Geotechnical Measurements and Explorations
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Lecture No. # 37

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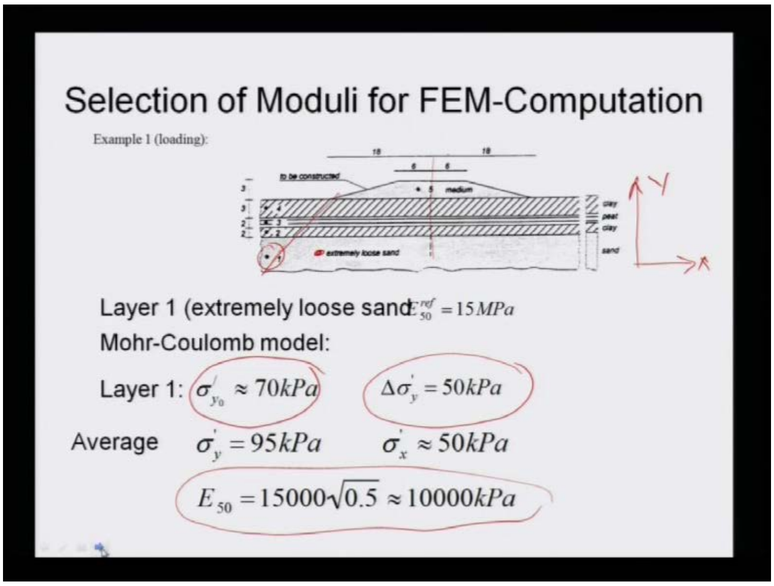

Last class we have discussed about this selection of soil moduli e and nu; how we will get it from laboratory test, and how it has to be used in the modeling purpose. And two examples; one is case of loading that is for FEM computation, and other is your for excavation has been discussed, once again just repeating. So, this is a case one of loading, how to find it out the moduli from for finite element method computation, for particularly embankment to be constructed, the soil layer is given clay, peat, clay and this is your sand; so for extremely loose sand, this consolidation has been done based on our correlation.

First you have to find it out for extremely loose sand, what is your sigma y or overburden pressure at the middle, and what is your increase in stress delta y is nothing but your increase in stress, sigma y prime is nothing but your overburden, I put it in X and Y direction; this is X and this is Y. So sigma y is your overburden pressure at the middle of this extremely sand layer, you can find it out gamma 1 h 1, gamma 2 h 2, gamma 3 h 3 like this at the middle you can find it out. Delta sigma prime that means increase in stress because of your embankment construction; because of this embankment construction, what will happen? Increase in stress, half of the embankment if I take how far this increase in stress at the center that because of embankment loading that has been calculated. Based on this average and E 50 has been found out that is your 1000 10000 kilopascal, this has to be used for your FEM modelling.

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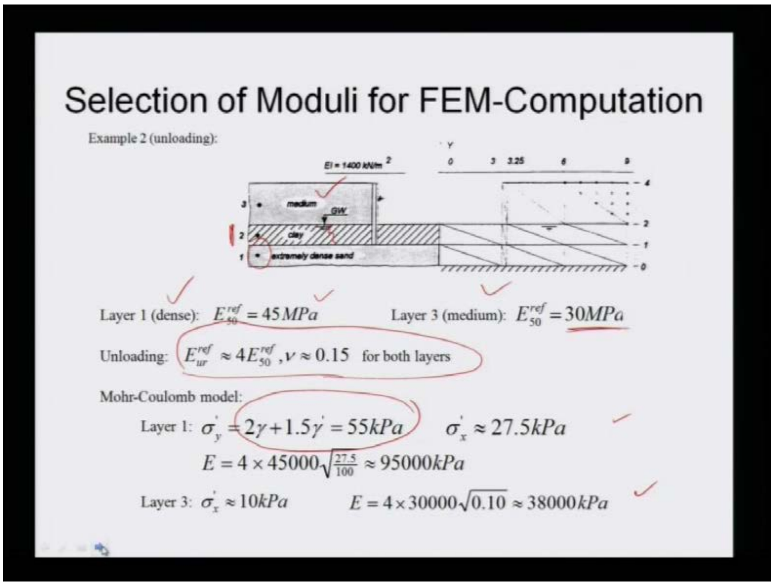

Now, second example is your there is an excavation that means the case, where this is unloading; the case where it is a loading; as I said, there are two cases, because we are taking the value from our oedometer test, loading as as well as unloading. In case of, if you look at here, there is a wall here, retaining wall here, and the wall is here, this part is filled of soil, and it has been taken out. Now, once it has been taken at this soil part has been gone that means this is your unloading case; in this unloading case, if it is decided to find it out what is your means moduli, particularly layer 1. Then for unloading case, you find it out what is your… Layer 1 for dense, E 50 is your 45 MPa as per our correlation; layer 3 is your medium that is E 50 that is your 30 MPa. Similarly, for unloading, if I take out this layer, this is unloading, this will be for both the layers, this will be 4 E 50, and nu is equal to 0.15.

Mohr-coulomb models you can find it out, for Mohr-coulomb model, what is your sigma y? Sigma y is nothing but your vertical stress 2 gamma plus 1.5 gamma, this is your h, 2 is 2 is nothing but 2 is your height, this is your depth, 2 into gamma, gamma for this; 1.5 look at here, this is your layer 1 - dense; so 1.5 that means 1, 1.5 gamma prime, because water table is here. Then sigma prime you can find it out; then you can get E; and for layer 3 similarly, you can find it out what is your sigma x; and E you can get it. These are all examples, how to find it out this, based on this correlations; and these correlations E to be calculated, and once E to be calculated, this has to be used for analysis, because soil stiffness is required particularly for analysis.

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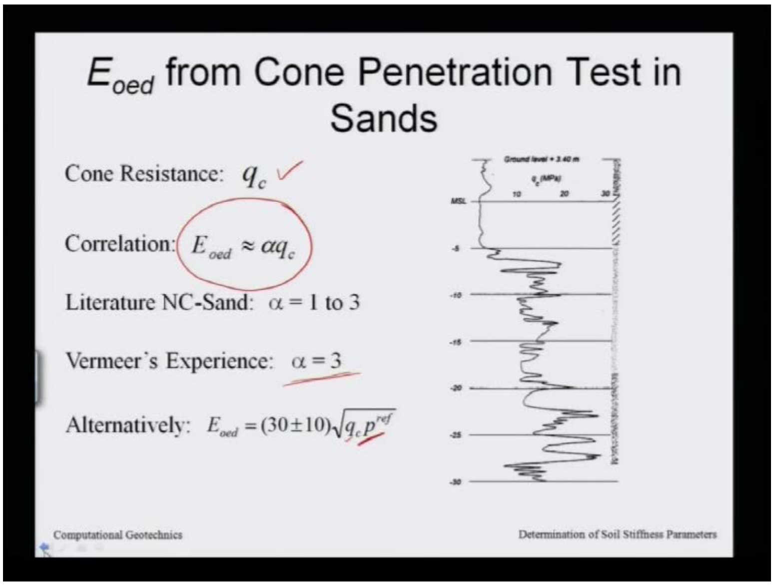

Now if I come back to these are all laboratory test; now what will happen soil stiffness from field test? So if I say E oedometer from cone penetration test in sand, how to I get it? Your cone resistance if I say q c, so the correlation is E oed that is equal to alpha into q c, alpha into q c. So literature says for normally consolidated sand, alpha is varying from… Alpha is a factor, it is varying from 1 to 3; and Vermeer's experience - alpha is varying alpha is equal to 3. So or alternatively, you can find it out E oed is equal to 30 plus minus 10 root over of q c into p reference; p reference is basically for your 100 kilo newton kilopascal, 100 kilopascal, and q c is your cone resistance. These are all correlations, if you have one set, if you have your static shear test or may be laboratory like oedometer's test. Another is your if you have a cone penetration resistance or a field test results, from there E oedometer you can find it out, E oed, you can find it out. Then once you get it E oed, E soil you can find it out also. That is from your cone penetration test or CPT test in sand.

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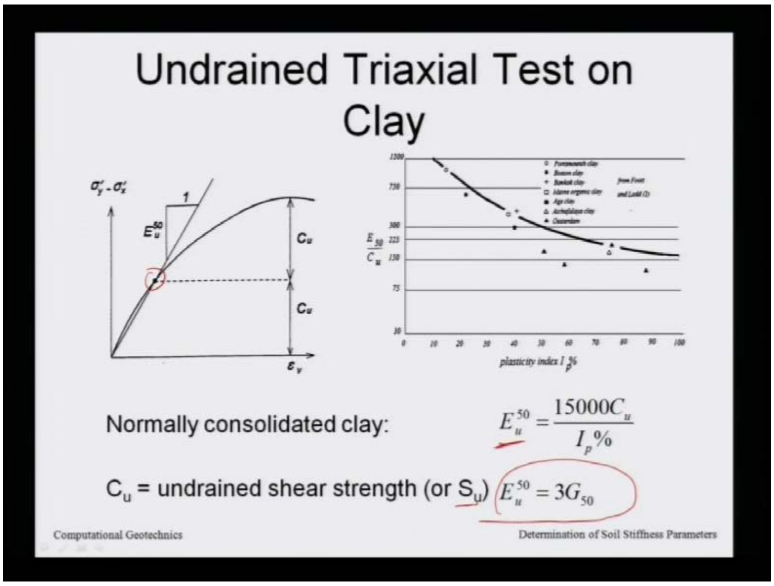

Second is your undrained triaxial test on clay. We have discussed earlier for sand; now if for undrained triaxial test on clay, this is your stress and strain, if I write it E u, if you look at here, it is your E u 50, taking a point at 50 percent of the stress and joining this tangent, and the slope of this, you can finding out this E u 50; from this E u 50, you can find it out 6 C u means undrained strength. So E u 50, based on these, this has been determined by this correlations has been given by ladd, foott and ladd, E 50 by C u; C u is your undrained shear strength versus your plasticity index; I p is your plasticity index, which is equal to… What is your plasticity index? Liquid limit minus plastic limit, this is your plasticity index.

So with that if this plasticity index, this empirical co-relationship has been given for different clays; if you look at these, this is a train line has been given for different test, different clays. So from this, normally consolidated clay E u, undrained strength E u at 50 percent stress, it is your 15000 C u by I p. C u is your undrained shear strength or S u; so from this, you can say that E u 50 is nothing but your 3G 50, G is your nothing but your shear modulus at 50.

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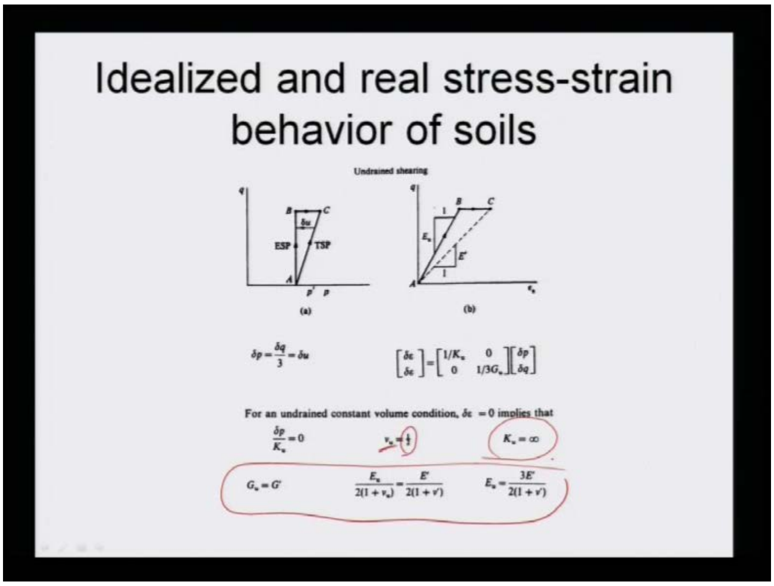

Idealized and real stress-strain behavior of soil: If you look at this, these are all just basic discussion, because this is completely a different phenomena; it will come under modeling part. If you look at these undrained conditions part b, if you look at this, going, and B to C, then unloading. So you can find it out from these, like for an undrained constant volume condition delta E, delta is your volume is equal to 0 implies that delta P, delta P by K u is equal to 0 or nu Poisson's ratio at undrained condition is equal to half, K u is equal to infinity or G u is equal to G prime; from this this correlations have been developed for real stress-strain behavior of soil, idealized and real stress-strain behavior of the soil.

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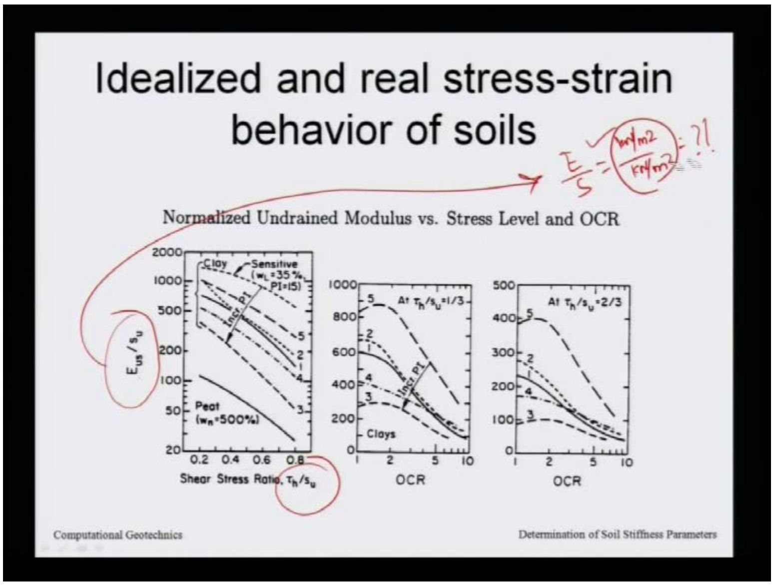

Now normalized undrained modulus versus stress level and OCR: If you look at this, this as a graph has been given for E, E is your modulus of elasticity, S u is your shear strength. So E u by S u or may be C u, you can say earlier it has been shown; if you look at this, E by C u, C u or S u it has been said here. So E u s by S u versus shear stress - ratio tau h by S u; if I plot it a normalized, because this has been normalized, modulus of elasticity E, this value is your stress for strain, so what is its unit? It is kilo newton per meter square; similarly, shear strength value has to be kilo newton per meter square. That means, normalized means I should give a chart or data in such a way that it should be in a dimensionless form, it should be in a dimensionless form.

If you look at here, the dimension of E by S, the dimension of E is same, and shear strength also is same; that means if I divide it this is nothing but a dimensionless form, dimensionless form. So, what will happen? Anybody can use this charts, because this has been given as an dimensionless form. And it is for shear stress ratio, any shear stress ratio, if you look at this, this shear-stress ratio has been given from 0 to 1 tau h by S u, so 0.2, 0.4, point all soil means, particularly clay soil it is varying from 0 to 1.

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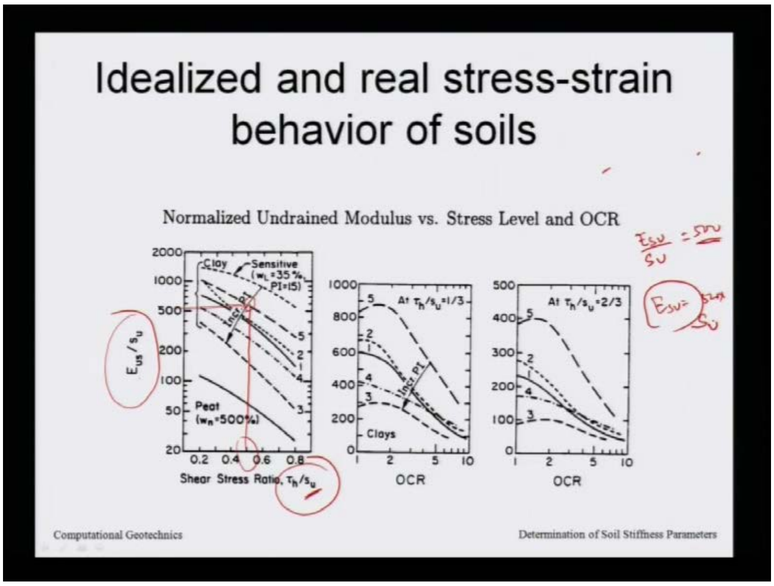

So in a range, if you find it out in the laboratory in a range, if you if you know your shear stress ratio, then from there, you can extend it. And depending upon your clay, if you look at your clay, this is your sensitive; sensitive means liquid limit is equal to 35 percent, plasticity index is equal to 15; that means from here to here, your plasticity index increases; for that laboratory test soil, you first find it out clay, what is its plasticity index, and what is the shear-stress ratio. If this two parameters you get; that means shear stress ratio and plasticity index, then you take it, where it caught it? Suppose it caught it here, then extrapolate this value from where, you can find it out E s u by S u; from here particularly this for example, you can get it E s u by S u is equal to suppose say 500.

Shear strength that you know from your laboratory test undrained conditions, from there you can find it out E s u undrained condition means modulus of elasticity 500 into S u. So these are all dimensionless charts, this will be very useful to find it out the E has been given ladd and normalized undrained modulus, if you look at here normalized undrained modulus versus stress level and OCR, what is OCR? Over Consolidation Ratio; Over Consolidation Ratio; if we look at here, again it is first one is E s u by S u by shear stress ratio, second one is your E s u by S u by OCR Over Consolidation Ratio

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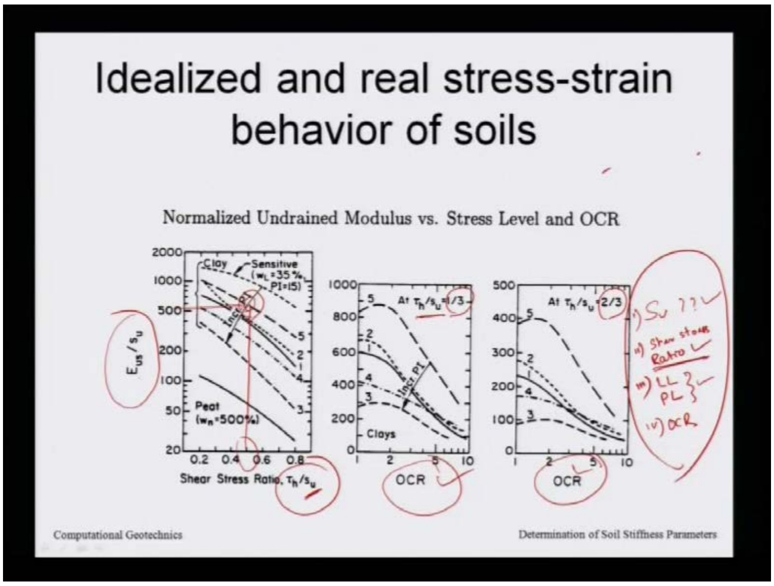

If you have for particular shear-stress ratio of 1 by 3 and for particular shear stress ratio of 2 by 3 for different for different over consolidation ratio; with that with this, if you that means three parameter you need to have define, three parameter you need to have do in the laboratory. First you will have to measure, first you'll have to measure the shear strength; first you will have to measure the shear strength, undrained shear strength in the laboratory for particularly clay that means from there, you will find it out shear strength of the soil, first one. Then second, from these shear strength, you can find it out what is your shear stress test? Then find it out shear-stress ratio; how the shear stress ratio, whether it is varying, what is a rame what is that range? It is 0.2, 0.3, 0.4 or 0.5.

Then after you find it out shear stress ratio, then find it out your OCR - Over Consolidation Ratio, you find your over consolidation ratio; once you get the over consolidation ratio, then from these you can find it out. That means from your shear stress ratio, if you know the shear stress ratio, then with this shear stress ratio, then find it out your plasticity index; that means Atterberg's limit, liquid limit, plastic limit, you will find it out your plasticity index. If you get the plasticity index with your shear stress ratio, then you can extrapolate your E s u by S u. Once you find it out E s u by S u from there, you can find it out what is your soil stiffness, for particular over consolidation ratio, you will get it.

So these are the correlation has been provided by Ladd; and based on your laboratory test, you can find it out, what is your soil stiffness parameters, how geotechnical parameters particularly from laboratory test, how far it is important, this particularly analysis, and the parameters required for analysis is your soil stiffness, as I said. So this has been given by Ladd for particularly different stress level, undrained modulus and OCR, as I said. You need to have this parameters that means shear strain parameter from the laboratory, and shear stress ratio from the laboratory, you can find it out liquid limit and plastic limit, then you can find it out what is your over consolidation ratio, if you know it OCR value that would be good enough.

So if you know all the parameters from the laboratory, based on your liquid limit and plastic limit, you can find it out what is its plasticity index. And based on the shear stress ratio from laboratories, as I said suppose this shear stress ratio is 0.5, and with your plasticity index, if you know the what is your plasticity index, then your corresponding E s u by S u we will get it, for a particular value of OCR for a particular value of o c r; and once you get E s u by S u you know the shear strength. So putting this value you can find it out soil stiffness of undrained conditions, when particularly undrained modulus soil stiffness or undrained modulus of clay; you can find it out; and that that to be used for computational purpose that that is a secondary means, these particular these slides, I am showing how laboratory test is useful to find it out your undrained modulus or drained modulus or may be soil stiffness that is your E and nu.

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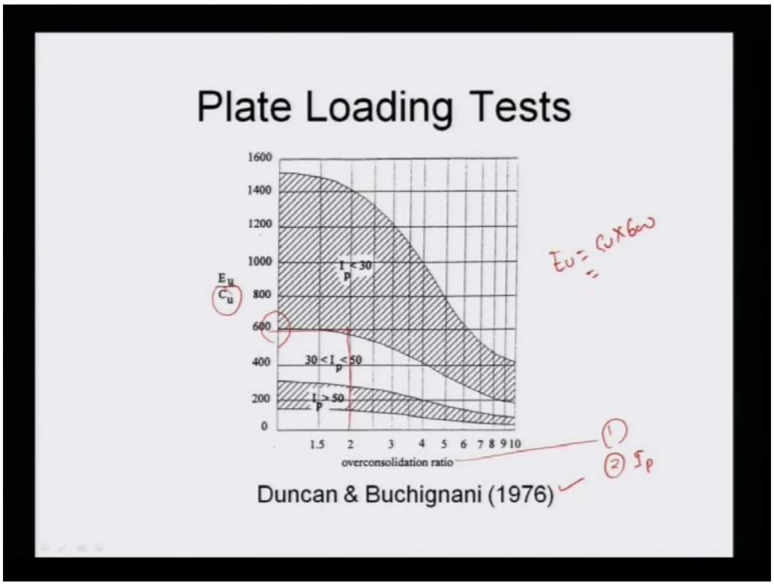

Then come back to another field test; one is your triaxial test has finished, we have finished; other is your oedometer test we have finished; that means consolidation test we have finished; based on the consolidation test, we can find it out e oedometer, means modulus of elasticity; based on triaxial data, we can find it out E of the triaxial or E of undrained depending upon drained test or undrained test; based on your cone penetration also, we can find it out E modulus of elasticity of soil. Now another field test that is your plate load test; based on plate load test, what are the things we can find it out? We can find it out E also; modulus of elasticity, as I said it is from stress versus strain, you can find it out E, earlier also I have discussed also.

So Duncan and Buchignani, 1976, they have given a relationship of undrained strength of E undrained of shear strength C u versus overconsolidation ratio from plate load test; overconsolidation ratio is varying from 0 to 10; and for different value of I p for fine grained soils, if you look at these generally plate load test preferred for coarse grained soils, but it is also required widely use for later on modified, and widely used for any kind of soil. So I p is greater than 50, this is the range they have given between 100 to 300; then this is your I p is less than 30, I p is greater than 30 and less than 50, it is varying 300 to 600; rest is your I p, I p, what is I p? I p is your plasticity index, I p less than 30, it is varying 600 to 1500.

So that means, you should know the over consolidation ratio; first parameter is your, you should know this parameter first over consolidation ratio. Second if you know I p - plasticity index, then very easily you can find it out from plate load test, you can find it out what how to find it out your E u and C u. These correlations has been given basically from all the plate load tests; these correlations has come from the plate load test. So from there you can find it out E u and C u. Then by multiplying C u, so you will get a value of any overconsolidation ratio of this I, so this will be 600 that means E u is equal to C u into 600 c u is nothing but your undrained cohesion; so undrained cohesion into 600 if you multiply, you will find it out soil stiffness or modulus of elasticity at undrained conditions of soil.

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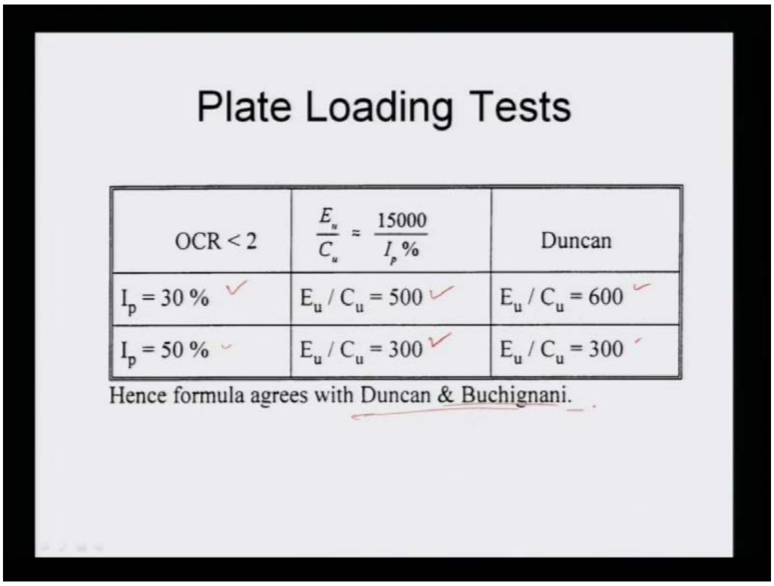

Now, from plate load test, another was given this Duncan and Buchignani, they have given this OCR value less than 2, I p is equal to 30 percent and I p is equal to 50 percent, what is the value of E by C u, E by C u, it is value of 500 and 300. So Duncan has given E by C u is 600 and E by C u is equal to 300. Hence this formula, this formula completely agrees with your Duncan and Buchignani, completely agree whatever the Duncan has given by this charts.

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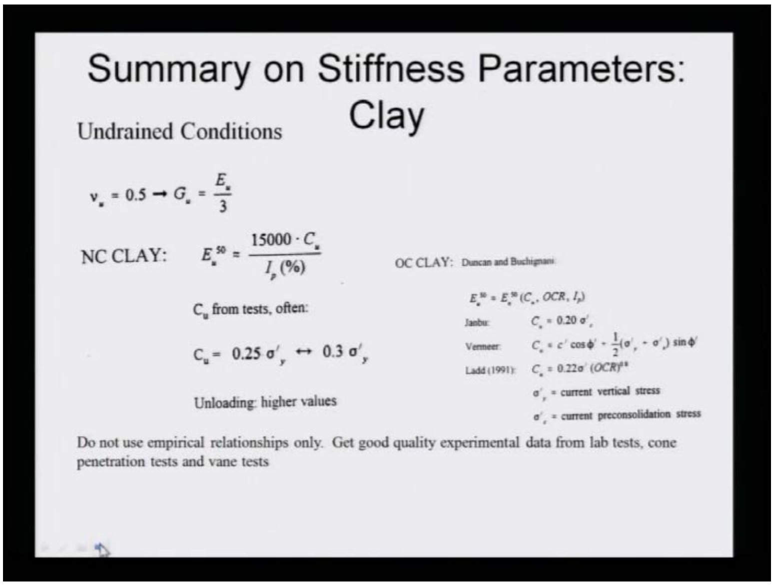

Now, if I summarize summary on stiffness parameters, particularly clay; that means there are two soils if I classify, one is your sand, other is your clay.

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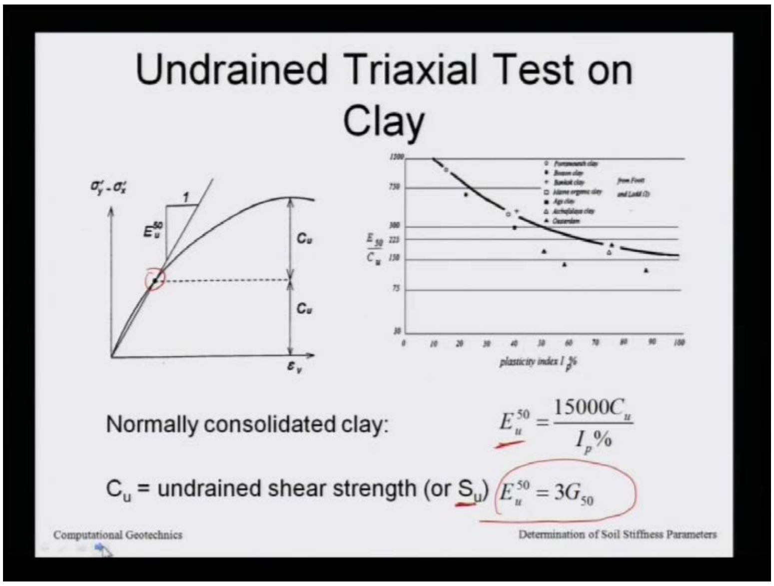

For clay soils, from where we can find it out this E, if I go back to that is from normal triaxial, undrained triaxial test, you can find it out E u, from triaxial test you can find it out E for your computational purpose. Then from based on the triaxial test, you can plot the charts. Then from plate load test also we can find it out, if you have a plate load test data, you can find it out E. So if I summarize undrained conditions, particularly this stiffnesss parameters of clay in undrained conditions, nu is your Poisson's ratio at undrained conditions that means undrained conditions again and again, I am saying that meaning is draining drainage is not allowed that means soil in undrained conditions.

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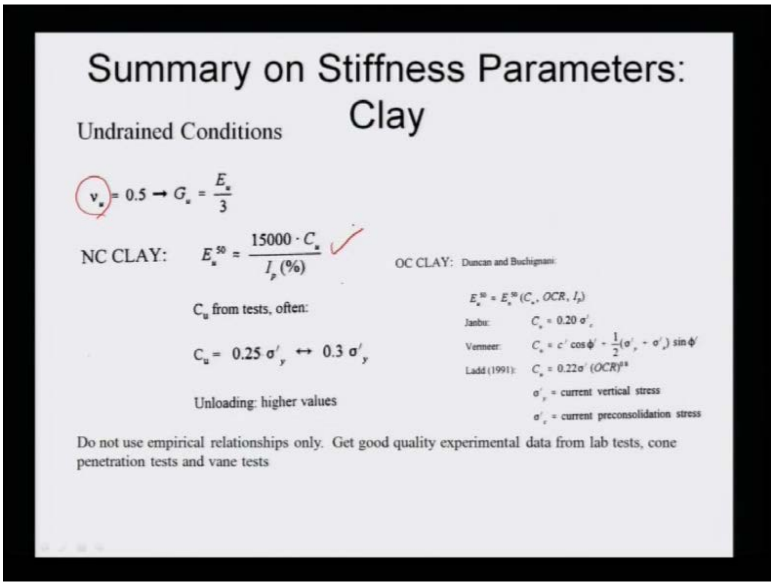

So poisson's ratio in undrained condition, u for undrained is equal to 0.5. So shear modulus in undrained condition is equal to E undrained divided by 3. So, for normally consolidated clay, this is the relation has been given, E u 50; for 50 percent, it is your 15000, 15000 C u by I p; this has come from here. Based on plasticity index and E 50 by C u based on your undrained triaxial test C u from the test, so loading and unloading; for overconsolidation clay based on the duncan and buchignani, this is your… from the plate load test, E u 50 is equal to E u 50 C u OCR and I p, this is a function of E u means modulus of elasticity in undrained condition is a function of C u, and OCR overconsolidation ratio and I p. So Janbu has given C u is equal to 0.20 sigma C. Here C u is equal to sorry I have earlier said it is undrained cohesion, undrained shear strength, slightly we mistake the C u is your undrained shear strength.

So Janbu has given these empirical correlation based on your overburden pressure, how to find it out C u. And janbu, vermeer and ladd, 1991, they have given how to get the value of C u from these correlations. So based on these if you know C u, if you know OCR, if you know plasticity index, then you can find it out your E u 50, based on your plate load test you can find it out; or if you have particularly undrained condition triaxial test you can find it out soil stiffness E u also; either from plate load or triaxial means, it is always recommended that do not directly, do not use directly empirical co-relationship. These are the empirical relation based on few test results. It is not the all over the world or not the all over the places.

So, do not use it directly means, you know this is your empirical relation, but you should conduct at least some experiment in the laboratory and the field; and look whatever experiment you have done in the laboratory and field, whether it is agree agreeing with the empirical relationship or not. If it is not agreeing, how far it is varying? Then only you decide whether you are going to use this empirical relation or may be this empirical relation with some correction factor, because this correction factor generally given based on the site specific; this empirical relationship, if you look at this Janbu, Vermeer, Ladd and Duncan, they have given this correlation basically based on your site specific.

So you can add always with these empirical relationship based on your site, where you are going to do; based on your site, based on the soil, what kind of soil you are using, you can always provide this correction factors with this empirical relationship. So, it is recommended, do not use empirical relationship directly.

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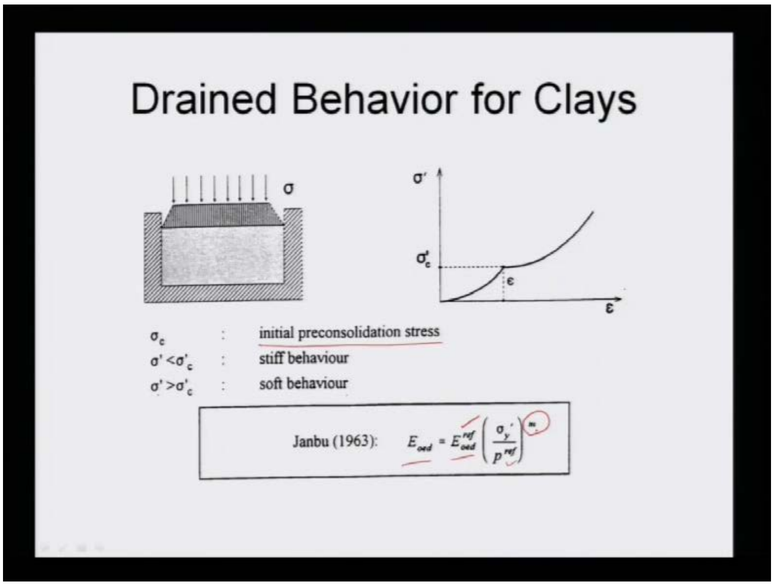

Now, drained behavior, this is in clay if I make it in to two parts; one is your undrained behavior, other is your drained behavior. In drained behavior what will happen? In drained behavior, initial preconsolidation stress is always there. So if sigma prime is less than your sigma C, stiff behavior sigma prime is greater than your sigma C; sigma C is nothing but is your preconsolidation stress; these things we have discuss already in the oedometer or consolidation test.

So, based on these particularly preconsolidation stress, drained behavior of clays means there are two clay; one is your undrained behavior and another is your drained behavior. In drained behavior, you can find it out this E value, based on your consolidation data; based on your consolidation data, this relationship has been given by Janbu 1963, E oedometer is equal to E oedometer with reference to your 100 kilopascal, reference is your 100 kilopascal sigma y prime by p reference to the power m; m is nothing but is your…

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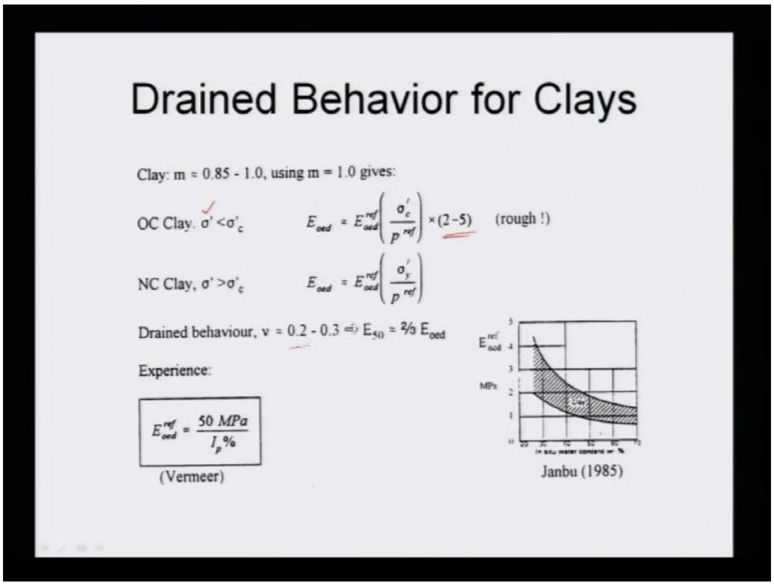

If you look at for clay, m is varying between 0.85 to 1. So generally, we use m is equal to 1.0. For over consolidated clay, yours overburden pressure is less than is your preconsolidation pressure; in that case, you can find it out E ode is equal to E ode reference sigma c prime by p reference 2 minus 5, it is an rough idea. For normally consolidated clay, overburden stress is greater than sigma c ode is equal to E ode sigma y prime by p reference. So for drained behavior, generally nu has been taken as 0.2 to 0.3 for drained behavior

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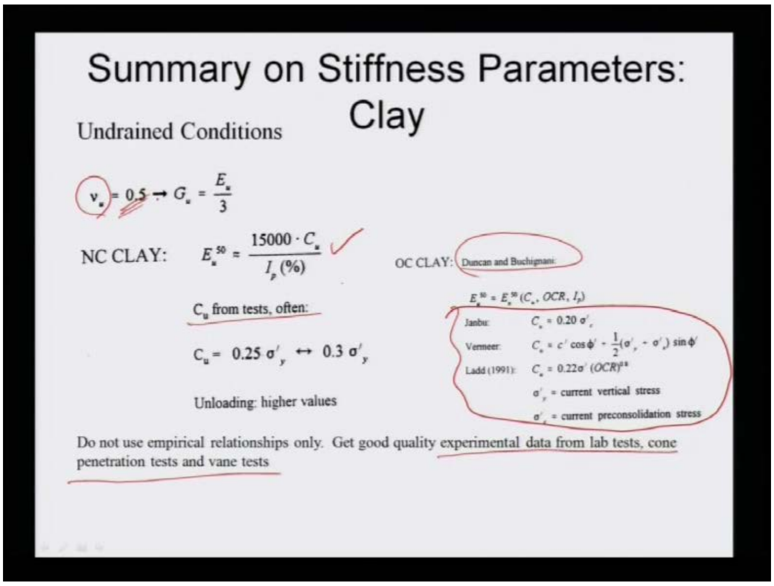

Earlier if you look at here undrained behavior; look at this difference; these parameters are required for particularly modeling. Now you have to decide, if you are going to take a clay sample, whether it is a drained clay or undrained behavior; what kind of behavior it is there? That means whole water is draining or whole water is inside; that means drained or undrained. Based on that, for undrained, it is nu is equal to Poisson's ratio is equal to 0.5.

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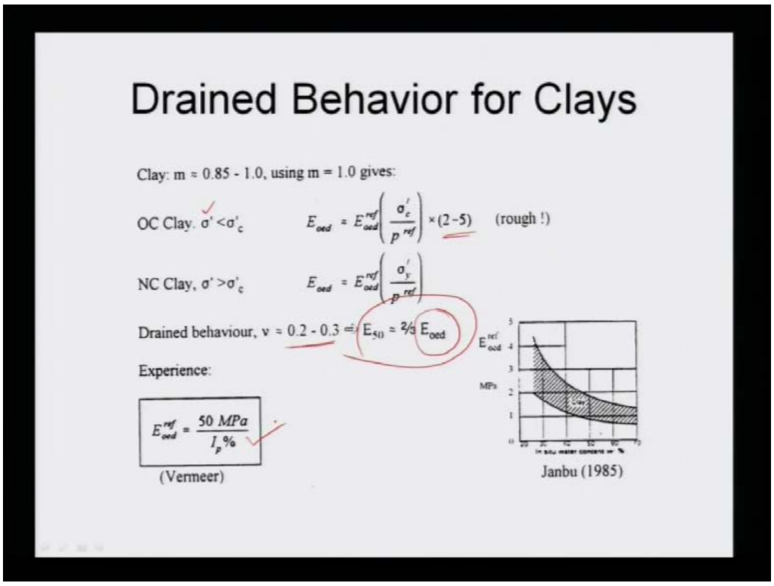

For drained, this Poisson's ratio is 0.2 to 0.3. So E 50, generally 50 percent stress with that E 50 is equal to two-third of E, whatever you are getting for your consolidation test. E oed is your oedometer test based, from there your finding out E. So, E 50 of the soil is equal to two-third of E oedometer; so E oedometer is Vermeer has given, based on these 50 MPa by plasticity index; they have given based on the plasticity; there are plenty of correlations based on your experimental data. So best idea is for a drained behavior of clay, first you have to decide whether this clay is a normally consolidated, over consolidated clay, what is this? That means, first you will have to find it out from consolidation, pre-consolidation pressure.

Once you find it out the pre-consolidation pressure, from there you will have to decide whether it is overconsolidated or normally consolidated. Once you get that, then you can use your correlations, and you can find it out what is your E oedometer means stress strain behavior from E oedometer, you can find it out modulus of elasticity oedometer. From there modulus of elasticity oedometer, you can find it out E soil in the actual field condition. This is your laboratory conditions. Consolidometer or oedometer is a laboratory test; E 50 this is your field.

Now once you find it out your… Once you get E field and E oedometer, then based on that laboratory test you can find it out for field. And once you get field, then another parameter is your for drained behavior nu is equal to 0.2 to 0.3. Then this is enough for your analysis or this is called your soil stiffness behavior. Once again if I summarize whole thing, once again if I summarize into whole thing that means entire soil has been divided into, classified into two; one is your sand, one is your clay. Then for if you look at these particularly sand, sand has been divided into two parts; one is your loose sand or silty sand, another is your dense sand.

So there are two kinds of test or three test you can get it; one is your drained triaxial test, other is your laboratory oedometer test; based on your triaxial test and oedometer test, there are correlations has been given. So from there, you can find it out E value of our loose sand or silty sand or dense sand, you can find it out E oedometer from oedometer test. And from triaxial also, you can find it out E. So this e value has to be used for modeling. Then this is your laboratory based data’s; then based on this some example we have solved. Then you can find it out also cone penetration test in sand; you can do cone penetration test in sand.

So this is your based on third part is your field test; case one is your laboratory test of oedometer test for sand; case two is your laboratory test drained triaxial test; case three is your from cone penetration test you can find it out E. And based on this E, you can simulate it to field, then you can find it out also nu. Then if I go to the clay, so basically clay it has been divided into two parts; one is your two two classification not two parts, two categories; one category is your undrained clay, another is your drained clay. So in case of undrained clay, how do you find it out? You find it out based on your undrained triaxial test, and as well as your from plate load test; based on these two test, there are some empirical correlations has been given; also some charts has been given; from there you can find it out E undrained conditions. Then once you get E undrained, you can find it out E 50 of the soil. Then for drained conditions, you can drained behavior of clay, then the parameter required to do, you have to first decide whether it is a normally consolidated clay or over consolidated clay.

So for these, you need to find it out, what is your preconsolidation pressure, preconsolidation pressure on the soil; for that you will have to require to do your oedometer test. From oedometer test, you can find it out or consolidation test you can find it out your preconsolidation pressure; based on your preconsolidation pressure, you can simulate, you can find it out whether it is normally consolidated or over consolidated clay. So from once you get normally consolidated and over consolidated clay, these are all behaviors has been given by Vermeer and Janbu 1985; so in terms of shear strength, you can find it out E oedometer. Then once you find it out E oedometer, from E oedometer to you convert to field, actual field conditions.

This is a simple cases, I have discussed some correlations; how the laboratory test is most important or the laboratory test parameters are important, why you are doing this geotechnical explorations of survey exploration and measurements, what for we are doing this measurement, this is a just in brief; how this parameter has been taken into consideration, and put it in as a value or parameter for your input parameter, for your analysis particularly, finite element, finite difference means all these modeling purpose geotechnique, modeling in geotechnique, how this experimental results are useful. And of course, this geotechnical modeling is not part of this.

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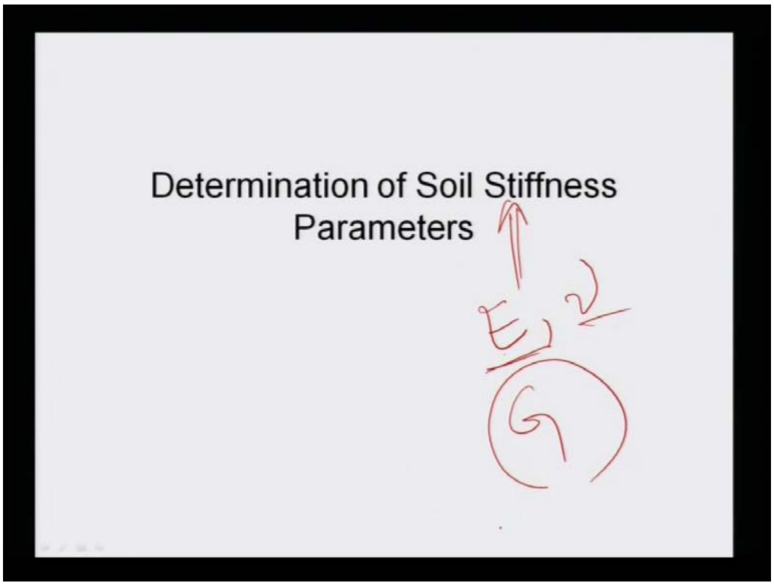

So this is all about your determination of soil stiffness parameters; basically soil stiffness parameters means E and nu; E is your modulus of elasticity and nu, once you know E and nu, you can find it out other parameter also shear modulus from this correlation, you can find it out. And these are the useful parameters for modeling of modeling or analysis.