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

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Lecture – 30
Control and Remedial Measures at Contaminated Sites – Part 2

Good day to all of you. In the last class we looked at control measures for contaminated sites more in the form of making vertical barriers around contaminated areas, so that the contamination did not spread beyond what it had already, you mean the area which is occupied by the contaminate should not increase. Today we look at some of the options for remediation. And again let me reemphasize remediation is a complicated task. You have to know all the chemical reactions which are involved between the water and the soil and the contaminant and the leachate and how do you reverse those and how do you bring back soil to it is original condition.

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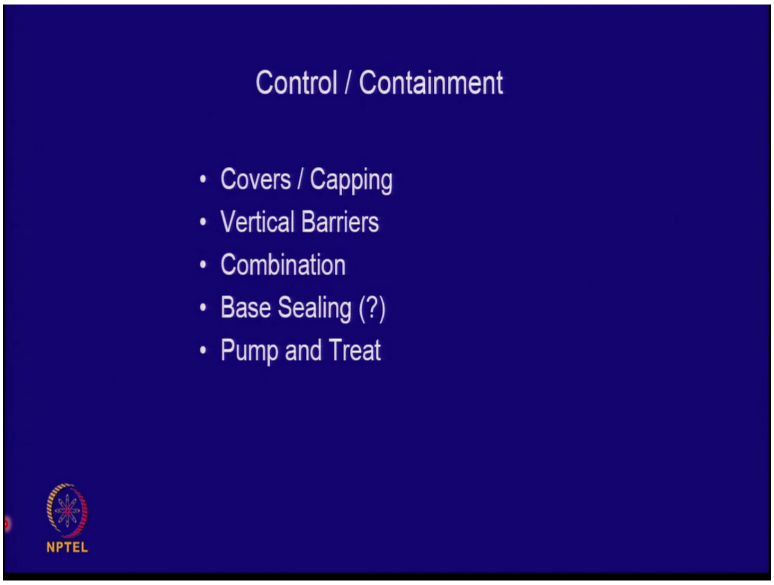

So, we talked about control and containment last time with covers and capping and vertical barriers and combinations. And today we look at treating.

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How do we treat the source, how do we treat the soil, how do we treat the pore gas, how do we treat the pore fluid, and how do we treat the ground water.

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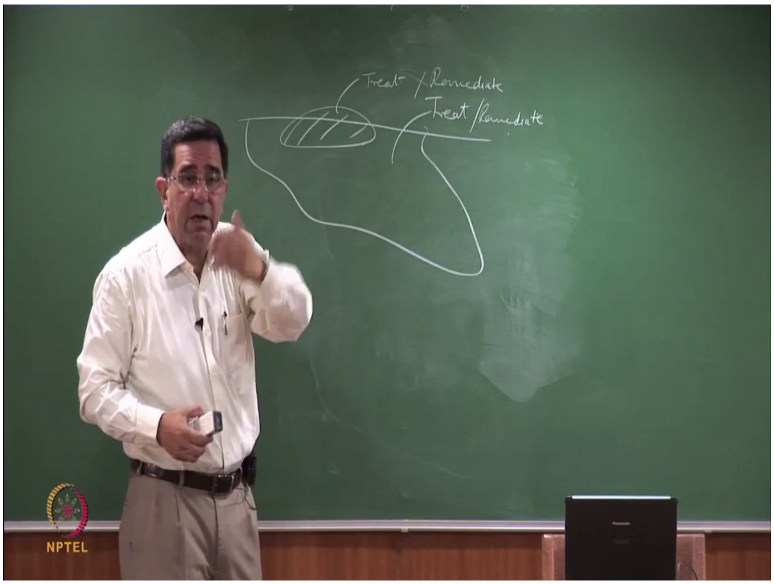

So, the aim is if I have the source. And if I have the contaminated site, then I have to treat and I have to treat or remediate. If everything is small, the tendency is let me excavate it and replace it with good material, local soil. If everything is large then it is not possible to excavate everything and replace it with good material. Even if you excavate it the good material that you are going to put back is it going to be the same material from which the contaminant has been removed or are you going to take good earth from some other place and bring it back.

If you are going to put good earth, then all this has to be disposed. So, either it will go to a landfill or you will have to treat and dispose it somewhere else. So, if you do not have the time to excavate treat and place back, you will excavate and fill with good earth and treat and dispose after treatment to whatever location from where you took that other earth. Or it will go to a hazardous waste landfill for encapsulation within the liner and the cover system.

So, we have to treat the source, the soil, the pore gas, the pore fluid and the ground water.

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One of the methods is excavate and treat. You excavate the source plus the effected soil and dispose in a landfill. Probably going to be the most cost effective, but going to you are going to lose some of the air space and the land fill. You might want to excavate the soil and do soil washing or heap leaching. Very simply put if you have got soil which is got containments which are soluble in water pass a lot of water through the soil the contaminants will come out in to the liquid phase and you can use the solid matrix bag. You might want to do physical separation; you have got soil which is contaminated. Which of the suppose the soil is made of sand and silt and clay sized material, which is the fraction which is lightly to have the contaminant in it. You have a soil which is made of sand silt and clay and you find that there is a particular contaminant, which fraction of that soil is likely to have the contaminant?

Student: One is clay.

While clay is likely to be most active because one it is colloidal it is net negatively charged so it is always the inerts the gravel and the sands are not that active. So, if you can fractionate it; that means, if you can do physical separation, may be you can discard the clay sized portion or it become much lesser and you can put it in the landfill. And the sand and the silt size portion you can reuse. So, physical separations sometimes helps you separate out the contaminated fraction of the soil from the non contaminated.

Another treatment which was possible for small amounts is after you excavate the material is to incinerate it. So, it has got some or you heat it if it is got high volatile organics or if it has got some other organic compounds you can incinerate it and that will be another way of treatment. And finally, you may also do by remediation or biological treatment by using some microorganisms. So, one of the ways of tackling contamination of small sites is excavate and treat.

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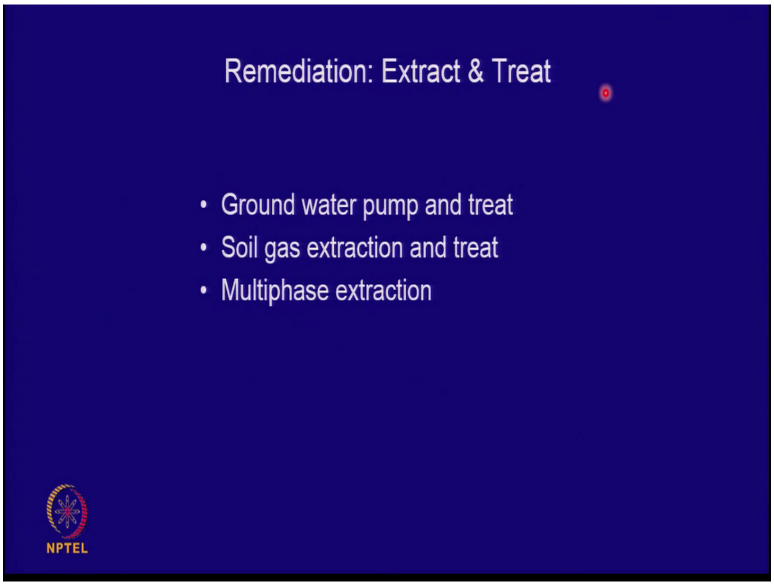

Another remediation philosophy is extract and treat. You have got soil which is contaminated, you have got ground water which is contaminated the philosophy is very simple. I take out the ground water because I can easily pump it out. And I will treat it and inject it, or I will take it out and treat it inject fresh water. The fresh water will wash this soil it is like intuitive soil washing. In the meantime I will treat this water and re inject it. So, you can continue to do the ground water pump and treat till the water which you pump out is clean. Which means that the contaminated ground water has been removed you have removed the contaminant and the ground water has come back to it is original condition. It also means that the ground water that you have injected is also wash the soil particles, so that if there were any contaminants on it they have been released into the ground water which has been again taken out and treated.

So, ground water pump and treat is very often adapted as one of the ways of contamination control, it is not a simple process it takes years. It may take years in a particular kind of soil, the whole plume has to be sucked out the whole residual contaminants sitting on the soil has to be sucked out. So, it may take years.

Soil gas extraction and treatment is relatively simpler, this happens around almost all petrol stations, the vapors of the petrol from the leaking tanks fill up the vadose zone; that means, the unsaturated zone always smells of petrol. So, you can just extract it using small wells pump out the gas inject fresh air and that is that is it. So, soil gas extraction and treat is also one of the solutions, which is adapted in most of the petrol stations. In some complex cases you have to do multiphase extraction; that means, you have to separate out the gas and the liquid and the solids and treat each one of them separately, but this is a rare case. So, we will not get in to this at the moment.

One of the philosophies is can we not transform the material. So, can I do insitu oxidation?

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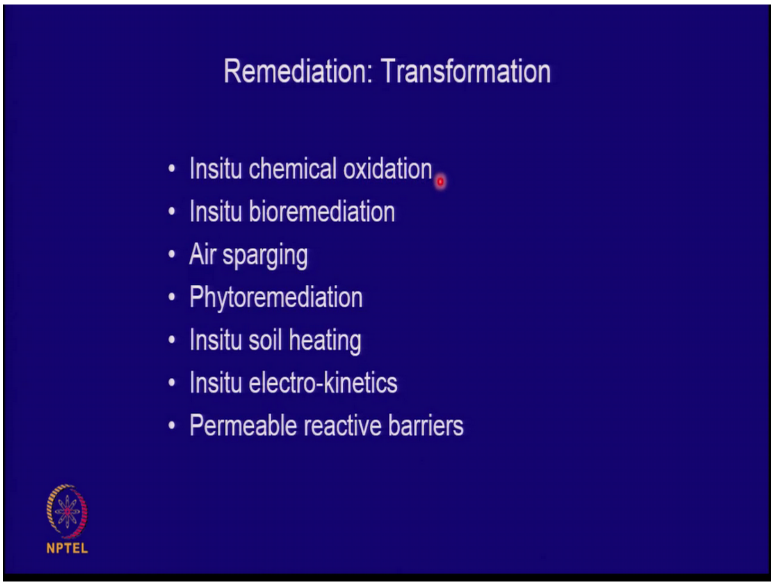

Can I do insitu bioremediation? Can I do air sparging? Can I do phytoremediation? Can I heat the soil insitu? Can I do insitu electro kinetics? You remember dewatering using anodes. So, can you do a net negative and positive charge where the contaminate will come to one of the electrodes, that is insitu electro kinetics. And can you use permeable reactive barriers. The idea here is to transform the contaminant to immobilize it. It should no longer be water soluble and travel with the water that is the thought.

If you continue with the immobilization or transformation another option which is insitu grouting or deep mixing.

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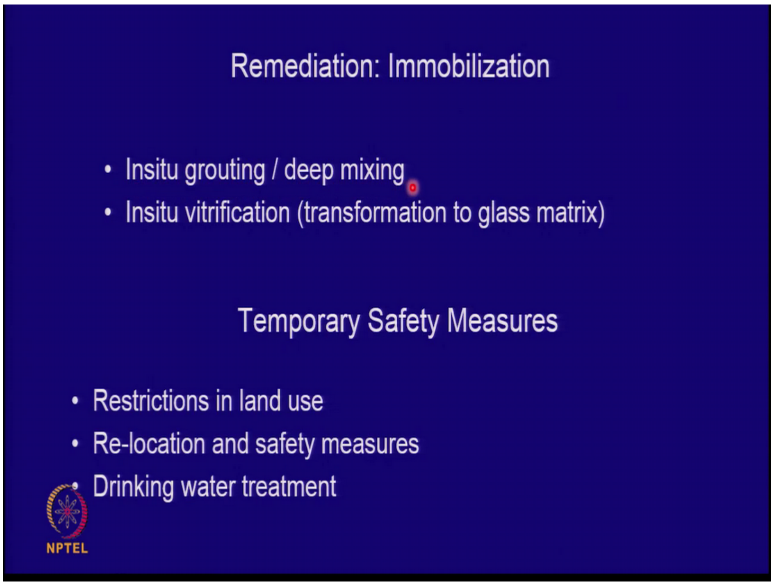

You got contaminated soil, why didn't you use the deep mixing technique using cement? If you can make a cemented matrix of the soil, at least the contaminant will not move forward. So, insitu grouting or deep mixing is also immobilization remediation technique. Of course, the ultimate is insitu verification not yet significant reality, but if you can either through high heat or through high voltage convert the matrix into a glassy substance, which will entrap all the contaminants, then that is also a technique that we would like to adapt; that means, transform the contaminated soil into glassy amorphous glassy matrix.

So, these are some of the remediation techniques which are adapted, which for which you will have to use the appropriate engineer, whether it is a chemical engineer or a thermal engineer or a biochemical engineer or a chemistry person expert, but temporary safety measures while we are doing all this is restrictions, in land use relocation of the people and adapting safety measures. And of course, drinking water treatment and actually closing all the ground water wells from which this material is coming out.

I said let us look at pump and treat because this is adopted the most often. So, let us say the in plan this is the source.

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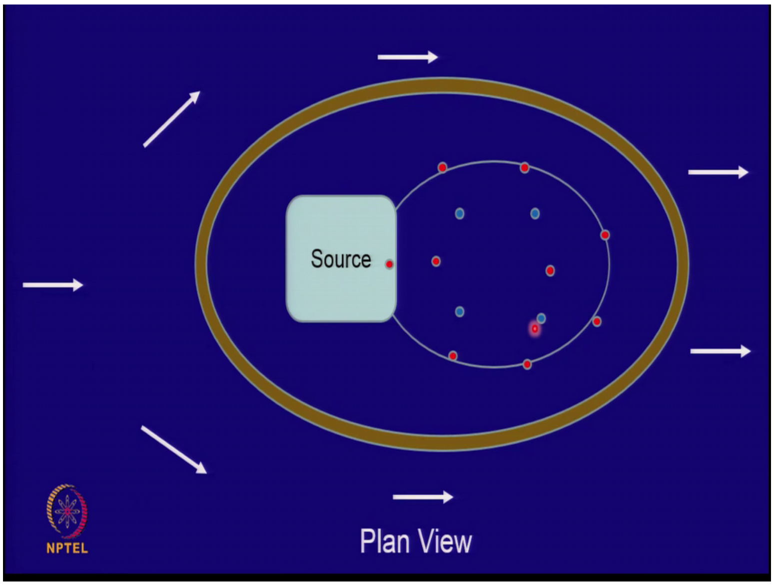

And this is a contaminated plume. My immediate reaction is let me control this plume from spreading and I put a vertical barrier all around it; however, I have to bring this entire area back to it is original condition, the source has to be go this has to go. Immediately what I start doing is this red dots can be my ground water extraction wells. I will decide what to do what the source I am looking at the technologies, but I have to start withdrawing my plume.

So, I do pumping out of ground water from the plume. And as somebody suggested that if you pump too much water you may have settlements, then I will also put these blue colored dots are the injection wells. So, simultaneously I will be extracting ground water, simultaneously I will be injecting. In a way of you look at it sectionally water is coming in and out it is washing the soil also, and it is maintaining the water table, and it is also we are treating the ground water. So, in section if I Let us say this is my ground water, this is the contaminated ground water and my plume let me say is here it is a large area plume.

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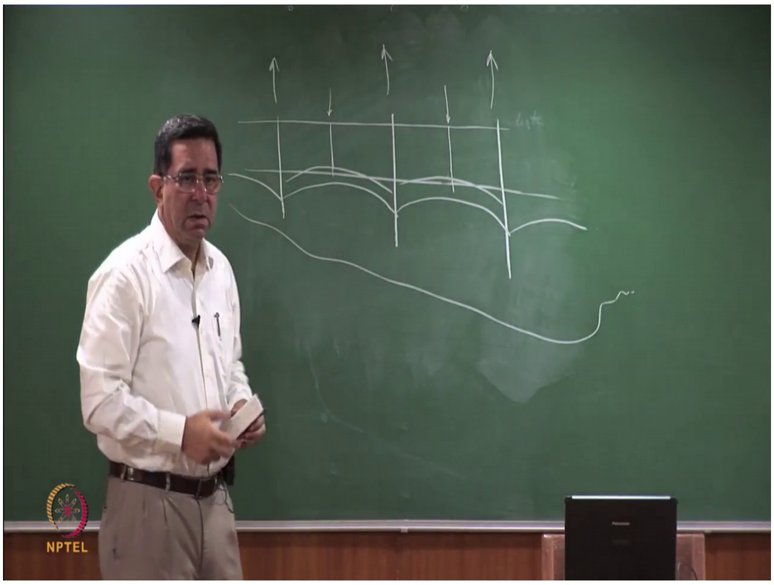

So, if I start extracting ground water, what will happen to my ground water level? My agree my ground water will lower and I will be extracting the and sending it to treat. So, I am pumping out the ground water.

If I now putting some injection wells, then what will these injection wells do? These injection wells will raise the level of this depleted and they will try and bring up the level back to it is original position. So, I have extraction wells which go to pump and treat after treatment the water comes in or in the beginning your sending in fresh water. And remember, so now, you are sending in the water here and you are taking out the water from here. So, there is an in a sense flow taking place like this right. So, clean water is travelling from one pump one well to the other, it is also washing the soil in between. So that is what is happening in your pump and treat.

So, you monitor this and the situation is as I said all the water is going out.

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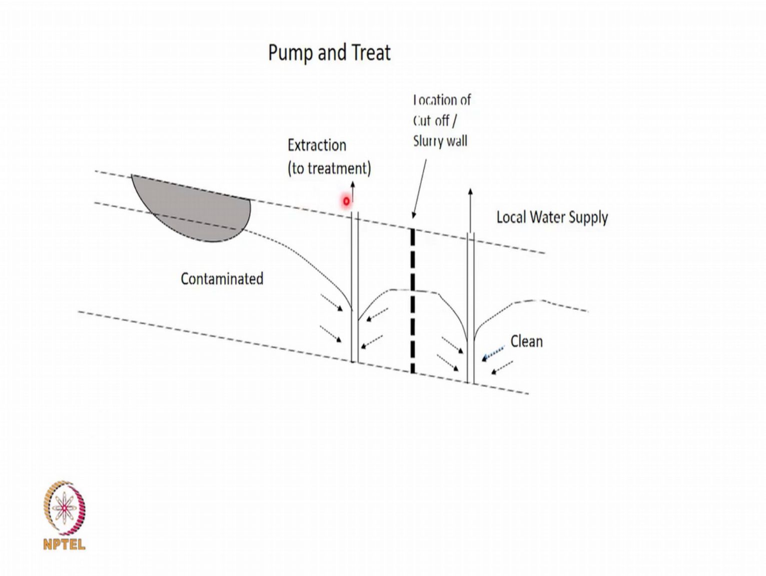

You can you can you put a slurry walls it may be a hanging wall.

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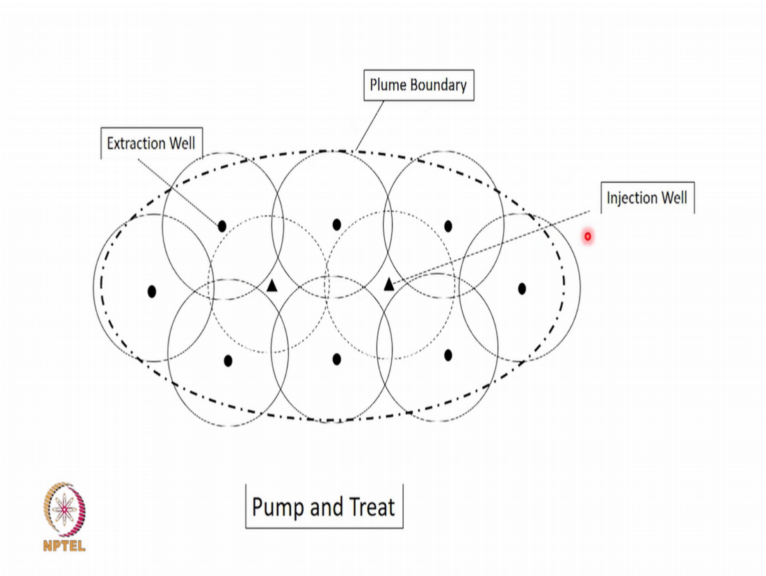

These are the zones of influence of your wells. And they are overlapping zones and this tringles are your injection wells and the circles are your extraction wells.

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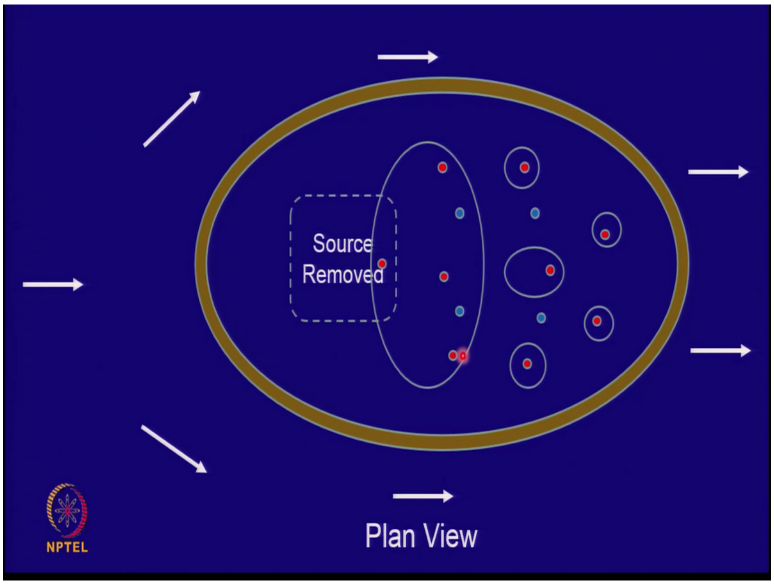

Over a period of Time what will happen is, the plume will break up into small pieces; that means, this is now back to fresh water, fresh water, fresh water or drinking water and the contaminated plume is here, here and here. And gradually all this plume will become smaller and smaller and the injected water will, in the mean time you have also removed your source. So, say several years hence you will find that you can bring this site back to it is original condition. So, pump and treat is a very often adapted methodology for areas where ground water contamination is taken place.

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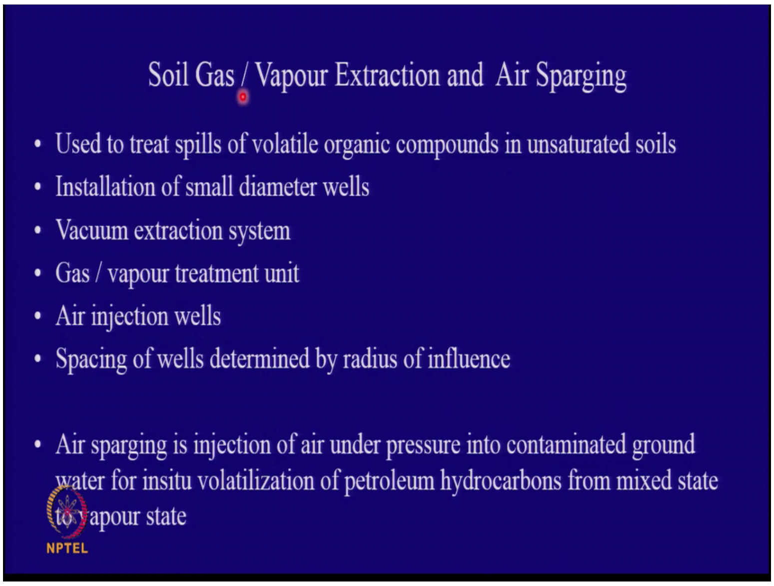

The other technique is a soil Gas or vapor extraction. I have told you volatile organic compounds in non saturated results soils this is the clean up, we install small diameter wells apply a vacuum to those wells the gas vapor will come out you send them to a treatment unit. You inject fresh air with injection wells and of course, the arrangement is very similar to pump and treat. Will come across the word air sparging. Air sparging is used when LMAPL and DNAPL hydrocarbons are mixed with the water. They may be floating on the top they may be in the middle they may be at the bottom. But if you send air in to it these will volatilize. And then you know you can extract that air and the vapor will come out. So, air sparging please use soil gas vapor extraction is for the vadose zone. You can not extract gas from the saturated zone. Whereas, air sparging is from the ground water zone.

So, air sparging is the injection of air under pressure into the contaminated ground water for insitu vitalization of the petroleum hydrocarbons from the mixed state to the vapor state. So, you send in the air and when you extract the air and along with the air outcome the fumes of the hydrocarbons. And eventually the, eventually the entire hydrocarbon volatilizes and is cleaned up, how would you wash soil? So, I have I have a small amount of soil. And my contaminant is water soluble. I have a excavated it using, let me say I have got a soil of the size of half this room. Is that a good volume? So, how will you wash this soil? I can use an excavate to dig it out. So, I have dug out the contaminated soil from this a side and it all come out to you, how will you wash this soil?

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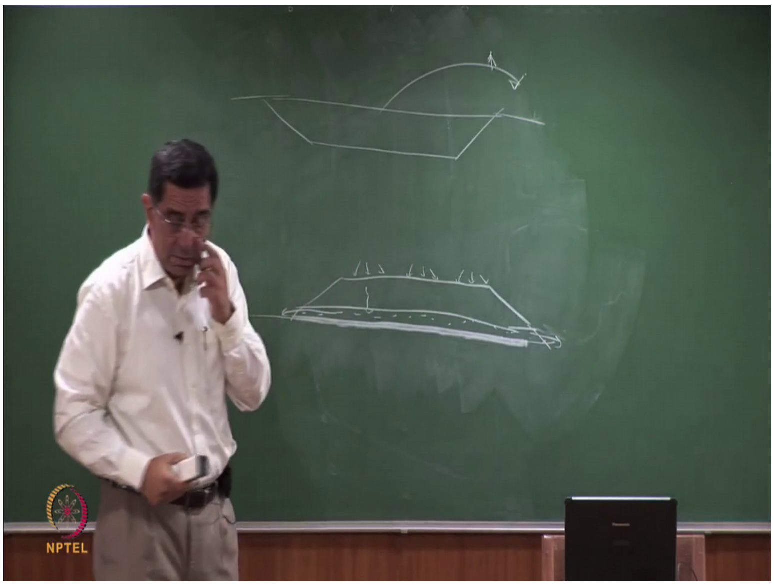

Any thoughts? If the if the soil is sand I will put it in a tub of water. Anything scares you about putting sand in water? Or I will make a big tank of water or I will take make a tank of water and put it little by little, what will happen the contaminate will come into the water because it is water soluble? Yes, all of it may not come out, but some of it will come out sand will settle very fast. So, (Refer Time: 18:10) the top treat it and you are not sure whether everything is come out take this sand again put it some in some more water. Will continue to do this till in the decanted fluid there is no containment. We can do it with sand or gravelly sand or sandy gravel because it settles in a few minutes.

Now just take the opposite I have silty clay, what will you do? You put silty clay in the tub of water, then you will wait, why? You want it to settle and then you will wait and you will wait. And you will wait, because it does not settle so fast. So, treating course grain soil is simpler than treating fine grain soils. So, if I have clay silt or sandy silty clay one of the ways to do it is to make a heap. I can the soil out of this quantity and I can do drip irrigation from the top, and the fluid will go through slowly and will come out to the bottom I will put a drainage layer, and I will put a liner so that nothing goes.

So, depending on the type of material you have you may do heap leaching, do it made drip irrigation at the top or basically you have to allow water to percolate. It may take several months, but that is fine eventually you will get water which is not contaminated, which means your soil has got washed. If you are in a great hurry, may be you would like to fractionate your soil, why because there is a chance that the contaminants are only in the fine grain.

So, you do sieving take out your course grain soil. Course grain soil will settle very fast it will be available for you very fast, the fine grain soil may require some treatment. So, suppose 70 percent of the material is course grain soil. So, half your problem is solved. Because course grain soil will come over the over the sea, you can wash it very quickly it settles very quickly, the fine grained soil is something that you have to tackle now are you going to heat it and burn it, are you going to do heap leaching or you going to add some chemical to it, are going to acidify it and release the contaminate, that is a separate problem.

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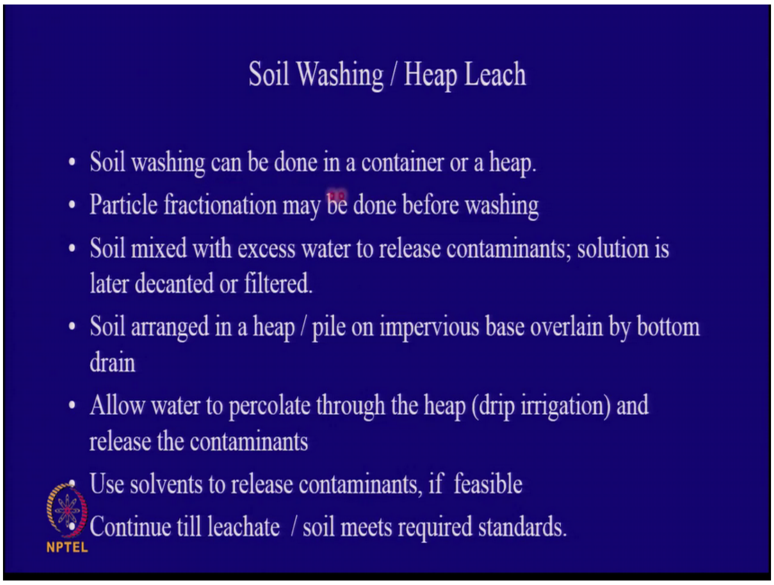

So, in a sense soil washing, soil washing can be done in a container or a heap. Particle fractionation may be done before the washing, soil is mixed with the excess water to release contaminants, the solution is decanted or filtered. If you are going to have too many fines you are going to have problem then the soil is arranged in a heap on impervious base, overlain by bottom drain. Allow water to percolate through the heap drip irrigation and release the contaminants. Sometimes you may add a little chemical to the water which is a solvent which will help faster release of the contaminants. That will depend on the chemistry of the problem. So, you can use solvents to reveal release the contaminants also, is actually like a mining are you are you getting like a mining technique. In the mine you are trying to get the over to come out of 99 percent of the rock. Here you are trying to get the contaminant to come out of a matrix which is full of soil only.

So, you continue till the leachate of the soil meets the required standards. So, that is the concept of soil washing. Any question which bothers you about soil washing? Bioremediation, well basically you use microorganisms to degrade and transform organic chemicals in contaminated soil.

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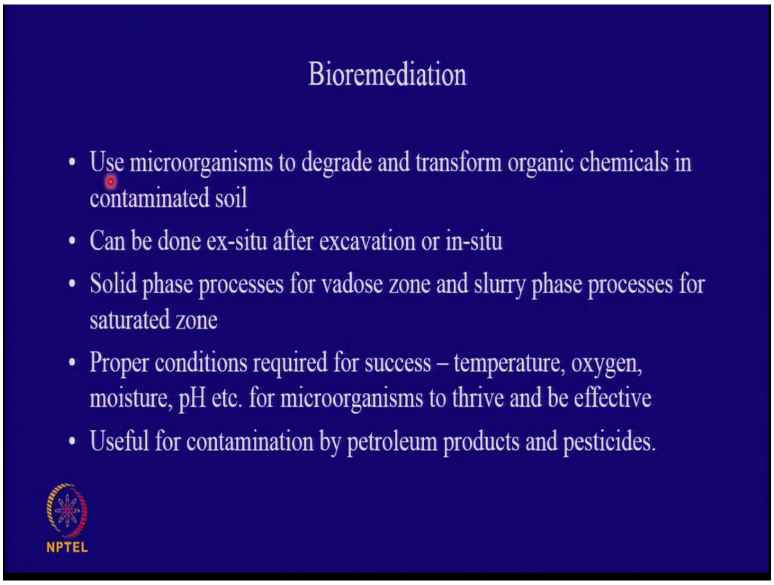

And usually when you have petroleum products or hydrocarbons or pesticides, if you have over dosed it you can introduce microorganisms. This can be done ex situ or insitu. Ex situ is much better because you can do it in a controlled environment. You can control your temperature, you can control the moisture, you can control the relative humidity, you can control the available oxygen.

So, better you bring out the soil excavate it and do it in a containerized manner; however, some at some locations bioremediation has been done insitu as well. And there you need very hardy microorganisms, but you are able to do it insitu as well. The processes when you are dealing with vadose zone are separate and the process is when you are dealing with the saturated zone are separate. Please remember these are different biological processes. All bioremediation exercises are not successful. Because proper conditions you may start with a proper condition, but you may not be able to maintain them so temperature oxygen moisture ph etcetera, a very important for microorganisms to thrive and be effective. But they have found useful for contamination which has been caused by petroleum products and by pesticides. A subset of bioremediation is phytoremediation. Phytoremediation is plants. So, I will just quickly do that.

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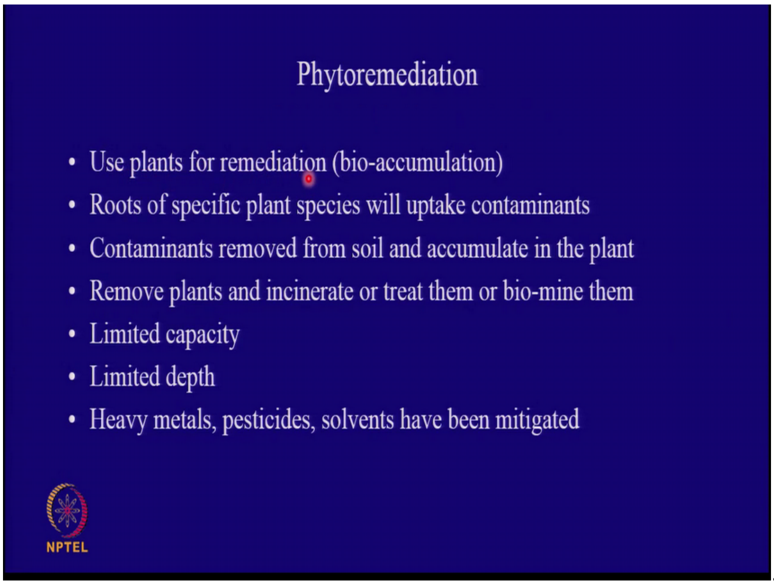

In fighter remediation you use plants for remediation, and the concept is a bio accumulation. What happens? You know roots of specific plant species will uptake not the contaminants, but the whole solution. As the roots uptake the water these containments will also come into the root and they will get deposited in the tissues of the plant.

So, you do bio accumulation of the containment inside the plant water will evaporate, salts will come and accumulate. So, contaminates are removed from the soil and accumulate in the plant, in the end you are supposed to dig up the plants and you may want to incinerate them or you might want to do some activities which makes you when you incinerate them you will get ash the ash will have the contaminate and that will be very small and then you can stabilize it and put it in a hazardous waste landfill.

So, you remove the plants incinerate them or treat them or bio mine them some people want to mine the stuff from the plants as well. Remember 2 thing plants have a limited capacity, process is slow and they only work up to the root penetration depth. Recently we were involved in a case where one huge distillery invest in India has contaminated the soil and the ground water including that in the fractured rock pillow. And I think the depth of contamination is about 20 meters. And you get this very dark colored dark tea black tea kind of liquor of contaminated water in the wells nearby. And fighter remediation was proposed by one of the research institutions. But I know of no plant in which the roots will travel 20 meters into the ground to pick up contaminant. So, phytoremediation is a near surface problems can be solved. Or you have to pump out the leachate and then put it into an artificial bio phytoremediation pad that you might create.

So, some heavy metals, pesticides and solvents have been mitigated by phytoremediation which works well for only the top meter or less of the soil in the top. So, these are some of the methodologies which are used these are evolving all the time, these are evolving all the time and success is limited. Pilot studies are a must before you undertake them. So, look at all the alternatives look at the one which has worked in the last 5 years test it on your soil, if it works then adapt it on a large scale is very expensive. I like to close this by talking about a case study, a before I do the case study because this is about a vertical barrier, any questions on remediation?

2 important things, as a geo technical engineer it is our responsibility that when we do extraction and injection all the soil feels it; that means, water is coming out, but from overlapping zones of influence, it is not that one well is doing well second well is doing well you will come back and say sir water quality is fine, but the zone in between which is not in the zone of influence still has some stuff which is harmful.

So, our design is a dewatering design, with the zone of influence overlapping. When I am injecting I have to ensure that the injection liquid reaches everywhere into the ground. So that is our role and if somebody comes and says that I would like to do insitu grouting, and I have to tell him look in clay you can not do insitu grouting, why? Somebody says no I have got a beautiful culture I have got this bio culture. All that we have do is introduce it into the ground, and these microorganisms will spread everywhere. So, you say I have got a 15 meter deep contaminated zone. So, which is says we will inject it at every one meter or 4 meter depth. You have to tell him it is clay I can not even inject water into clay. You can make a bore whole I can go and place this bio culture at that level, but how is it going to travel.

So, as geo technical engineer you can say fine if it is sand, yes I can inject I can pump in I can make a well I can pump in the water. But if it is clay it is not going to go you can do hydro fracturing you have done that in ground improvement, like make a root like structure, but then your design should be like that your spacing of the wells has to be very close together if you are going to have over lapping hydro fracture points.

So, geotechnical engineers is our role that we must be able to tell you see insitu injection and insitu grouting is so magical. I can take cement I can inject it in to the ground and I can make soil into rock, how do you how does it sound to you? I can make a whole I can take some quick fix fevikwik, I can inject it into the ground and my whole soil will become very hard like rock. The point is you try and inject it is not going to go into the soil. Grouting only takes place in gravels and sands, it does not take place beyond that may you use some pm 9 or some other grout chemical grouts, they also have limitations in penetration. And in any case you are not able to give a uniformly cemented matrix, where your whole will be maximum cement will be around the pipe, maximum cementitious material as you travel further away the cementitious material will be less, how do you give assure me that it is equal everywhere. Then the automatic choice is excavate, pulverize, mix and let have there be intimate contact between the chemical and whatever has to it has to react to it. So, these are things where geotechnical engineers have to play a important role.

Student: Sir.

So, I would like to finish off with a quick case study on vertical barriers.

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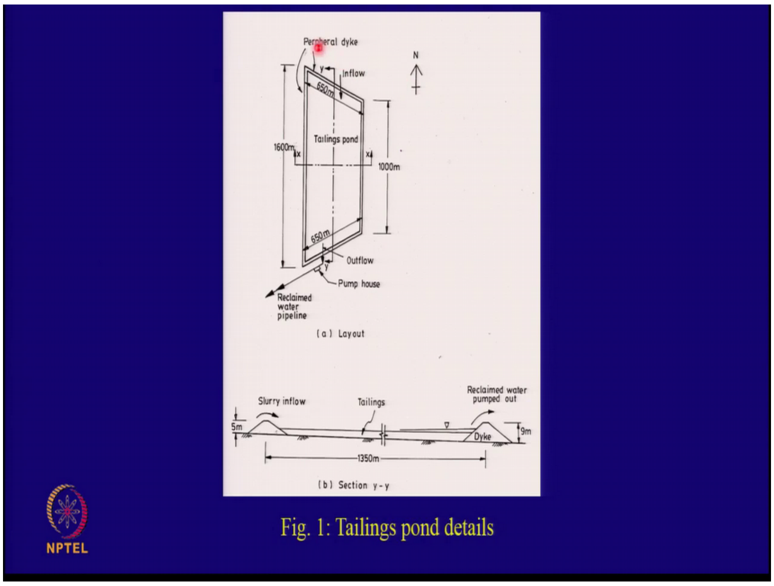

Fig. 1: Tailings pond details

This is a tailings pond in one of the western states of India, 1600 meter 1.6 kilometer long and about 0.6 kilometers wide. Tailings have been placed in it till one day it was told by the pollution control board that look your lead content is high. This is a hazardous waste pond it does not have a liner please do something about it. There was a 5 meter high embankment at one end mine at the other end tailings had only filled up to 2 to 3 meters there was a lot of capacity which was available.

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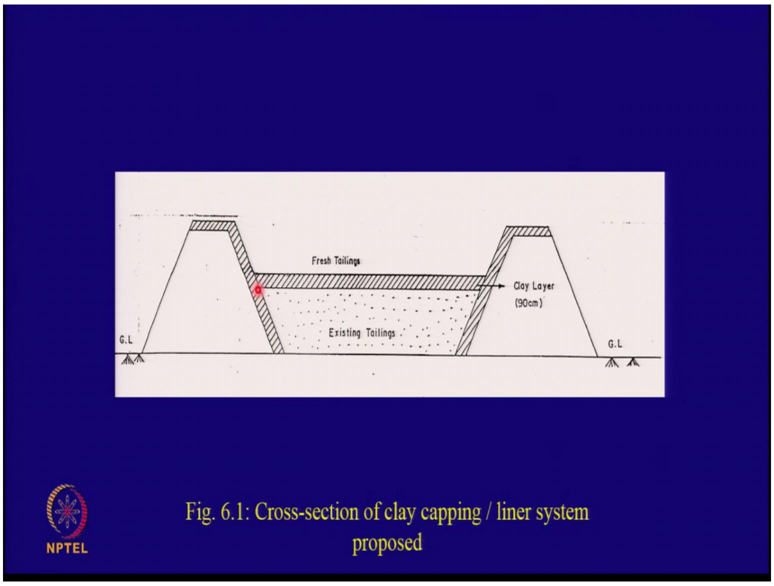

Fig. 6.1: Cross-section of clay capping / liner system proposed

That is the tailings pond, that is the tailings pond this is a slurry water.

One of the consultants gave the solution that aright. Now this is hazardous let us put trap it. And then let us fill the (Refer Time: 31:53) tailings on top. This will work as cover and a liner for the new tailings and cover and nothing will go through. But the problem was if you put a layer here with time these tailings which are hydraulically deposit will settle and this will all have seepage paths and it would not work.

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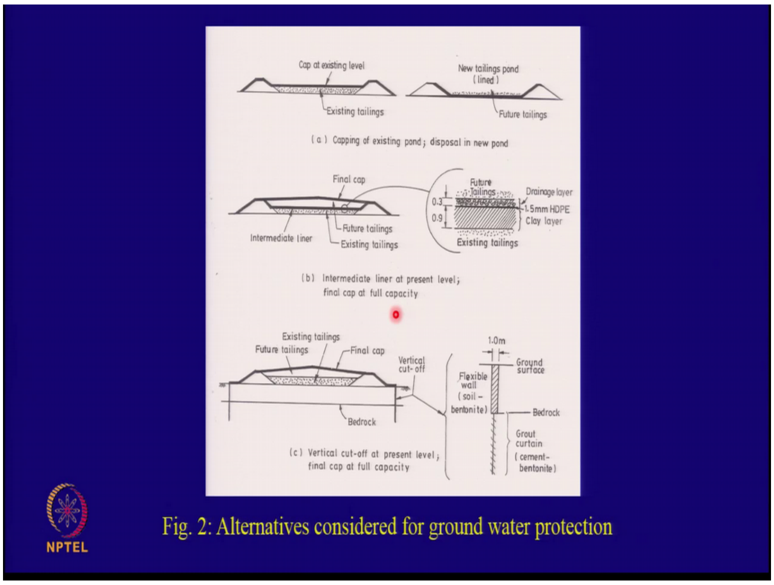

Fig. 2: Alternatives considered for ground water protection

So, this work got referred to as and after looking at various options IIT suggested that why do not you why do not you continue to put the tailings. But ensure that nothing escapes the pond, you know, water was seeping through the embankment and below also. So, let us put vertical cut offs. And then when the tailings reach the top we will cap it.

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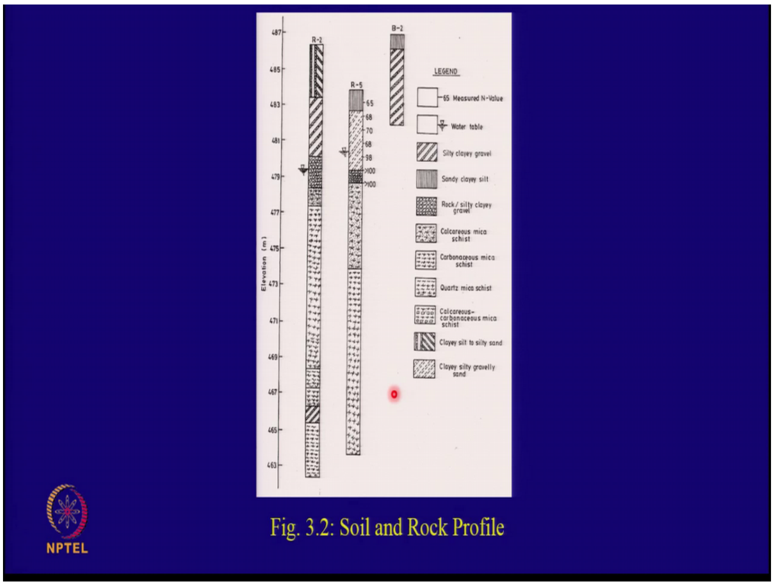

Fig. 3.2: Soil and Rock Profile

So, we started doing the investigation First sight investigation were done and this kind of result was obtained, there was you know soil at the top and then rock at the bottom, soil at the top rock at the bottom, this is some more and the generalized soil profile was like this.

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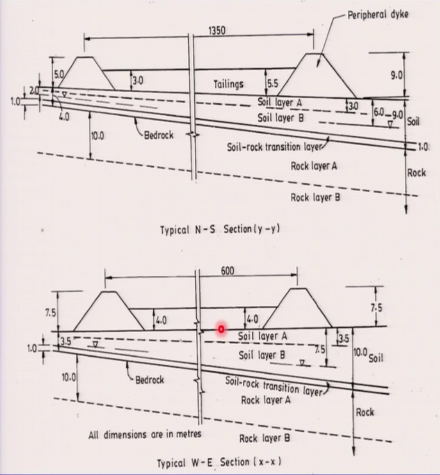

Fig. 3: Generalised soil and rock profile

They were 2 types of soil layer A soil layer B. Then rock layer A rock layer B. Rock layer A was disintegrated rock with high permeability. And rock layer B was the actual impervious rock. So, the thickness of this was 2 meters to 6 to 8 meters, and that those way your tailings and these were the embankments.

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Table 1: Properties of Tailings, Soil and Rock

Strata	Type / Classification	Grain Size Distribution (%)				Atterberg's Limits (%)			Insitu Moisture Content (%)	Insitu Dry Density (t/cu.m)	Insitu Permeability (cm/sec.)
		Gravel	Sand	Silt	Clay	Liquid Limit	Plastic Limit	Plasticity Index			
Tailings	Silt, sandy	0	5 to 40	52 to 80	7 to 15	NP	NP	NP	8 to 28	1.40 to 1.55	1.5×10^{-4} to 2.0×10^{-5}
Soil Layer A	Silt, sandy, clayey, low plasticity	0 to 10	25 to 40	30 to 50	10 to 30	25 to 30	13 to 25	12 to 15	5 to 8	1.60 to 1.80	2.0×10^{-5} to 8.0×10^{-5}
Soil Layer B	Sand-Gravel, silty, clayey	15 to 55	20 to 40	15 to 30	10 to 20	NP to 20	NP to 10	NP to 10	6 to 16	1.70 to 1.90	1.5×10^{-5} to 6.0×10^{-5}
Transition Layer (Soil to Rock)	Gravel-Disintegrated Rock Fragments	Predominantly gravel and cobble sized material with fines				--			--	--	--

Strata	Type / Classification	RQD (%)	Insitu Moisture Content (%)	Dry Density t/cu.m.	Water Absorption (%)	Field Lugeon Value (Pump-in Tests)	Unconfined Compressive Strength (MN/m^2)
Rock Layer A	Highly weathered and fractured Carbonaceous Mica Schist	0 to 45	0.7 to 1.9	2.40 to 2.70	2.6 to 4.1	2 to 78	10 to 38
Rock Layer B	Compact and moderately strong Carbonaceous Mica Schist	43 to 96	0.1 to 1.2	2.40 to 2.80	0.1 to 1.0	1 to 2	40 to 60

NP = Non plastic, RQD = Rock Quality Designation

So, we looked at the Types of soils soil arrays soil layer B rock layer A rock layer B tailings. We studied all the engineering properties, tailings had a permeability of 10 to the power of minus 4, 70 meters per second soil had a permeability of 10 to the power minus 5. Rock layer A had very high pump in test 78 lumens very high. But rock layer B was impermeable one to 2 lumens was the value; that means, the inflow was very low. So, this was a good impermeable rock. So, it is proposed that in the soil will make a vertical cut off wall and will make a grout curtain in the rock.

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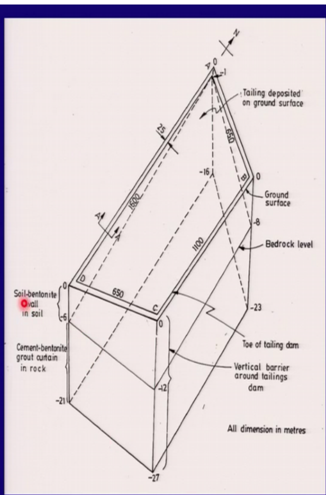

Fig. 4: Simplified view of vertical cut-off barrier

up to the lower rock level.

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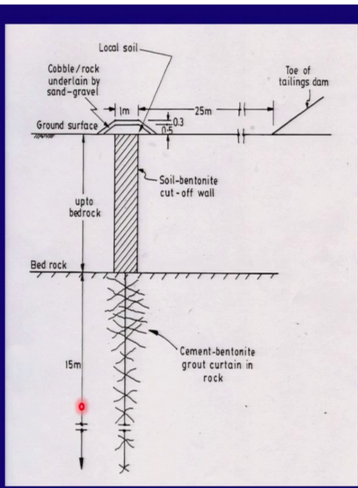

Fig. 5: Sectional view of vertical cut-off barrier

And this was proposed soil bentonite cut off wall and cement grout curtain 15 meters in to the rock. There was no way you could make the wall you can not excavate that rock with a trench cutter. And we started working how to make this the required permeability of the wall was 5 into 10 to the power of minus 7 centimeters per second not 1. For a vertical wall the required permeability was 5 into 10 to the power of minus 7 centimeters.

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Table 2: Results of Laboratory Analysis

Soil	Classification	Grain Size Distribution (%)				Atterberg's Limits (%)		
		Gravel	Sand	Silt	Clay	Liquid Limit	Plastic Limit	Plasticity Index
Excavated Soil (ES)	Silt, sandy, gravelly, clayey, low plasticity	20	30	35	15	25	13	12
Local Top Soil (LS)	Clay, silty, sandy, medium plasticity	2	31	45	22	41	21	20
Borrow Area Soil (BS)	Clay, silty, high plasticity	0	7	67	26	54	23	31
Bentonite	Clay, very high plasticity	0	0	24	76	492	58	434

We could use the excavated soil We could use the local top soil there was a borrow area about 20 kilometers away. These where the 3 options. All of them were plastic materials the excavated soil are too much gravel. So, it went out of the reckoning for making the vertical wall.

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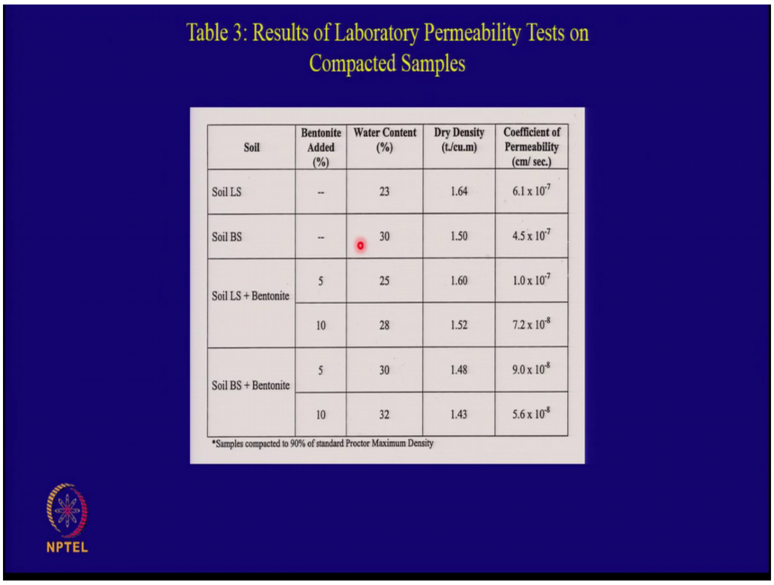

Table 3: Results of Laboratory Permeability Tests on Compacted Samples

Soil	Bentonite Added (%)	Water Content (%)	Dry Density (t./cu.m)	Coefficient of Permeability (cm/ sec.)
Soil LS	--	23	1.64	6.1×10^{-7}
Soil BS	--	30	1.50	4.5×10^{-7}
Soil LS + Bentonite	5	25	1.60	1.0×10^{-7}
	10	28	1.52	7.2×10^{-8}
Soil BS + Bentonite	5	30	1.48	9.0×10^{-8}
	10	32	1.43	5.6×10^{-8}

*Samples compacted to 90% of standard Proctor Maximum Density

When I took the local soil and the borrow area soil the permeabilitys were 10 to the power of minus 7. We were very happy we wanted 5 into 10 to power of, but this is for compacted soil you know (Refer Time: 35:11) compaction in a cut off wall you are not able to compact the soil. It is just sent in by slumping. And then we added bentonite 5 percent 10 percent and really the permeability is decreased. And further from the borrow area soil the permeability went to minus 10 to the power minus 8.

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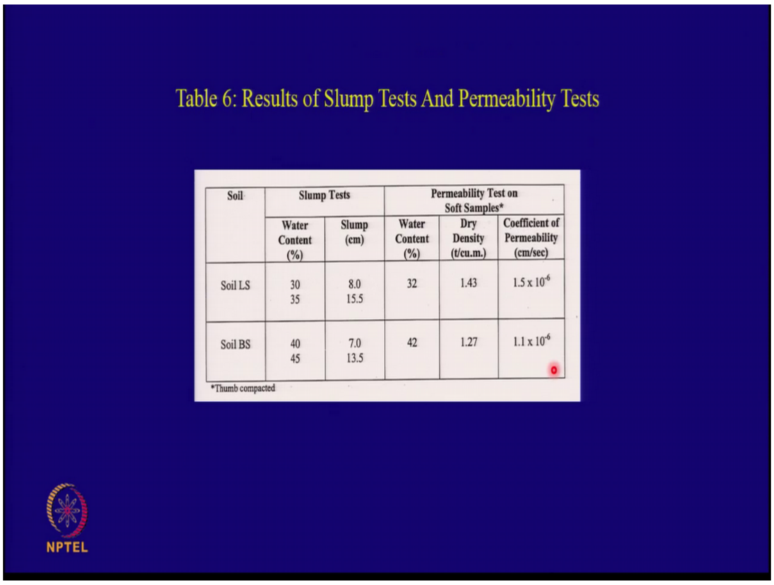

Soil	Slump Tests		Permeability Test on Soft Samples*		
	Water Content (%)	Slump (cm)	Water Content (%)	Dry Density (t/cu.m.)	Coefficient of Permeability (cm/sec)
Soil LS	30 35	8.0 15.5	32	1.43	1.5×10^{-6}
Soil BS	40 45	7.0 13.5	42	1.27	1.1×10^{-6}

*Thumb compacted

But we needed high slump material. So, with local soil when we were adding 30 percent slump was 8, but when we add 35 percent slump was near 16. So, this was good, but because you were using such high water contents a permeability was becoming 10 to the power minus 6. With compacted soil the permeability was 10 to the power of minus 7, but not here. Similarly here when I use 40 42 percent 45 percent my slump was 15 of 13.5, but permeability went up.

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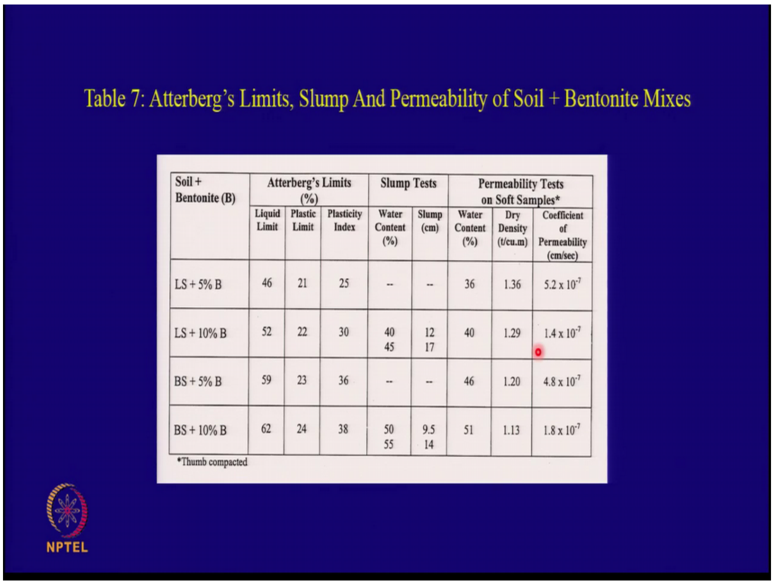

Soil + Bentonite (B)	Atterberg's Limits (%)			Slump Tests		Permeability Tests on Soft Samples*		
	Liquid Limit	Plastic Limit	Plasticity Index	Water Content (%)	Slump (cm)	Water Content (%)	Dry Density (t/cu.m)	Coefficient of Permeability (cm/sec)
LS + 5% B	46	21	25	--	--	36	1.36	5.2×10^{-7}
LS + 10% B	52	22	30	40 45	12 17	40	1.29	1.4×10^{-7}
BS + 5% B	59	23	36	--	--	46	1.20	4.8×10^{-7}
BS + 10% B	62	24	38	50 55	9.5 14	51	1.13	1.8×10^{-7}

*Thumb compacted

So, what we did was we said Alright we will use local soil plus 10 percent bentonite and borrowed area soil plus 10 percent bentonite and let us see what the permeability comes for high slump material.

So, to local soil plus 10 percent bentonite if I add 40 percent water, slump was 12 to 17 and permeability was acceptable 1.4 into 10 to the power of minus 7. Similarly for borrow area soil with 10 percent bentonite, when I am using higher water content 50 to 55 percent water content, I was getting 14 percent slump and I was getting the requisite permeability. Now comes the question which was asked, that what happens to the stability. The question that was asked by somebody was that when you make these vertical, I have this embankment, One of the embankments.

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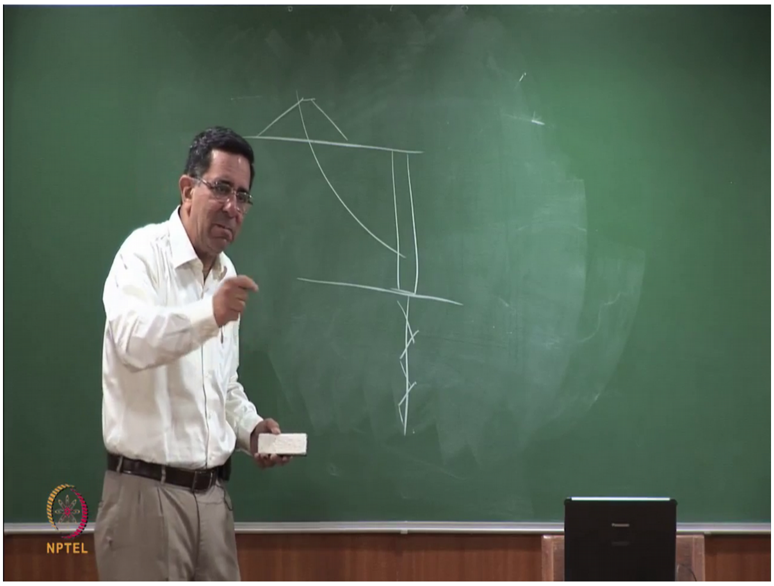

I am going you make my trench here and then I am going to do grouting.

Now, when I make my trench here, I am going to fill it with slushy loose soft clayey material. So, you know is this it can there be a this is a vertical cut of 8 meters. So now, we have to make this stronger. So, it is a mix design problem, very simple. You took soil and you added bentonite to get the low permeability. Now you take the soil and the bentonite and add cement to get good strength; that means, as deposited material will get strength not from compaction, but from the cement.

So, the next set test that we did was to add cement. So, let us look at local soil plus 10 percent bentonite plus 10 percent cement. And after 7 days I was able to get a strength of 130 kilometers per meter square. And this I was able to get a strength of 71. So, this is the mixture that we used sorry, oh sorry this was the mixture that we finally, used for the purpose of preparing the vertical cut of wall. And if I could show you the permeabilitys were acceptable the requirement was 5 in to 10 to the power of minus m you see when you add cement what happens does the permeability go up or does it go down.

Cement will granulate the soil agglomerate it. So, permeability goes up. So, you add soil you added bentonite the permeability went down, I want you to see these values local soil plus 10 to the 10 percent bentonite at high slump was 1.4 into 10 to the power of minus 7. Borrow area soil was 1.8 into 10 to the power minus 7. When I added cement this went up to 7 and 5.5; however, this was acceptable for us. Both we excepted and we got the strength that we wanted. And now this material became stronger than the soil around it. And therefore, they would not be a problem of instability. So, we would not cut the wall in one go. We would make sections of this wall and then you would put in this material such that limited sections were exposed and when it would set in and about 7 days it would have good strength.

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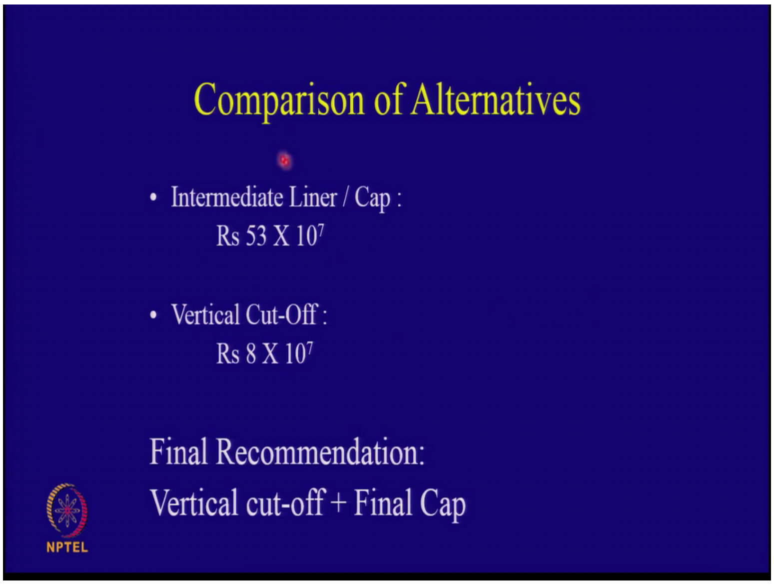

So, this was proposed. And in comparison to that one kilometer 1.6 kilometer by 6 hundred meter liner which was proposed was very expensive. The vertical cut off wall was less expensive and this is what was adapted. So, the process of design was a mixed design. And the process of implementation is another issue because you have to do intimate mixing; everything has to be mixed in a plant outside, because you are now mixing soil with bentonite with cement. And then you have to place it back in to vertical cut off wall. So, any questions on this? Either on the case study or on the remediation that we did. But this is the way one has to proceed like a mix design to be able to get a correct mix for soil clay walls soil bentonite walls or soil bentonite cement walls. So, we will stop here, have a good day, all the best.