**Application Of Soil Mechanics**
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**Lecture # 33**

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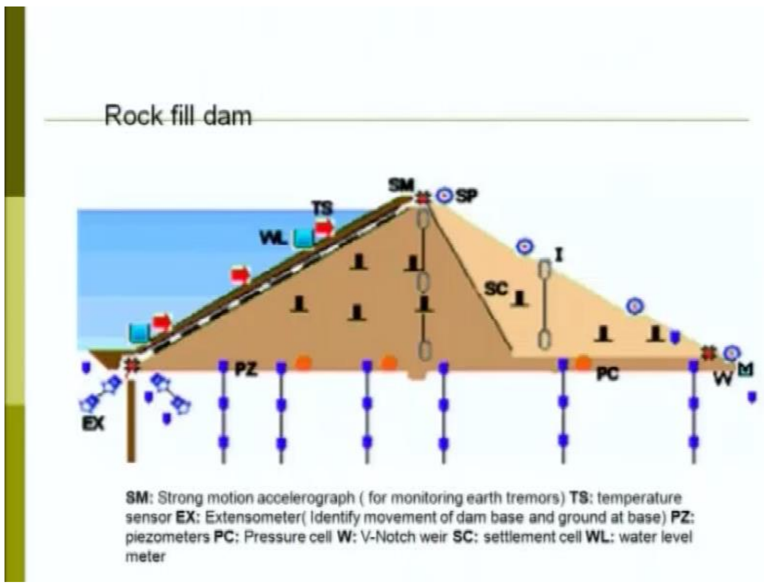


Earlier we have discussed different techniques of monitoring this ah earth dam construction. Now this is a typical figure, it shows this how this instrumentation has been made. If you look at SM means Strong motion accelerogram, SM is here Strong motion accelerograph, so monitoring particularly earthquake tremors, and TS is your temperature sensor. If you look at here, this is your temperature sensor at the along the surface of this slope. EX is your extensometer, identify movement of your dam basement, and PZ is your piezometers, that means how much is your pour water pressure developed, this is for PZ. PC is your pressure cell, if you look at the PC, these are all typical red color.

This is PC, PC and PC. Pressure cell along the width of these dam, along the length direction it has been placed, so that how much pressure transferred from this dam to the foundation soil, you can measure it. SC is your settlement cell, and WL is your water level meter. This is your WL, WL is your water level meter. These are all your water level meter.

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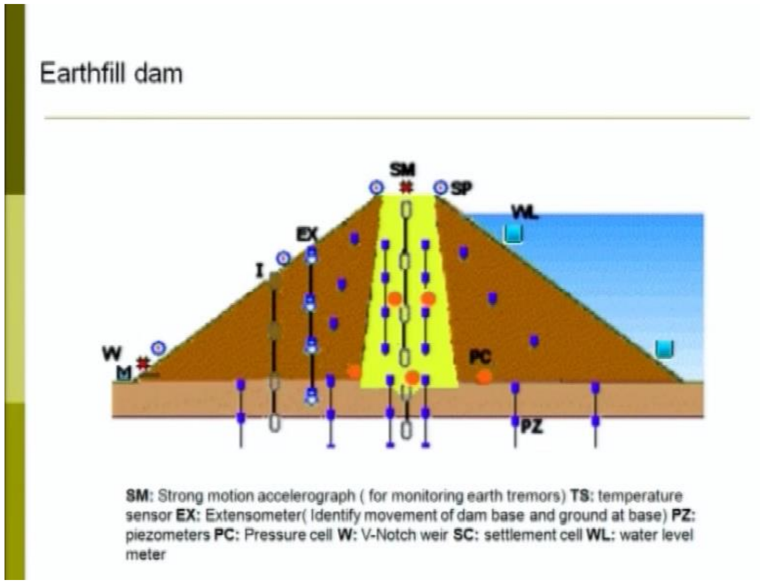


Then similar kind of also, there is another also earth fill dam, one is your, this is your rock fill dam, second is your earth fill dam. In this case of earth fill dam, in the core if this is the core, this is your core part, in this core, you have yoru SM – strong motion accelerograph. And you have also your SP and as well as your ah pressure meters. All virtual instrument has been placed ah in case of earth fill dam in the core.

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Then key components for design of instrumentation that means put in redundancy that means instrumentation will get lost due to construction activities and equipment will stop working. So protect equipment from the contractors that means put in safe areas, mark equipment, and protect it during installation and post installation. Then last is your spend money so can remotely monitor and collect data. And consider data analysis cost also. This part also you have to taken into consider.

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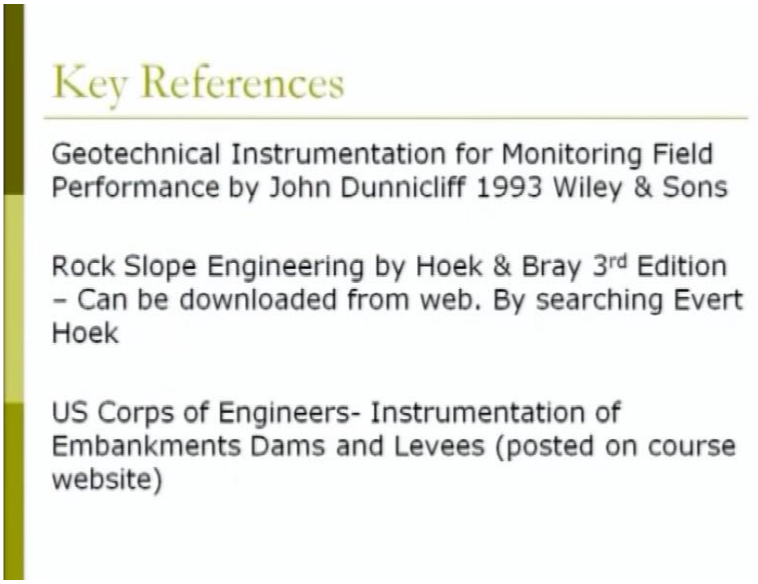


Then these are all your references taken from the Geotechnical Instrumentation for Monitoring Field Performance by John Dunnicliff 1993 Wiley and Sons ah publications. And US Corps of Engineers – Instrumentation of Embankments and Dams and Levees. So these are all your key references.

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Now next slide we are going to start a new topic that is your design [noise] of your reinforced soil structures. Design of reinforced soil structures, this is also part of Application of Soil Mechanics. Reinforced soil structure that means, soil structure whatever is there, it has been reinforced by outside material.

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Now reinforced earth structure; it is particularly this why there is reinforcement required particularly earth structures, to exhibit a certain level of stability against your earthquake events that means how importance of the structure and particularly that area of what is the seismicity of that area concerned, that will also taken into consideration.

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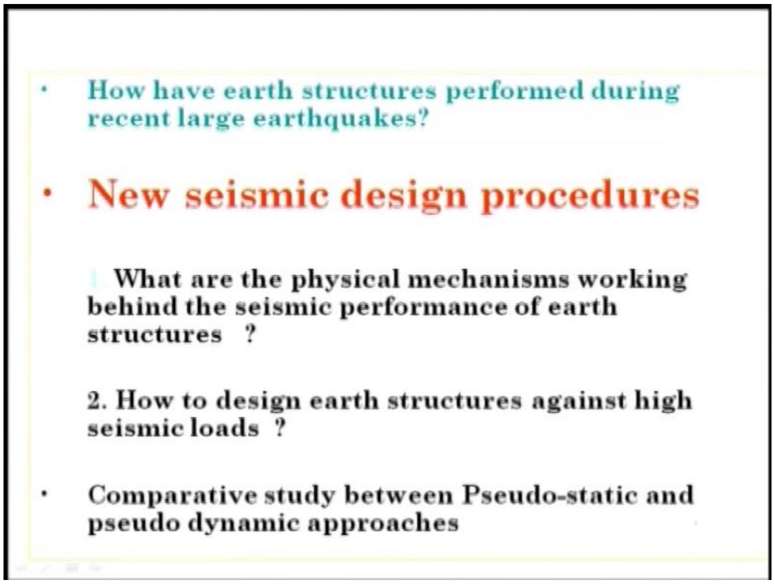


How have earth structures performed during recent large earthquakes that means that is your new seismic new design procedure. In seismic design procedure, number one is your what are the physical mechanism working behind the seismic performance of earth structures, what is the physical, what is the physics behind it. How to design earth structures against high seismic loads, how to design; then a comparative study of different design methods, approaches.

Recent case histories in Japan, in 1993 to 2007 of earthquake magnitude varying from 7.6 to 6.6. Now earthquakes caused severe damage to highway embankments, and un-reinforced retaining wall is typically shown in the following slides. In the slide, particularly, where the earthquake caused a severe damage that means highway embankments, particularly, embankments, and un-reinforced retaining structures.

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If you look at here gravity type of retaining wall; it happened in 1995 earthquake, Nanbu earthquake. This is your gravity retaining wall, this retaining wall is gravity retaining wall, the damage has been made, it has been taken from that side, how the damage is there, because of earthquake.

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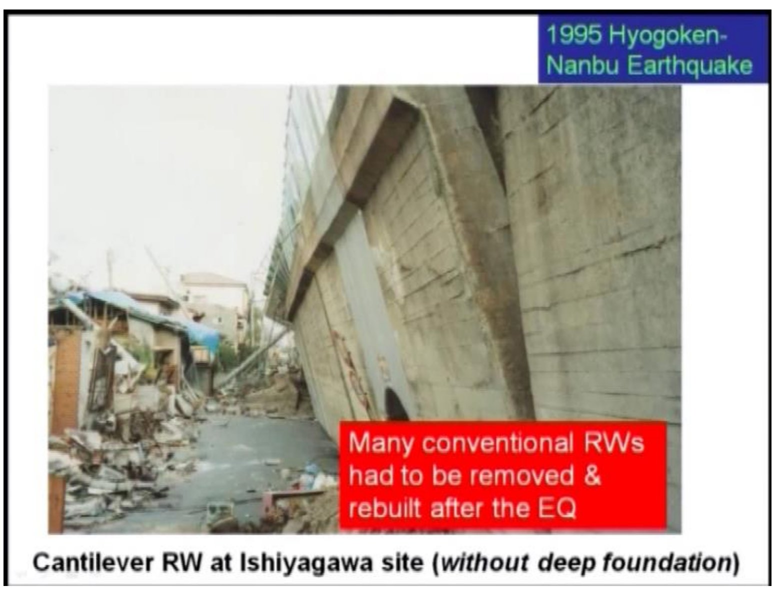

Now second one is your cantilever retaining wall. If you look at here, this is your cantilever retaining wall, this damage because of your nineteen ninety five ah Nanbu earthquake. Then this cantilever retaining wall is without any deep foundation.

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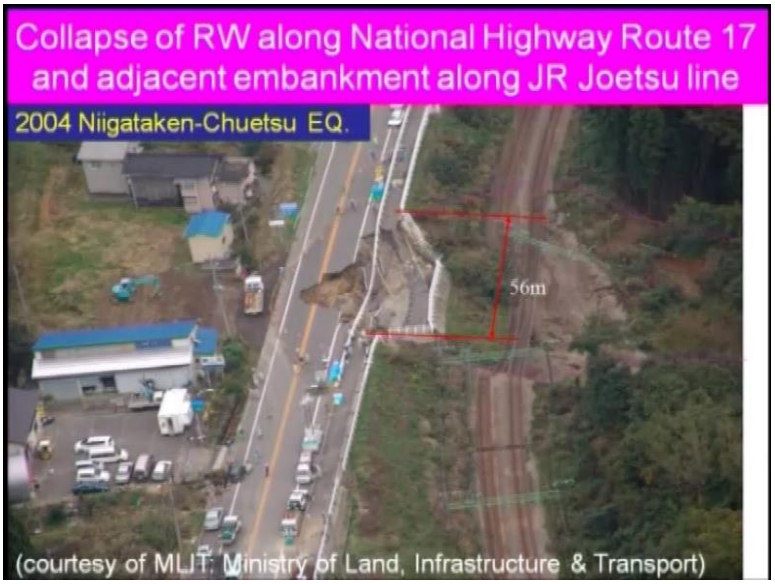


Second is your collapse of retaining wall along National Highway Route seventeen and adjacent embankment along Joestu line. It is said 2004 Niigataken earthquake. If you look at here, it is in this particularly, this area is your 56 kilometer and sorry 56 meter. It has been damaged because of your earthquake.

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Then collapse of retaining wall along National Highway Route seventeen. If you look at here, reconstructed during ah particularly using GRS retaining wall. GRS retaining wall, how the construction has been going on. This is the first one is your means collapse of your retaining wall. And this is by using your reinforced earth how this construction process is going on.

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Then again 2004, Niigataken earthquake, one is your tunnel; there is a damage of the tunnel. Also it lies near by the river, that is Shinano river near by this river, this is your damage. Failure of unreinforced embankment, this is one is your retaining wall; I have shown now. On reinforced embankment, it has never been reinforced. It is just un-reinforced embankment. It is in case of it is two thousand four Niigataken ah earthquake, if you look here this, embankment how this there is a failure of un-reinforced embankment. Then same also un-reinforced embankment.

Then collapse of retaining wall at Kashiwazaki city, because of two thousand seven Niigataken earthquake. If you look at here, collapse of the retaining wall here, this is collapse of your complete retaining wall. These are all examples. Involved in large-scale landslide. If you look at here, large-scale landslides also occurs, ah because of landslides, there is a gravity type of retaining wall, it also collapsed.

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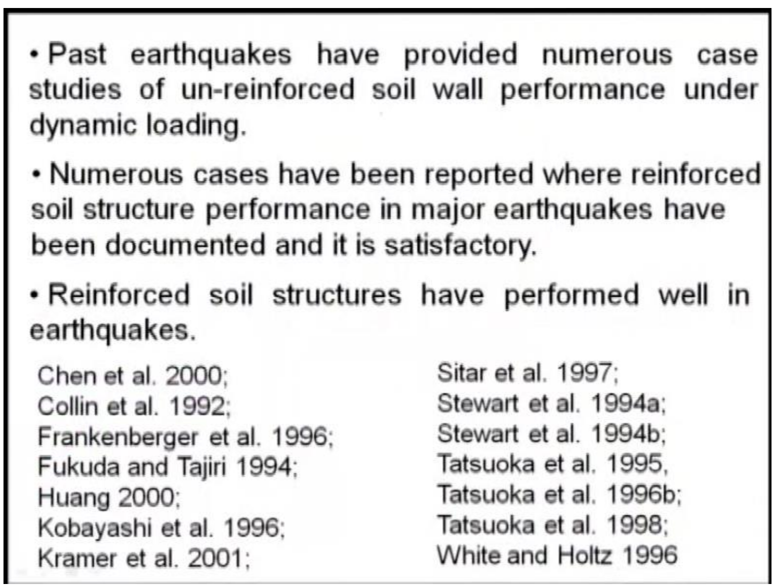


That means past earthquakes have provided numerous case studies of un-reinforced soil wall performance under dynamic loading. That means if I go to the previous study, it gives numerous case studies, these are all your case studies in Japan, where your un-reinforced soil wall performance under this dynamic loading or earthquake loading. Numerous cases have been reported where reinforced soil structure performance in major earthquake both means we have case study of reinforced as well as un-reinforced soil wall performance under earthquake loading. Reinforced soil structures have performed well in earthquakes. These are all reported, people who are reported in reinforced soil structures, how it has been performed particularly during your earthquake.

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Reconstruction of failed walls using geosynthetic reinforcement. If you look at here, reconstruction of failed wall using geosynthetic reinforcement, these are all your geosynthetic by using geosynthetic reinforcement. Geosynthetic reinforcement if you look at here, geosynthetic reinforcement, there is a reconstruction of this failed walls.

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Then reconstruction using combination of geosynthetic reinforced retaining structures wall and anchoring. If you look at here, these are all your anchoring. Anchoring has been made, here this point if you look at this, this is a point of your anchor, anchoring has been made, this is a point of your anchoring. Along with your geosynthetic stabilization also soil nail, these are all called anchoring by means of soil nailing.

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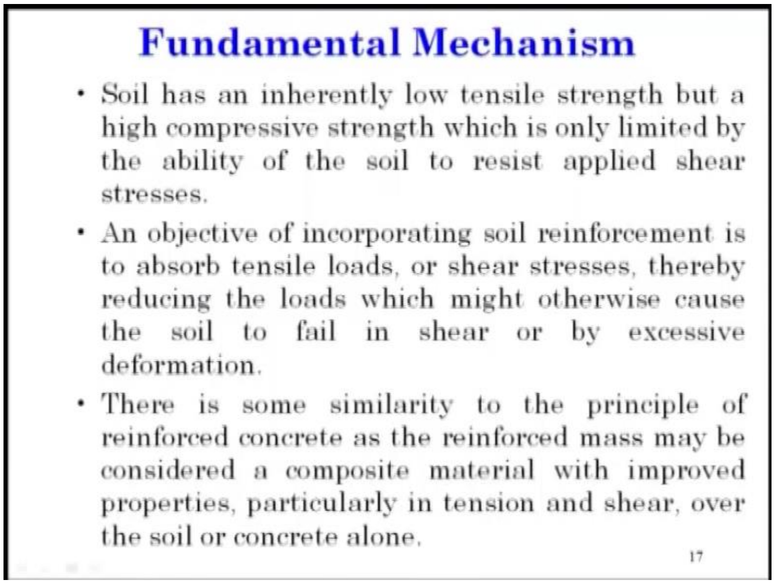

Now whatever we have discussed these are all your case studies discussion means basically one is your un-reinforced retaining wall as well as embankment. There are case studies, how it fails during earthquake, then how it has been constructed. To sustain your earthquake loading, then what is the fundamental mechanics. Soil has an inherently low tensile strength. As you know, soil has an inherently low tensile strength but a high compressive strength which is only limited by the ability of the soil to resist applied shear stresses. Soil has high compressive strength which is only limited by the ability of the soil to resist applied shear stresses.

An objective of incorporating soil reinforcement is to absorb tensile loads, or shear stresses, thereby reducing the loads, which might otherwise cause the soil to fail in shear or by excessive deformation. That means reducing loads, once you are reducing load, what will happen to that load. This load cause the soil to fail excessive load to cause this soil to fail in terms of by shear or by means of excess deformation. If I by means, if I reduced this load coming to the soil by applying, by giving your soil reinforcement then also it satisfies this design criteria.

There is some similarity to the principle of reinforced concrete as the reinforced mass maybe consider a composite material that means soil with reinforced wall, if this is a soil, the if I say it, it is soil with reinforcement. These are all your reinforcement, reinforcement soil with reinforcement that means there is some similarity to the principle of reinforced concrete as the reinforced mass may be considered a composite material. Soil with your reinforcing material, may be considered as a composite material with improved properties, particularly in tension, shear and over the soil or concrete alone.

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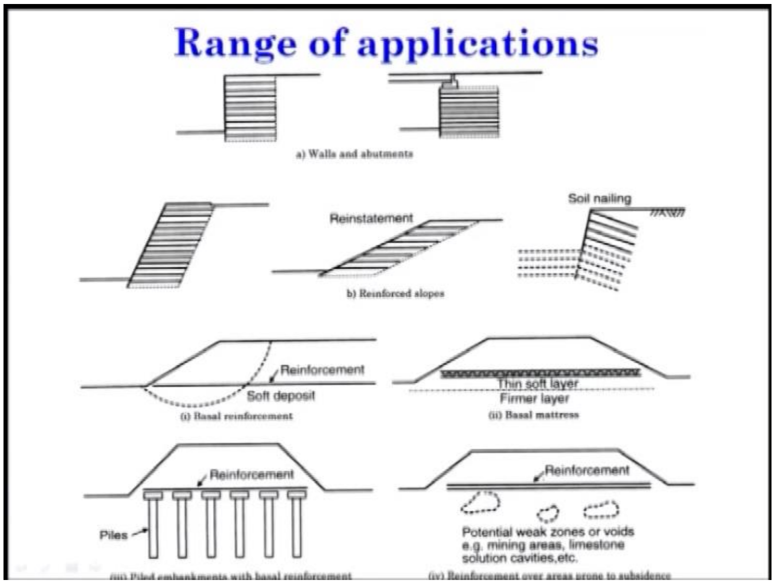


Now range of applications. This reinforced earth wall range of application. If you look at number of applications is your, where some applications just I have numerous. One is your abutments; this is your wall, and abutments. Second is your reinforced slopes; there is simple slope and this slope has been reinforced by means of geotextile or other materials. If you look at these are all your reinforced slopes. You can reinforced this slope by also soil nailing. Then if you look at here, reinforced slope is your reinforcement can be provide at the base of your slope, you can provide the reinforcement. This is your reinforcement has been provided at the base of this slope or you can provide reinforcement along the slope, that means if firmer layer with a thin soft layer you can provide. Also you can provide reinforcement in pilled embankment. If this is your pile, then at the top you can provide your reinforcement, then embankment you can provide. Then reinforcement over area of prone to subsidence that means potential weak zones or voids. If there is a potential weak zones or voids, then above this you can also provide reinforcement.

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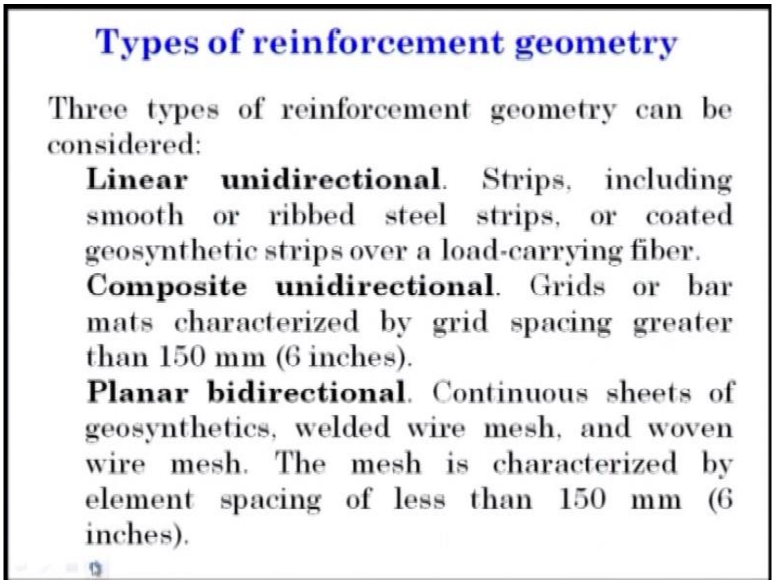


Types of reinforcement geometry; three types of reinforcement geometry can be considered. First is your linear unidirectional that means strips, including smooth or ribbed steel strips, or coated geosynthetic strips over a load-carrying fiber. Second is your composite unidirectional; one is your linear unidirectional, second is your composite unidirectional that means for example, grids or bars or mats characterized by grid spacing greater than 150 mm, this comes under composite unidirectional. Then is your planar bidirectional that means continuous sheets of geosynthetics, welded wire mesh, and woven wire mesh. The mesh is characterized by element spacing of less than 150 mm, this is your planar bidirectional.

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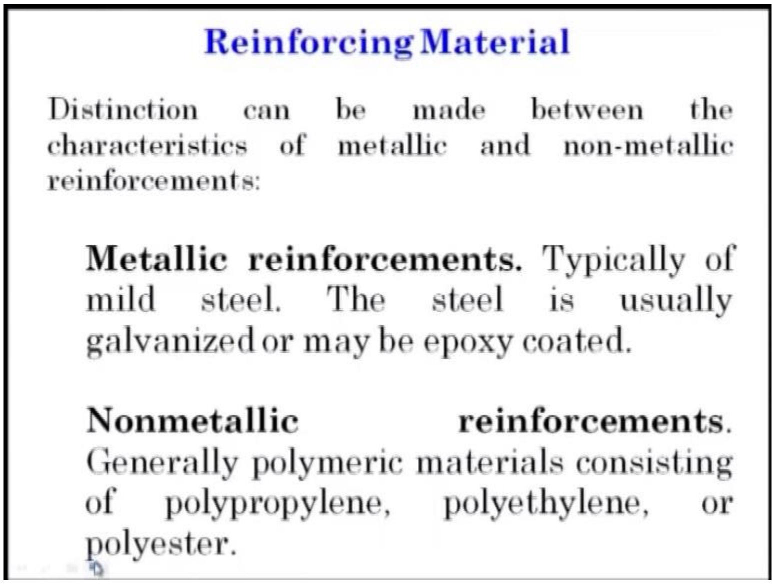


First we have discussed about the mechanics then second part we have discussed types of reinforcement geometry. What are the different types of geometry? First one is linear unidirectional, second is your composite unidirectional, third is your planar bidirectional. Then third part is your reinforcing material. What are the different materials used as reinforcement. Distinction can be made between the characteristics of metallic and non-metallic reinforcements that means metallic and non-metallic reinforcement can be characterized. Metallic reinforcement, typically we are using mild steel. The steel is usually galvanized or may be epoxy coated, look at it may be epoxy coated. These are called metallic reinforcement. Nonmetallic reinforcement, generally in case of nonmetallic reinforcement will provide polymeric materials ah that means consisting of polypropylene, polyethylene, or polyester that means non-metallic reinforcement generally polymeric materials, it consist of polypropylene, polyethylene or polyester.

Reinforcing materials are two types, one is your metallic reinforcement, generally we used mild steel with coated with epoxy epoxy; and second one is your nonmetallic reinforcement, this is a polymeric material, it may be polypropylene, polyethylene or polyester.

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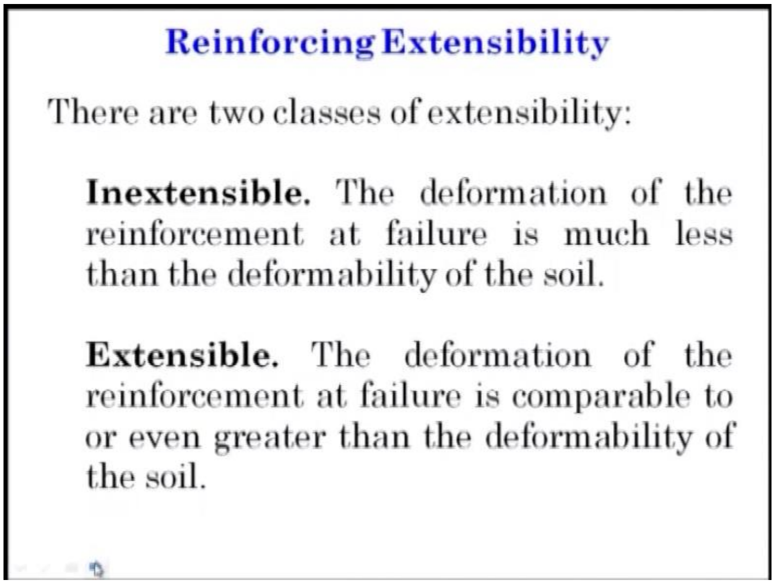


There are two classes reinforcing extensibility, then next part is your ah fourth part is your reinforcing extensibility, there are two classes of extensibility – inextensible and second is your extensible. In case of inextensible, the deformation of the reinforcement at failure is much less than the deformability of soil. Inextensible means, if I compare with these soil mass that means the deformation in the soil mass will be more and the deformation of the reinforcing material or reinforcement is less.

Second one is your extensible; if I look at the extensible, the deformation of the reinforcement at failure is comparable or even greater than deformability of soil that means if I compare with this soil, this if it is extensible reinforcement that means the reinforcement may be equal to the your deformation of your soil. Or the deformation of reinforcement, is even more than your deformation of soil, that means two classes of extensibility; one is inextensible means every reinforcing material is extensible. But we classify into inextensible and extensible.

The moment which say inextensible that means if I compare with this soil, the deformation in reinforcement will be less as compared to soil. But in case of extensible, the deformation in a reinforcement will be same to be your deformation of soil or maybe more than your deformation of soil, so that is why it is called, extensible.

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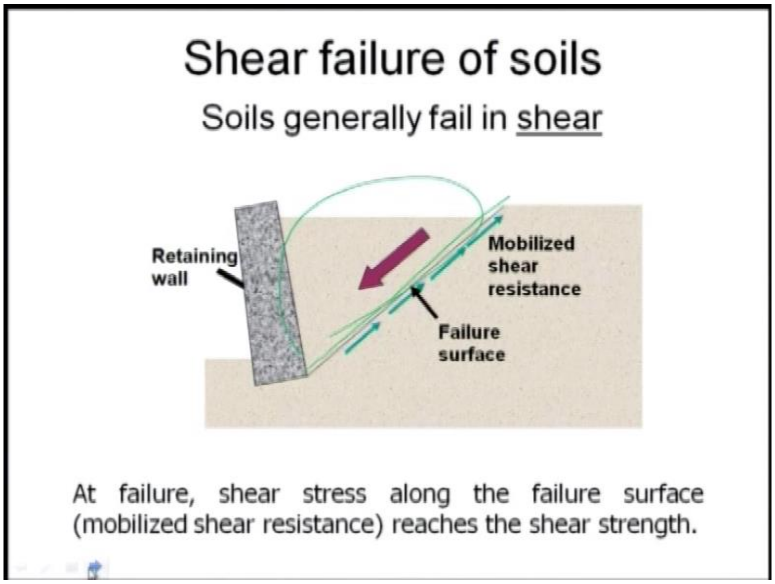


Now shear failure of soil, soil generally fails in shear. If you look at the basic mechanics, there is a retaining wall; retaining wall has been constructed to retain the soil mass, so that a structure or manmade ah structure can be made above the retain soil. If you look at how this shear failure occurs, soil try to push this retaining wall. If you look at the animation, soil try to push this retaining wall, that means if retaining wall is away that means it acts active earth pressure. Look at this. There will be a mobilization of shear resistance, and there will be a failure surface. It doesn't mean that entire part of the retaining mass of the soil will fail, there will be a mobilize shear resistance and failure surface, this is your failure surface, that means inside this failure surface, mobilization of shear resistance occur.[noise] At failure, shear stress along the failure surface reaches the shear strength. At failure, shear stress along the failure surface reaches your shear strength of your soil.

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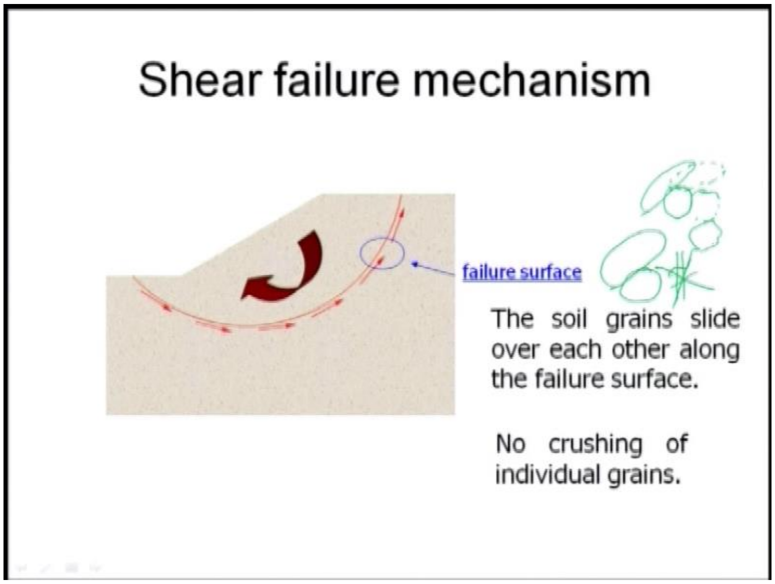


Shear failure mechanism If you look this shear failure mechanism failure surface, soil grains slide over with each other along the failure surface, that means if I say this is my failure surface, that means soil grains slide over each other along the failure surface. No crushing, in this case, no crushing of individual grains; crushing means no breaking of individual grains, that means soil will, soil grains will slide over each other. If there is one soil grain, if there is another soil grain, what will happen, the soil grain the dotted line is slide over, the soil grain is slide over another soil grain, that means there is no crushing of individual grains. That means if this is your soil grain, if there is another soil grain, it should not be like a crushing or breaking of soil particles, no.

So this is the shear failure mechanism. If I take a along the failure surface, I get take a small element, what are their acted. Now if you look at here, at failure, shear stress along the failure surface – tau, at failure. This is my failure surface, at failure, shear stress along the failure surface, this is the shear stress along the failure surface, this is called tau, reaches your shear strength of soil that is called tau f – shear strength of your soil that is called tau f.

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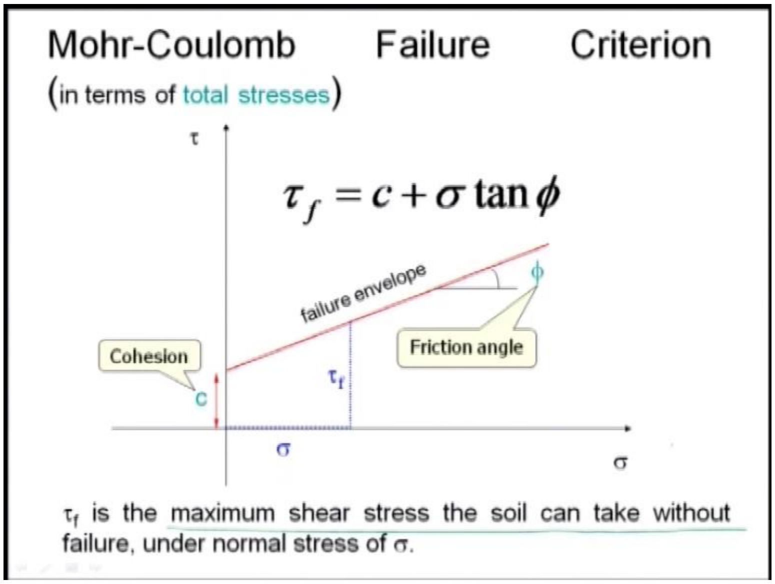


Mohr-Coulomb failure criterion that means in terms of total stresses if I draw the Mohr-Coulomb failure criteria that means tau f is equal to c plus sigma tan phi. C is your cohesion and tau f is your failure envelope and phi is your frictional angle. Tau f is your maximum shear stress the soil can take without failure, tau is your maximum shear stress, soil can take without failure, under normal stress of sigma.

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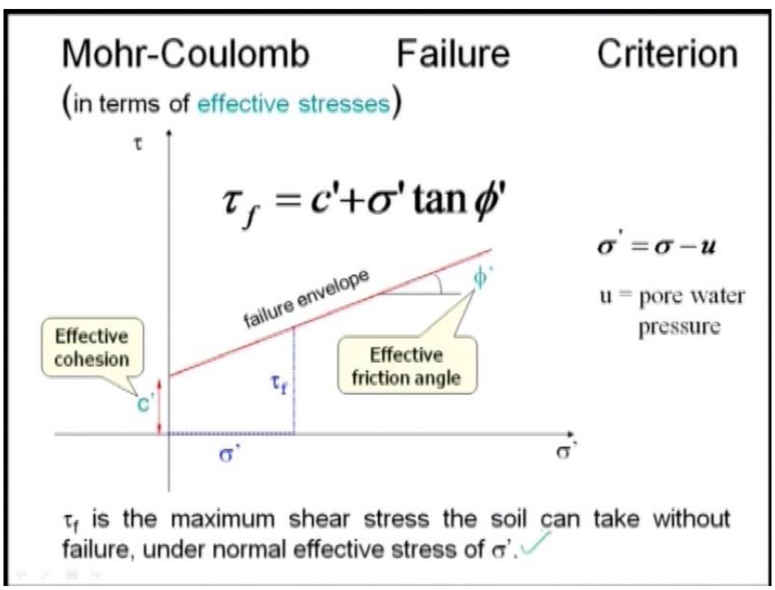

Then Mohr-Coulomb failure criterion in terms of effective stresses, effective stress angle is your phi prime, and effective cohesions is your c prime. And sigma prime is equal to sigma minus u; u is equal to pore water pressure, so this is Mohr-Coulomb diagram shear stress versus your normal stress. Tau f is the maximum shear stress the soil can take without failure, under normal effective stress of sigma prime. Look at here, total stress and effective stress, it is your sigma prime. If I go to the total stress, if I go to the total stress, it is only the sigma, in that means that total stress there is no generation of pore water pressure or maybe ah the pore water pressure expulsion means complete pore water pressure has been generated, so has been built up. So in case of effective stresses, this will be your sigma prime.

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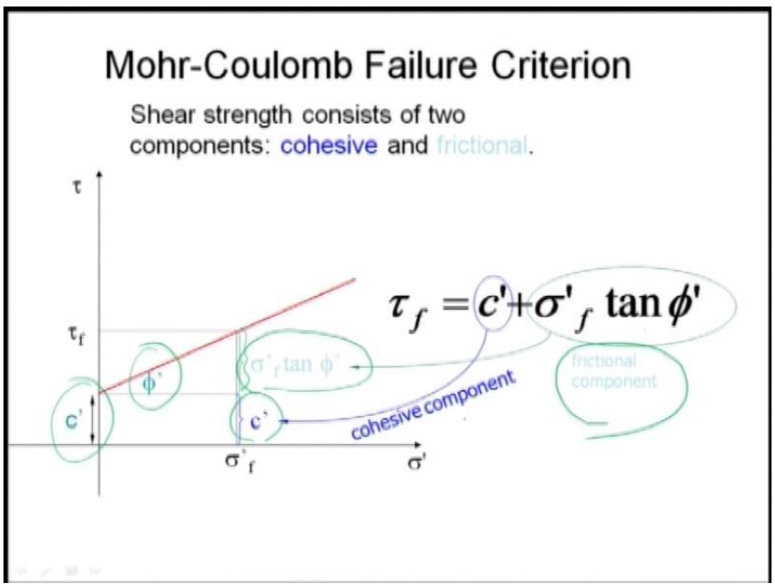


So Mohr-Coulomb failure criterion, shear strength consists of two components; cohesive and frictional. This part is your intercept cohesion, and angle is your friction. So tau f is equal to c prime, c prime sigma prime f tan phi prime. So as I said c prime is your cohesion component, and sigma f tan phi prime is your, this part is your sigma phi tan phi, this is your sigma prime tan phi prime. This is your frictional component and this part is your c prime, this is your cohesion component.

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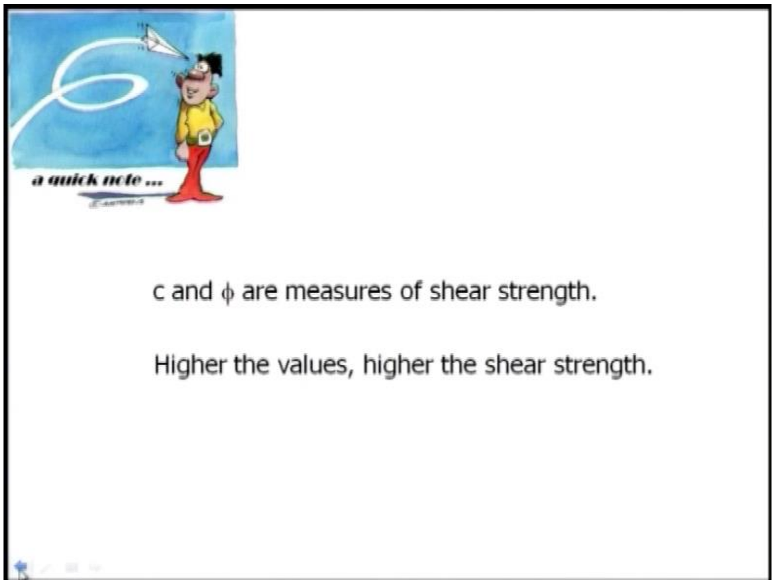


A quick note c and phi are measures of shear strength. Higher the value means higher the value of c and phi, higher the shear strength, higher is your shear strength.

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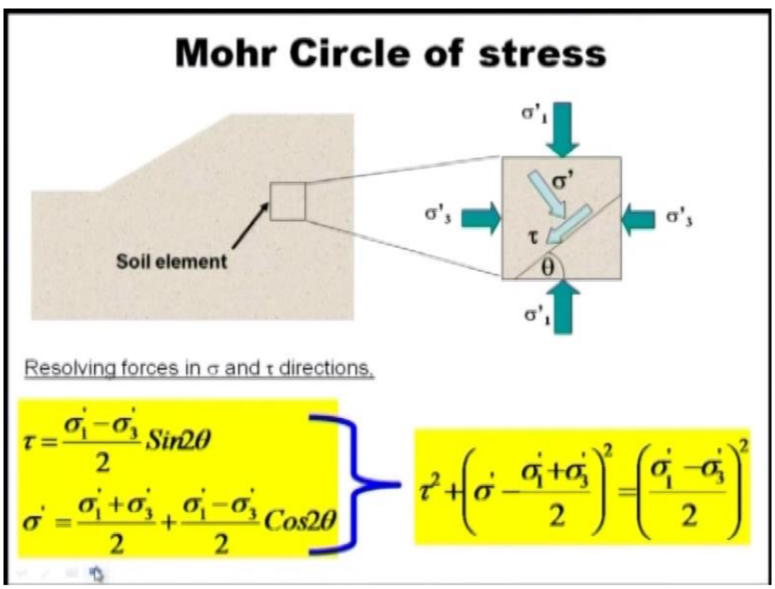


Mohr circle of stress. If this is your soil element, if you take it soil element in the soil mass, then this will your sigma one prime and sigma three prime. And with this, a theta then you are getting tau and sigma prime. Resolving forces in sigma and tau directions, you will get it tau is equal to sigma 1 prime minus sigma 3 prime by 2 sin 2 theta, then sigma prime is equal to sigma 1 prime plus sigma 3 prime by 2 plus sigma one prime minus sigma three prime by 2 into cos 2 theta. Then you will get also another equation in terms of tau square plus sigma prime into sigma one prime plus sigma 3 prime by 2 whole square is equal to sigma 1 prime minus sigma 2 prime by 2 whole square.

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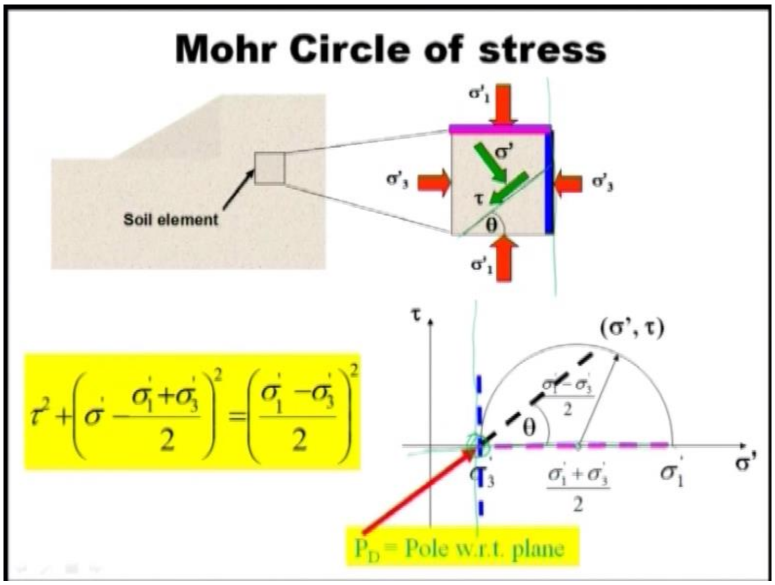


Now if I draw a Mohr circle between sigma one prime and sigma three prime. If you look at this is my Mohr circle, and this is your centre sigma one prime plus sigma three prime by 2, and this will your sigma 1 prime, radius will your sigma three prime by this is your radius. Now intersection of principal plane is your pole as I said, intersection of principal stress ah is your pole, so what will happen, if you look at here, sigma one is your major principal stress, sigma three is your minor. So sigma one is acting in this direction, intersection that means this is your sigma one, and sigma three is acting the plane is like this, sigma three prime drawing a plane like this, this is your sigma one plane then intersection of principal plane that in this point. This is your pole, with respect to pole, if you draw a line of your failure plane at an angle theta, where it touches that is giving your sigma and tau at failure plane. I will stop it here; so next class, I will go in details of Mohr circle of stresses.