Geotechnical Engineering – II
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Lecture – 2
Shear Strength of Soils I

So, welcome to lecture number-2 CE-330 in Geotechnical Engineering-II. In previous lecture, I have talked about the topics which I will be covering in this course and the books for your reference. And the first topic of this course would be the shear strength of soils. It is a very wide topic for discussion.

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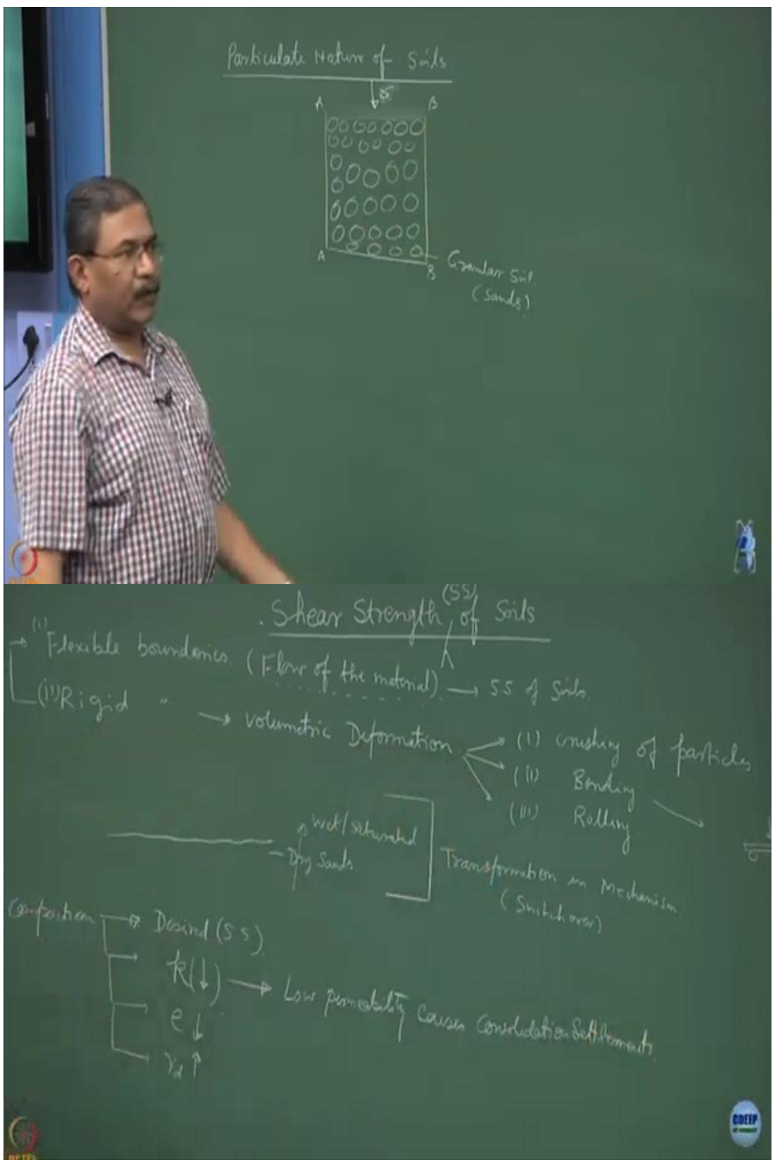

So, I will divide it in several parts and to begin with I will be creating some situations where the shear strength of soils becomes important to be considered. So, remember, we were talking about the particulate nature of soils in the Geotechnical Engineering course number-1. And this is a I had talked about a container which contains soil; and to begin with let this be granular soil. So, this is the granular soil like sands. And this is contained in a container and this container is connected or there is a piston inside, and through which I apply the load or stress sigma.

Then we created two situations out of this; one is the container happens to be a flexible boundary container. So, that means AA and BB are flexible. The second situation which I talked about is (*Read as AA and BB) are rigid; and then we were talking about the deformation characteristics of the soils, is it not? So, just for a quick reminder when you are dealing with the flexible boundaries, what is going to happen? The moment you apply this stress, the boundaries have a tendency to deform. And what is going to happen to the granular material. This has a tendency to flow out.

Flow of the material and that time we skip this part for discussion; we did not enter into it. We said this is what we are going to discuss in the second course. Meaning thereby we are more interested now in understanding how the flow of the material occurs. And that has something to do with the shear strength of the soils.

The second case we have analyzed quite a lot when the system is rigid and you are trying to pressurize it from the top. What is going to happen? This is what is going to result into volumetric deformation all right, and this is where we discuss about the three situations how the deformation takes place if you remember. Any idea? Or you have forgotten? The first one was the crushing of the particles, all right, second one was?

Student: (())(04:40)

Professor: Very, yes you are right; third one would be rolling. What about the second one? You are right. Bending and this is where we talked about an equivalent system where. So, this is what we have said two particles when they come closer to each other, the crushing at the tip is going to occur. And this is how the deformed shape would look like; this surface area is going to be higher than the tip of the contact. So, this is the area after crushing. The bending mechanism was we assume that the fine particles in the system are platelets; and they are simply supported on the rollers, which are nothing but the granular material.

And then if you load them, they will deform; so, this is how the deformation is going to occur. So, this is the deformed shape. You are right, the third mechanism was rolling; and we are more interested in understanding what rolling does to the system. That means in this discussion which is Geotechnical Engineering-II we will be mostly talking about the flexible boundaries where the flow occurs, and the rigid boundaries where the rolling might occur. Clear, and this is where shear strength comes into the play. Is this alright? Any question? Now, I hope you understand if the flexible boundaries are there and if I am load is still loading them, what is going to happen?

To consider this, I am sure you must have walked on a sea beach with dry sands. This thing also we discussed in the previous lecture. So, if you are walking on the sea beach and suppose this happens to be dry sands, what happens? How do you feel? You tend to sink? Is it not? You cannot walk; you cannot drive a vehicle is this okay? So, everything is linked together. Now, the moment this dry sand gets converted to the wet or saturated sand what happens? The system requires strength.

And you can drive vehicles, you must have seen on beaches; is it not? So, they can drive a car also. What has happened? There is a switch over of the mechanism from a dry system to the wet saturated sands. Water is entered into the pores and water provides tensile strength. So, the first time I am using the word strength of the material; and from where strength is coming just because of the water entering into the pores. The moment this sand again dries up, it becomes loose, no effect. And then we have talked about the bulking of sands and all those things. The density is maximum at the point where you have bulking occurring.

Now suppose, so this is the first situation where I have talked about transformation of mechanism. Sometimes we may also call this as a switchover of the mechanism. This is what we talked about the granular system and then we said in this case even if it is saturated, consolidation is never going to occur. Why? We said consolidation settlements of the granular system are going to be 0. Is this correct? So, let us now discuss about a tricky material which happens to be a fine grain material. This system is easy to handle; but we are not so lucky now to have many deposits of sands.

So, when we switched over our discussion on the granular materials, not sorry not on the granular materials, but on the cohesive soils. How did we deal with them? We compacted them, compaction characteristics. And if you remember the whole idea of compacting the soil was to what are the main objectives to achieve the desired shear strength? Correct. So, cohesive soils when you compacted them, compaction would result into the desired shear strength; what else? I am bringing down the permeability.

I do not want water to pass through the systems which I have created. So, this was the k-value I would like to decrease; void ratios decrease, γ_d increased. Clear, is this correct? What about the consolidation? Now, these systems are quite prone to the lag in pore water pressure dissipation; why? Because of the low permeability. So, low permeability causes consolidation settlement is this part. And then we have done the analysis of the consolidation settlements.

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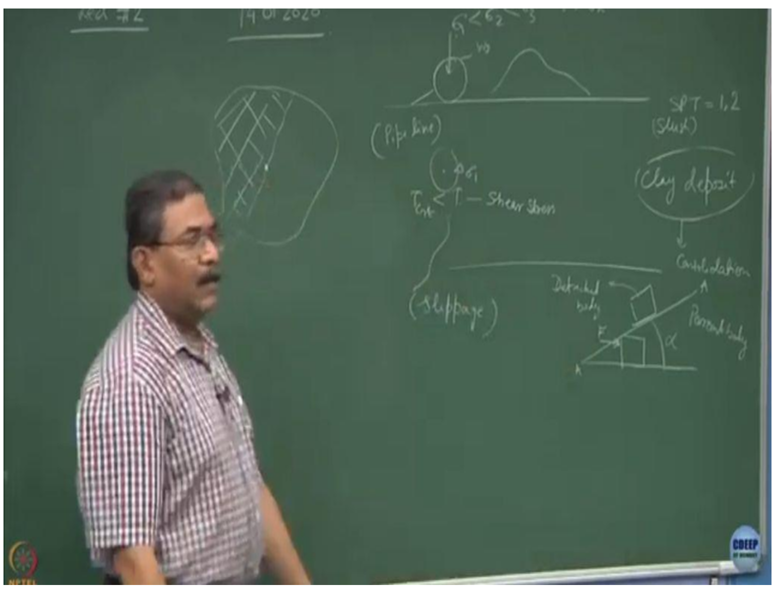

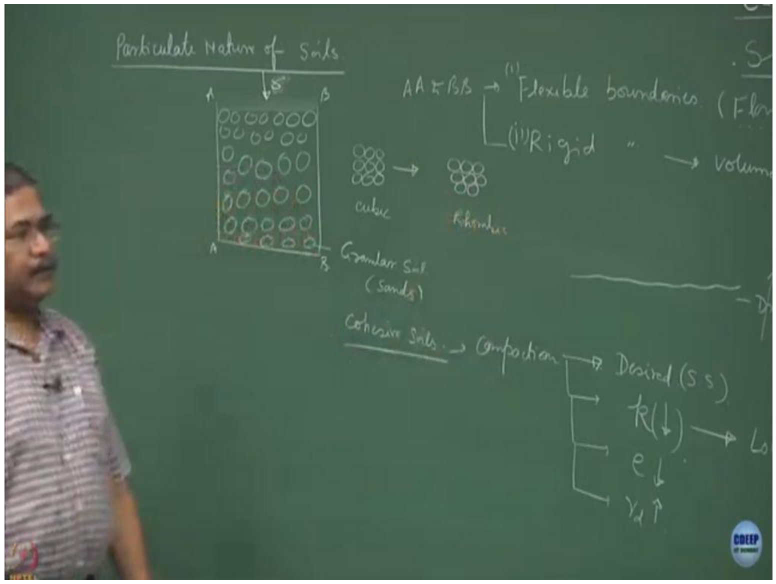

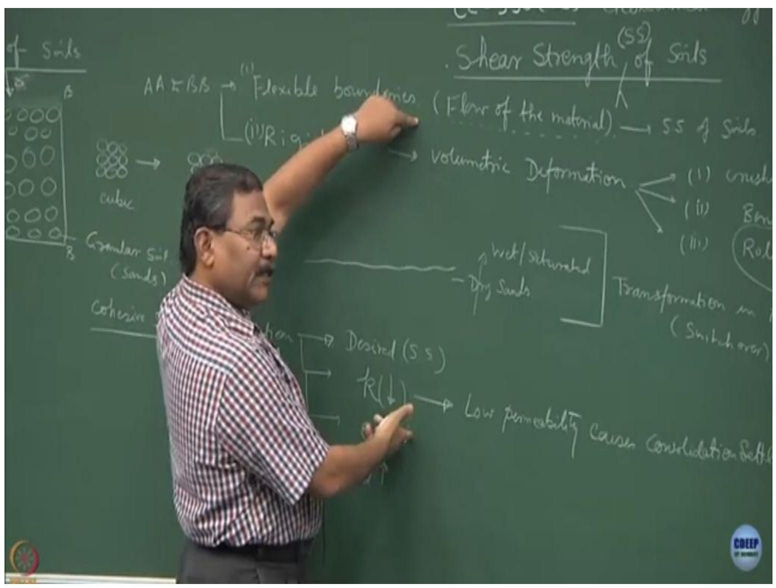

We obtained the stresses which are acting on a system. So, suppose this is a situation where you have a clay deposit. The moment I use the word clays its understood that this is going to be a saturated system, and it is going to consolidate the moment we expose it to the external loading. So, suppose if I ask you a question this is slush. In our language, slush is something on which I cannot even stand; I will sink. And foundation engineering course, you will come across a term which is known as standard penetration test SPT value. This is let us say 1 to 2; you cannot stand here even.

But, suppose if I ask you a question, if I want to construct a facility on the top of this, be it a pipeline cross-country pipeline. So, in the offshore most of the time the subsurface soils are organic marine clays, highly sensitive soft water saturated systems. Now, the question is if you cannot stand on the deposit because of this poor strength, this again is a shear strength of the system corresponding to the clay deposit, which is liable to consolidation because of the external loading. Three clauses I have added. Initially to start with the pipeline has its own self weight or dead weight.

These are kilometers long pipeline two to two and a half meter diameter pipelines carrying either your fiber optic cables, utilities, data connectivity, whatever, crude oil any type of supply, lifeline of the society. Now, the question is how are you going to install the system on this type of a deposit? And where the switchover of the mechanism is going to occur, from consolidation to shear strength? That is what actually I am going to talk about. So, I have created a situation where you have analyzed a situation where external loading was causing settlement of the clay deposit.

Now, we have to go one step ahead. So, because of the self weight of the system, the chances are that the pipeline may settle a bit. But you are going to charge the pipeline very soon, you are going to pass the fluid or some utility. So, what is going to happen? The self weight of the pipeline is going to increase. So, imagine if you started with let us say σ_1, and σ_1 was good enough to create some settlements over here because of $\Delta\sigma_1$. $\Delta\sigma_1$ we have computed by using different types of charts, (14:45) charts, all sorts of equivalent rectangular area, circular area and what not.

So, I know because of this sigma1, delta sigma1 is getting created. And this delta sigma1 is causing consolidation. But as per the requirement, suppose if I have to load the system excessively. So, from σ_1, if I go to σ_2, from σ_1 suppose if I go to σ_3, partial discharge of the utility from the pipeline to the full let us say up to σ_n. Initially, I will send let us say 1 m column or sorry 1 cm column of, let us say fluid, 2 cm, 10 cm, 100 cm, 200 cm and so on. So, truly speaking what I am doing? I am loading the system continuously, and hence the stresses are going to increase.

Now, the question is what is going to happen? I hope you can realize now. Beyond a certain limit of consolidation, if the stresses are too excessive in nature, what is going to happen? These stresses are going to cause development of the shear stress over here. So, this is the τ, which is defining the shear stress. The more and more you load the system, the more and more shear stresses develop at a given point. And then what is going to happen? There is a possibility that this shear stress might become higher than the T critical.

Very specific case of the strength of materials which you have done in your undergraduate courses. You know how to find out the critical shear strength of the material. Now, what I have created situation is because of the external loading, settlement ceases. And beyond that critical load, the shear stresses developed in the system; and these shear stresses if they become critical, much more than the critical shear strength, what is going to happen? So, here in the granular system, this was the rolling.

In case of the cohesive material what is going to happen? There will be a slippage; is this okay? If I keep on loading the system, what is going to happen? The particles will first, starting from cubic arrangement, is this okay? What is going to happen? And if I tamp it from the side that means I am shearing it applying some shear stress. This is how the system would become more dense, first of all. So, this is a transformation from cubic to rhombic. If I further shear it, because of the development of the shear stresses, what is going to happen?

The particles would have a tendency to get lifted up from here and come and get settled over here. I think I give you an example in the snooker board, if you spread all the balls and then try to confine them like this. Hand motions are very important to see because then you can realize better. So, you have all these snooker balls and then you just try to bring them together, what is going to happen, they ooze out. Now, this is a mechanism which we are trying to ultimately simulate what nature does to create a tectonic motion and formation of the Himalayas at the same time the lakes.

So, because of the development of shear stress in granular material, there will be a rolling over of the grains; you are right. When we are talking about the cohesive soils, rolling is not possible. What is going to happen? The slippage is going to occur. What is the slippage? In engineering mechanics, you have done these type of problems.

So, it is a extended example of the case which you have already studied in Engineering Mechanics. Suppose, if I give you a situation like there is a horizontal plane and there is a block lying over here. And then if I apply a force, you find out the kinetics and kinematics of the system; that you can do very easily.

Now, second situation would be, if I keep on inclining this plane. So, starting from a horizontal plane, suppose if I create a plane which is inclined to the surface at an angle of alpha. What I have done is starting from a plain horizontal ground, river in breadth; I have created a sloping ground, sort of a hillock. And suppose if this block comes and sits over here, now what is going to happen you analyze this also. And what did you do in this analysis? You have obtained α critical value for incipient motion of the block. You got this point that is also shear strength.

And where is the shear acting at the contact point of the block and the slope. Is this part Correct? Let me extend this model further for the case of the soils. So, if you come back to this situation and if I zoom out this point, how it will look like? So, this situation would be as if there is a rigid body infinite soil mass. At this point, slippage is occurring; that means there has to be a parent body and there has to be a detached body. So, that means in this system, I have created a detached body and I have created a parent body.

So, out of this whole body, there could be a development of a shear plane; and this shear plane is equivalent to the surface AA. And there are chances that this block might start slipping along this boundary with respect to the parent body. Is this part clear? That is this whole mechanism is being controlled by the shear strength of the system which is acting at this point. Any questions? Yes, so far so good; no difficulties. You have already studied everything; I am just creating situations out of it.

So, that means what we have learned today is excessive loading would result in a little bit of settlement, but more of the shear failures. So, all foundations are designed based on this concept of how much loading the system can take before the entire thing slips off. Now, this is a case which I have created of the landslides, rock falls. Your slopes are so critical that the chunk or the pieces of the rocks they start coming out; they get detached from the parent body and they start falling down.

And hence your Khandala-Mumbai Express Highway is blocked choked; is this okay? How many examples we have cited? We started with the granular material particulate nature of the soils. We have defined these mechanisms, out of which we have created two situations which are of our interest due to the excessive loading.

And then we have gone to decide about the mechanism which is going to govern the failure of the system. So, remember in this case, as far as the loadings are small, there could be excessive settlements, settlement failure. But, the moment loading becomes excessive, the chances are that from consolidation; it might get converted into the shear failure.

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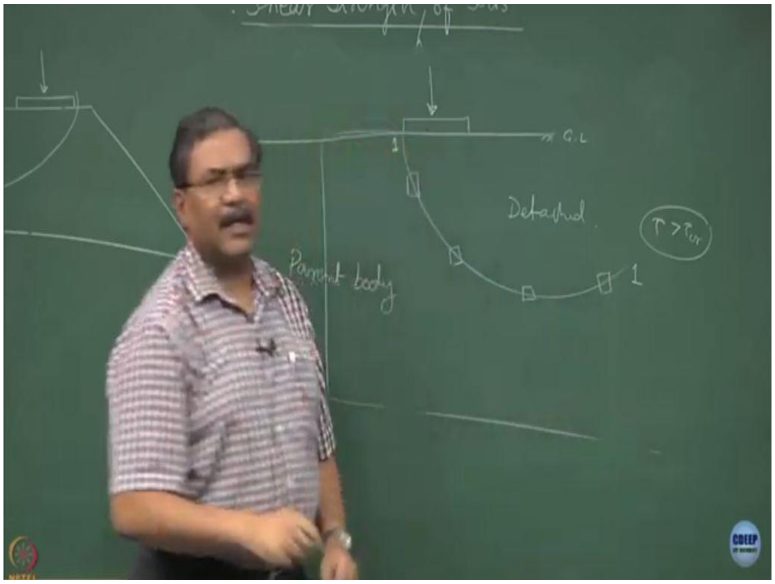

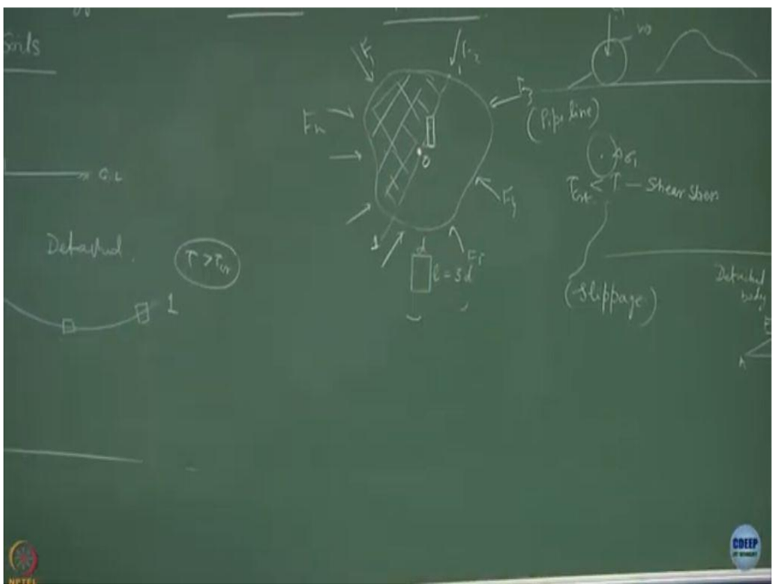

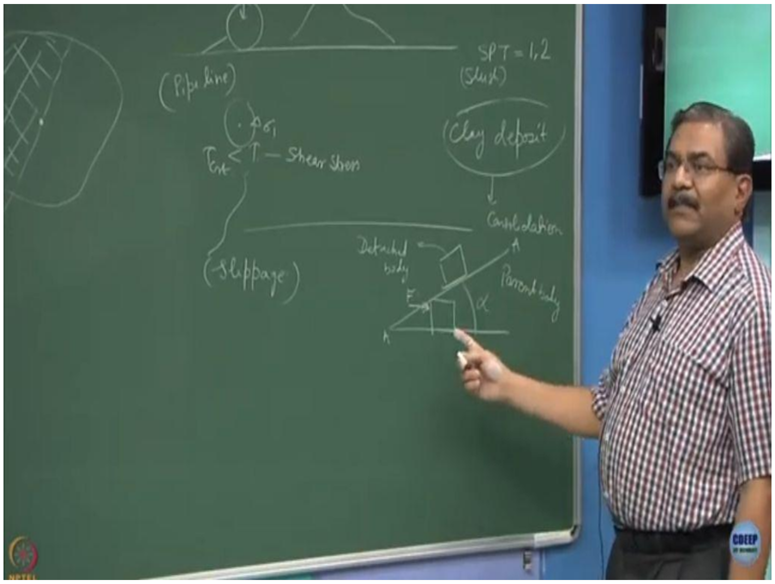

So, this is a horizontal ground. And suppose if I lay a foundation over here; you must have gone to ice cream shops, ice-cream parlors. Have you ever seen this scooping effect? You ask him to give you one scoop of the ice cream? What it has? There is a scoop; exactly do it like this again. No, it is like grabbing and detaching it from the media. So, like all sorts of haulers which you have, which are used for construction of the civil engineering work. So, look at the motion of the hand. These fingers go deep inside the soil, and then there is a pull towards yourself.

So, you are detaching the whole soil mass and grabbing it and taking it out and keeping it here. Now, this mechanism nature does and we will simulate it by using these theories. So, if you extend this model over here, what you will realize is one of the possibility of the failure of the foundation would be something like this, scooping effect. Is this correct? Look at the motion. So, you are pressing it hard. Sometimes what happens see if I have a duster and if I just press it on the board very hard, what is going to happen?

The chances are that it may slip off. Unfortunately, I cannot demonstrate it here; but you can realize this happening. So, this is the motion or this is the soil mass which is going to get detached from the parent body. So, this happens to the parent body and this is the detached portion; and what we will call this surface as 1-1. This is a slip surface about which something is slipping with respect to another stationary body. This situation is exactly similar to this in nature; you will not have very much plain, linear inclined surfaces whatever surfaces you are going to have.

So, next time when you go towards hilly terrains, you will find that most of the slopes fail like this. There is a scar formation and the soil mass simply gets removed from here and gets deposited at the downhill side. Suppose if I have embankments, until now you have studied how to construct embankment by compacting the soils, very good. You achieve certain amount of shear strength; you achieve certain amount of void ratios gamma-D, which is worthy enough to support the external systems on it. And you laid the foundation of railway track. The same situation may have happened here also and this will be disaster.

You made the system very strong by compacting it by selecting the right materials, so that no consolidation settlement occurs over here; everything went alright. But, if you do not take into account, the effect of shearing of this material and the loading which is going to come on the top; the chances are the whole system may fail along this surface. You can create several of these situations; I hope the point is clear. So, let us move now ahead with the analysis of these situations. And that is what actually I intend to do.

Now, the question is if I take an element out of this surface, so look at the way I have drawn an element. It is a cylindrical element and we call it as a triaxial element. So, off certain diameter and off certain length, where length is two times the diameter). Why? You studied the isobars and consolidation test setup also; the diameter was three times the height of the sample. Why? To entrap all the isobars of 99 percent stresses within the sample, uniformity of the stress distribution.

So, we call this as a typical triaxial sample. I am very much interested in understanding what is the state of stress on this sample. Similarly, I may take a sample over here, I may take a sample over here, I may take a sample over here, I may take a sample over here. And what I am trying to prove is that why this surface 1 to 1 is so unique that the failure is going to take place along this only, and the answer is simple.

And the answer is at each and every given point of this surface 1-1, the condition tau is greater than tau critical is being satisfied. Is this part okay? No issues? Each and every point is on the verge of failure because of external loading. It has not failed, but it is on the verge of failure. Any amount of samples in sampling which you do, and I can take out the sample standing outside and lowering down a cylindrical sample holder, pushing it in the ground and taking it out. This is how the sampling is done.

So, I am interested in knowing what is the state of stress at these elements; and these elements are infinitesimal elements, very small elements points. So, in other words, on this rigid body what I want to do is I am going to say that if several forces are acting from outside F1, F2, F3, F4, F5 so on, Fn. What is the net effect of these forces? And this is a rigid body. So, we are ignoring the effect of deformation. This is equivalent to what I said over here. You took the right soil, you compact the right thing at right gamma-D, right e-value. You made a very compact strong system.

But, even then it is failing why because of the external forces which are going to cause a state of stress at a given point on a plane which we are defining as a failure plane. Because you must be realizing that all the mechanisms have now been clubbed together and we are not studying anything in isolation. In first course what did we do?

Characterization of soil separate, compaction separate, seepage separate, stress acting on the soil separate, consolidation separate. Now what I am doing? These are tools for me. So, truly speaking Geotechnical Engineering-II is the conglomeration of the idea which you get from Geotechnical Engineering-I. And the whole idea is to solve the practical problems; so that is what we are doing. In other words, if I say that this is a plane, let say 1-1. And if I am very much interested in knowing this state of stress at the point O; how I will be going about it?