Environmental Geotechnics
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Lecture- 50
Swelling, shrinkage and cracking characteristics of soil- 3

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I will continue discussion on Swelling, shrinkage and cracking characteristics of soils with subtopics shrinkage characteristics. In previous lecture we have talked about swelling characteristics; now this is where I like to discuss few issues or the scenarios or the situations, where such studies become very important what is the importance of studying shrinkage characteristics of soils; followed by the mechanism of swelling again. And you will wonder that why I should be repeating mechanism of swelling, the reason is that swelling and shrinkage they are related to each other.

So, we will try to understand what links them together these two mechanisms; then what are the factors which influence shrinkage phenomena or shrinkage characteristics of soils, followed by mechanism of shrinkage. Few definitions which are used for defining this phenomena, then how would you determine shrinkage characteristics of soils and then what is the application of these studies? The application of these studies would be if you can come up with some classification scheme for soils; based on their swelling, shrinkage and suction properties, our task will be complete.

Now, this is a classification scheme which would be more welcome than the one which are existing in the present day scenario; the common sense says that when we talk about swelling, shrinkage and suction they will be including in them the physico-chemical and mineralogical properties of the geo materials which other classification schemes do not include. So, this seems to be a very potential area for researchers who are working in this subject to classify soils based on their swelling, shrinkage and suction characteristics though this is a big challenge and a big work.

Now, based on the previous studies, some relationships which have been proposed by the researchers; I will be covering them in today's lecture. Now these important relationships will be informing us how swelling shrinkage and suction are related to each other. And this will be followed by cracking characteristics which I intend to cover in the next lecture.

And when we talk about cracking characteristics it has to be linked with tensile strength of the soil. Now, just to remind you when we study swelling, shrinkage and cracking characteristics it is a interesting way to define the soil water environment interaction. And this is what I had enunciated in the previous lecture, that whatever we have covered in this course get summed up when we talk about these three peculiar characteristics of the soils.

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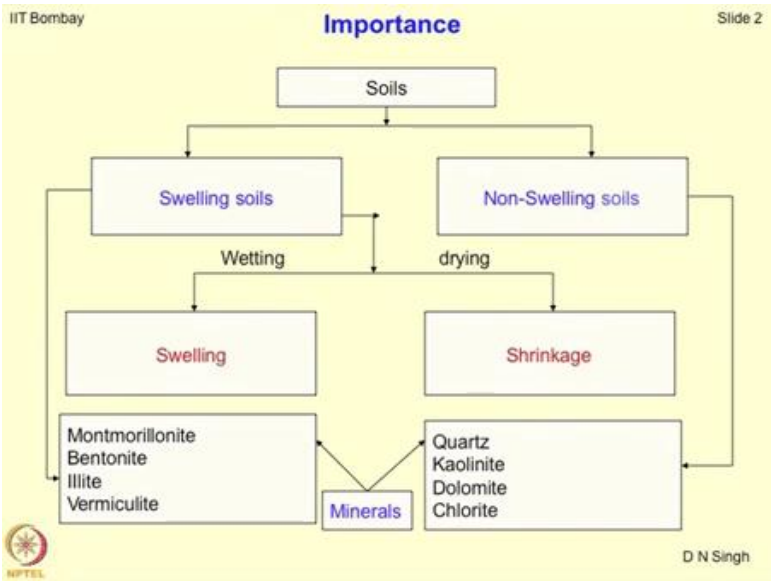

So, as far as importance is concerned though it must be clear to all of you; when we talk about soils, the basic handicap is how to differentiate between swelling soils and non swelling soils by doing some very simple test experimentation, identification schemes and so on.

So, if you can classify the soils very grossly whether they are swelling type of soils or non swelling type of soils; at least you have a strategy in mind that how to use them or whether not to use them, alright. So, you think of a mathematical algorithm where in by putting all the attributes of the soils which are swelling type and the soils which are non swelling types, you can create a software or you can create an algorithm which gives you a direct answer what should be the application of a certain soil or whether this type of soil should be avoided in civil engineering or geotechnical engineering practices, ok.

It so happens that non swelling soils are not going to respond to any interaction either with water or with air or with environment; so they are passive materials. And whatever little bit of interaction is taking place is because of the mineralogy. That means because of very high surface area; these soils may show you a bit of interaction with external elements.

Now, truly speaking, for all practical purposes non swelling soils would be dormant soils, they will be passive soils and they do not come in anyway either threat to you when you are adopting a strategy for doing so many construction. And I hope you will agree that classical geo mechanics mostly deals with these type of soils; either it deals with these type of soils or it assumes soils to be non swelling, alright.

So, the biggest challenge is when we talk about swelling type of soils; now when we say swelling type of soils, we have to study their two characteristics; that is how do they respond when they become wet and how do they respond when they become dry. So, this is where wetting and drying phenomena or the mechanism becomes more important.

When soil comes in contact with water the swelling takes place, when water gets expelled out from the soil it becomes shrinkage. Say good example of shrinkage would be desiccation cracks where, the top layer of the soil which is exposed to direct sun keeps on evaporating moisture out of it.

And then, after a certain limit of moisture, these desiccation cracks or shrinkage cracks will appear on the surface of the soil mass. However, the reverse phenomena is true for swelling of the soils where water ingresses into the material and the matrix of the soil and volumetric deformation takes place. So, in short, both these mechanisms are nothing, but volumetric deformation of the material over a period of time without application of any external loading. So, can I use the word here volumetric strain associated with time? So, in classical mechanics, geo mechanics have you used this term somewhere deformation of the material over a period of time?

Student: (Refer Time: 07:13).

That is right, so that is nothing but a creep mechanism. So, creep you have used in terms of secondary consolidation and that too for the materials which are very passive; which are non swelling type. But when the minerals are active, they are swelling type or shrinking type this time dependent phenomena or the mechanism becomes much more important than the loading which is going to come over it. And that is the reason why you need to characterize soils which are either shrinking type or swelling type alright.

So, if you look at the mineralogy of these soils; what you will notice is swelling type of soils will have typically montmorillonite, bentonite, illite or vermiculite as the clay minerals alright. These are all fine grained materials or the minerals having very high surface area and their physico chemical mineralogical properties are quite different than the minerals which may have almost the same size or the shape, but a different chemistry and different mineralogy.

So, these are the minerals which we are normally interested in finding out or identifying in the natural soils. And based on these minerals we can say whether the soil is swelling type or non swelling type. So, it would be very interesting and very futuristic to make it or develop a model, where you can talk about the shrinkage and swelling characteristics of each mineral.

And once you have such isolated blocks, you can put them together to come up with a generalize model for a C-ϕ natural soil to define swelling and shrinkage characteristics of the material alright. So, on a scale from 0 to 10 or 0 to 1 or 0 to 100, if you know or if you can map the properties of these minerals and by applying certain weight factors ok, if you know the weight percentages of the minerals present in the natural soil; you can

come up with a model which should be valid for solving problems related to day and every days requirement or whatever.

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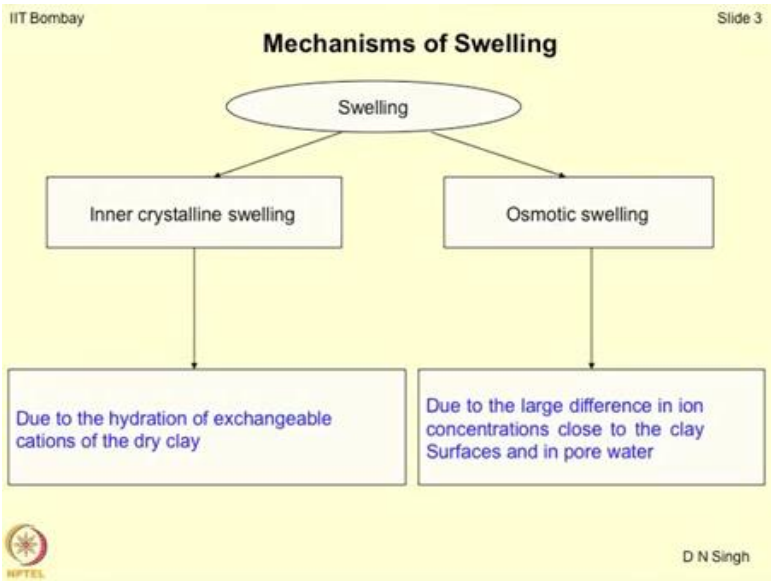

So, what is the mechanism of the swelling? As we discuss the previous lecture there are two different types of swelling mechanism. Again we can classify them in inner crystalline swelling or osmotic swelling; what is inner crystalline swelling? This is due to the hydration of exchangeable cations of the dry clay.

So, when clay has come in contact with water; hydration of cations is taking place and because of that there is a double layer formation. And this double layer is responsible for increase in volume or size of the clay particles; what about the osmotic swelling? Osmotic swelling is due to the large differences in ion concentrations, close to the clay surfaces in pore water. So, this is where the pore water or pore fluid chemistry becomes more important.

There is some osmotic pressure develops between the clay platelets or the clay minerals and the pore solution which is present in the solution. So, these two simple mechanisms govern the swelling property or the swelling potential of the soil mass.

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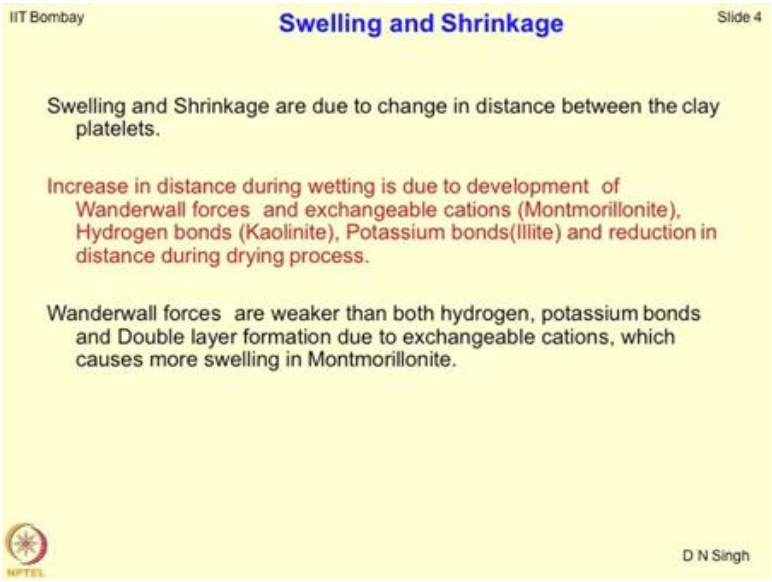

Now, how would we correlate swelling and shrinkage? So, the first thing which comes to the mind is that these two are different or opposite mechanisms. So, swelling and shrinkage are due to change in distance between the clay platelets.

Now, what is causing this distance between the clay platelets to change? You cannot say moisture, it is basically the water which goes inside and then ultimately what happens? What type of forces are getting exerted on the system?

Student: (Refer Time: 11:16).

That is right; so in some cases this is Van der waal forces which are going to affect the spacing between the clay particles or the clay platelets. So, this is where increase in distance during wetting is due to development of Van der waal forces and exchangeable ions; mostly in case of montmorillonite. And what is your exchangeable cations? It is nothing, but cation exchange capacity of the mineral.

So, put together when you talk about the Van der waal forces and the cation exchange capacity, this results in swelling phenomena. There could be a situation where hydrogen bonds which are most prominent in kaolinite and the potassium bonds, which are more prominent in illite also may result in reduction between the distance of the platelets during drying process. But which structure or which bond is more stronger out of the three that is your Van der waal, potassium and hydrogen bond?

Student: (Refer Time: 12:20).

Hydrogen bond is the strongest bond somewhere in between falls the illite or the potassium bond and the weakest bond is Van der waal force. So, if you ask a question which potential is more detrimental for the properties of the soils? Shrinkage, that means, the plates coming close to each other or plates going away from each other; which one is going to be more critical or which one is more feasible? In other words which one is going to be dominating out of the two either swelling or shrinkage; other parameters other factors?

So, it is a interesting spring theory or a spring analogy you compress the spring and you release it. So, what is happening here? Once you compressing the system, the plates are coming close to each other and when you leave the system like this, what is the tendency? The tendency of the system is to swell; what is the significance of this? You think of a situation when soil mass immediately comes in contact with water.

There should be some time lag between water ingressing the platelets or the distance between the platelets. So, what should be the first mechanism? It should be shrinkage or it should be swelling? See swelling is because of ingress of water; that means, you require enough time, where water goes into the distance or the space between the two platelets. So, this is going to be a phenomenon which is associated with some time lag; what should be the instantaneous mechanism? Shrinkage.

Student: (Refer Time: 14:12).

But swelling will take some time for water to ingress into the.

Student: (Refer Time: 14:17).

Pore spaces.

Student: (Refer Time: 14:19).

When you boil milk on the surface what do you find? There is a? Skim formation; what do you notice on the skim? Whatever type of stresses are developing on the skim.

Student: (Refer Time: 14:39).

How, how do you make sure this? When you boil milk, so you should boil at least 1 litre of milk today; these are tensile forces or they are compressive forces acting on the film. Why these tensile forces occur? The first is temperature difference between the either side of the film. The top is exposed to environment, bottom portion of the skin is expose to the very high temperature; so these are the thermal stresses which are developing on the skim.

The same thing is going to happen in nature when the top surface is exposed to the environment and the inner surface is exposed to water table; what type of stresses are going to develop? They are tensile stresses. So, tensile stresses are always associated with shrinkage or swelling.

Student: Shrinkage.

Why not swelling? You imagine before you answer anything, when the soil system is swelling; whatever stress is going to exhibit. In other words, can swelling be beyond tensile strength of the material? Can shrinkage be beyond tensile strength of the material?

Student: (Refer Time: 16:03) to the tensile strength would be the (Refer Time: 16:05).

What is causing change in moisture content of the soil mass?

Student: Separation.

No, all these. See given a chance if soil is passive; nothing is going to happen to it. Why? Because it has a very stable bond between the plates which percolation of water ingress water is not going to change much. That means, in this case ionic forces or ionic valency is much more higher than the repulsion forces which are going to act between the plates. That means, this type of system will not show much of swelling; now to my understanding both swelling and shrinkage they are related with tensile strength of the material. Now which one is going to be more detrimental, swelling or shrinkage?

Student: Swelling.

Why? So, to maintain the entity of the control volume system cannot swell beyond a certain limit. What is the meaning of this? The tensile strength cannot be mobilized

beyond a certain limit. Now, when you talk about the shrinkage; what is happening here? Now shrinkage is nothing, but in other words the tensile strength of the material. So that means, swelling happens to be certain fraction of the tensile strength, but tensile strength happens to be a shrinkage strength of the material.

Now, this is the theory which people are trying to prove. Now, unfortunately this phenomena cannot be studied just by considering physico-chemical aspects only. Now, this is where you have to understand the type of heat which is associated with wetting of the material, which is mobilizing either plates to move away or plates to come close to each other. And that is where electromagnetic forces, Van der waal forces are coming into play. So, this is something which is really challenging in worth probing.

So, Van der waal forces are the weaker forces than hydrogen bonds or the potassium bonds. And double layer formulation or the formation due to exchangeable cations which causes more swelling in montmorillonite. Another way of looking at this would be if the entire space between the two plates gets occupied by cations which are exchangeable easily; what is; what is going to happen? You require more volume more space where more parking of cations would ultimately result in to.

So, CEC is a phenomena which is much more important for defining swelling of the material; not the shrinkage of the material as such. But tensile strength should be a phenomena, it will be defining shrinkage of the material. So, what you all noticing is that the mechanism between a soil; in a soil may shift from swelling to shrinkage just by varying little bit of environmental conditions, little bit of the forces which are acting between the particles; that means, just by changing the chemistry of the pore fluid.

Somebody was asking sometime back that you are getting negative a FSI value; do you get an answer to this? So, can you create a structure of the platelets which is less than the natural structure or natural arrangement of the grains in terms of volume? Answer is yes, if I change the pore solution and its property completely. So, you are creating a new structure or new structure which is going to be very stable and hence the volumetric response of the system could be less than its natural response.

And that is where you may find the FSI value becoming negative because you have used a fluid kerosene or something, which is responsible for changing the grain structure of the deposit; response is different correct that is right.

Student: (Refer Time: 20:33).

Property will get modified, see what you are doing is you are making a suspension in a fluid and just align the suspension to settle down. This can be done in a polar fluid, in a nonpolar fluid; when you talk about a particular fluid its reaction with a certain mineral will depend upon lot of other parameters; clear? So, a natural state of equilibrium between the grains which a certain pore fluid will be creating will be its trade mark.

So, from a from a state of equilibrium which is due to water when you change the pore fluid; you can create a state of equilibrium where the volumes could be higher than this or volumes could be lower than this; is this ok? So, depending upon what type of reaction is going on between the fluid or the pore fluid and the minerals; you may create another structure of the grains which could be less in volume as compared to the structure in water alright or it could be more than that.

So, if it is more than that which happens in most of the soils your FSI is positive and you say your soil is swelling. But if it is not the situation and the volumes are decreasing, your FSI is bound to be negative, but you will not report it as negative; you will use that this happens to be a shrinkage phenomena where because of the chemico physical and pore solution interaction, the volumes are less as compared to the volumes which we are creating in water. This could be one possibility of getting FSI you know so called negative.

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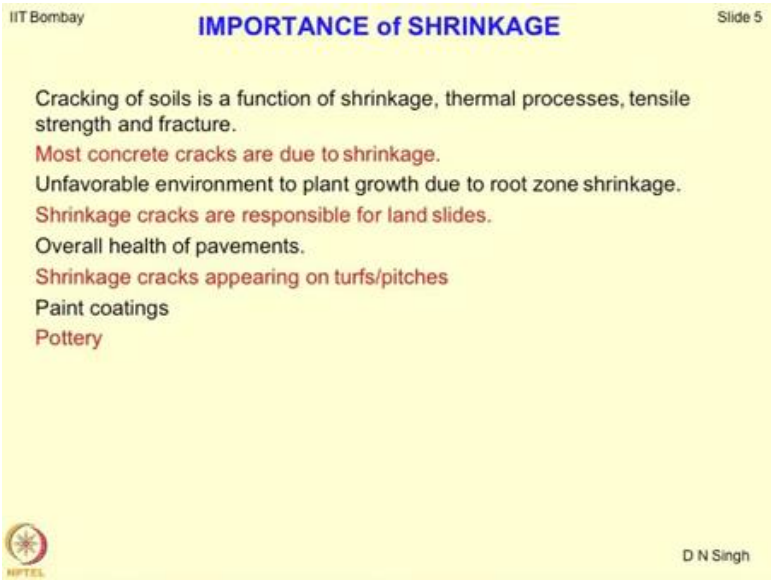

So, let us talk about few situations where discussion regarding shrinkage is very important or the importance of the shrinkage. The first and foremost situation is cracking of the soils, which is the function of shrinkage, thermal stresses, thermal processes, tensile strength and the fracture.

See, here I have been very conservative in writing thermal processes, I have not very clearly written here thermal stresses. Any reason which comes to your mind? What is your speculation? I could have written here thermal stresses rather than thermal processes. If you go a bit more into the thermodynamics of the system, we never talk about you know deformation of the minerals itself.

Whenever we talk about deformations either in terms of swelling or in terms of shrinkage; this is converted to the double layer deformations. But at elevated temperatures or subzero temperatures; how minerals are going to behave in terms of their physical entity is a very very trivial parameter. So; that means, you think of a model where thermal expansion of the mineral should also be considered when we talk about its exposure to some thermal gradient; which is quite possible.

So, cracking of the soil is a function of shrinkage properties; all sorts of thermal processes and then the tensile strength and the fracture. So, we will be studying about tensile strength fracture in the next lecture and that is the reason why shrinkage and swelling properties are being studied in details by the researchers because everybody is really bothered about cracking of the soils.

So, when you want to come up with some models which will define cracking properties; both swelling and shrinkage become input parameters or important parameters. You have heard about the concrete cracking due to the shrinkage which test normally you do to define shrinkage properties of concrete. Yes, some of you somebody said rightly correct; how do you find out shrinkage in concrete?

Student: (Refer Time: 25:11).

What is the name of the test Le something?

Student: Le Chatelier.

Le Chatelier ok; do you perform this type of test for soils? No, but we can perform and then we can come up with.

Student: (Refer Time: 25:29).

What is soundness? Then, so truly speaking Le Chatelier experiment will define the volumetric deformation of the material, which is again related to what is happening at aggregate level when it comes in contact with alkalis. So, when you say aggregate soundness; what is the significance of this? How aggregates are going to react with alkali? So, is alkali aggregate interaction which results ultimately in volumetric deformation of concrete; do you agree? So, that is the reason you are measuring these three properties which are lumped together and the index is expansion index or soundness index.

So, these type of tests can also be done for soils for defining its soundness or defining its deformation properties. For people who are into agriculture; shrinkage is a very very important phenomena; why? Unfavorable environment conditions you know to plan growth due to shrinking of the root zone; your plants may die; if the soils are shrinking type or swelling type depending upon the type of pressure, they are exerting. Shrinkage cracks are responsible for actuation of landslides; any logic any reasons comes to your mind can you prove this?

So, another question is out of swelling and shrinkage; if I give you a C ϕ type of a soil; what swelling will do to C ϕ material and what shrinkage will do to C ϕ material? Can we say in a very gross term that C ϕ material becomes more frictional and C ϕ material becomes more cohesive because of swelling or because of shrinkage; I hope you agree with this philosophy.

So, this has to be you know quantified; that means, alteration of C ϕ material into pure cohesive material because of swelling; system becomes more uniform, more cohesive. Though it is losing its cohesion as a function of time, but in the gross term; the system is becoming more and more cohesive clear? But when you talk about shrinkage; it is the tensile strength which is becoming more important, the system is becoming more frictional in nature.

I am just giving you lot of ideas where you can think you know how to put numbers or how to assign numbers to these mechanism so that you can come up with some working models. So, shrinkage cracks are responsible for landslides any situation like to sight here why it happens. Apart from this more mechanistic way of looking at things; let us say why shrinkage cracks are responsible for landslides?

Student: (Refer Time: 28:50).

Sorry?

Student: (Refer Time: 28:53).

How shrinkage crack develops in landslide actuation? That is the question. What are tension cracks? You say tension cracks develop in, in the hills or may be in a heap of soil. What type of cracks are these? How do you differentiate between tension cracks and shrinkage cracks? Due to intrusion of water, landslide will take place that is right you are triggering landslide because of intrusion of water into the slope; that is true.

But the question is different, the question is what is the difference between tension cracks and shrinkage cracks? And what causes failure of the slopes? Now, when you use Rankine's theory minus 2 c root k_a or plus 2 c root k_a; when we use minus 2 C root k_a; what type of cracking is this? Is it a tension crack or shrinkage crack? It is a tension crack ok. What is causing this type of tension to occur in the soil mass?

Student: (Refer Time: 30:11).

You are right, you know these are tension cracks. These are shear strength which is causing tension cracks to develop, clear? But when we say shrinkage cracks, shrinkage cracks need not to be a tension cracks. But these cracks would be superficial as I was saying correct they are superficial cracks, but they give enough chance for water to get accumulated and because of this some external forces maybe acting on the system which may cause failure, alright.

So, tension cracks are associated with shear strength property of the material, but shrinkage cracks may not be associated with shear strength properties of the material. So, then the question is shrinkage cracks would be associated with what? They will be

associated mostly with environmental conditions and physico mineralogical properties of the material.

And if you put them in sequence shrinkage cracks would be responsible for generation of tension cracks, clear? So, what it indicates is it is more important to understand shrinkage cracks and to not to allow shrinkage cracks to appear so that you can make slopes more stable; is this part clear?

So, when you are doing this, you have to understand the mechanism of shrinkage and then you will have to devise a methodology by which shrinkage in soils can be minimized. And how would you minimize this? By adding some sort of minerals which are self healing or self sealing type ok. Overall health of pavements; the type of cracks which develop on pavements particularly your concrete pavements or rigid pavements; what type of cracks are these? Why do they shrinkage? These are basically reflection cracks.

So, yes because we are talking about shrinkage of the material; these are superficial cracks which tend to migrate into the material. So, this is where the crack propagation or the shrinkage pattern propagation in the material becomes more important. What causes these type of cracks to develop in pavements?

Student: Environmental conditions.

Environmental condition; mostly alright not the concrete, but the environmental condition; again what is the reason? The one side of the slab is exposed to environment, another side of the slad slab is exposed to different temperatures. So, there is a temperature gradient between the thickness entire between the entire thickness of the slab. And hence the pavement will be having thermal stresses which may cause or which may result in shrinkage cracks.

Shrinkage cracks appearing on the turfs and pitches of different soils, paint coatings. Have you ever noticed on the buildings just after painting within 3, 4 months 5 months; the chipping off of the paints why it happens ? And then other question is who will study this? Again it is related to the moisture conditions; if the walls are wet and if you paint them as the dry climate comes, there is a gradient between the inner surface of the paint and the outer surface of the paint.

Warping stresses develop on the paint surface and the paint surface gets peeled off. Now, this subject is of you know quite interest to people who are working in chemical engineering. We have heard the other day; however, we have lot of problems to handle already and to deal with the soils, which are already quite heterogeneous, inhomogeneous to differentiate between the type of cracks which develop, what causes them, how to correlate different properties alright so that you can come up with a model to define the shrinkage strength or the tensile strength of material and so on.

Now, these are the challenges in front of geotechnical engineers mostly. And of course, you can put a series of other problems like cracking of the core of the dam, (Refer Time: 34:58)apron of the dam and so on. Another good example is in potteries; is it not? The biggest problem is if you use a soil which cracks because of its heating or autoclaving, the whole idea of making a pottery gets defeated. So, if I give you different type of minerals montmorillonite, kaolinite, halloysite; which mineral you will be using for making potteries?

Student: Kaolinite and halloysite.

Why?

Student: Because they have (Refer Time: 35:34) these swellings will (Refer Time: 35:37).

Yeah, they are stable minerals.

Student: (Refer Time: 35:39) property which (Refer Time: 35:40).

That is right. So, suppose if I ask you to isolate foundations of soils from the environment; base isolation normally structure engineering people do what do they do? They isolate the foundations from rest of the environment by putting some damping systems so that the earthquakes will not strike and they will not be detrimental to this health of the structure.

Suppose, if I ask you to use minerals for designing a barrier system, alright for the foundations. So, what you should be doing; if you have a deposit where you have mostly swelling type of soil is this normal normally done in practice or not something like this

what I am discussing? See in most of the places the thumb rule is, you remove the soil fill it up with good soil what is the good soil?

Student: Non swelling.

Non swelling that is right; so this is being done for last so many years; thousands of years, but now the question is we cannot afford doing this anymore. First of all you excavate the soil where you are going to dump; this is the question number 1. Nobody is going to allow you to touch the soil unless you have a strategy in city like Bombay, where would you dredge, where you will place it, where will you dump it these are the biggest questions. So, you think of a system where base isolation of the footings can be done by using the minerals which will help you in reducing the activity of the soil.

Of course, this also is being done; ground improvement by using some chemicals, when you inject chemicals in the soil mass what is that you are doing? You are fixing the distance between the platelets with the help of a chemical. So, it is basically a chemical bonding between the platelets and what type of forces you have overcome? You have caught the nullified the forces which are electromagnetic, Van der waal forces acting between the clay platelets alright.

So, this is the physics and chemistry of the processes which you are normally using or which you are employing for treatment of the ground.