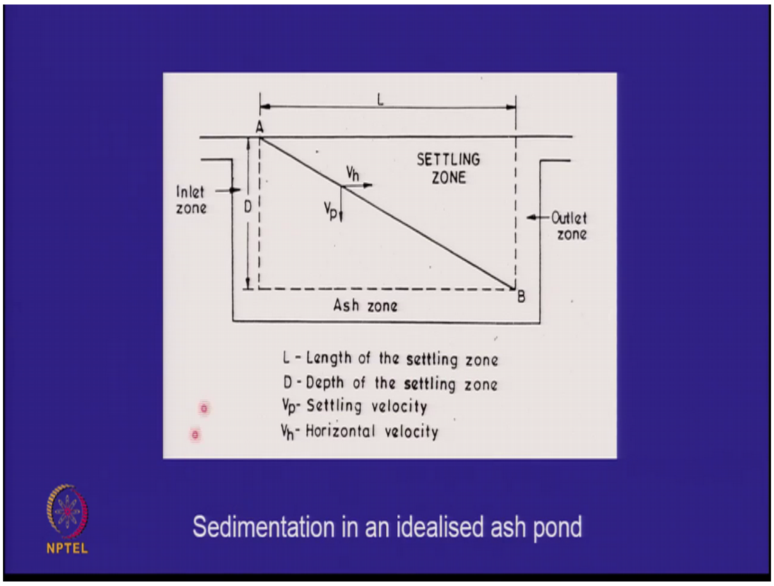

The only thing which I want to bring to your notice is that when a particle enters the pond and this is an idealized tank which I am calling a pond of depth D length L and width W, then as this particle moves forward with the forward velocity it moves downward with the downward will (Refer Time: 39:51) due to it is weight and you remember stokes law you remember hydrometer analysis.

So, we can find out that what is the terminal velocity of that particle and what we want is that by the time the slurry has moved from this end to that end, this particle should have fallen down to the depth D. So, that it does not come out with the over flowing water.

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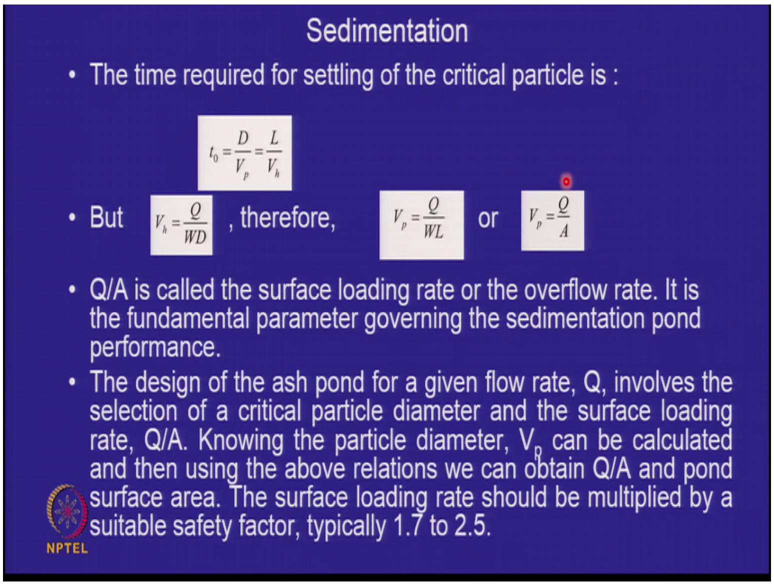

So, it is a relatively simple computation about the kind of areas that you need, we are not going to go into detail about this, but one of the equations which govern is the velocity of the particle in the downward direction is the inflow divided by the area. From the stokes law you know the terminal velocity, you can find out if you know your q coming in you can find out your area as q by Vp. So, the finest particle will have the lowest v and it will give you the highest area.

So, to catch all your fine particles, how much is the area you require you do it through a sedimentation analysis and typically you believe me when you do these computations, you are requiring areas of the size of 2 kilometers by 2 kilometers or 1.5 kilometers by 1.5 kilometers adequate ancient time.

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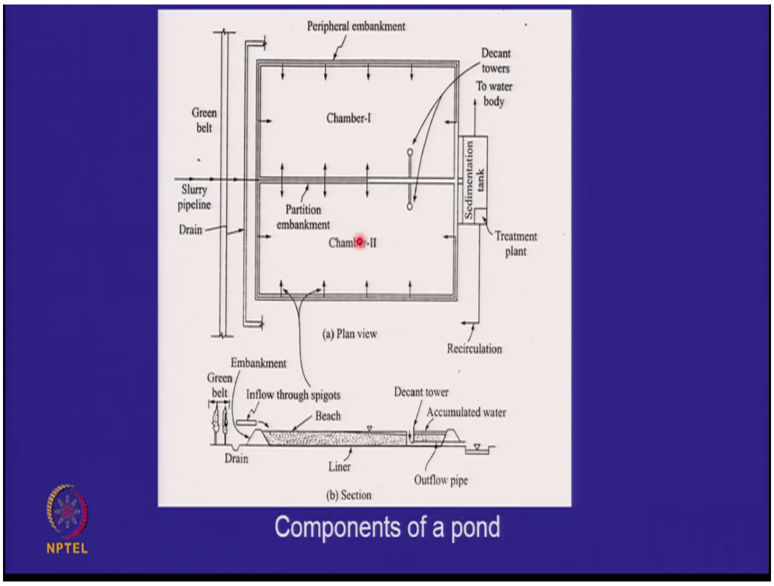

This diagram we have already done earlier, once we do work out the area we make two ash ponds one working at one time the pother working at the other time and we decant the fluid through this.

So, we when we say that I need a travel length of 2 kilometers by 2 kilometers, I what I mean is from this point where I am discharging my slurry to this point where I am decanting my slurry; that means, from here to here, I must have adequate length of flow that my particle settles down and does not come out. If I have a ash pond which is smaller than what I need the fines are going to come out and that is what happens because of restrictions of areas, you do not have much. So, the tendency is some other fine material tends to go away. So, we will stop here at this point, and we have to look at one more aspect and that is the decantation arrangement, you know once the slurry water has come in and the particles have settled, how do you decant the water and that will do in the next class, but if you have any questions I will be happy to answer.

So, you have seen what are the different layouts, so plan views of the ponds we have seen we raise them incrementally, we have identified the critical issues in the stability analysis, we have recognized the role of we have recognized the role of phreatic line being very critical to stability and how the internal drains keep the phreatic line away from the downstream phase and as long as we do a good design it is fine, but there are many old ponds in which the starter dykes did not have a internal chimney drain, and we have constructed them they have gone higher and higher and that sometimes leads to a problem and how can we remidiate that situation will take up in the next class any point which bothers you.

Student: Under that.

Prof. Manoj data. So, the question being asked is that I have shown you all this, why do not I consider the seepage under whether the water is seeping bellow or not will depend on what the embankment is sitting on, but I am just going to focus on stability, if this is my critical failure surface or this is my critical failure surface, then you know factor of safety is resisting over driving whether it is resisting movement over driving movement, whether resisting force over driving resistance over driving right and that is along this failure surface. When I compute the driving what is the main contributor to the driving. The weight and the slope angle just make it into a simple infinite slope something wants to go down it is w, and the downward component of w is the driver, the normal component of w tan phi dash if we are looking at c dash equal to 0 materials, we all recognize that both for tailings and for ash c dash 0.

So, the normal stress tan phi dash is the resisting, the resisting force goes down because of pour water pressure right if the if the pour water pressure is formed I am going to do my stability analysis, what is my pour water pressure going to be determined by here? That is the phreatic line and that is the point on which the stability. So, it is about the phreatic line on the top. So, seepage from bellow will change the amount of seepage that is occurring.

Student: Piping on the.

Yeah that that is the different issue all to that is not a slope stability issue. So, the question being asked is if you are on a impervious foundation then there will be seepage through the dam and then there will be see seepage beneath the dam. At the moment I am bothered about the seepage through the dam because I do not want the dykes to fail right. If you have seepage below the dam first question is does it affect the factor of safety, unless seepage below the dam changes the phreatic line then it is not going to make it raise suppose I have gravel at the bottom always quickly make this simple. Suppose I have gravel at the bottom what will happen to the phreatic line it will drop. So, it will only add to your stability of the embankments, when the phreatic line drops this is you can drop here.

So, as far as the slope stability of the embankments is concerned that is not a concern. The second issue is being talked about is the water is flowing underneath the embankment and is coming out from the downstream side, it can do piping right. So, how do we handle that? Flow beneath the wear is the ideal case to examine this problem; now water can go through the top of the wear all water goes from underneath. So, how do we tackle flow beneath the wear, how do we prevent the toe of the wear having a problem?

Student: (Refer Time: 46:26).

Prof. Manoj data; if your hydraulic gradient is high and it will cause piping and upward flow will cause the problems first you have to put an inverted filter at the toe that is the answer. An inverted filter at the toe will not allow fines to get washed out, if your height exit gradient is large then you put a vertical cut off; what should be your exit gradient.

Student: (Refer Time: 46:50).

Prof. Manoj data; 1 by 5. So, if you have any issue now there that you find that your exit gradient is coming more than one 1 by 5 which is a factor of safety 5 ended by the way then you would like to put a vertical cut off valve what will happen? When you put the vertical cut off valve the length of flow will increase the exit gradient will go down and it will go down to below 1.5. So, flow beneath the dam has to be treated like that, flow through the dam is the one which effects the stability of the downstream slope. So, we have been focusing on stability of the downstream slope primarily because of this reason.

Student :(Refer Time: 47:25).

We will have a look at the question being asked is what is the type of distress that you see in this slide, do they does the downstream slope fall, does one dyke fall or do two three dykes fall. Now will we will have a look at it we are going to have a lecture on type of failures (Refer Time: 47:41) inhabitations, but believe me once embankment of ash pond or a tailing pond begins to move it begins to move in a big way, and the slurry comes out like water, it does not it is not a small failure it may move down several 100 meters down and tailings dam we have moved two kilometers, the slurry has gone out like waters.

So, the whole there is a breach in the embankment as we will see. So, we will stop here and we will take up the decant tower and other arrangements in the next class have a good day.