Environmental Remediation of Contaminated Sites Prof. Bhanu Prakash Vellanki **Department of Civil Engineering Indian Institute of Technology- Roorkee**

> Lecture - 34 **Hazardous Waste Disposal Site/TSDF**

Hello again, so welcome come back to the latest lecture section. So we have been discussing the relevant aspects with respect excavation or you know some of the aspects of the scenarios when excavation cannot be or is not feasible and then we moved on to looking at landfills and that context we were looking at a port let source.

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ASSESSMENT OF THE PERFORMANCE OF ENGINEERED WASTE CONTAINMENT BARRIERS

Committee to Assess the Performance of Engineered Barriers Board on Earth Sciences and Resources Division on Earth and Life Studies

THE NATIONAL ACADEMIES PRESS

The one developed by National Academies Press which was the easy assessment of the performance of engineered waste containment barriers.

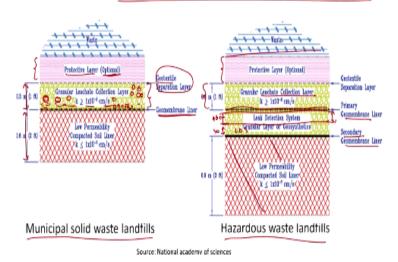
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And that context we looked at one point less schematic or side view for municipal solid waste landfill this are what are typically required obviously as we discussed for hazardous resuscitation landfill we are going to have 2 liner systems and municipal solid waste landfills we are only going to have typically the law management that we have only or one particular line of system is good enough right. So, let us look at some of the other aspects typically from what we say uses let us see.

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PRESCRIPTIVE MINIMUM BOTTOM BARRIER SYSTEM



There let us look at there minimum what we say requirements right and we do have similar requirements that CPCD mandates more or less those guidelines are based on the guidelines that we see out here right thought so one for municipal solid waste landfills and the other for

hazardous waste landfills what we see here so the waste out here and then obviously as we see they say that protective layer below the waste is optional.

But typically one would what would say suggest having that right because you do not want to damage this particular leachate collection system and also the linear out here also we discussed the Geo textiles separation layer where the fine particles are going to be prevented from moving what we would say or seeping down into and clogging the leachate collection systems so that is what we have here and around 30 centimetres thick.

What we say leachate collection system so typically granular collection what do we say gravel here and then perforated pipes out here and then some sand out here at the bottom. Let us see so sand out here typically at the bottom right and then the perforated pipes and then the gravel obviously all around right. And beneath that obviously we are going to have different kinds of liners here.

We are talking about Geo Membrane liner and then again contacted or impermeable layer again that of around 60 centimetres beneath that particular HDP or the geo membrane linear now so this is for the land fill what we have for the hazardous waste landfill now. So, obviously the waste and similar to the relevant particular a protective layer we are going to have what do we say an optional protective layer similar to the municipal solid waste landfill.

And again similar to the municipal solid waste landfill we are going to have the primary leachate collection system and then the HDP membrane or geo membrane liner. But typically from what I have seen in India let us say rather than immediately having these leachate detection system or leak detection system pardon me they typically have what we say clay layer here of few centimetres thick a compacted clear layer of a few centimetres thick.

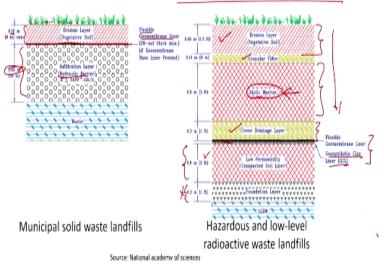
Maybe 45 centimetres so thick and then beneath that they have this leak detection system right off again at around 15 or 30 centimetres thick here. So, typically 30 centimetres and then clay of around 45 centimetre thick and then the secondary liner and then they have the compactive clay

that is what I have absorbed and a few landfills in India any way again CPC had shown guidelines but more or less they are from this particular these guidelines from the US.

And I think it is from the RCRA or the resource conservation and Recovery Act right so this is what we have.

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PRESCRIPTIVE MINIMUM FINAL COVER SYSTEM UNDER



And then from obviously the cover systems or final cover systems obviously that is remarkably important because these landfills are supposed to what do we say stay out there for hundreds of years if not obviously more so obviously you do not want to have what you say your rainfall seeping through your hazardous waste and leading to greater leachate generation or you know relevant issues out there.

So typically obviously you are going to have vegetation out there. Again that I was I saw that that type of vegetation actually what we say led to greater what we say loss of water through evaporation. That is something that some interesting data that I saw earlier as in without way station the loss of rate of loss of water from the surface was a little lower and actually when you had some kind of vegetation.

But I cannot remember which kind you know the due to vapour transportation the relevant rate of loss of water was actually higher and then you have the erosion layer or vegetative to soil as we

see here again around 15 centimetre thick and flexible geo membrane liners another liner at the top obviously and then infiltration barrier and then the waste the hydraulic barrier let us say and typically that seems to be around 45 centimetres thick.

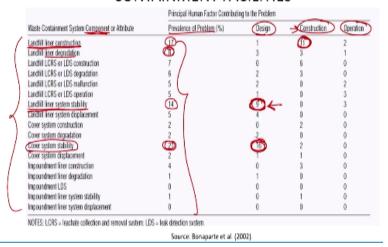
So, for hazardous waste landfills what do we have same case as the erosion layer but then a granular filter and then a biotech filter obviously but again in Indian context I do not see people going with this and then a cover drainage layer obviously right. You want to collect any particular water that comes through this particular layer let us see. Cover drainage layer and another liner here obviously.

And then the GCL or geo synthetic clay liner typically this is the HDP let us see and then against soil and then a foundation again, I did not see this lot in the Indian context. And then the hazard switch so typically what we see in the Indian context and erosion layer a granular filter a cover drainage layer and these two kinds of liners or at least one and then the clay and then the relevant a hazardous waste.

These are the final cover as in closing down the landfill and I need to obviously cap the landfill and this is the kind of covered that I need to have and obviously I could see around one and a half to two meters thick, covered. Right so again let us move on.

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TYPES OF PROBLEMS ENCOUNTERED AT WASTE CONTAINMENT FACILITIES



So, obviously you know we looked at you know very briefly any way the different kinds of layers that we need to have beneath the landfill and our beneath the waste and above the waste and typically let us say let us just try to understand what are the usual causes. Let us see that lead to failure off different landfills and what do we have here. Here we have the different kinds of components let us say variables that failed.

And here we have prevalence of the problem use and what do we see? What is it attributed to? is it the design the construction or operation that leads to failure of the relevant system? So, as you can see you know landfill liner construction is a major case and typically during construction obviously you know it failed a lot. So, when you are placing the liner let us say you need to be remarkably what we say a cautious.

Or you know how or a higher experience with what did we say operators. Because typically from what I have seen where they have the seam let us see you know you are not going to have one liner to cover the all the landfills. So you are going to have to well the lines together and typically they do the vacuum test or present test let us see say as an you know where is the pressure dropping a bit.

Or what do we say over this particular scene or such that they introduced some pressure let us see. Or maintained some pressure and see if the pressure drops after a certain few minutes and such and in the same case with vacuum they tried to see look at that particular integrity. But to my knowledge you know only randomly or it seems looked at in India as in not all the seams are tested randomly they are tested.

But obviously you know for greater a factor of safety or to be on safer side. We should or one should promote what we say is such testing at all the relevant teams. That is one aspect that they are relevant liners fail at a lot and other than that let us say depending on how you are laying the liner and what you are laying about the liner even during construction itself or the stage of construction itself you can damage the linearity.

As again what the thickness we are talking about a 2mm thick here let us say. And then as you

know load the relevant materials over that as in the lead leachate collection system or so on and

then your waste let us see or at least during construction rates. So, the leachate collection system

you are going to help puncturing the relevant landlord such and the other aspect is obviously

liner degradation different aspects.

As in let us say a liner is not compatible to the relevant type of contaminants. Or let us say you

know the quality of the liner has degraded because of its exposure to sunlight or due to extreme

temperatures high and low temperatures and so on and so forth. So, those are some aspects and

another aspect is obviously landfill liner system stability. And obviously here you see that the

line of system stability.

Let us see is a consult importance and the issues typically with design let us see. Landfill liner

system stability and then more obviously cover system stability that fails a lot as you see the

cover system stability. And again issues with respect to design lecture so typically construction

and some cases and considerable cases. It is due to the faulty design literate so let us just straight

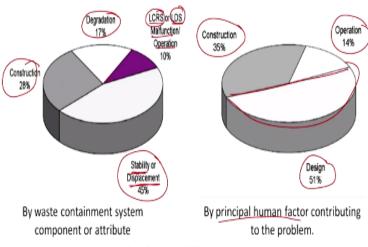
to have an over view.

Obviously you can go through these other aspects to see what are the common causes for liner

failure. Not Liner failure pardon me issues with the landfill so here we see that.

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GENERAL DISTRIBUTION OF PROBLEMS



Source: Bonaparte et al. (2002).

This is with respect with the type of failure let us see so, most aspects are with respect to stability or displacement let us say right typically of the liner up right and again along the slopes. So, here you have the leachate collection and removal system and leak detection system this is the primary and the secondary one. And so during either malfunction or operation typically let us say a malfunction is because let us say the design was poor or you do not have a geo textile layer.

So, that you are fine particles do not seep through and block your what we say leachate collection systems so that is something that you need to look at obviously right and obviously degradation of the relevant components and during construction itself constable issues. But obviously as we see stability and displacement of your relevant competence form a constable what we say here.

A fraction of the failures now so with respect to the principle human facto as you see a majority of the relevant failures are due to poor design and then issues due to improper construction or improper care during construction and some due to operations so obviously as we see you know design and construction are remarkably important and again especially with respect to the stability of the relevant competence.

So that is something to keep in mind let us say when you might either look at evaluating a landfill or you know going about designing a landfill. That is it.

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LIQUID COLLECTION RATES FOR DOUBLE-LINER LEAK DETECTION SYSTEMS			
Stage	Initial Rate (I/ha/day)	Active Rate (Uha/day)	Postelosure Rate (l/ha/day)
Geomembrane			
Mean average monthly flow	307	187	127
Minimum average monthly flow	4	0	Ī
Maximum average monthly flow	(2.144)	1,603	328
Sand/Geomembrane/Compacted Clay			
Mean average monthly flow	114	142 22.7	64.4
Minimum average monthly flow	114	22.7	0
Maximum average monthly flow	(1,192)	672	274
Sand/Geomembrane GCL			
Mean average monthly flow	(133)	(22,5)	ത ←
Minimum average monthly flow	0	0	0
Maximum average monthly flow	(984)	284	0.9

So, let us move on here so liquid collection rates for double liner leak detection systems so recently when I was evaluating the landfill you do some particular issues and such I wanted to know let us say, what are the expected rates. As in initially I how this particular leachate collection system or the primarily primary leachate collection system pardon me and beneath I have the secondary leachate collection system or the leak detection system.

So, for a given particular landfill given its characteristics and such I want to know let us say you know the relevant data that is being provided by the landfill operator. Is that does that seem fine or is that unusual? As in does that point to any particular failure or such. So, for that I just look at some data out here so what do we have here. You know a different kind of systems one is just the geo membrane one is the sand geo membrane and compacted clay.

And the other is sand geo membrane and this geo synthetic clay liner or typically the HDP liner and then we have the initial rate and active rate and then the post closure rate. Post closure rate I am done with the relevant what to say is the landfill is at its full capacity I cab landfill. And you know that is the post closure rate that I am looking at where am I looking at? That is in the leak detection systems so the liquid collection systems let us see.

Liner detection systems leak detection systems right and initial rate as in let us say I just come sit in the landfill and I am just starting to operate my particular landfill. And then whenever there is rain fall let us obviously you know all this particular rainfall typically let us says depending upon how you constructed your particular landfill is going to end up as leachate right. So, you are going to typically expect considerable levels of leachate generated.

During that particular initial period and even during the active period as an as you keep moving up let us say until you reached your particular soil or the you know surface a level you are going to still have how considerable levels of what we leachate generated. And that is what typically or you know during or until you close the particular landfill you are going to have this active rate.

So, let us look at that so let us look at the mean typically mean during the active rate or initial rate is considerably higher as you expect when compared to the active rate and the post closure rate. So, after post closure rate you will see that there is still considerable what do we say? Volume of the leachate being generated here we have litres per hector per day. But obviously the one in the initial period is almost twice or more than twice of what you would see.

Or expect in the post closure rate so that is something to keep in mind and more importantly you see that you know there is a great variation right in the amount of leachate that is detected in the leachate collection system. What are we looking at? We are looking at the leak detection system the secondary system and that is the where we are expecting or you know we are observing these levels of leachate being collected.

And as you see you know the considerable variation 2144 litres per hector per day and the other around 4 why is that? Obviously because of let us say monsoon and non monsoon seasons are periods of rainfall and so on and so forth. And that is something obviously you will see and obviously post closure rate you see that the maximum is not a pretty high rate. It is more or less in originally nearer to the mean.

So, in the case of these geo synthetic apart from geo membrane and compacted clay obviously now or how greater protection let us say I would expect that the rate of infiltration of this but leachate into the leachate detection system. Let us say it is going to be relatively lower and that is why you see that let us see here the average is 307 and here 114 lit and same case here for during the active rate and during the post closure rate.

And more importantly the maximum is relatively to the last so why is that important. Let see I look at the maximum as in the leachate collection system has a limited capacity as and it can only pump out let us say a given amount of leachate per time rates here. So, if you are ending up if you are unable to let us say withdraw that leachate that is piling up in your particular leachate collection system you are obviously going to how issues now.

So thus let us say you know you need to be able to balance your particular design of the leachate collection system and the leachate what do we say? Disposal System or treatment system with the maximum amount of leachate that you expect to infiltrate through to your particular leachate cultural systems. That is something to keep in mind and obviously when I have this geo synthetic clear liner.

I see that it is a pretty less right but more or less on the same lines along the sand geo membrane and Go but typically you see that the maximum is relatively to be attenuated and even in during the active rate let us say it is considerably less and here during post closure almost zero obviously geo synthetic clear liner and it has what we say too little to know what do we said that connectivity does let water go through typically let us say unless you have punctures and such.

But some compounds might diffuse but I am not a greatly sure which compounds but I know you some can diffuse the right. So, this is something to keep in mind let us say you are evaluating a landfill and you see that at a particular stage. Let us say during your initial rate let us say you see a particular what was we say the rate of collection of leachate? Then you can at least thumb rule to see if you know whether your landfill is operating at what is it the normal level.

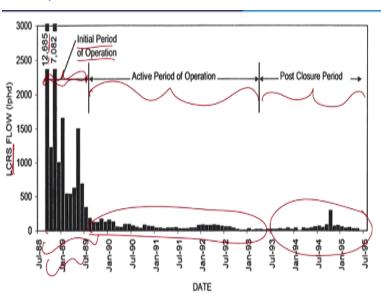
Or at there any failures that you need to be concerned about you can look at these general data let us say that we have out here to evaluate let us say at a preliminary level anyway whether your landfill is still has some integrity or has it failed now. So, that is something to look at and source again keep in mind that this is again from the relevant document that I talked about earlier.

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Leachate collection and removal system (at an MSW landfill in Pennsylvania)

So, here leachate collection and removal system at a landfill in Pennsylvania.

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So, what do we have here now this is obviously a municipal solid waste in landfill this is from the leak detection system though the secondary landfill? So, what do you see let us say during this particular period of initial period you see that leachate detector is considerably height? Which are detected in the initial rate initial period right is considerably high. And then during the active period we are not a lot and obviously post closure may be non at rate.

This is from municipal solid waste landfill I guess where they have 2 leachate collection systems

and here we have one for leachate collection and removal system. This is not the leachate

detection system keep that in mind is the primary leachate collection and removal system. So,

obviously I will see here initial periods you will see a constable quantities of here we do have the

relevant periods of operation highlighted.

So, initial periods we see that you know considerable amount of leachate is generated almost

what is it now? 12685 days 8 litres in this per month maybe. You can break that down and during

active period still considerable volume but not as much as during the relevant initial period. And

then during post closure right and keep in mind that municipal solid waste landfill you are going

to have microbial activity and so on and so forth.

And also let us say a as your due to contacts and let us say you know you are going to have also

a moisture or water coming out of your particular you know waste. And also degradation by parts

could be water. You know different cases out here so an initial period comes through

concentrations not concentrations volumes of leachate generator and that is something one needs

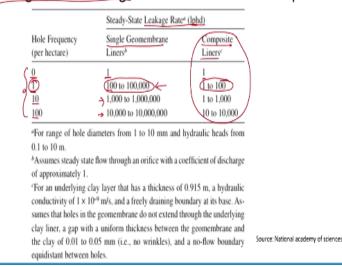
to keep in mind.

When you are designing your leachate collection and removal systems there is something to keep

in mind there.

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Leakage Rates for Single Geomembrane and Composite Liners



So, again what are the typical leakage rates for a single geo membrane and composite planner. Let us see so if as I mentioned to you during construction you can have you know a whole state or punctures in your particular a lighting system. So, here let us say for different what do we say a whole frequency per hector obviously we are going to look at the relevant a leakage rate in litres per hour per day.

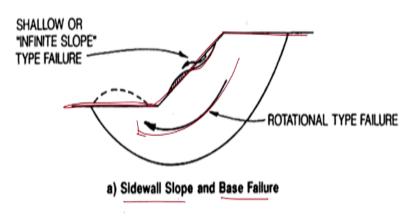
So, for single geo membrane and composite liners or the hdp line of states so here, let us say obviously there is nothing and still obviously you are going to have some particular leakage and then for one whole per hectare you will see that the leakage in your particular Geo membrane liner based what we say leachate. What do we say? A collection and not collection pardon me the impermeable layers which are if they are only single geo membrane layer.

Obviously you still have or even how consumable leakage rates even when you have one whole per hectare now so keep that in mind. But for composite liners obviously we see that it is relatively less. Again same case the greater the number of holes in your particular liners the greater the do you say the leakage rate but typically for composite liners relatively less again. These are these data you can use to let us see understand let us see how well was the relevant liner constructed and such and so on and so forth to analyze your landfill.

If you detect any issues after you know our during operation that is here right. So, that is something that we look at.

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MODES OF GLOBAL STABILITY FAILURE.



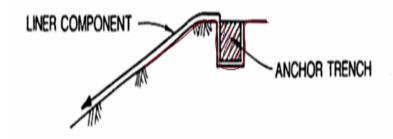
SOURCE: Mitchell and Mitchell (1992).

So, let us move on to I think failure is here so different types of failure let us look at that so one case is let us say you do not hear the slope and here is the what do you see the bottom of your perpetual landfill so depending upon the kind of slopes in the material out here we have side slope and base failure as in the whole thing just rotates out here. That is what you see out here or shallow infinite slopes out here to right.

So, different kinds of a slope failure here one is the sidewall so obviously you know the people from with geo technical background are relevant here as and when you need to construct the landfill you also need to analyze the side slope stability now. That is something of constable importance.

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MODES OF GLOBAL STABILITY FAILURE.



b) Pullout of Liner System Components from Anchor Trenches

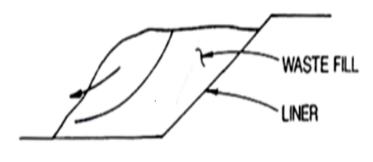
SOURCE: Mitchell and Mitchell (1992).

So, the second case is when you know the liner is pulled out from the anchor trench as I mentioned we need to have an anchor trench as and the liner needs to go through under this particular anchor trench. So, this is the anchor trench so depending upon the stability of that particular liner component and this particular trench. You are going to have to look at the relevant calculations with respect to liners steep page and so on and so forth.

And typically let us say yes if you do not design not well again you are going to have pull out of the liner. A liner coming out from underneath the trench so that is something that is another cause of the particular failure.

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MODES OF GLOBAL STABILITY FAILURE.

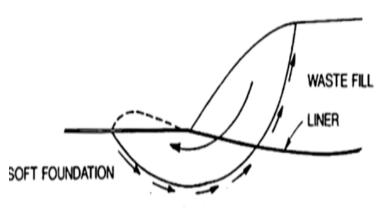


c) Failure Through the Waste Pile

Let us move out to the other aspect obviously failure through the waste fill and the waste itself can shift. Let us see here you have the liner and waste can obviously have what we see the relevant what do we say. A non uniform pressures being exited and through that particular case again you can have relevant failure again and again.

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MODES OF GLOBAL STABILITY FAILURE.

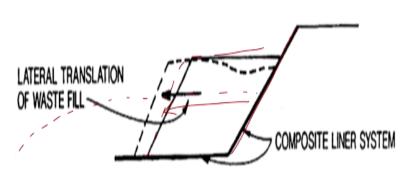


d) Failure Through the Waste, Liner, and Foundation

So, failure through the waste liner and foundation probably one of the most case scenarios out here so a soft foundation you see that you know again non uniform distributions. Let us see and again issues with respect to search stability. So, here this is typically the worst case of failure that you would see out here.

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MODES OF GLOBAL STABILITY FAILURE.



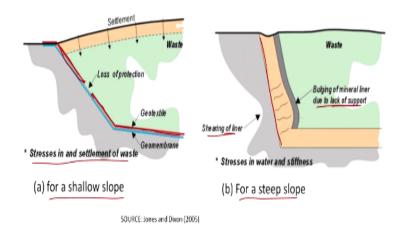
e) Failure By Sliding Along the Landfill Liner System

SOURCE: Mitchell and Mitchell (1992).

And this kind of failure typically we do absorb as an van you pile up a waste you know a non uniform man and what do we see that where what we observe the failure by sliding along the landfill liner system. So, let us say if I do not have a relatively more uniform distribution of my waste and I pile it up alongside and my slope is relatively high, I can have this failure by thus particular waste sliding along it.

So, lateral translation of the wasteful but something that can cause issues out here in the liner now as this waste shifts let us see so that is something to keep in mind.

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And let us move on to other kinds of aspect at the microscopic level so again let us say for a shallow slope and here you have the relevant waste you can have let us say share in this particular what do we see a liner this is the side view obviously and this red particular liner is the geo textile liners. And as you can see you are going to have separation of this relevant particular liner or share in the liner due to stresses in the settlement of the waste.

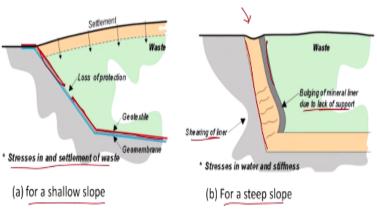
Or during the settlement of a waste as I mentioned here let us see if you just take the liner up without the proper what we see layers protecting this liner and you know different stressors let us say that can lead to the irrelevant shear and failure of the relevant line. And again let us say depending upon obviously the steep slope to way to steeper slope and then you are going to have obviously have against shearing of line.

And why is that because of lack of support again bulging of the mineral liner here so different ways of failure and I think this is a common cause at least in the Indian context at least. And keep in mind that once you start piling up the waste it is near to impossible to or not even feasible let us say dig out the base and such and then look at the behaviour of the relevant or the state of the relevant liner and so on and so forth.

So, the design is a one remarkably important aspect obviously relevant to both and are obviously required the involvement of both and environmental news and geotechnical engineers lectures or engineers with geo technical background so let us move on.

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Mechanisms of local side slope integrity failure

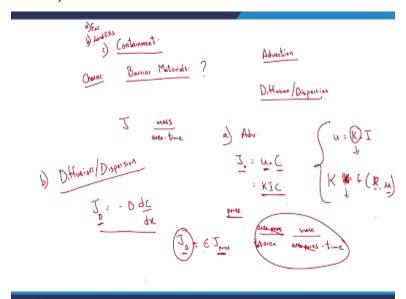


SOURCE: Jones and Dixon (2005)

So, again the mechanisms for local side slope integrative failure so until now we have looked at the landfills in general and some of the cases are aspects that we need to keep in mind. So, the next aspect that we are going to look at obviously is containment so as in let us say I do not want to excavate the waste and take it to some other location and either treated or disappointed in a landfill or you know I cannot treat the relevant ways to add the particular sites.

Due to various reasons for so what can I do? I can try to see to it that this particular waste is not transported or the compounds are not transported to different locations are we know are too wide area. Let us see so one aspect is we can look at containment.

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So, typically we are looking at different barrier materials let us see so again we have looked at excavation we have looked at landfills and we are now looking at containment let us see. We are just trying to contain the relevant waste so a different barrier materials are out there but typically what is it that we are looking at with respect to choosing let us say a butler barrier material let us say what are the characteristics of the barrier of materials that we need to be concerned about.

So, here we are preventing or trying to prevent the transport of the contaminant from one location to the other so there are two kinds of modes of transport obviously. What are they? One is the advocate to transport or by advection and the other by diffusion let us see. Diffusion and or dispersion let us say so there are two kinds of fluxes. Flux is nothing but mass per area per time flux. J what is that.

The mass of the contaminant or compound per area per time let us say so I have to two kinds of fluxes here. One is due to advection let us say case a is due to advection and the flux is due to advection = what now? It is going to be = Darcys velocity into the concentration of your relevant compound and again what is does is philosophy or how can I get that? That is going to be = to hydraulic conductivity times the slope of your energy gradient or hydraulic gradient let us see.

The energy gradient the slope of that particular a gradient now so you recall the KI and K is the hydraulic conductivity so KIC is again what is the advection now? Now let us say of ground water or water is flowing through let us say in this context water is flowing through the relevant particular pose let us say and then you are going to have the contaminant also transported along with this net flow off the is particular groundwater.

So, in that case I am going to have what we say transport of the contaminant due to advection. Again hydraulic conductivity will depend upon both the media and also the type of fluid that you have. So, let us say this is also a function of it is going to be a function of intrinsic permeability or permeability of that particular media and also the viscosity of that particular fluid now so this is our depend upon or the hydraulic conductivity pardon me is dependent upon both the media.

And the fluid now k here is the intrinsic permeability and new is the irrelevant viscosity and again we do not need to go into great detail here but what this flux here now it is the Darcys velocity times the concentration that = KIC so that is due to the advection now. So, what is it due to diffusion now or how much of the contaminant will be transported by diffusion or in the case of the sub soil let us see where we have?

We are also going to have this dispersion because of the tortuosity of the relevant or tortuous spot that is available to the relevant water molecules now. So, how does this diffusion go about I think we discuss this or mentioned this a lot of times but typically let us say in one location you have higher concentration of a particular component and another location let us see you have lower concentration of that compound.

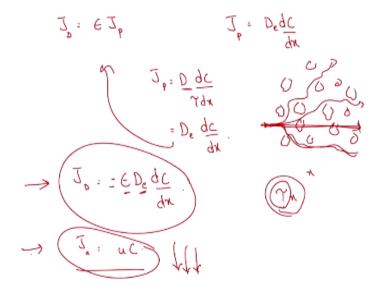
So, then again to call it potential let us say we are going to have what we say this but your diffusion driving the contaminant transport from a particular location where it is at higher concentration to a particular location where it is at a lower concentration. So, diffusion what we would want to do it would want to see too that the concentration of the same at all locations so the compound would travel from a particular location.

Where the concentration is higher to a particular location where the concentration is lower or you know drives it in that particular what do we say direction let us see. But keep in mind that diffusion is the game of random though so again diffusion so what did the flux due to diffusion though. So, typically we know that it is DDC/DX. Here we are assuming that it is in one direction that is a decent assumption out here.

But as we see that you know you are going to typically have the diffusion only through the pores only through the pore let us say. And how can I reflect this? A normalized a diffusion coefficient not diffusion coefficient pardon me. There is a normalize flux right said due to diffusion with the diffusion only through the pores. How can I get that? That will be = to the porosity times the one due to what do we say through the pores let us see.

Yes, that is what I am going to have as in this calculates let us say what does this calculate mass per mass of the contaminant being transported per area of the pores per time. So, if I multiply that by porosity area of the pores if I can think of that. Let us see fraction of the pores by total area. Let us see right total area so I then end up with this particular flux normalize flux let us see right so that is going to be called porosity times the flux through the pores. And what are those particular variables now.

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So, JD = porosity times the flux due to the pores and how can I calculate that? As I know it is going to be dependent upon the diffusion coefficient and concentration gradient. What is this dC/dx giving you an idea about as a apart along the particular dimensional let us say what is the change in concentration? Obviously the change in concentration is high or the slope is high let us say with respect to the contaminant concentration.

Obviously the diffusion fluxes will be greater, right and if there is only a small change in concentration from one location to the other along that particular dimension obviously the flux is going to be relatively lesser. That is what you see out here so the greater the change in concentration along that particular dimension the greater the flux in that particular dimension but one aspect we need to keep in mind is that as we discuss earlier let us see.

If these are the soil particles these are the soil particles and as a compound comes in here it does not go through like this. Because you are going to have soil all out here and the groundwater will you know are the compound can travel in different directions or we will end up travelling in different directions. So, while this distance might be x it might actually or it will actually end up travelling a distance of Tau x.

Tau x is called the tortuosity factor right so typically rather than travelling just this particular distance of fact because of tortuosity it is going to travel a greater distance which we are going to represent by tau x. So, if I put that in here that is going to be equal to the diffusion coefficient times DC/Tau dx so that is going to be equal to D or disperse for d let us see dc/dx so now plugging this backend.

I am good to have JD = - porosity times this particular dc/ dx so this is the flux due to dispersion and diffusion. That is right this is the dispersion coefficient which also includes takes into account the tortuosity factor or the torturous part of this particular contaminant. And also the diffusion coefficient and this is the porosity and why is it native? Because we know that the concentrate the diffusion drives the transport of the contaminant from a region.

Where the concentration is higher to a region where the concentration is lower so and what did we have for advection that is going to be = u * c so I guess I am running out of time so in the next session we will just look at a particular or you know plug in a few values for these particular variables as in for porosity dispersion coefficient and so on and so forth and look at let us say how low the let us say these two fluxes compare.

As an if it is surface water lies in a river or such let us say you know let us say you drop some dye or colour in that particular surface water. You can obviously visually see that you know the dye is being transported let us see. But if it is subsurface obviously the groundwater flow velocities will be relatively slow let us say a few meters per year so in that context what is it both advection and diffusion play an important role.

But in surface waters let us say when the speed of this particular fluid let us say or the velocity of flow of that particular fluid is adequate high only advection is important and diffusion is negligible in such a case so that is something to keep in mind. But obviously in these barrier systems what are we trying to do? Or in these containment systems we are trying to decrease the flux to advection.

We are trying to decrease that as much as we can so then we are going to just plug in a few values and compare the TIPCO. What do we say the rates of transport through the barrier as in even when you put a barrier you still have diffusion driving through the relevant particular transporter the contaminant and advection will be less but it will not be zero so let us just try to see how they compare and what are the relevant values? and I guess with that I will end todays session and thank you.