# Environmental Remediation of Contaminated Sites

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## Lecture – 36
## Introduction to Solidification and Stabilisation and Case Study

Hello again, welcome back to the latest lecture of this session. So we have been discussing remediation of soils and sediments in that context we are looking at solidification and stabilization right so let us dig right in now regret him now so we talked about solidification and stabilization so what are the major aspects or players that we that we have here right so obviously we need to have.

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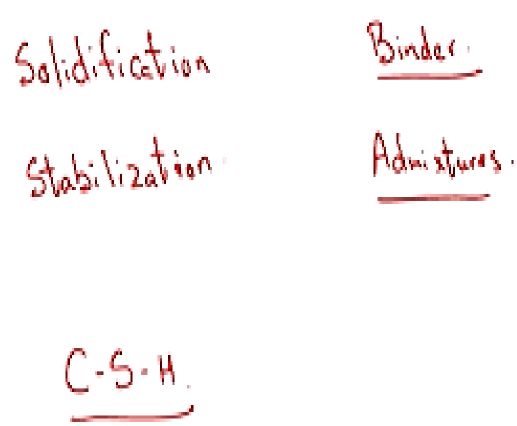


Solidification right solidification typically improving the physical properties and stabilization by make the contaminant immobile or even less toxic let us see. So obviously in this context solidification we are trying to bind the relevant material let us see so what do we need we need a binder now right we need a binder now yes so what are the what do we say kinds of binders that we have we are going to look at that.

So again the binders such that let us say it is going to improve the physical characteristics of the waste when its mixed with let us say water and the waste let us say so binder water and waste well form a particular mixture that improve the fiscal strength let us say and obviously we are also going to how were looking at admixtures right typically binders are had a relatively high fractions let us say right.

And admixtures in very low fractions or content and these are used let us say to make the compound less toxic or degrade the compound while its within this matrix or such right. So again solidification and stabilization and typically we need to add a binder and obviously depending on the type of contaminant you will also maybe add an admixture now right so what are some of the binder that we look at obviously right.

So to improve the strength physical strength of particular slurry let us see I know you have water and you have this containment and you have other matter out there and you want to improve the strength the strength of this material or this slurry pardon me so what will you add you will add a binder and what kind of binders do we typically have we have let us say cement obviously right. So cement how does that work.

Obviously, so have you typically have let us see when cement hardens calcium, silica, hydrate complex or CSH complex is formed right calcium, silica, hydrate complex CSH and that is the matrix that imparts strength d to this particular you know concretely at right or hardened cement pardon me.

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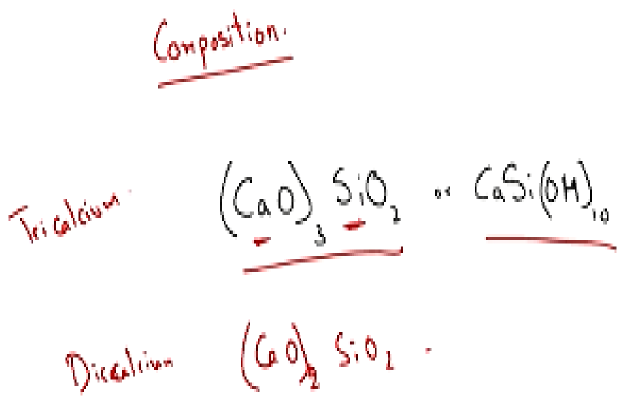

So let us just look at what we have here so here let us say we have different types of cement right first let us say if we talk about composition let us say but you know this is what is the formula for cement so here we help Tri calcium right and we can also have Di calcium as in Ca02 Si02 right and also calcium, silica and aluminium or calcium, silica and iron right you can have different types of these particular elements in there.

But typically we are almost always going to how C and S or calcium and silica right so once you add them to water let us see all right what good is what is going to happen.

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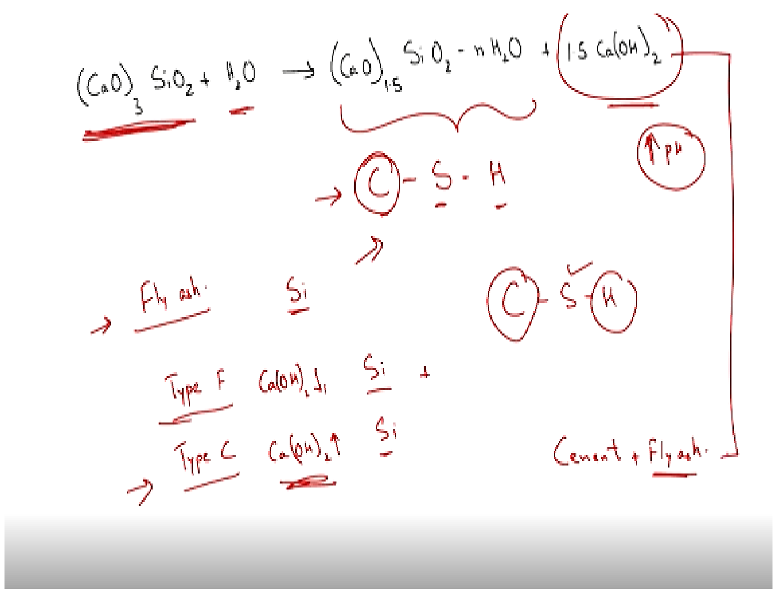


So add this particular cement this is cement as you see the tri calcium right to water you end up forming this CSH matrix right calcium silica hydrate right so CSH matrix right calcium, silica hydrate right so CSH matrix and obviously again CaOH2 is given out obviously what will this do it will increase the ph so that is something that we will have to look at or consider later. But keep that in mind that when we add cement right to water.

You know we are going to have this particular hydration and this hybrid CSH matrix strong. So you are going to have this CSH matrix form right so other than cement water some of the other what we see materials that you can maybe think of that can act as a binder now right. So typically we are looking at improving the physical strength right so what is one substitute for a cement that you can typically think of let us say.

That can end up are leading to formation of again the CSH matrix now. So obviously you know where we can think of fly ash right so you have different types of coal and thermal power plants let us say when you burn the particular coal you have the relevant ash and that is typically we have the relevant fly ash here right so again in a fly ash what do we have what is this rich in it is typically rich in silica it fly ash is typically rich in the silica content right

So to form the CSH matrix what do you need you still need the calcium ratio right so you can add you know some lime or calcium in the form of lime right are let us say it depending upon the type of fly ash you will also maybe have some lime you know inherent in that fly ash. So pardon me depending upon the type of coal so we have type F coal and type C coal okay. So different levels of purity right.

So type F coal typically has less CaOH let us say right and type typically C has more calcium right obviously both will be rich in the silica content right. So in this type of where the calcium content is less and type C where calcium content is more obviously in type of right you need to have or add lime let us say right why is that obviously you need a source of calcium right because you are already have S and you need to add calcium.

Right and then water obviously and CSH matrix right that is when that is where it is going to be formed type C you need not maybe add calcium because you already might how significant or significant or constantly or sufficient calcium and your particular a fly ash there right. So again that is something else or as we looked at if I am adding both cement and fly ash I where can I get the source of this particular calcium.

As you see from the hydration of cement you release those particular calcium hydroxide and that again can act as a source of calcium for the fly ash let us look at the relevant reactions here.

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$$1.5\,Ca(OH)_2 + SiO_2 \rightarrow (CaO)_{1.5}(SiO_2)\cdot nH_2O$$

$$C\text{-}S\text{-}H$$

So here I have let us say fly ash right and add calcium right and then again what do we end up forming it CSH matrix here right so again CSH matrix right and again people look at a slag from again blast furnace and such and so on right. When they are different binders so typically though we have people look at cement and fly ash right so that is something to keep in mind and what are we trying to form frequently the CSH matrix now right.

But in part the strength more or less and how does this particular contaminant going to be transformed let us say there are different ways but if can be let us say it can be absorbed onto this particular matrix. Let us say I think it is called a twin guide substitution right or it can precipitate out let us say precipitation reactions can occur complexation reactions can occur right complexation I think we have a metal and ligand so on and so forth.

So you apply the relevant law again and you are going to how complexation right and you how maybe degradation to depending upon reduction pardon me let us say our oxidation. Depending upon the type of admixture you add and so on and so forth so what do we look at we need to look at adding the relevant binder and if required relevant admixture and so on and so forth so let us look at some of the other aspects right.

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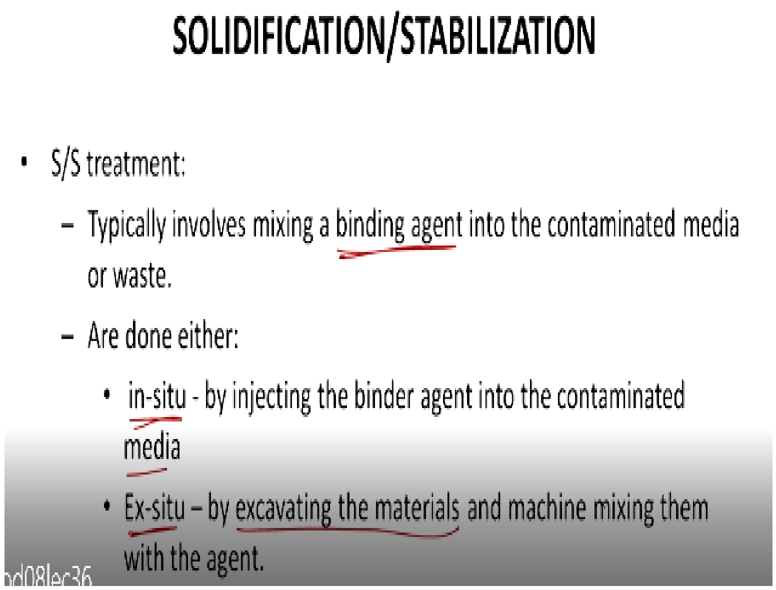


So solidification stabilization what is it now binding agent is typically your cement fly ash and so on we have some other binders but you know these are the binders typically use digging. So contaminated media or so obviously can be done in-situ right by injecting the binder into containment media or it can also be done Ex-situ by excavating the materials and then mixing them with relevant agent and offsite or such and then disposing them.

Again keep in mind that let us say if your hazardous waste you cannot directly dump it in the landfill because there are certain regulations again even for the kind of ways that you can dump in a landfill with respect to their leachability or such let us say right so that is something typical to my knowledge Ex-situ is more widely practised in-situ not a lot. But we will look at the relevant data I think we have a decent a schematic later on.

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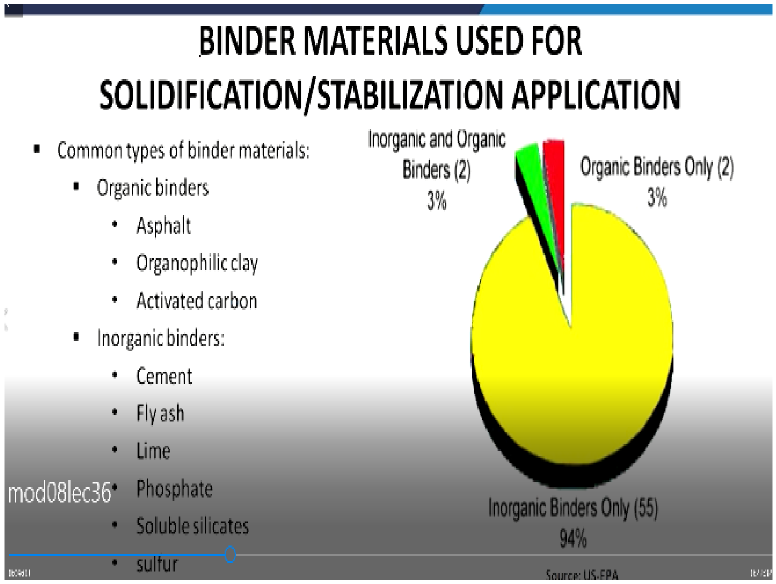


Right so here what are the different types of binder materials now right so we have some organic binders but typically we end up using a lot of inorganic binders and that is something that you can see again the sources US EPA right environmental protection agency so we have in organic binders typically as you see the fraction or you know which are the major fraction of the binders that are typically used.

So you have a combination of inorganic and organic binders this is sometimes used to promote let us say adsorption if I can also say degradation. For degradation you obviously need an electron acceptor and a donor so if one of those is missing let us say the organic compound can act as that let us see depending upon the type of compound and only organic binders but that is relatively rarely used as you can see.

Organic binders what do you see obviously activated carbon as fault and different types of clay and in organic binders which form majority of the binders are cement fly ash and lime obviously you might need lime when conjunction with fly ash phosphate again which can either lead to precipitation let us say of the relevant what do you say it compound or adsorption let us say or even complexation and soluble silicates or sulphur.

Relatively less widely applicable let us say phosphates sulphates, sulphur and silicates and so on. But typically cement fly ash and lime and typically as you can see they are the most popular or widely popular binders.

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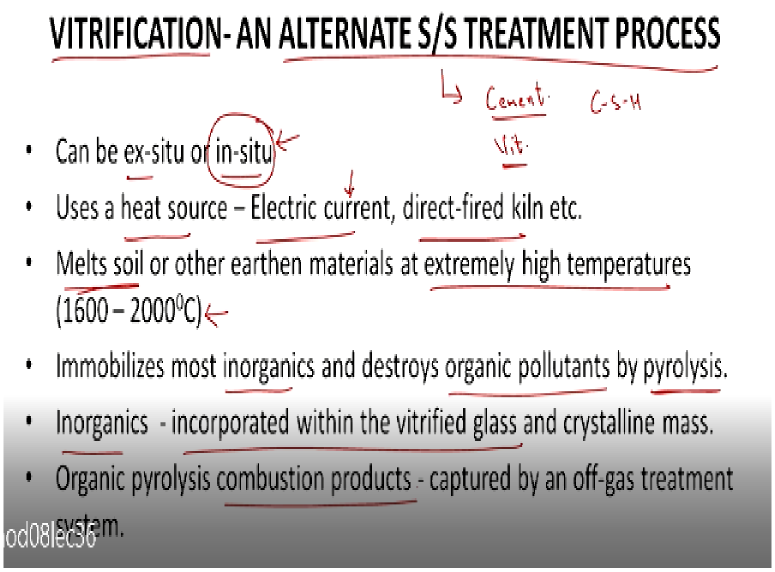


So one other what do we say we have solidification stabilization is vitrification though I do have that as an alternate solidification and stabilization treatment process. So typically there are two kinds of let us say what are they two kinds of solidifications stabilization Cementous where I am adding cement or trying to form the CSH matrix and the other one is vitrification right and what did the solidification about it more or less.

You provide enough heat say that the sand let us say that you have in your particular mixture let us say is going to melt and then once it cools down its going to form a kind of a glassy material and as it cools down its going to encompass like let us say right encompass pardon me everything that is in within that particular study. So what do you need obviously you need sand and you are going to apply considerable amount of heat?

And let us say you are going to meld the sand and while it hardened cools down and hardens you are going to have a glassy kind of a material form that is going to encapsulate all the relevant contaminants. But obviously you need to put in considerable high concentrations of your not concentrations considerably high temperatures so thus cost is going to be relatively high and application is typically for let us say a radioactive waste and so on and so forth. Let us look at some of the other aspects.

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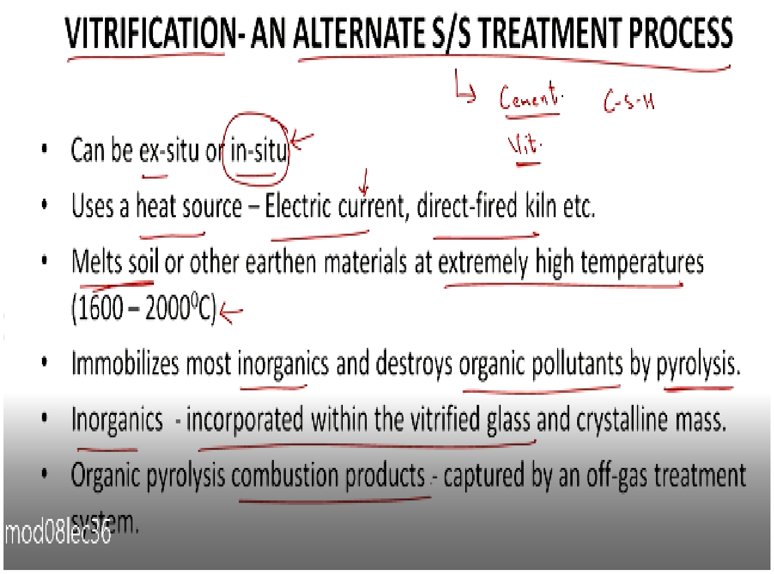


So here obviously can be ex-situ or in-situ but typically verification as good choice of ex-situ is not feasible and you are looking at in-situ techniques right you need a heat source can electric current direct fired kiln etc typically use in-situ right and then obviously I will say it is not I do say soil here its typically sand right typically soil or sand pardon me at high temperatures as you can see you need to maintain or achieve pretty high your temperatures right

So it immobilizes most inorganics and depending upon the type of organic pollutants they can be destroyed by pyrolysis right and in organics as I mentioned will be incorporated within the vitrified glass you know as this particular mass cools down you are going to have that incorporated within it right. Organic pyrosis combustion products if they are wall tyre or such an off gas treatment needs to be a required right.

And so again depending upon the site conditions and depending upon type of contaminant you can go for vitrification right.

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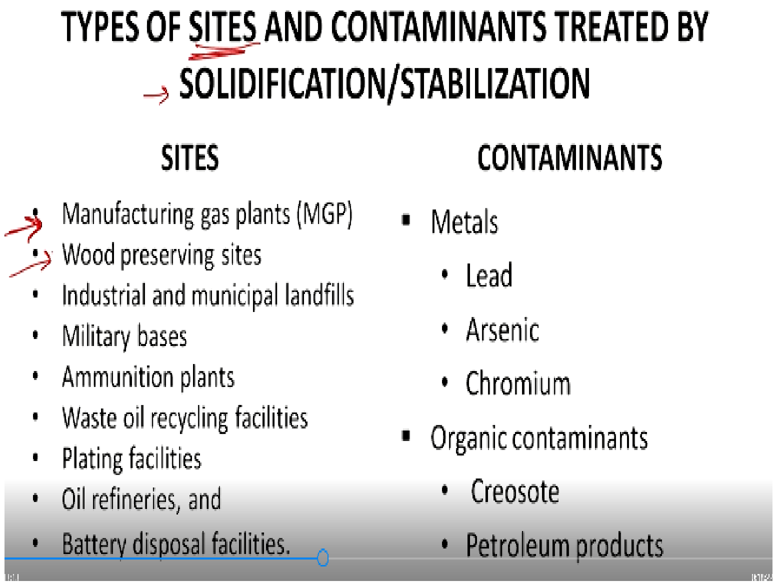


So let us move on so different types of sites that have we typically are typically what do we say remediated by solidification stabilization right let us look at what they are manufacturing gas plants widely in India maybe because its well too less initialize maybe not a lot but yes so but in India we face this a lot wood preserving sites let us see right our wood treatment sites and so on, certainly industrial and municipal landfills that is a great aspect.

Military bases too because of the type of ammunition or the firing ranges that you have let us say you know typically we find applications of solidification and stabilization plants there in the military bases and the ammunition plants certainly oil recycling facilities or even electro plating facilities or industries where you have heavy metal let us say contaminating relevant soil plating facilities and oil refineries and battery disposal again heavy metals and so on right.

So what are the typical contaminants that people tried to remediate right what are they typically metals mostly metals and we have lead arsenic and chromium looting the list but obviously depending upon type of heavy metal you can have most heavy metals let us say or if you have a site like Moradabad the one that we discussed when we were looking at excavation right what did we have people who are trying to extract heavy metals from this waste right.

And you now have a soil contaminated with relatively high concentrations with different kinds of so what do we say different heavy metals right. So in that case obviously what is the one pretty decent way to go about remediating that particular site its solidification and stabilizations as in I believe that the regional office in there they asked me what are the relevant options such that you know he cannot put in a lot of money.

He cannot really you know see to it that heavy machinery comes in or such a remarkably heavy machinery comes in or exit to is not a great option for him right he wanted something in-situ. So in that context maybe solidification and stabilization is one particularly good way to go about things right again more on that later. So organic contaminants let us say typically petroleum products and by parts during distillation and so on so again different contaminants and sites.

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**EFFECTIVENESS OF SOLIDIFICATION/STABILIZATION ON GENERAL CONTAMINANT GROUPS FOR SOIL AND SLUDGES**

| Contaminant Group | Effectiveness |
|---|---|
| *Organic* | |
| Halogenated Volatiles | ▲ |
| Non-halogenated Volatiles | ▲ |
| Halogenated Semivolatiles | ■ |
| Non-halogenated Semivolatiles and Non-volatiles | ■ |
| Polychlorinated Biphenyls | ■ |
| Pesticides | ■ |
| Dioxins/Furans | ● |
| *Inorganic* | |
| Non-volatile Metals | ■ |
| Radioactive Materials | ■ |

■ = Demonstrated Effectiveness ▲ = No Expected Effectiveness ● Potential Effectiveness

Source: Technology Performance Review: Selecting and Using Solidification / Stabilization Treatment for Site Remediation ; Barnett et al.

So, as you see the effectiveness obviously of solidifications stabilization depends upon the kind of the soil or the media and the type of contaminant let us look at what we have here so we have here that you know this is from the technology performance review again typically EPI or ITRC publish this. So, selecting and using solidification stabilization treatment for remediation let us so you can look at these technology documents.

Let us say to be able to understand the applicability of your particular or a applicability of solidification stabilization pardon me to your particular site right so we have let us see cases where the effectiveness was already demonstrated and also cases where no effectiveness is expected and where let us say no it is not been demonstrated but we have a literature available through research let us say that says it is a potential candidate

So, let us look at the demonstrate the effectiveness and obviously as we discuss the real for in organics right it is widely used and demonstrated so non volatile for metals and radioactive materials solidification stabilization is a great way to go about remediating contaminated site obviously depends upon the extent of contamination the depth and so on and so forth right so for let us say again for PCBS right.

PCBS again we have we have a lot of them and contaminating the relevant Moradabad site PCB again from EVS so again a good way or good particular technique there for remediating this soil would be solidification stabilization whereas we have our wide variety and we have heavy metals we have PCBS and so on and so forth and even for sites with pesticides I think we have a case study coming later on and semi wall tiles or non wall tiles.

Obviously it should be relatively non volatile or semi volatile so relatively less to know the efficiency let us see it would be for volatile compounds right and maybe for dioxins again present at your particular Moradabad site it is a potential effect units but depending upon the binder and such we need to obviously understand the relevant site before you know being able to do what do we say confirm or deny such effectiveness let us see.

So, again what do we have typically for metals pretty good for PCBS also pretty good right and obviously for volatile compounds which would prefer to stay in the gaseous phase rather than in the acquiesce phase or not solid for me acquiesce phase let us say obviously you want to have not you want a have solidification stabilization is not a great way to go about it right.

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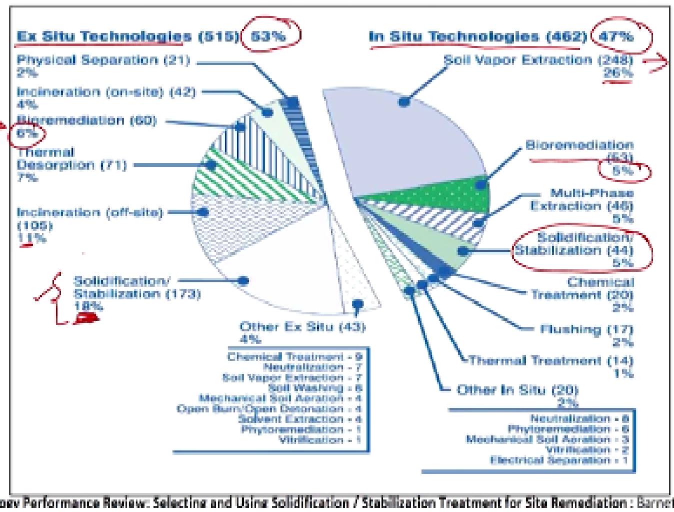
## SOURCE CONTROL TREATMENT TECHNOLOGIES




hnology Performance Review: Selecting and Using Solidification / Stabilization Treatment for Site Remediation : Barnett et al.

So, let us move on so here this is one good document and not document pardon me a picture or a pie chart I want to look at so here we have source control treatment technologies again from EPI or the relevant technology performance review right selecting and using solidifications stabilization treatment for site remediation so first let us understand that actually ex-situ technologies and in-situ technologies.

Typically, ex-situ are relatively more favoured and in-situ relatively less but still you know they are both neck and neck and within ex-situ you see there are a lot of them but as you can see a majority of it would be by solidification and stabilization within ex-situ even with in-situ we will have solidification stabilization as you can see but to be less what do we see a wide use that the adapter now right since we are looking at this particular pictures.

Also let us try to look at some of the other aspects that we have already looked at for example, bioremediation has looked at 5% let us say again obviously within in-situ chemical treatment on such we are going to look at that later so let me not come back to that here right what else have you looked at let us say again obviously only solidification and stabilization and so on again bio remediation off site.

Again relatively less percentage right so again as we can suit typically we see that solidification and stabilization is remarkably widely used look at the you know what did we say its pre eminence here all the others are at maximum is 11% here right and I think more or less that is it maximum is small as that soil very protects traction as we discussed in terms of in the context of a national education.

We are going to discuss this later against soil vapor extraction right so obviously the component is relatively more water than you can go with the soil vapour extraction and such but its obviously again an in-situ to take right so that we are going to come back to that so solidification and stabilization remarkably widely used right so let us move on so here we are just going to look at a few sites are a couple of sites.

And then on to a relatively more detail with respect to the how to go about solidification and stabilization and workout a particular practical problem and then we look at a few case studies but for now let us see well just look at a couple of sites pardon me to understand what goes on.

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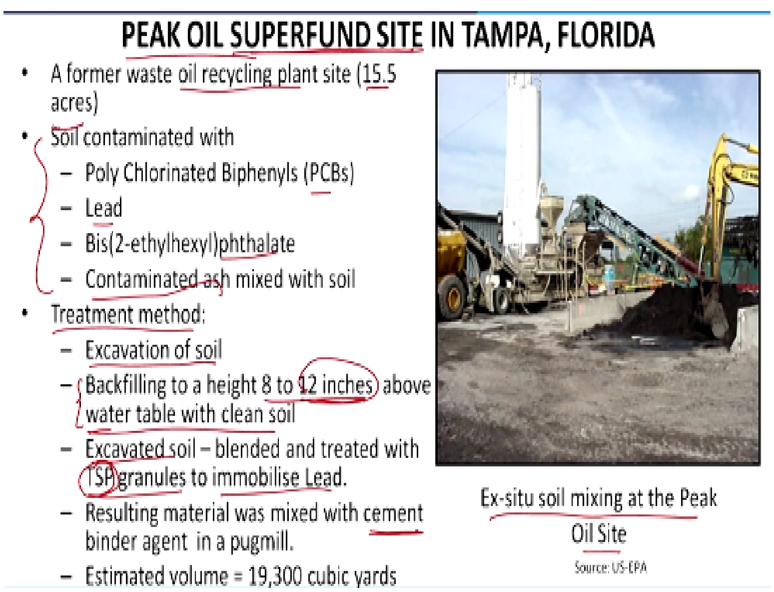


So, here we have a superfund site superfund is how they classify based on the level of cleanup required let us say and the US, they classify some sites as superfund sites anyway a peak oil superfund site and in Florida right again ex-situ soil mixing at peak oil site right ex-situ anyway so what do we have here so it was formerly a waste oil recycling plant and here we have an area of 15.5 acres right and then again as is the case with such sites.

You have the containment with the wide variety of contaminants what are they PCB heavy metal pilot's plasticizers and contaminant ash too right so we have different kinds of what we say compounds here are contaminants so what is the treatment method that they have followed itself the remediation techniques, pardon me, so they excavate the soil and then also backfill or put back some decent or the non contaminated soil let us say to height of 8 to 12 inches.

One inch or 12 inches means I guess it is one foot above the water table with clean soil first they excavate the soil to that particular contaminant zone and then put back let us say not put back put in fresh soil and contaminated soil so that it does not obviously disturb the ground water table I guess so that is why they are putting in putting it to in to such an extent that its one foot above the water table.

And then excavated soil blended and treated with granules to immobilize the lead okay and then again this is an add mixture right and then resulting material was mixed with cement which is your binder in a mill pug mill more or less what is the volume as you can see 19000 cubic yards and say one yard is approximately a meter so 19300 meter cube constable volume again right so let us move on.

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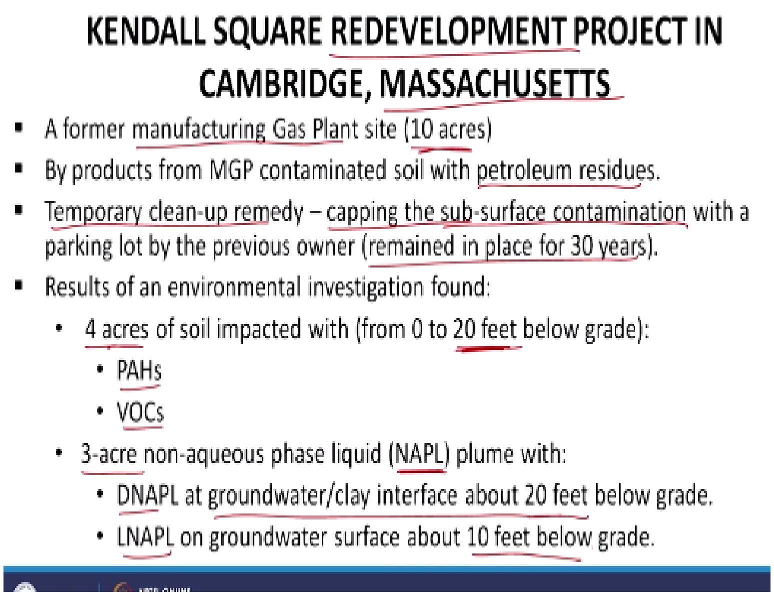


So, here we have another site a redevelopment project and Massachusetts right again why did I choose these sites so I guess just to be an overview or let us say we are going to get case studies but typically I did not find enough data in the Indian context that is why we are looking at these sites anyway right so now we have a manufacturing gas plant and that is around 10 acres and by products right again with petroleum residues.

And what was the temporary cleanup this is something that we discussed earlier it was capping the subsurface right the capped it right for example let us say I know they just capped it as containment they are just trying to contain the what do we see a contaminant they do not want the contaminant to be transport dory at wider areas so the temporary cleanup remedy was just capping the contamination right and that was in place for 30 years looks like.

And then after the relevant investigation they found that 4 acre of soil was contaminated from for up to 20 feet up to 20 feet right you know one foot is around 12 inches right three feet is typically what do we say a one meter right so here we have almost 7 or 6 meters deep contaminated a zone here right aromatic hydrocarbons water logged going to carbons and also 3 acre NAPL something that we looked at non aqueous space liquid.

And the context of groundwater contamination so again we had the DNAPL at groundwater and clay interface for about at about 20 feet and LNAPL on groundwater surface around 10 feet below the grade right so DNAPL is a dance a non aqueous phase liquid so obviously that is why you would expect it to go further down and LNAPL is closely relative so that is where it is a relatively higher the not elevation here compared to the DNAPL it is higher location right.

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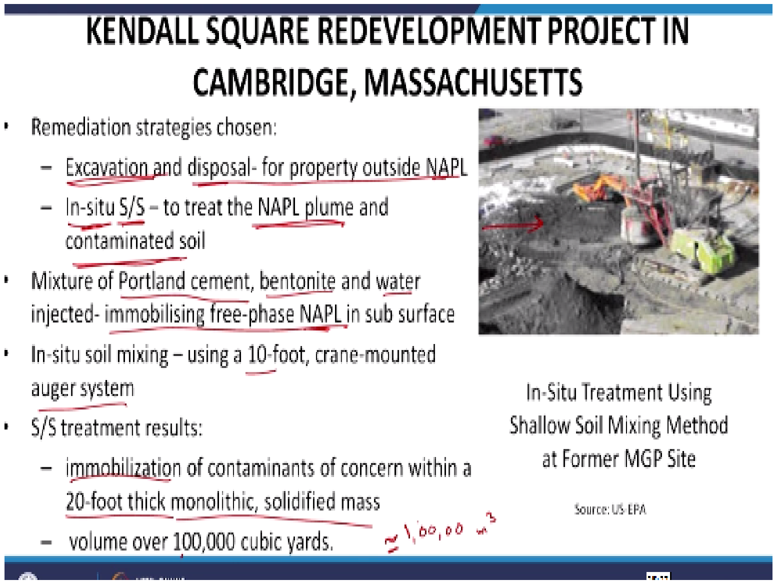


So, that is what we have here let us what people have done right so excavation and disposal outside NAPL and in-situ solidification stabilization to treat the NAPL plume and contaminated soil right so excavation and disposal for the outside the NAPL for NAPL outside the property pardon me and in-situ for to treat the NAPL plume and the contaminated soil right so that NAPL that they could capture they were trying to excavate that and take it out.

And the contaminated plumes where you know NAPL is already throughout your particular or has been diluted but as spread over a wider extent obviously as you know pumping and treating it out or such is an issue maybe bioremediation could have been carried out so there but they went for solidifications stabilization institute right so what else have they been up to so what did they look at they looked at Portland cement bentonite clay and water is injected.

So, thus immobilizing the NAPL in the surface subsurface what they do cement clay and water right again trying to solve more or less and thus obviously in this process of solidification you are also stabilizing the relevant material which is NAPL in the subsurface right and how they do that obviously as you can see here this is a picture from the relevant side using a 10 foot crane mounted auger system.

You know the auger system I guess right and based on that you know while the churning it and they also injected the relevant binder here right so what do we have here we have a immobilization of contaminants up to 10 foot thick monolithic solidified mass it is monolithic now right up to 20 feet and then volume as you can see as almost 1 lakh meter cube right that is a remarkably high volume as you can see its almost equal to 1 lakh meter cube.

Based on our information that 1 yard is more or less equal to a meter at 1 lakh meter cube so you understand the extent of sites that are remediated are typically remediated by your particular solidification and stabilization right so let us move on so what are the aspects.

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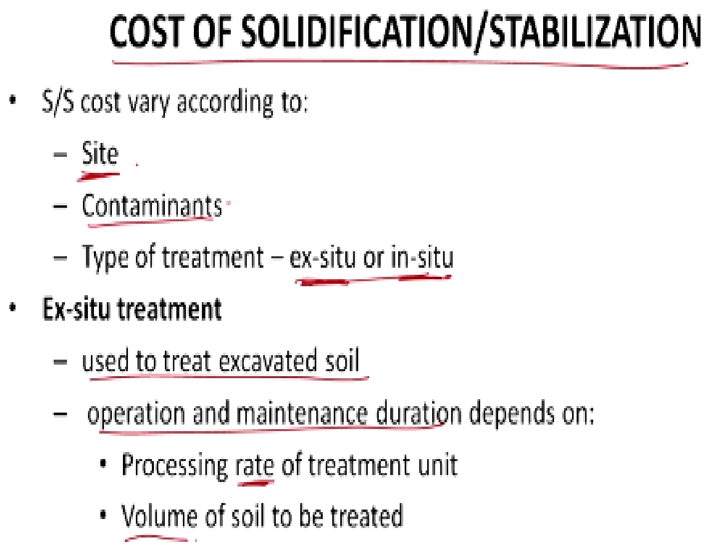


That affect the cost of the solidification and stabilization obviously the site the bigger the site obviously you know it is going to be affect the relevant cost the type of contaminant based on the type of contaminant right you will also have to choose whether it is feasible for in-situ or you need to go for ex-situ but obviously I do have seen and the relevant pie chart most of the times we have to go for ex-situ to the right.

Site contaminants and the ex-situ or in-situ they obviously play a role so if it is ex-situ treatment it is use to treat excavated soil so you are going to take out this to particular offsite location and then you know add the relevant admixture or binder and then treat it and dispose so and then again the operation and maintenance obviously depends upon the rate at which you can process your particular system let us see or the contaminated media now.

And obviously the volume of soil as we saw earlier I think we looked at 10 to the power of 5 meter cubes of soil that is more or less an average not average but still slightly above average volume of soil to be treated let us see obviously site and type of contaminants right and site meaning that more or less we typically look at the amount of binder that to be added here right

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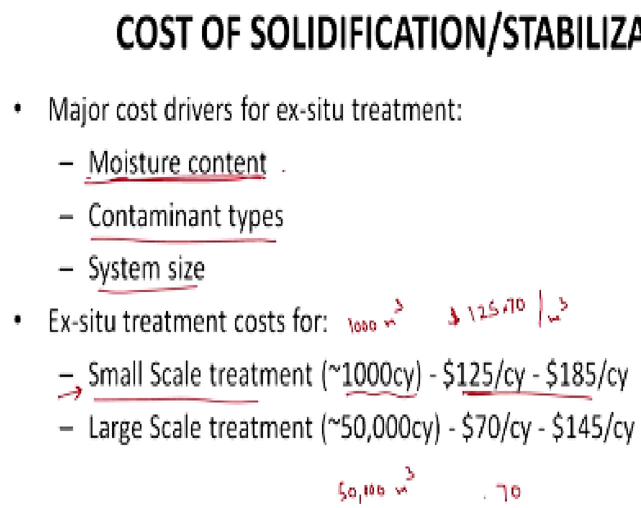


So, here what are the major cost drivers for ex-situ so if the moisture content is relatively high you know that is an issue right the greater the moisture content let us say the greater the relevant what we see a treated material is going to be more permeable pardon me permeable and also the greater the chances that let us say your contentment is more mobile and so moisture content is an issue.

Type of contaminant because then you need to choose your admixtures accordingly and also the size of your particular system but I for example, it is here for a hundred cubic yards let us say when I say small scale treatment it depends upon a hundred cubic yards let us say here 1000 meter cube that we are clasping as small scale treatment large scale is 50000 meter cube around 50000 so as you can see the costs are around 125 dollars.

So, into 70 rupees now maybe 75 per meter cube right to depending upon the site obviously again a right we have 70 dollar per meter cube I guess it is the matter of scale that is why the cost is slightly coming down for large scale treatment per unit but obviously the total cost is obviously going to increase right so let us move on.

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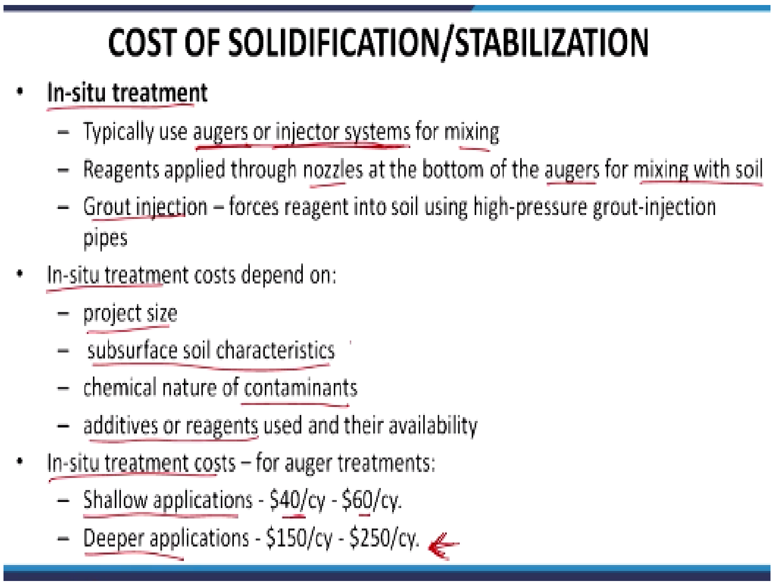


So, what else do we have an in-situ treatment though typically we use augers or injector systems and nowadays you India we have our particular systems are a construction techniques are such are pretty advanced you know the so these kinds of construction techniques or pieces of equipment are not an issue so we use augers or injectors systems for mixing and then reagents are applied through nozzles.

Again this we looked at maybe in the context of PRB when or the permeable react to barrier when we were injecting I believe fine slurry off zero ware and tire into the subsurface right reagents can be applied to nozzles at the bottom of the augers while the mixing is done with the soil right or again in grout injection we would go into that in great detail so obviously a treatment costs institute what we depend upon project size.

And what are the characteristics of the relevant soil again moisture content and so on and so forth the type of the contaminant again and thus additives or reagents used and so on so forth institute what are the costs are obviously you see the costs are relatively lower but only when they are shallow applications but when they are deeper obviously different kinds of techniques need to be used and thus as you see the cost is relatively high.

So, it depends upon the type of subsurface or the subsurface soil characteristics and the extent to which are the depth to which the contamination has taken place right so with that I guess I end todays session because we are running out of time so in the next session let us say we are going to look at some of the more technical aspects that we need to consider when looking at solidification and stabilization.

As in let us say how particular waste and I have waste to be contaminated with many heavy metals let us see how do I know which PH to maintain because typically at particular PH you know the solubility of these heavy metals is less right so I need to maintain a high enough PH even when I conduct the TCLP test on this waste the heavy metals will not reach out I say but as we know at one particular PH right.

There is no one particular PH at which all the heavy metals are going to be pretty low so it is a balancing act so you need to first choose the PH and then you need to also differ depending upon that you need to look at how much cement to add how much fly ash to add how much water to add and how much of the waste I guess the fractions of these right? So we are going to look at those calculations and so on and I guess with that I will end today’s session and thank you.