Ground improvement
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Module No. # 09

Lecture No. # 39

Microbial Geotechnology and Ground improvement

In this lecture, I would be talking about emerging aspects in microbial geotechnology and ground improvement. this area of geotechnology where you are trying to improve the ground using the microbes, has been something that people have been perceiving in the research and I felt that some of the advance topics also need to be understood in this area of ground improvement.

Because in this ground improvement area we have lot of traditional techniques that we discuss in the course so far and also the emerging techniques like this, and many emerging applications as well which are suppose to be very sustainable.

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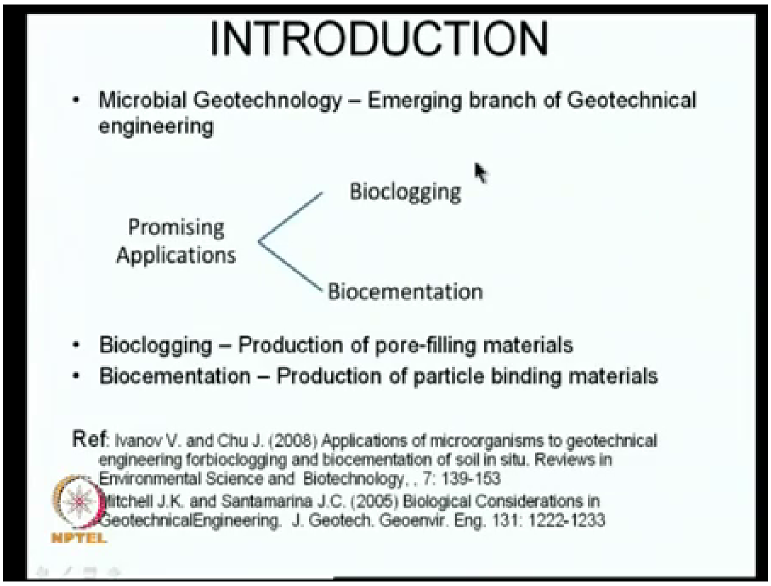

And In this talk, I would be talking about the applications as I just mentioned you have this microbial geotechnology something that has come that is emerging in the recent times and I would be talking about two applications namely bioclogging and biocementation.

Bioclogging is nothing but, the you know you are trying to produce pore-filling materials for example, in sands the permeability of the material is going to be high, but if you by introduction introduction of this bacteria if you are able to have some clogging, then the permeability of the material comes down, as a result the seepage losses are also going to be less and it is going to be more stable.

So, this is an interesting application and normally we use clay in the case of if you want to reduce the permeability of sand and but then both this when clay is not available or you know it or it is a you know more a sustainable material to use bioclogging.

The second thing similarly is that, you trying to introduce cementation -normally we use cement in the case of some materials to introduce cementation in the form of bonds but, if you are able to get the same cementation effect using some sort of bacteria then it is going to be very nice.

So, you are trying to introduce this concepts of bioclogging and biocementation which is something that they are like, we say we can say that they are more sustainable technologies because bacterias are always available in nature and at the same time you are able to have a good advantage of this materials.

there is some you know at the reference for this work actually i must draw from the papers of ivanov and chu who have particularly chu has been working in the area of ground improvement a lot in this area and he has contributed significantly and this is a paper from one of the journals of environmental science and biotechnology.

And ,they thought for some of these ideas have been articulated by professor mitchell who is an authority in the area of soil behaviour and santamarina who is also a professor in the j geotech these two professors have lot of vision and they use of biomaterials or bioclogging or biocementation or use of biotechnology in the year of geotechnology.

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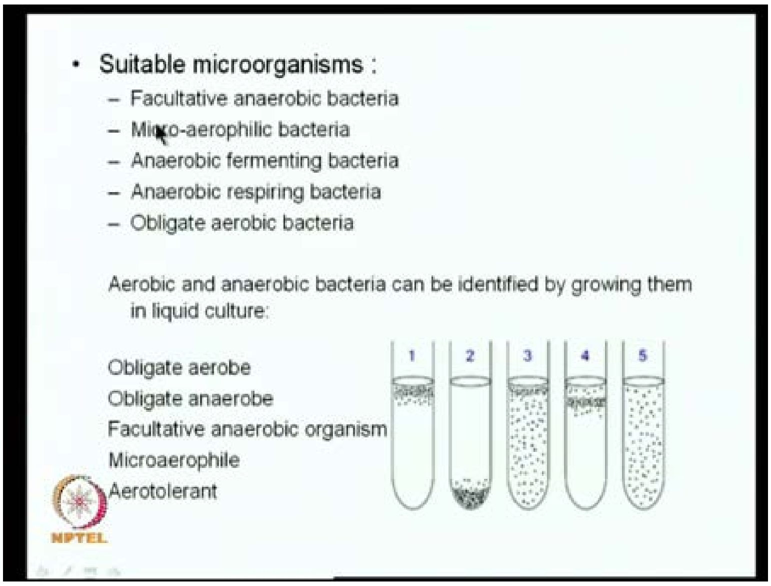

This is what it is and in this connection we need to identify suitable microorganisms. They are of different types one is facultative anaerobic bacteria I mean Facultative anaerobic bacteria ,micro-aerophilic bacteria, anaerobic fermenting bacteria anaerobic respiring bacteria obligate aerobic bacteria there could be different times in fact it is said that the the billions of bacteria that will present you know the count is so much that you know it is an unexplode area in the area of biotechnology.

Ah what are all these means may be from engineering point of view I would like to just make some simple differentiation- it is said that aerobic and anaerobic bacteria can be identified by growing them in a liquid culture- for example, if you take a tube and then leave them and the possibility is that if the bacteria needs oxygen or there they survive more in oxygen they come up so that is what I meant by aerobic bacteria but, then if they go down away from the water then you can say that it is another big bacteria.

So, then there could be some bacteria which is called facultative they can be everywhere in general and you know they are resist they they are generally occurring then the other one was that that is what it means that, they do occur in general and particularly in anaerobic conditions.

And then micro-aerophilic bacteria what it means is that, they are more towards attracted towards this is particular one you know this is a first one corresponds to obligate aerobs obligate obligate anaerobes and then the facultative anaerobic organisms could be like this- micro-aerophiles they they are close to they want the presence of air sometimes another one you have aerotolerant one.

So, one can understand that the suitable micro organisms that one can have in soils are that like facultative anaerobic bacteria, micro-aerophilic bacteria, anaerobic fermenting bacteria, anaerobic respiring bacteria, obligate aerobic bacteria.

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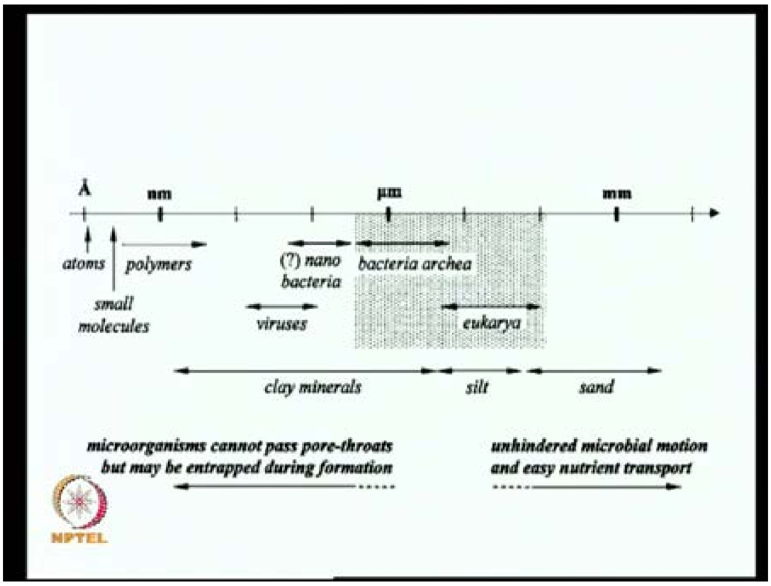

So, there are some of these listing is given and one should have a look at what the size of the bacteria is people are aware that these are all very very small size living matter and they have one can say that the range is in terms of the mm's to micro meters to even nano meters people are even questioning do you have nano bacteria.

So, definitely you have a bacteria of a very small sizes in the range range of mille meters to micro meters and and if you look at the scale you know in terms of mille meters, micro meters and nano meters and some of the atoms and polymers and molecules do come here but, when you are trying to use with soil you should understand the grain size distributional and particle size in soils.

So, definitely the clay minerals have certain like say for example, seventy five less than 70 microns we can call them as clays and you have silt and sand materials so definitely there is some sort of relationship you know one can definitely you know the size of the bacteria is somewhat compatible with the sizes that we have.

And one can really look at this, as a means of understanding the interaction between clay minerals in the bacteria- so, if you look at this size you know the size beyond this particularly so this area corresponds to silts and sands and here what it means is that unhindered microbial motion and easy nutrient nutrient transport so the it is going to be quite affective but, if you want to the size is going to be very fine, micro organisms cannot pass pore throats but, may be interrupt during formation. So, if you want to use it properly so you need to really distinguish these two, that the size has a big role in understanding the use of bacteria in soils.

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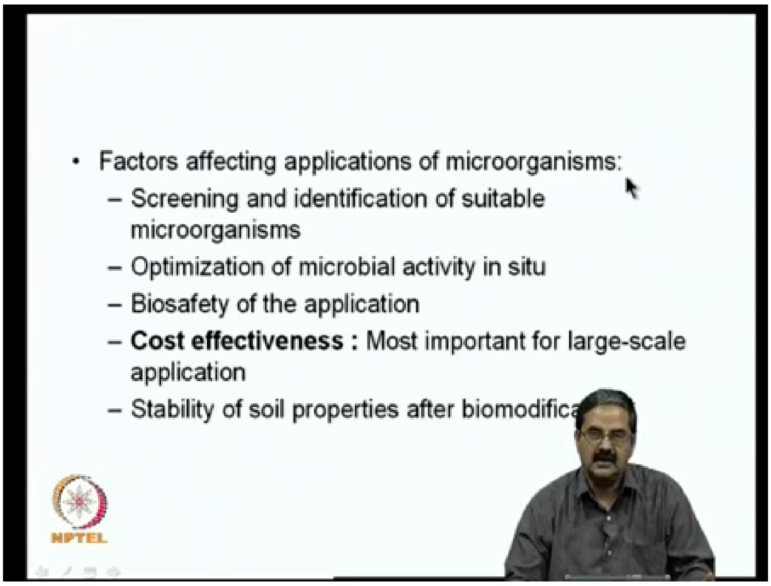

What are the factors that affect the application of micro organisms -the first and foremost thing is you must be able to screen and identify suitable micro organisms you know there are too many.

And you must be able to identify the right ones for the right purpose- optimization of the microbial activity in-situ when you are trying to apply in the field there are so many variables and you need to put the right quantity so that you have that effect obtain.

Then bio safety of the application, is something that is also very important like safety is an issue particularly when you are trying to deal with bio materials and it should not lead to complicated problems like viruses and other things.

So, cost effectiveness is something that is very important that you should consider for large scale applications may be for laboratory studies and extra self studies it is all that but, then when you are looking at large scale applications one should see that the what are bio material or the technique that you have got one needs to be cost effective.

So, then you should also see the stability of soil properties after bio modification. so what happens to the soil properties after you modified them with bio materials bacteria so the factors affecting the application of microorganisms are you know you need to really understand that you have a couple of issues here and see that you there satisfied to get the maximum effect of these materials.

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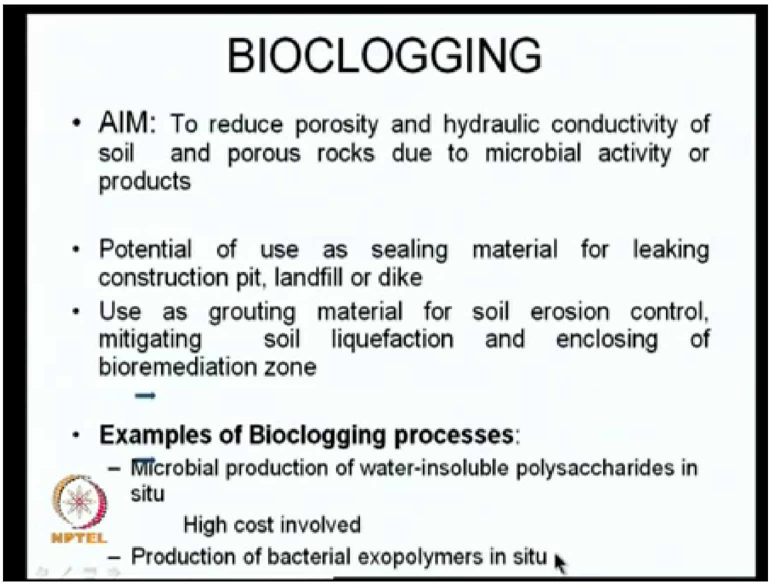

I would just mentioned about bioclogging the bioclogging is something here is to reduce porosity and hydraulic conductivity of the soil and porous rocks due to microbial activity of products- so it is where do you use it its use is to use as a sealing material for leaking construction pits, landfills or dikes you know wherever there is a leak definitely the porosity is more and you would like to reduce a leakage so you put this by clogging.

Then, there are some cases where use as a grouting material for soil erosion control migrate, mitigating liquefaction and also enclosing of bioremediation zone- so what it means is that you can use this materials as for bioclogging ,so similar to use as a grouting material grout material can be used for you know mitigating liquefaction and also of enclosing of bioremediation zone.

So for example, you have a bioremediation zone you need to be contained in a particular area you do not want you want to isolate the area from the next or available areas so you you can use bioclogging.

Examples of bioclogging could include microbial production of water insoluble polysaccharides in-situ and of course, it involves high cost production of bacterial exopolymers in-situ and this is another thing so if you just look at detailedly.

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Table 1 : Microbial Processes that can lead to bioclogging

Physiological group of microorganisms	Mechanism of bioclogging	Essential conditions for bioclogging	Potential geotechnical applications
Algae and cyanobacteria	Formation of impermeable layer of biomass	Light penetration and presence of nutrients	Reduce of water infiltration into slopes and control seepage
Aerobic and facultative anaerobic heterotrophic slime-producing bacteria	Production of slime in soil	Presence of oxygen and medium with ratio of C:N > 20	Avoid cover for soil erosion control and slope protection.
Oligotrophic microaerophilic bacteria	Production of slime in soil	Low concentration oxygen and medium with low concentration of carbon source	Reduce drain channel erosion and control seepage
Nitrifying bacteria	Production of slime in soil	Presence of ammonium and oxygen in soil	Reduce drain channel erosion
Sulphate-reducing bacteria	Production of undissolved sulphides of metals	Anaerobic conditions; presence of sulphate and carbon source in soil	Form grout curtains to reduce the migration of heavy metals and organic pollutants
Ammonifying bacteria	Formation of undissolved carbonates of metals in soil due to increase of pH and release of CO_2	Presence of urea and dissolved metal salt	Prevent piping of earth dams and dikes
Iron-reducing bacteria	Production of ferrous solution and precipitation of undissolved ferrous and ferric salts and hydroxides in soil	Anaerobic conditions changed for aerobic conditions; presence of ferric minerals	Prevent piping of earth dams and dikes

In this table of course, it may not be visible but, one can read form you know read the original papers ah you in this table you know there are different different items mentioned one is physiological group of the microorganisms.

What type of groups they belong to say for example, algae, aerobic and facultative by anaerobic bacteria then oligotrophic bacteria, nitrifying bacteria, sulphate reducing bacteria, ammonifying bacteria, iron reducing bacteria there are many types of bacteria and I must confess that one should have a good knowledge of the biotechnology or microbiology here and it is always better to interact with the microbiologist who understands your requirements and also the you know help in the experimentation at laboratory scale, to see what effect they have in the actual response of the soil.

When you have so many types of bacteria then, the mechanism what is that mechanism that one can have the mechanisms of bioclogging could be a few, like in some cases it could be formation of impermeable layer of biomass like a formation of impermeable layer of biomass is formed.

Then there is a production of slime in the soil and the production of slime in soil then production of slime you know ah precipitated matter production of undissolved sulphate of metals metals and formation of undissolved carbonates of metals in soil due to increase of ph in the release of carbon dioxide, production of iron or ferrous solution and precipitation of undissolved ferrous and ferric salts and hydroxides in soil.

So there are some various mechanisms that one should really look look at it in terms of the analysis and then you know look at what is going to happen and what could be the likely mechanisms when when when you have certain bacteria.

Then ,once you had certain bacteria the things is there are essential conditions that are required for effectiveness of this system- so you take a particular bacteria say for example, algae it needs light penetration presence of nutrients algae cannot grow without the presence of light and nutrients common example is algae growth in the lakes.

Then, aerobic and facultative anaerobic hydro bacteria presence of oxygen and medium with a ratio of carbon nitrogen more than twenty and then in some other places it could be low oxygen low concentrations in oxygen so nitrifying nitrifying bacteria presence of ammonium and oxygen in soil.

So some of these things have been mentioned here and one needs to understand that yes these conditions have to exist to have maximum benefit then you have this conditions like if understand this the you have the right bacteria and you also understand the mechanism that you can get then also the condition is satisfied.

The applications are there, you know so for example, there are few like if you are trying to have algae and this bacteria, it reduces the water in filtration to slopes and control seepage. That the other thing is, in some other bacteria where aerobic bacteria which are available avoid cover for soil erosion and control and slope protection so the advantage is that, it helps as a cover you know so slope protection is there reduce in some other bacteria like this where you have oligotrophic bacteria in this manner reduce drain channel erosion and control seepage.

The other applications are reduce drain channel erosion and so, for example, sulphate-reducing bacteria it has grout curtains and and many other things.- so if you have a ammonifying bacteria it prevents piping of dams and piping in earth dams so, me of these applications are mentioned.

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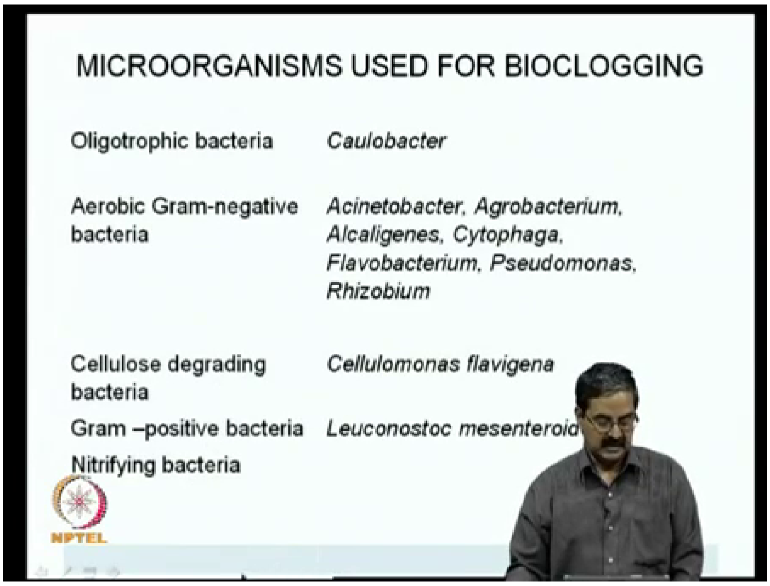

So, one should be I mean little more thorough in understanding some of these concepts we have some more microorganisms used for bioclogging you have been mentioned here like you can see here that you have number of candidate bacteria for geotechnical purposes.

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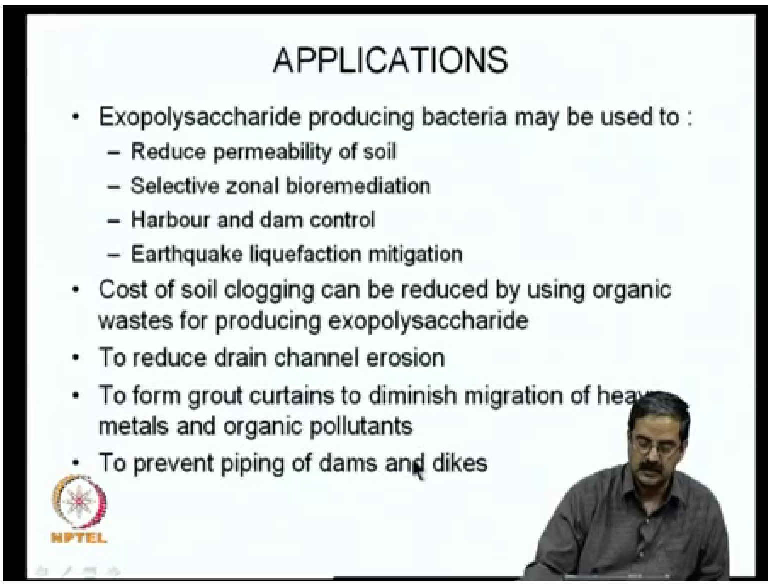

Some of the applications include exopolysaccharide exopolysaccharide producing bacteria you know this one of the products that you get ,you know if these material is there exopolyssacharide which is produced by bacteria it is useful in reducing permeability of the soil, selective zonal bioremediation, harbour and dam control, earthquake liquefaction mitigation.

Cost of soil clogging could be reduced by organic wastes for producing exopolysaccharides to reduce drain channel erosion, to form grout curtains to diminish migration of heavy metals and organic pollutants, to prevent so there are some

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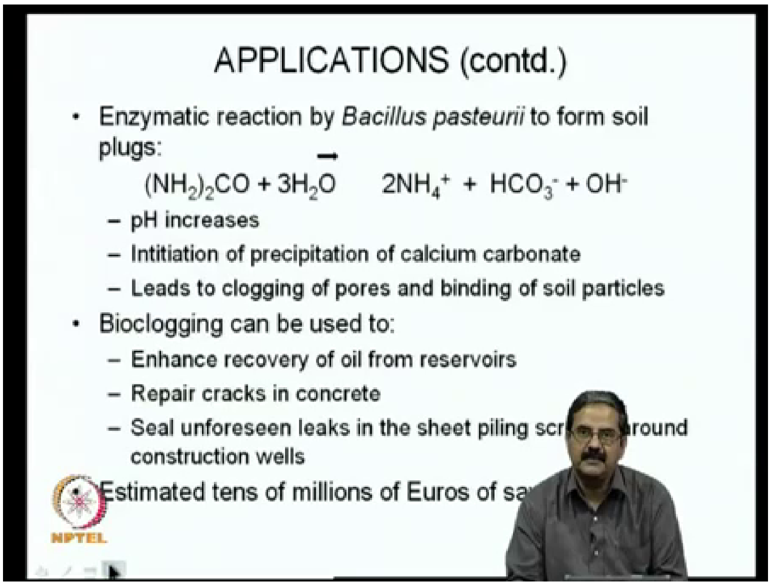

Applications mentioned a typical applications say for example, one should understand the reactions reactions you know the enzymatic enzymatic reactions. For example, using in the case of bacillus pasteurii to form a soil plug you know soil plug leads to reduction permeability- naturally soils have say for example, if you have a chemical reaction like this with you you can see that it releases ammonia and then hydro sodium say sodium bicarbonate and hydroxyls the effect is that it increases the ph it initiation of precipitation of calcium carbonate because in soils you have some amount of calcium and leads to clogging of the pores and binding of the soil particles.

So, the bioclogging can be used to enhance recovery of the oil from reservoirs repair of cracks in concrete, seal unseen unforeseen leaks leaks in the sheet piling screens around a construction wells and we will estimate that no the cost of growing bacteria is not significant compare to other forms of say for example, repairing of cracks with cement in concrete it is going to be quite expensive.

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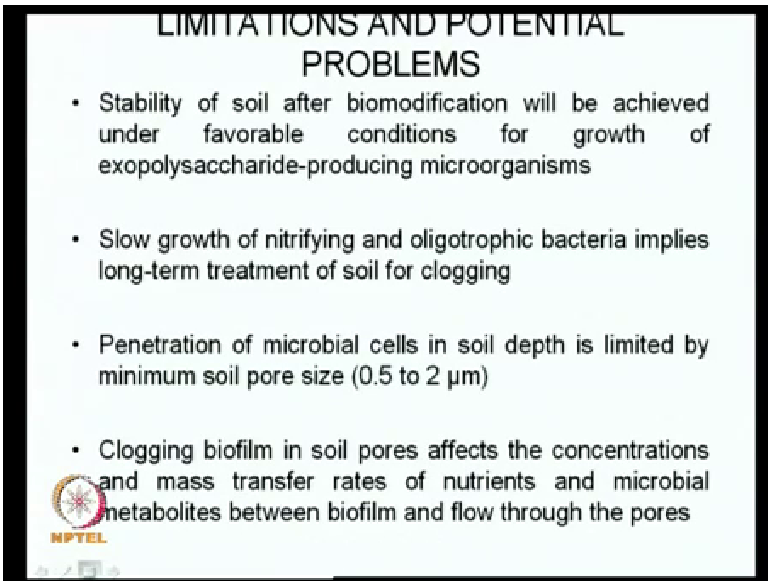

Whereas this bioclogging could be much cheaper so people say that it leads lot of savings in cost -one should also understand that once these are all as I said exploratory techniques and lot of research is required, people have been trying to look at it and definitely in the area of ground improvement the sustainability as become a key issue.

Ah for example, people you know in the if there is a the pile to be used pile needs a use of steel and concrete and then if you look at the quantity of steel and concrete that can be used in a project and you compare with a stone column and if they same both of them the same the of the same purpose say for example, load carrying capacity if you are able to design in such a way that, the load carrying capacity because of the piles is same as that due to stone columns definitely, the carbonic rates that you save or the weightage the carbon print print reduction is better in the case of stone columns.

But even stone columns need aggregates stone aggregates.- so if you have any means of reducing this stone aggregates it is very good and so like that and then if you are trying to use some bio say for example, instead of stone columns you try to use waste materials in the in the column structure and also try to contain them in some form definitely it will going to be cost effective or more sensible from environmental point of view.

So there are lot of issues and that is why I said people have been looking at these bioremediation techniques as well ,for improving the ground for improving the ground.

So, the stability of the soil after bioremediation will be achieved under favorable conditions for the growth of this exopolysaccharide-producing microorganisms microorganisms and there are certain things like you know it is not quick but, then it take some time and slow growth of nitrifying and oligotrophic bacteria implies long term treatment of soil for clogging, sometimes the bio materials needs sometime for reaction and favorable conditions are also there.

Penetration of microbial cells in soil depth is limited by minimum soil pore size as I just mentioned the size of the pores is quite important and fortunately I think you have bacteria for for every soil size. Clogging biofilm in soil force affects a concentrations and mass transfer rates of nutrients and microbial metabolites and between the biofilm and flow through pores- so this is an important point to be noted.

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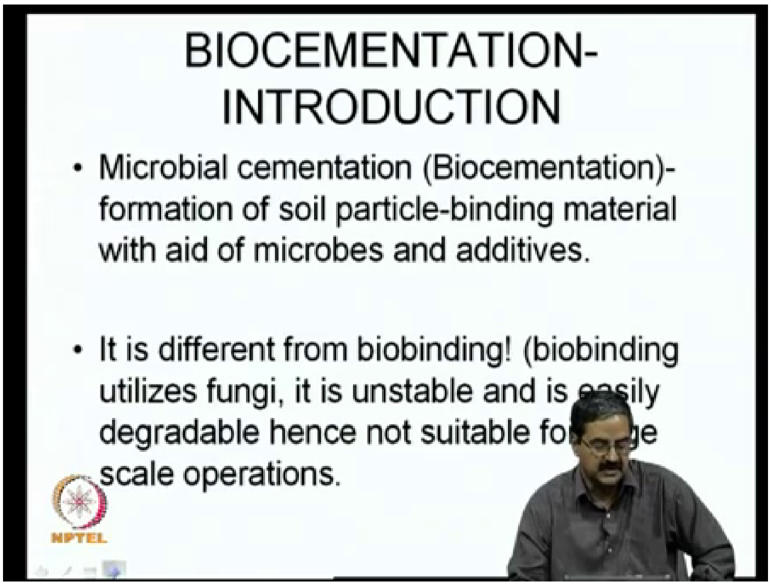

Now what is biocementation- so you have understood a bit of bioclogging where the permeability can be reduced, now what do you mean by biocementation biocementation is similar to you know you try to cement the particles so formation of soil particle binding material with the aid of microbes and additives additives so you are trying to cement the materials using this bacteria.

And there is small difference, people also use fungi in bio binding and it sometimes bio binding what they say is using fungi is unstable and is easily degradable hence would not not suitable for large suitable applications whereas, bacteria is seems to be much better.

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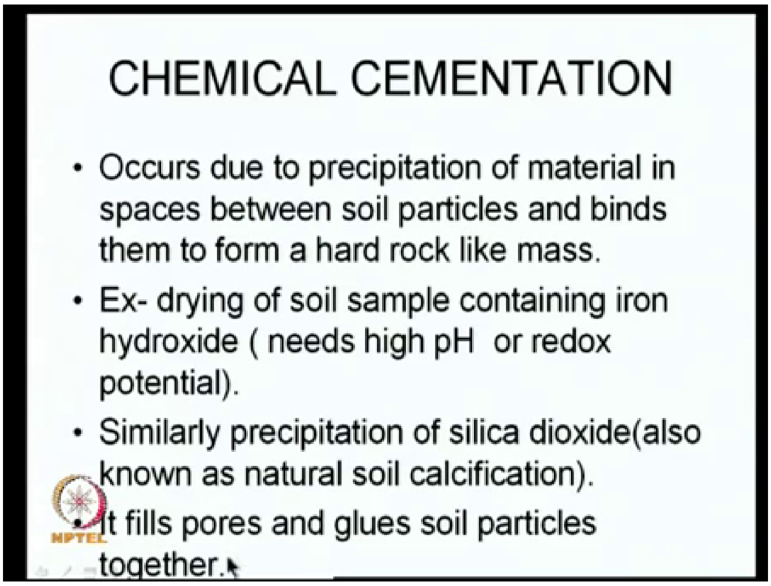

And in because of in the bio cementation processes you have the precipitation of materials in spaces between soil particles and binds them to form a hard rock like mass-for example, ex-drying of the soil particle containing iron hydroxide say for example, if you like to have a soil sample you know increase a strength of the soil containing iron hydroxide definitely bacteria treatment will help.

Similarly precipitation of silica dioxide actually these all this is also called as natural soil classification it also helps you know in ah cementation products it fills pores and glues soil particles together.

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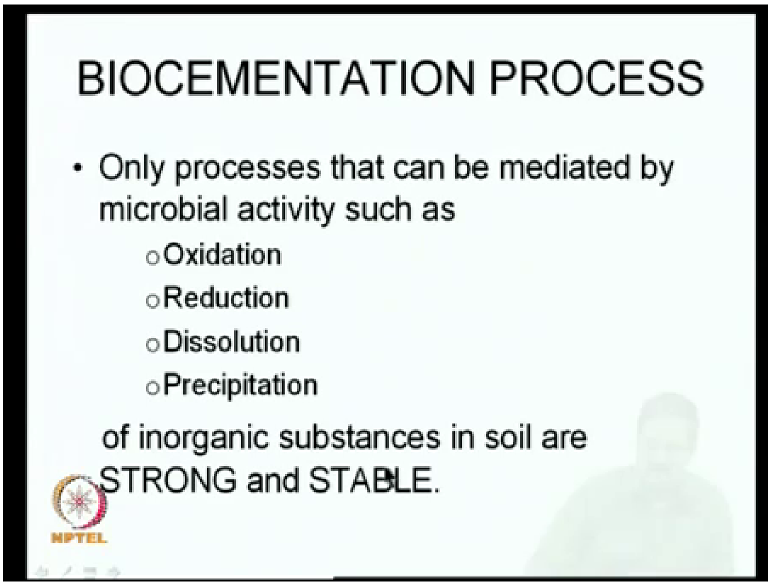

So, in the biocementation processes you have a a couple of activities like oxidation ,reduction, dissolution, precipitation of the organic inorganic substances in soil and they are strong and stable.

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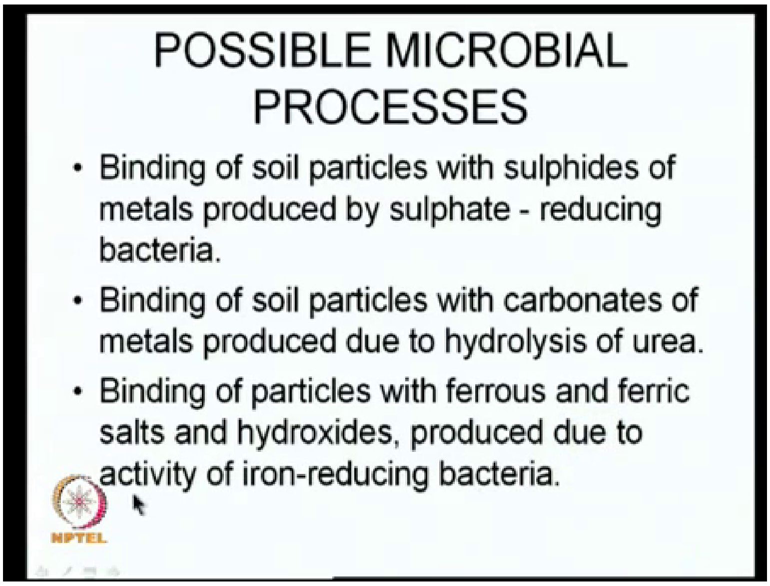

So, the some of the processes that we have in this thing is that what are the processes that you have in the case of ah cementation -binding a soil particles with sulphides of metals produced by sulphate reducing bacteria.

So if you have sulphate reducing bacteria so they release the sulphides of the metals and then they are useful in binding -so binding of the soil particles with carbonates of the metals produced due to hydrolysis of the urea.

Then, binding of particles with ferrous and ferric salts and hydroxides produce due to activity of the iron reducing bacteria.

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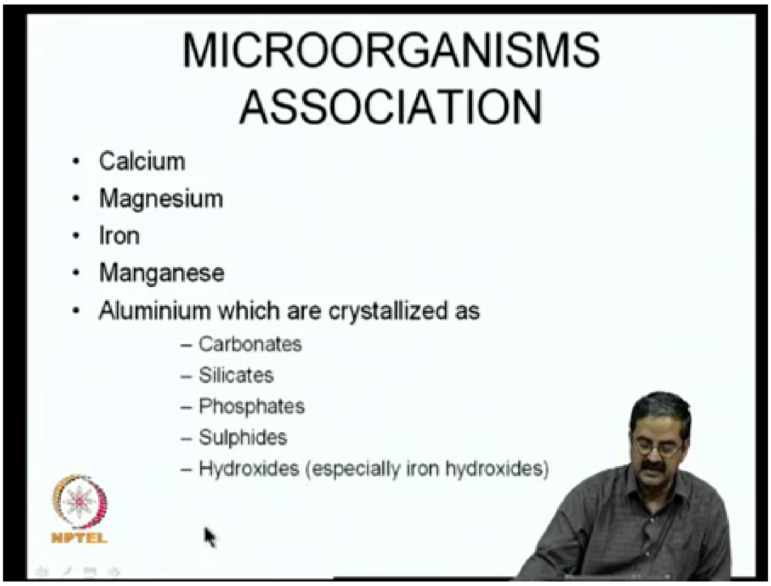

So you have couple of materials that are required here say they are quite helpful in the in the formation of cementation if you have calcium, magnesium ,iron, manganese and aluminum which are crystallized as carbonates carbonates, silicates ,phosphates and sulphides and hydroxides definitely the there is a possibility that you get good cementation.

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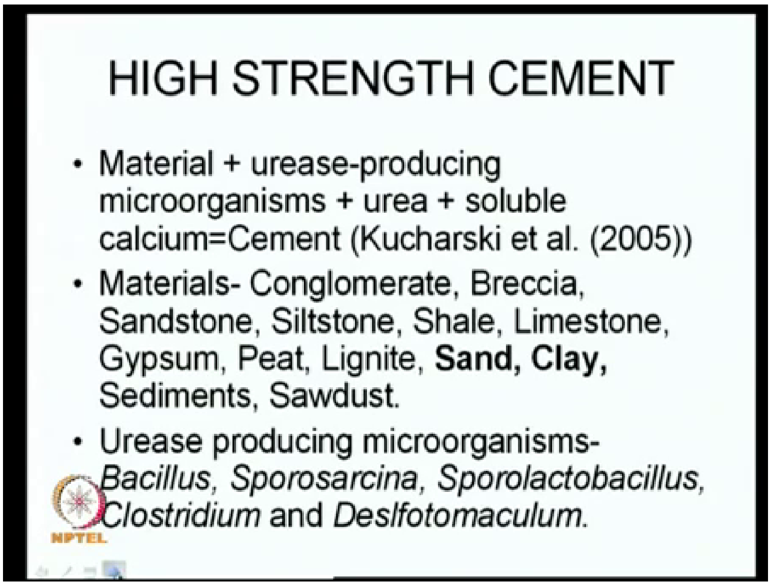

One can get good strength in the material for example, material plus urease-producing microorganisms plus urea plus soluble calcium it can lead to a cementing material you know there is a research done on this line like this is a urease is a material so which can be produced by the the microorganisms and that that leads to cementation.

So materials are nothing but, conglomerates, breccias, sandstone, siltstone ,shale, limestone gypsum peat ,lignite sand clay sediments and sawdust if you have some of these materials and you have urease-producing microorganism microorganism and all these combination definitely, it leads to high strength materials and urease-producing microorganisms are bacillus, sporosarcina, sporolactobacillus, clostridium and deslfotomaculum.

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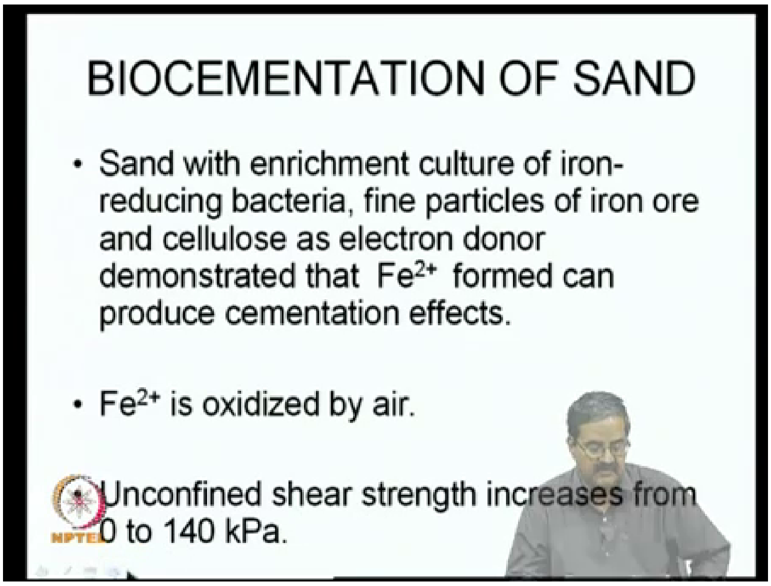

So of course the, I must we must know that it is not easy to remember these names but, I think as I said we need to help take the help of ah bio microbiologist or biotechnologist in this area to come out with meaningful engineering solutions.

Sand enriched with culture of iron reducing bacteria, fine particles of iron ore and cellulose as electron donor demonstrated that Fe plus two form can produce cementation effects so in fact they noted that the unconfined unconfined shear strength can increase significantly by big number.

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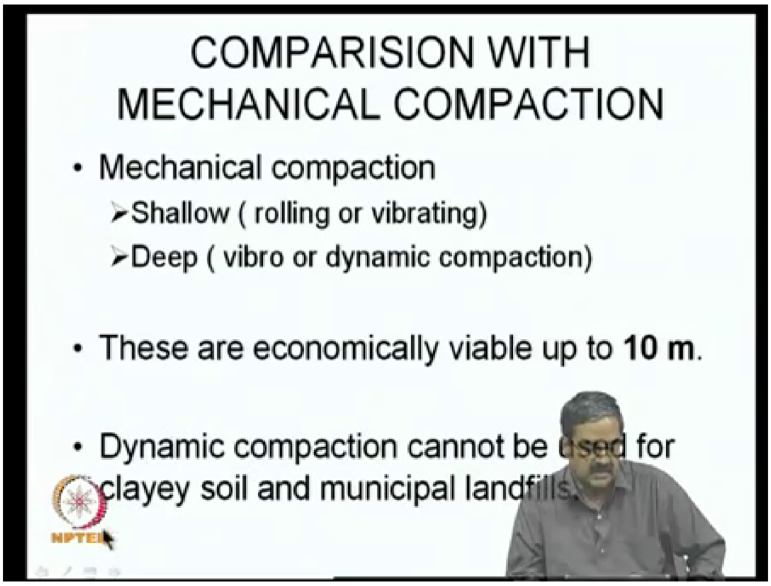

Then how do you really use it in a field, like you know the thing is that we know that you normally compact mechanical compaction is done as I just mentioned in the one of the earliest earliest lectures mechanical compaction is normally done using shallow it can be classified as shallow and deep where a in the case of shallow compaction use rolling or vibrating machines.

In the case of deep mixing or deep compactions you use vibro or dynamic compaction methods and these are economical up to ten meters deep and dynamic compaction cannot be used for clayey soil and municipal soil waste.

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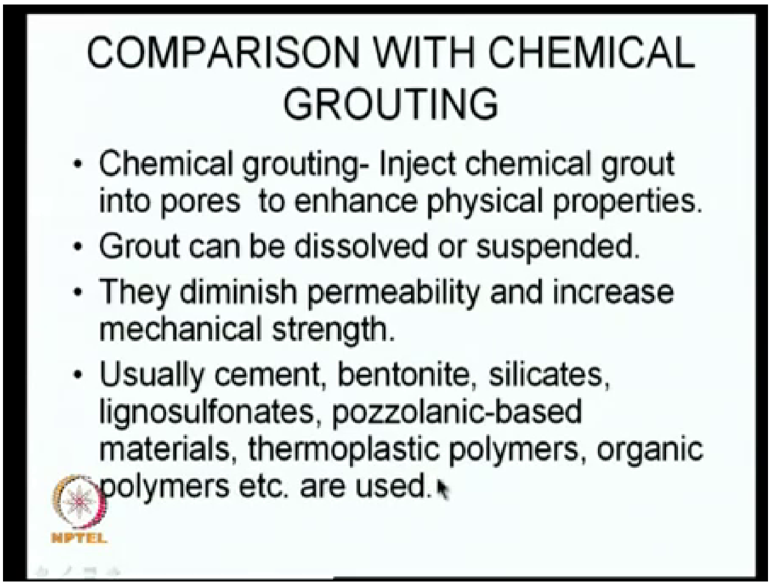

So when you cannot do that then the advantage is that of course, you are trying to compare them with a conventional techniques that is what is what we do in mechanical compaction or mechanical modification.

The other one is you are can also compare them with the chemical grout where you try to inject chemical grout into pores to enhance physical properties and grout can be dissolved or suspended and they reduce a permeability and increase mechanical strength and people normally use cement ,bentonite, silicates ,lignosulfonates, pozzolanic-based materials thermoplastic polymers and organic polymers etc.

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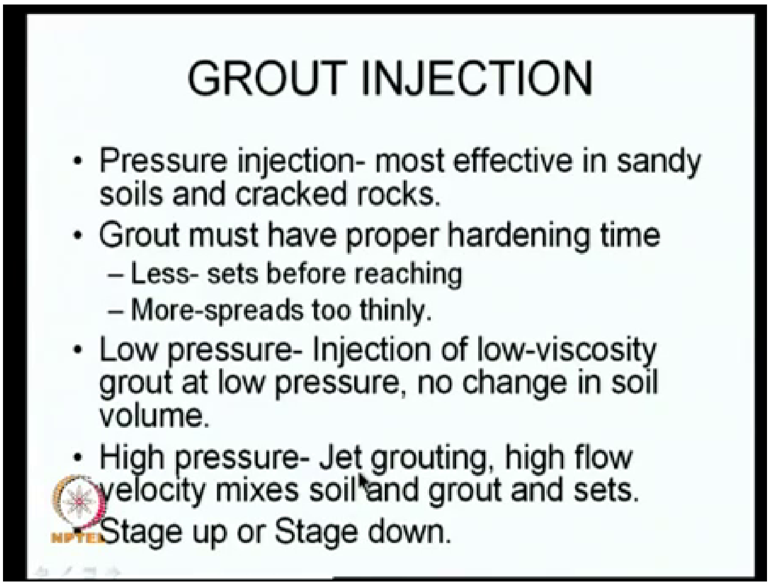

And we know about the method of grouting and pressure injection grouting can be done in sandy soils and rocks and we also have studied that the grout must have proper hardening time and low pressure low pressure in is required in the case of low viscosity grout at low pressure ,no change in soil volume high pressure can you know there is another classification that we already studied jet grouting, high flow velocity mixes and grout and sets and there are lot of issues that we already studied.

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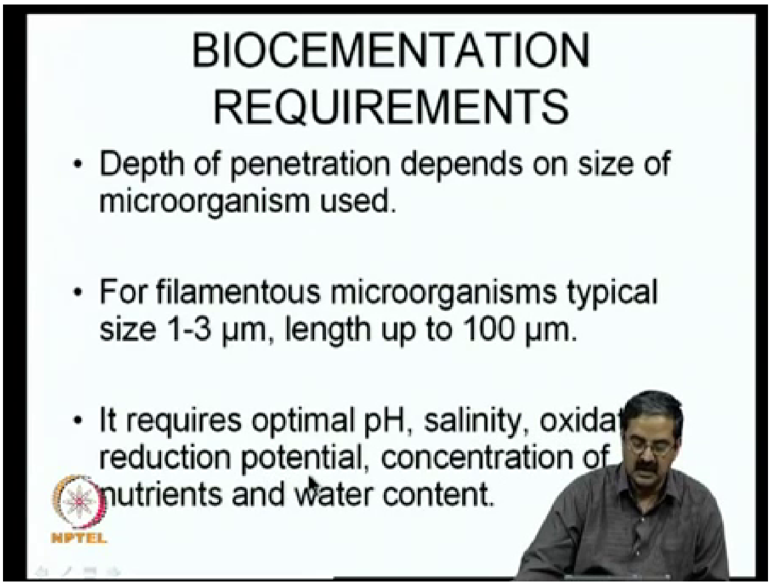

But then ,when you are trying to use these materials like as I said biocementation the biocementation requirements are as follows -depth of penetration depends on the size of the microorganism microorganism used- for filamentous microorganisms typical size is one to three micro meters lengths up to hundred micro meters- it requires optimum p h ,salinity ,oxidation reduction potential concentration of nutrients and water content.

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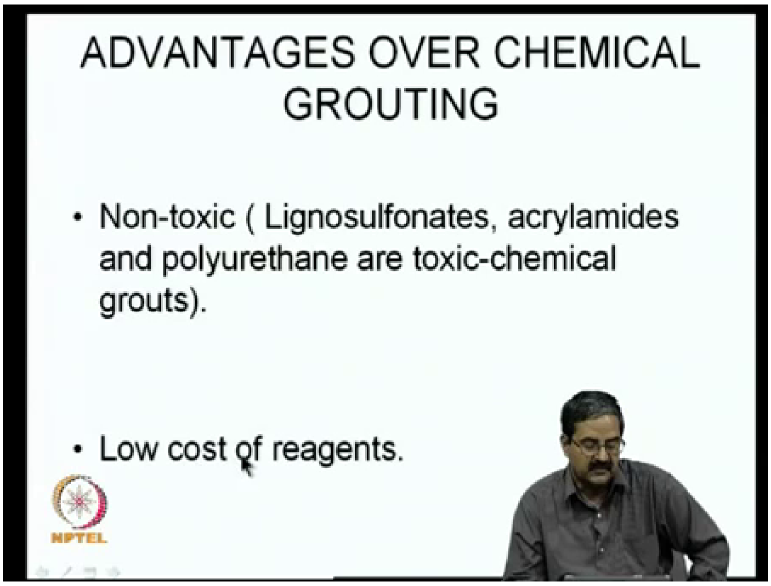

The advantages over the chemical grouting are that they are non-toxic say for example, if you look at a lignosulfonates, acrylamides and polyurethane or some of them are toxic-chemical grouts this actually I discussed this when you are discussed about grouting and the cost of the reagents is low there is some cost comparison that was given in the paper that I just read.

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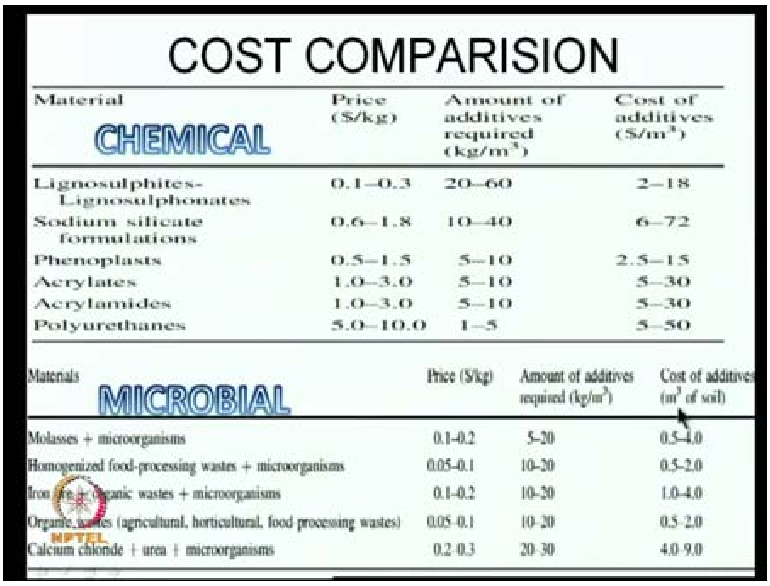

COST COMPARISION

Material CHEMICAL	Price ($/kg)	Amount of additives required (kg/m^3)	Cost of additives ($\$/m^3$)
Lignosulphites-Lignosulphonates	0.1–0.3	20–60	2–18
Sodium silicate formulations	0.6–1.8	10–40	6–72
Phenoplasts	0.5–1.5	5–10	2.5–15
Acrylates	1.0–3.0	5–10	5–30
Acrylamides	1.0–3.0	5–10	5–30
Polyurethanes	5.0–10.0	1–5	5–50

Materials MICROBIAL	Price ($/kg)	Amount of additives required (kg/m^3)	Cost of additives (m^3 of soil)
Molasses + microorganisms	0.1-0.2	5-20	0.5-4.0
Homogenized food-processing wastes + microorganisms	0.05-0.1	10-20	0.5-2.0
Iron ore + organic wastes + microorganisms	0.1-0.2	10-20	1.0-4.0
Organic wastes (agricultural, horticultural, food processing wastes)	0.05-0.1	10-20	0.5-2.0
Calcium chloride + urea + microorganisms	0.2-0.3	20-30	4.0-9.0

And you can see that when you are looking a chemical grouting you know you lignosulphites ,sodium silicate formulations ,phenoplasts acrylates acrylamides polyurethanes the price is you know little high here say point one to point three even here polyurethanes are the highest, the amount of additive required per k g k g is a meter cube k g per meter cube so it is also given cost of additives is also given.

So it is little per dollar in terms of the dollars it is given- when it when you compare this and look at microbial treatment molasses plus microorganisms the cost is somewhat less you can say the price is point one to point two five to twenty k g per meter cube is additives required in the cost is point five to four and see its comparatively less comparative any of these numbers

And homogenized food processing wastes and microorganisms iron plus organic wastes plus micro organisms organic wastes calcium chloride plus urea plus microorganisms you know you can see that ,there in order shorter or a cheaper compare to chemical grouting.

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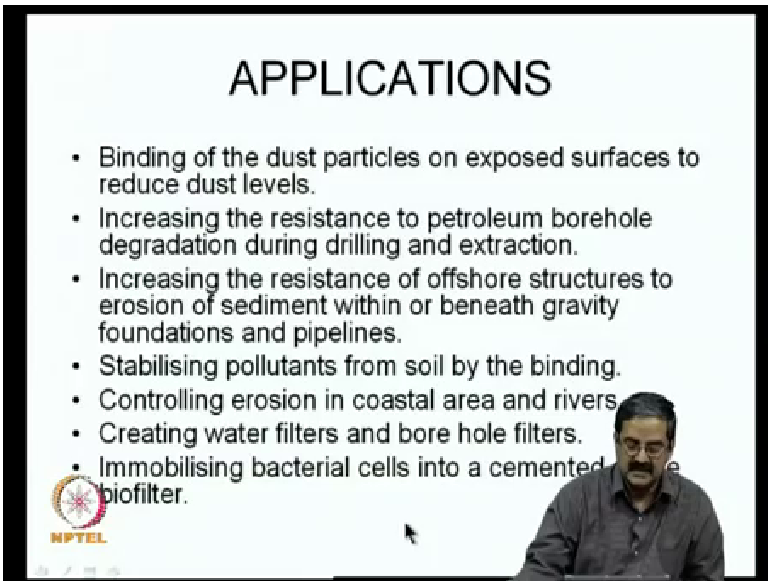

So where you can use them -you can use them in the enhancement of stability of retaining walls say for example, if there is a cohesion that is required normally we have a good backfill draining draining fully draining backfill you know if you want to improve the stability of the retaining walls in some sense and of course, one should design here what is the where is what is the problem actually how what are the stability calculation that one can think off. -

And if you are looking at retaining wall stability, embankment stability and dams you should make lot of calculations and make sure and if the parameters do not satisfy this ah stability requirements then you need to go for improvement and improvement now say for example, you are trying to improve the cohesion or the strength or the stiffness.

The parameters that you need for the retaining walls in the embankments and dams are, the strength properties essentially like you want higher strengths so that the factors of safety can be higher then also you want deformations to be less ,so that stiffness can be improved so if you have a stiffness improvement and strength improvement if if by using this microbial matter or the bacteria then it is useful ,and one should do lot of experiments to confirm yes this improvement is there and it can be sustained for a long term and you know one should understand that properly.

Then ,the second thing is reinforcing or stabilizing soil to facilitate the stability of the tunnels or underground constructions increasing the bearing capacity of the piled or non piled foundations reducing the liquefaction potential of the soil treating pavement surface strengthening tailing dams to prevent erosion slope failure in fact in some of the places where tailing dams you know they are all materials that are removed from mining and then, they have a tendency to slip away and causing lot of risk due to slope failures-

So or erosion failures one should see that by suitable strengthening ,the erosion failures are avoided -then constructing a permeable reactive barriers in mining and environmental engineering.

So ,the applications are there the binding of the dust particles on exposed surfaces to reduce dust levels like you know if the bacteria can keep that dust from not going into the air that is good thing and increases of resistance to bore petroleum borehole degradation during drilling and extraction extraction in fact we used certain muds to increase a borehole stability but, if any way biofilms can help in increasing the borehole stability it is going to be nice.

Increasing the resistance of offshore structures to erosion of sediment within or beneath the gravity foundations of the pipelines, particularly in offshore structures because of the erosion there is a possibility that the foundations of the pipelines and ah or other structure we will have a serious problem.

So, if we can increase by introducing some biomaterials there is an increase in strength or stability then it is going to be good- stabilizing soil pollutants from soil by the binding of course, the movement of the transfer of or the of the pollutants can be reduced by this material material you know.

Controlling erosion, control erosion is something that is very important creating water filters and borehole filters, immunizing immobilizing bacterial cells into a cemented active biofilter these are all.

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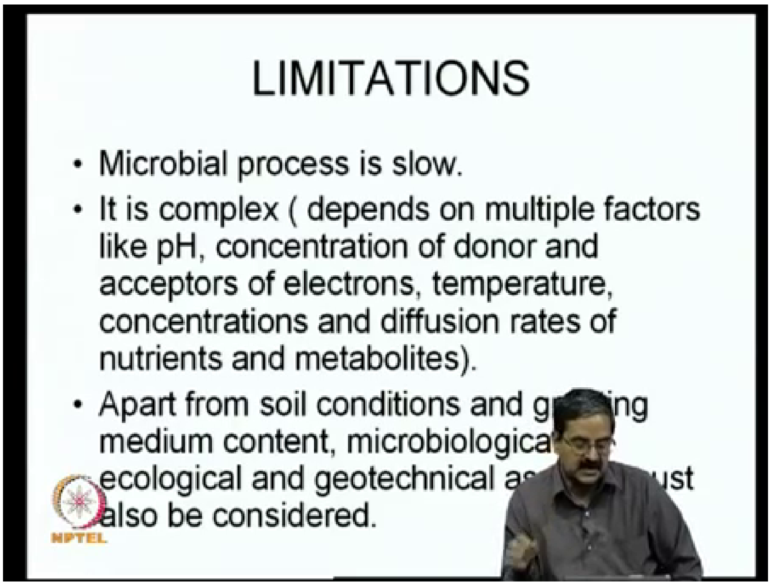

Some applications that one can have and one should understand that the process of microbiology microbiology are little slow. And it depends on complex factors like ph, concentration of donor and acceptors of electrons ,temperature ,concentrations of and diffusion rates of nutrients and metabolites metabolites present -apart from the soil conditions and the grouting medium content microbiological ,ecological and geotechnical aspects must also be considered.

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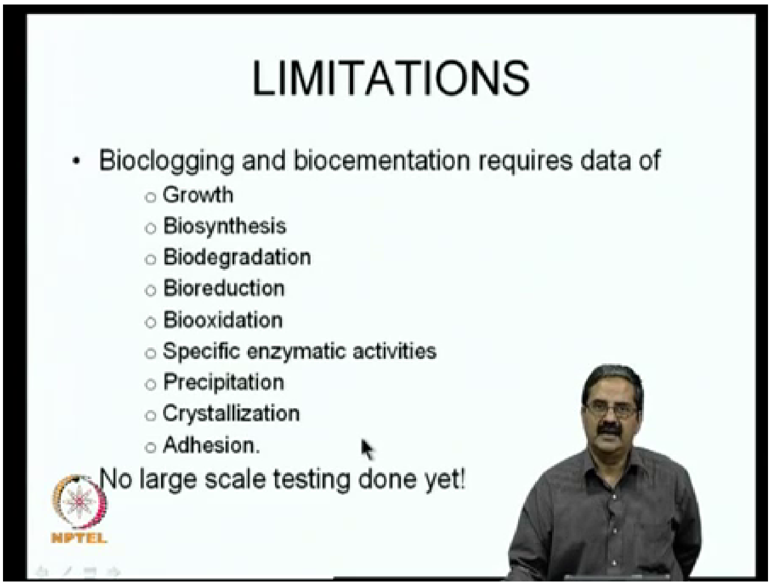

Ah bioclogging and biocementation require the data of growth of the bacteria the biosynthesis ,the mechanism of biosynthesis, the biodegradation ,the bioreduction biooxidation specific enzymatic activities precipitation crystallization a,dhesion so these are all some important inputs like see when you add bacteria into soil you must be able to understand what is the growth of bacteria and how is it going to react with the soil.

So some of these various mechanisms are listed here such as biosynthesis, biodegradtion bioreduction ,biooxidation specific there could be specific enzymatic activities all these things should be understood even precipitation of certain salts are also possible so people have done at a laboratory scale some of them but, not much laboratory work big scale work was done you know big field test was not attempted.

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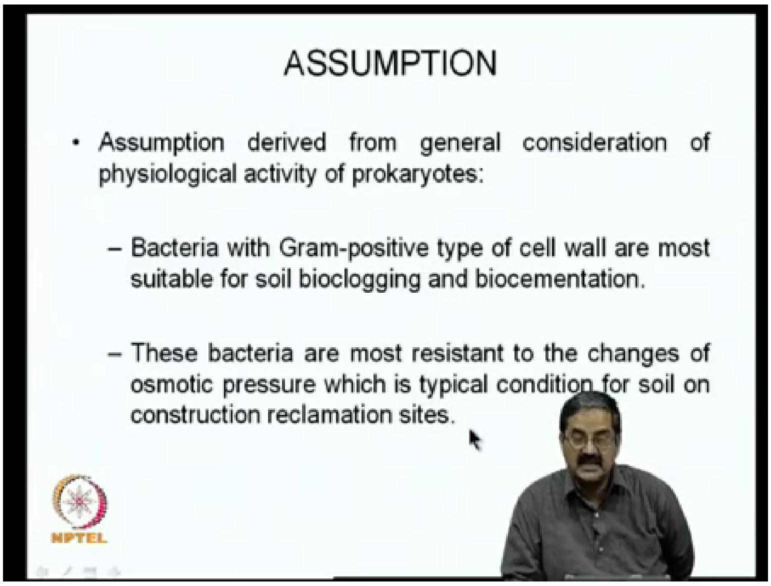

And hopefully, people take it seriously this is just a beginning may be the serious work started only about four five years back ,people have been working on these lengths and in Japan and in Singapore and in places like us assumption derived from general consideration of physiologoical activity of prokaryotes prokaryotes.

So, bacteria with gram-positive type of cell wall are most suitable for soil bioclogging and biocementation- these bacteria are most resistant to changes of osmotic pressure which is typical condition for soil and construction sites so, definitely if the bacteria able to satisfy these two requirements definitely they are going to be very helpful.

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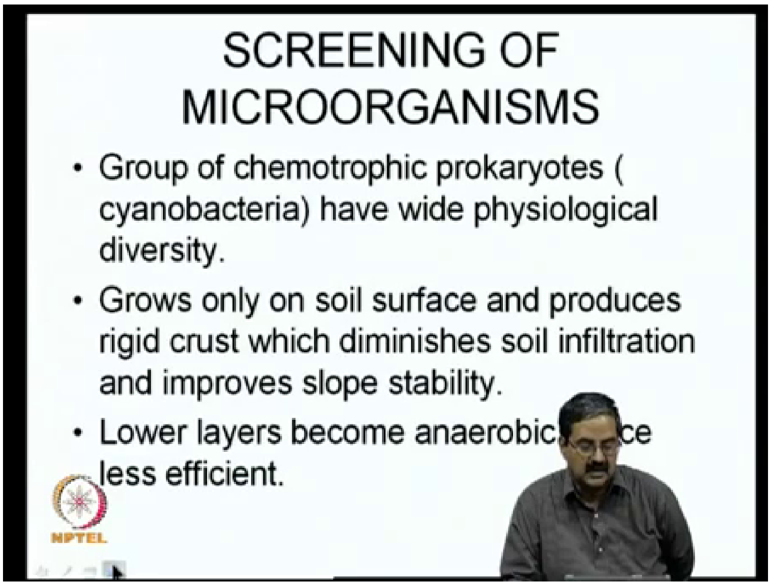

Then, screening of microorganisms you need to identify the group of chemotrophic prokaryotes which have wide physiological diversity, growth only on soil surface and and produces rigid crust which diminishes soil infiltration improves slope stability- so lower layers become anaerobic and hence less efficient.

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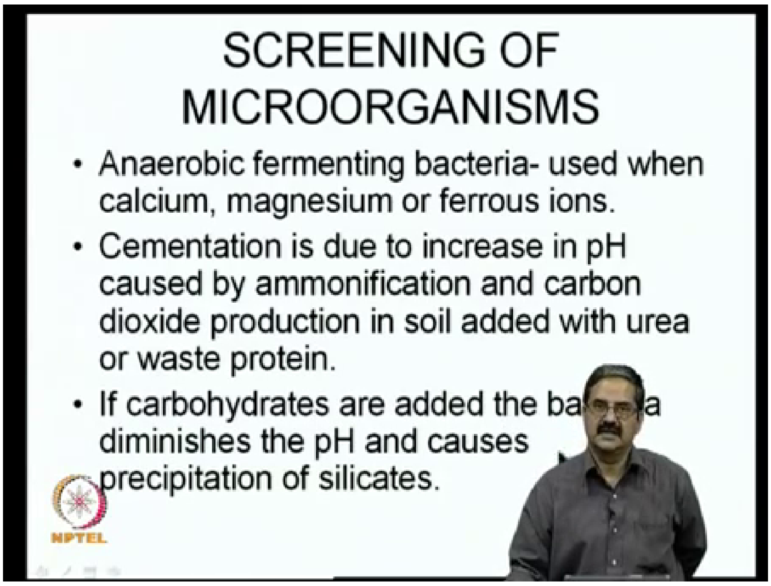

So one should understand that, there are many processes in screening and say for example, if you have anaerobic fermenting bacteria they you should be used when calcium and ah magnesium or ferrous ions are present -cementation is due to increase in p h cause by ammonification and carbon dioxide production in soil added with urea or waste protein -if carbohydrates are added to the bacteria they they added the bacteria diminishes the ph and causes precipitation of silicates this is another one.

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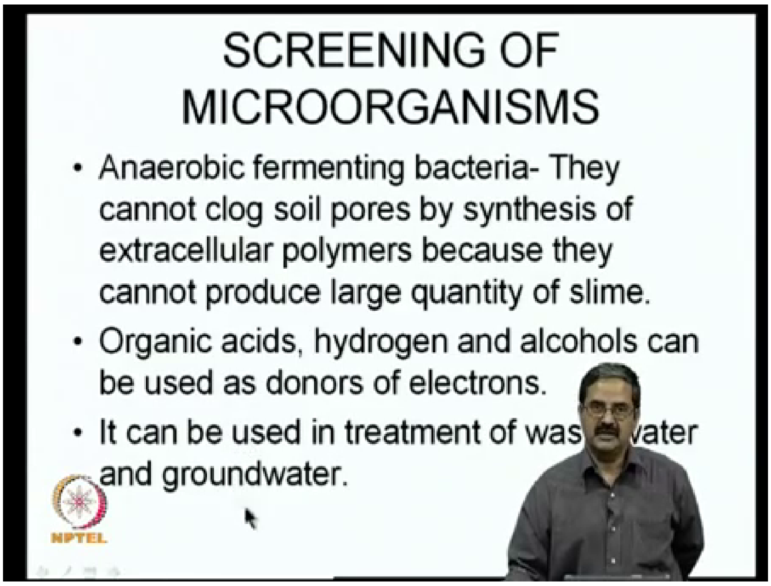

So anaerobic anaerobic fermenting fermenting bacteria are you know they cannot clog soil pores by synthesis of extracellular polymers because they cannot produce large quantity of slime. Organic acids hydrogen and alcohols can be used as donors of electrons and some of this can be used for waste water treatment as well or even the groundwater

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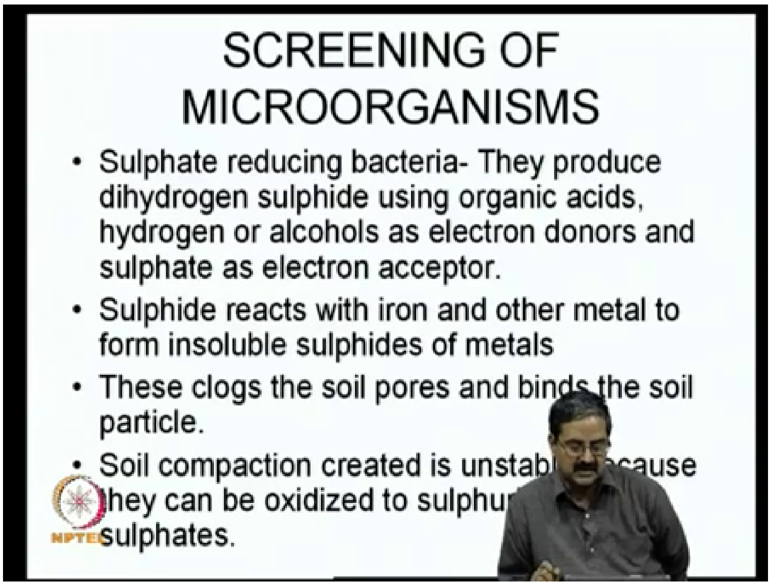

So you have sulphates reducing bacterias as I just mentioned earlier they produce dihydrogen sulphide using organic acids hydrogen or alcohols as electron donors and sulphate as electron acceptor. Sulphide reacts with iron and other material to form insoluble sulphides of metals these clogs the soil pores and blinds the soil particle the soil compaction created is unstable because they can be oxidized to sulphuric acid or sulphates.

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Most suitable bioagents are once that produce big quantity of exopolysaccharides which usually promote formation of the cell aggregates -they can work in both aerobic and anaerobic conditions both microzones of aerobic and anaerobic co-exist. There are some examples here ex alcaligenes ,enterobacter and some of them given here.

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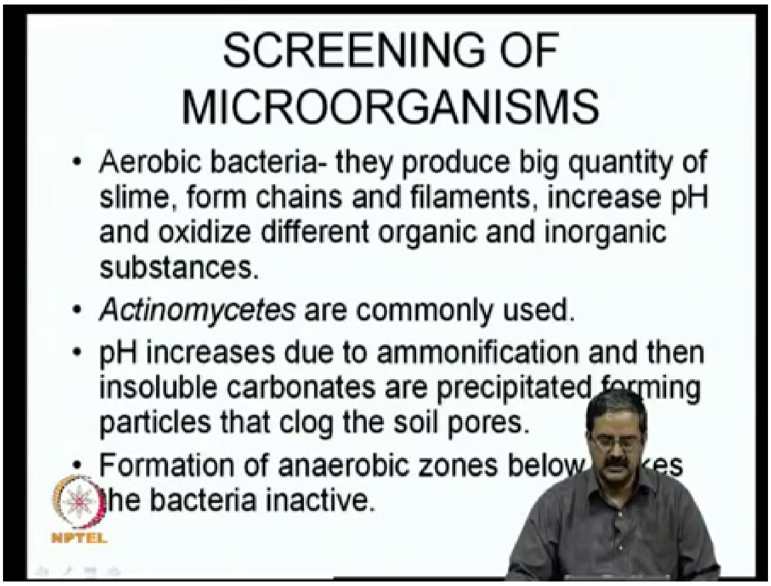

There are some examples here ex alcaligenes enterobacter and some of them given here -aerobic bacteria they produce big quantities of slime form chains filaments and increase p h and oxidize different organic and inorganic substances -you have actinomycetes are also used p h increases due to ammonification and then insoluble carbonates of precipitated forming particles that clog the soil pores- formation of anaerobic zones below the dikes into bacteria inactive below the formation of anaerobic zones below makes the bacteria inactive.

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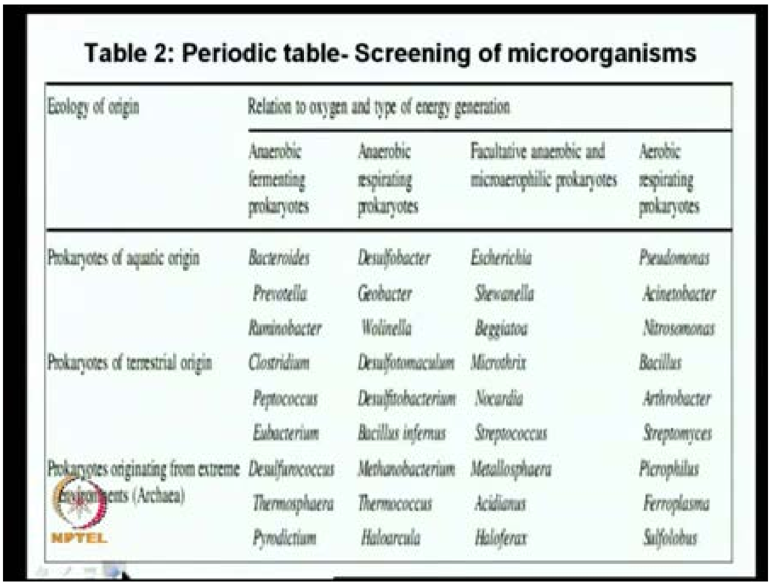
Table 2: Periodic table- Screening of microorganisms

Ecology of origin	Relation to oxygen and type of energy generation			
	Anaerobic fermenting prokaryotes	Anaerobic respirating prokaryotes	Facultative anaerobic and microaerophilic prokaryotes	Aerobic respirating prokaryotes
Prokaryotes of aquatic origin	*Bacteroides*	*Desulfobacter*	*Escherichia*	*Pseudomonas*
	Prevotella	*Geobacter*	*Shewanella*	*Acinetobacter*
	Ruminobacter	*Wolinella*	*Beggiatoa*	*Nitrosomonas*
Prokaryotes of terrestrial origin	*Clostridium*	*Desulfotomaculum*	*Microthrix*	*Bacillus*
	Peptococcus	*Desulfitobacterium*	*Nocardia*	*Arthrobacter*
	Eubacterium	*Bacillus infernus*	*Streptococcus*	*Streptomyces*
Prokaryotes originating from extreme environments (Archaea)	*Desulfurococcus*	*Methanobacterium*	*Metallosphaera*	*Picrophilus*
	Thermosphaera	*Thermococcus*	*Acidianus*	*Ferroplasma*
	Pyrodictium	*Haloarcula*	*Haloferax*	*Sulfolobus*

So ,there is some way of screened mechanism here and relation to oxygen and type of energy generation of course, these are all taken from literature one needs to really do some experiments on this one can.

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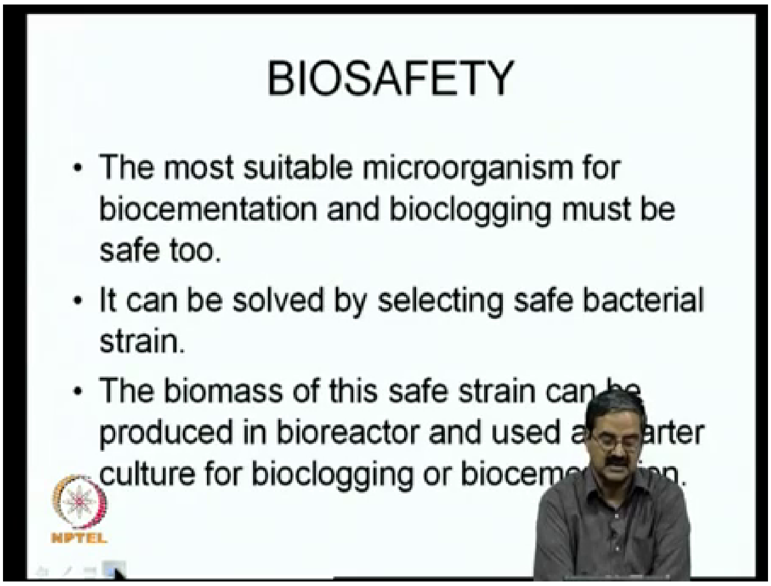

So very important thing that I mentioned earlier was that the biosafety the most suitable microorganism for biocementation bioclogging must be safe like you are trying to use it it should be safe it can be soiled by selecting a safe bacterial strain. The biomass of this safe strain can be produced in bioreactor and used as a starter culture for bioclogging or biocementation.

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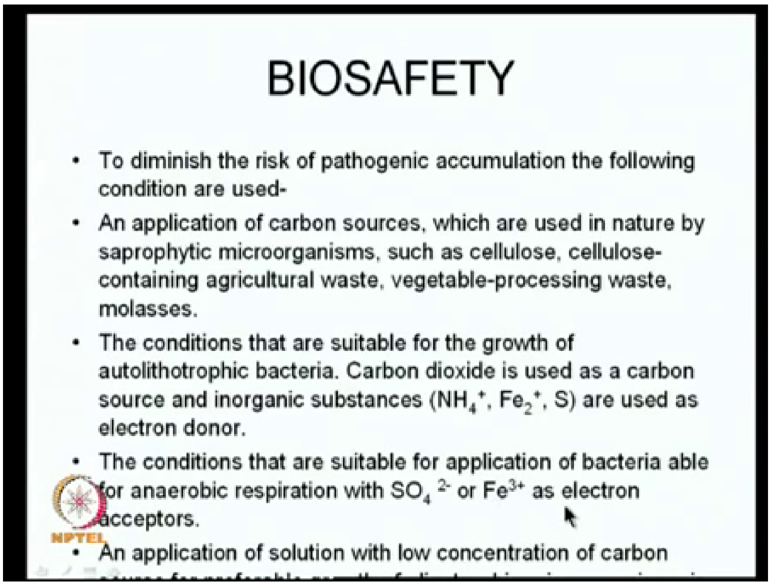

And to diminish the risk of pathogenic accumulation the following conditions are used an application of carbon sources which are used in nature by saprophytic microorganisms such as cellulose, cellulose containing agricultural waste vegetable-processing waste etc.

Conditions that are suitable for the growth of autolithotrophic bacteria- carbon dioxide is used as carbon source and inorganic substances are used as electron donors -the conditions that are suitable for application of bacteria able for anaerobic respiration with sulphate and ferric ferric ion as electron acceptors acceptors The application of some of these halocarbons are quite useful

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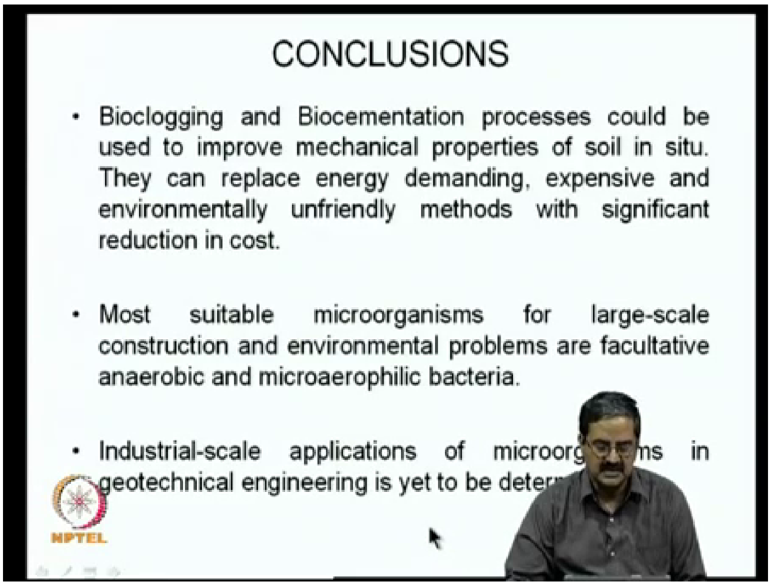

And it is important that the bioclogging and biocementation processes could be used to improve the mechanical properties of the soil in-situ they can replace energy demanding expensive and environmentally unfriendly methods with significant reduction cost and I must also say that experiments that are conducted by you know in the chu and other authors ,they clearly indicate that there there is a permeability of the order you know the reduction of the order.

Say example instead of minus four center purpose sec I mean minus minus two center purpose second it became minus four which means an order of hundred even there was a good strength increase. most suitable microorganisms for large-scale constructions environmental problems are facultative anaerobic and microaerophilic bacteria

So what it is clear is that this bacteria are more general and one can use them for large-scale construction and industrial-scale applications of microorganisms in geotechnical engineering is not yet started and likelihood is that, the ah you know some of these though they are an experimental scale. If they have if they go to commercial scale the possibility is that, like they can be an industry within themselves in the sense that, similar to a ground improvement technique companies that you have for a grouting.

One can specialize in trying to understand understand what type of soil you have in a particular application and look at what type of microbe should be used what should be the are the conditions sufficient and if the conditions are sufficient how can you i mean you should be actually a fill laboratory experiment and then come out with the dosage and other requirements and environmental conditions and find out the optimum benefit.

Say for example, if you are reducing the permeability, you try to come out with laboratory values of reduction permeability as compare to the original value or if you are looking at strength improvement look at what exactly is order of strength required and also do a laboratory with a number of laboratory test and try to replicate the same in the field trials as well before one can go for field application.

So, they have large-scale industrial applications one people need to see with this I would like to say that the biocementation and bioclogging have a significant role to play in the development of what is called ah sustainable geotechnical engineering practice. And considerable research is required though it has been done at a limited scale in many places there is a lot of scope for geotechnical engineering to understand bio matter and material characteristics and that is only possible in association with a suitable group of engineers who are also trying to cans give some inputs into the whole system and with result that you have improved bio cementation or bioclogging systems that can be used for field practice.

The other point that I would like to just mentioned here is that though there is an emphasis on ah biomatter here, I would like to mention that in the earlier lecture is also I was mentioning about the use of natural fibers say for example, or natural geotextiles for the the increasing a slope stability.

And ah say for example, there is a steep slope of about sixty degrees and the definitely because of the rainfall there in erosion of the slope and definitely use of you know the geotextiles natural geotextiles say for example, coir or a jute geotextile can help in that process.

And similarly, I I I was saying certain applications of certain ah root penetration you know you try to identify certain plant species and one can say that the roots will penetrate into the soil you know they what happens if do in the erosion is that, a thin layer of soil of say for example, thirty two centimeters comes out and that once some soil starts coming out it leads to large scale reductions and finally, there is a whole instability region sets in and then seepage starts and all that.

The first step would be in such case would be is to arrest the erosion itself per say and that is only possible by erosion control mats which are being practice in many places and in northeast or some other places people have been using specific varieties of plants say for example, vettiver is something that people have been using in northeast on trial basis.

And people claim that the penetration of the roots can be to the extent of about a half a meter so that the half and then the rate rate of penetration of this could be about three to four months or something so in a and then if you start in a season where the a well heard of the rainy season or something the possibility is that there roots can grow in that time before the rain set in and you may ensure some sort of stability.

And a couple of issues are also more important here ,when you are trying to choose a particular plant species you know again you need have the density the type of material then the density of plantation ,then their effect one should do laboratory studies also and also field studies before you go for large-scale application -what happens most of the time is that the the you know some of the you know i have seen certain cases sometimes as I say biomaterials or biostabilization take sometime.

So, it is better that you know even some a combination of a regular ground improvement techniques and the biosystems are used I will give you an example you have a say forty degree or forty five degree slope and there is lot of rainfall definitely ah forty five see the slope may be unstable say for example, for a particular inadequate prone area.

And what you should do is that, to arrest deep seated failure say for example, the to the extent of two to three meters or beyond you know three four meters one should use techniques like soil nailing, which can increase a deep seated deep seated stability and if you are trying to increase a sufficient stability one can go for either the bio um biomaterials that I just mentioned about the growth of bacteria bacteria and also the growth of plants.

So some of these combinations are going to be definitely helpful and increase in you know it is a combination see it is very difficult to completely completely have a sustainability ensured in the sense that, there is lot of gap already say for example, these techniques are not well proven one problem is that, people have been talking about the ah biotechnical stabilization concepts except in the case of slope stabilization of shallow slides it has not taken significantly ,and there are also, me research that is done say for example, how to reduce the settlements you know reduce a settlement.

Where say for example, you take a soft soil and then the soft soil has a tendency to undergo lot of settlements but, definitely that order of settlement if you want a particular level of strength it needs to the soil needs to undergo lot of deformation.

One way is that introduce certain matter like a biomatter and then see that the biomatter clogs the soil I mean occupies the soil pores or even binds a soil particles such that, when you apply the load the stiffness is higher and that can leads to reduction settlement and then you can strike a balance between applied loads. Say for example, in a particular ground improvement project the apply preload could be of the order of say for example, hundred k p a if you are able to reduce ah surcharge of the preload to may be ten k p a it is a big difference and if you are able to identify for the ninety k p a improvement suitable biological treatment in the form of a either the bacteria it is going to be very very beneficial.

So, what I would like to say is that the ah area the working on the sustainability aspects in ground improvement has picked up and people had need to really do lot of experiments and see that do filters as well and see that they have I mean I mean you come out with guidelines you know for example, particularly the bio material as I just mentioned ,they are all site specific and they need lot of conditions what is applicable in a particular area cannot be applied in something else because the conditions could be different.

So with this conditions one should really conduct field trials apart from laboratory trials field trials are essential essential for before one attempts large scale applications so with this I I personally feel that you we have come to a very ah ah broad understanding of various aspects of ah ground improvement in this thirty nine lectures that I conducted so far right from need for ground improvement.

And then we discussed about various methods such as ah you know mechanical stabilization of mechanical modification, thermal modification, then hydraulic modification modification by inclusion such as reinforcement.

Then we have extensively covered the use of geogrids ,geosynthetics, soil nailing, micropile and also we discussed about the use of biotechnical stabilization systems and all that so I would like to may be in the next class which is the last lecture I would like to summarize summarize give some more information on the ah you know how the further you know how new techniques.

You know see the thing is that new techniques are also necessary like maybe I will just discuss on nanotechnology and its applications, in the three lectures that I was just addressing thirty eighth lecture we discussed about the geo engineering and then trying to recover heat from the ground which is nothing but, in fact the ground improvement area has taken a new meaning that, you are trying to say that geoengineering nowadays there is a lot of discussion on how to handle the ground and how to make use of the best of the natural resources.

So in the last three lectures, I was last two lectures particularly I was talking about you know geothermal energy and the systems that are required and today we discussed about the use of ah biological or you know bio microbiology systems into geotechnical engineering or ground improvement.

And I will also discuss about nanotechnology in this next lecture and you know then we will just see that I think you know there is a lot of scope for nanotechnology in ground improvement and we will give some case studies as well so with this I conclude thank you very much.