Advanced Soil Mechanics
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Lecture-56
Summary of Module 4

Welcome back, so in the last lecture we have seen some model problems related to critical state model. And it is usefulness in predicting the final state or the failure state of soil, knowing the initial state and the critical state parameters. So, with that we have finished what we have targeted for module 4 in this course. So, in today's lecture we will summarize what we have learned in module 4.

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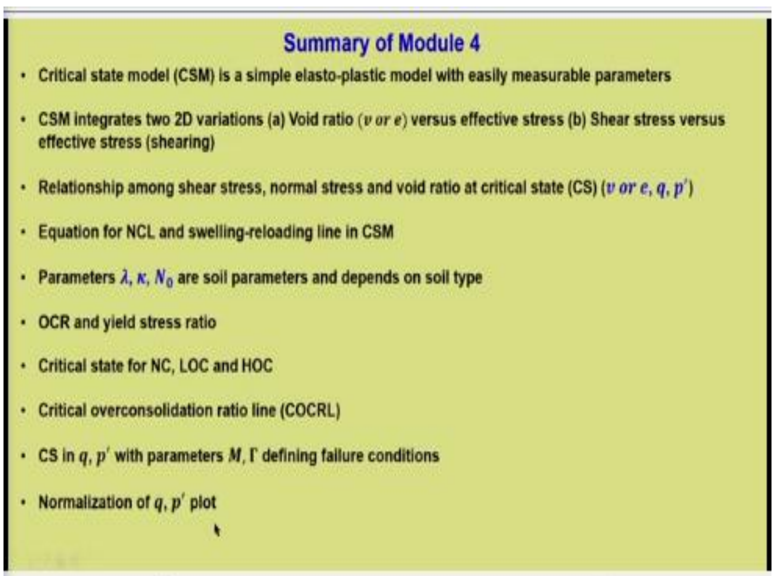

So, it is a summary of module 4. Critical state model CSM is a simple elastoplastic model with easily measurable parameters. Now there are several other models as well, but what makes it different is that it is simple to understand. And the parameters are easily measurable from whatever routine tests that we know, so that makes it a bit different from the other models. CSM integrates two 2D variations, the void ratio versus effective stress and shear stress versus effective stress.

Now probably you will understand the uniqueness of these two. Like the one dimensional consolidation, it shows how the volumetric change happens. And how the yield curve expands or the reference yield curve depending upon the pre-consolidation pressure or the yield stress, where the shear stress developed is zero, or it is negligible. Then the failure condition is defined by q p’, once you start shearing the shear stress develop and that progression is given by q p’.

So, integrating these 2 is the very basics of critical state, relationship among shear stress, normal stress and void ratio at critical state in v or e, q, p’ plot that also we have seen. Equation for normal consolidation line and swelling-reloading line in critical state model and the relevant parameters λ, κ, N_o are the soil parameters and it essentially depends on soil type, mostly you can treat it to be a fundamental property.

Then we discussed about OCR and yield stress ratio, we have brought out the difference between the 2 and where one is advantageous than the other. Then we have seen the critical state for normally consolidated LOC and HOC. Then we defined critical over consolidation ratio line COCRL, there is a bit of difference between this line and the critical state line. And let me again repeat here in some of the books when wet and dry state of the soil is defined, it is also defined with respect to critical state line, but COCRL if that is the line which actually separates, normally consolidated LOC from HOC, but there is a small difference between both. Critical state in q p’ with parameters M and γ defining failure conditions, so the other one was where q = 0 one dimensional consolidation, from where the λ κ N_O comes and the failure is essentially defined by M and γ.

Then we have normalized q p’ plot and we have proven that NCL becomes a point, CSL becomes a point and that leads to the further state boundary surface concept, where we treat this to be unique. So, on normalization it all boils down to a particular point, so in that sense we have understood the uniqueness of normal consolidation line and critical state line.

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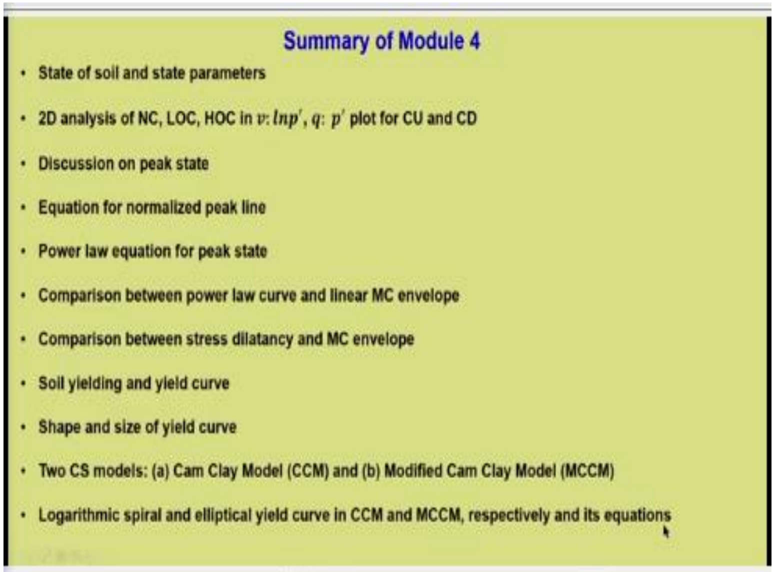

State of soil and state parameters, we have extensively discussed that. 2D analysis of normally consolidated LOC, HOC in vln p’ and q: p’ plot for CU and CD. So, for a typical triaxial compression test we have discussed all these cases. Then the peak state which is relevant for the dry state of the soil that is for HOC has been discussed in detail. And equation for normalized peak line also we have seen.

In addition to the Mohr Coulomb representation of peak line, we have also seen the power curve with the concept that it should pass through the origin. Then we have made the comparison between power low curve and the linear Mohr Coulomb envelope. Comparison between stress dilatancy and Mohr Coulomb envelope, in the same lecture we have done that. Then a very important concept of soil yielding and yield curve was discussed.

Now without this the explanation is not complete and that is where this course is different from the UG concepts what you have learned. Rather the strength, the failure those things we could still conceive from our undergraduate background, but then adding these points like yield curve and interpretation of the results with respect to yield curve. And how it fails from further the elastoplastic state from where it starts, so these things were slightly additional in this particular course.

Then we discussed about shape and size of yield curve, where we have seen different types of shapes, where logarithmic spiral was one, and the other prominent one was ellipse. Then now there are different other models which are critical state models and modified versions of even modified Cam Clay by including various features, they are also existing. But in this particular course we have restricted ourselves to modified Cam Clay.

But there are several other models as well, the participants are interested, you should read through those and those are very well explained in the literature. Two critical state models we have dealt in this course, one is the Cam Clay model and the other one is modified Cam Clay model. The elliptical and the logarithmic spiral yield curves have been discussed and the equations were obtained.

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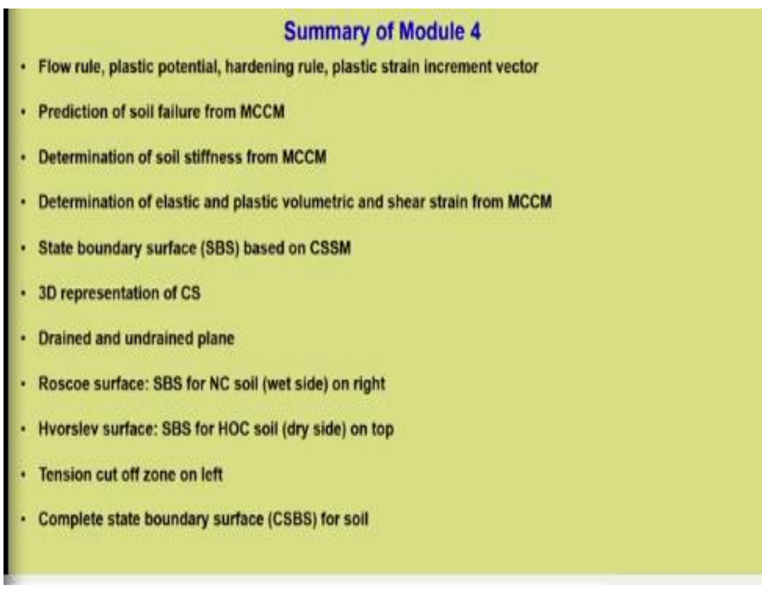

Flow rule, plastic potential hardening rule, plastic strain increment vector which is needed for understanding the plastic response of geo material has been introduced. I would not say that the discussion is extensive for this, because there is a huge amount of information that is needed further to appraise better the plastic behavior of geo materials. But we have set the stage for further understanding, so we have just discussed very briefly about these concepts and how it is relevant for Cam Clay model.

Then we have went on to explain prediction of soil failure from modified Cam Clay model. Then we have done the determination of soil stiffness from MCCM and further elastic and plastic volumetric and shear strain from MCCM. So, how by knowing the initial state and the critical state parameters, we can predict how the soil progresses towards failure using MCCM. This was demonstrated, this was studied and this was demonstrated in the form of some model problems.

Then we could understand the state boundary surface SBS based on critical state soil mechanics. The 3D representation of critical state, the drained and undrained plane which becomes relevant for while defining the state boundary surface. Then we have seen Roscoe surface, which is the state boundary surface for normally consolidated soil, that is a wet side. And that forms the boundary on the right, then we have Hvorslev surface which is a state boundary surface for HOC soil which is on the dry side and this forms the boundary on top.

And the tension cut off zone on the left, and the bottom we have the axis, axis of isotropic line. S and the same is the mirror image downwards if you talk about extension**.** So, we have discussed basically for compression in this particular course. Then we discuss the complete state boundary surface for soil. Then we have shown if not in terms of tension cut off, peak and normally consolidated line in the case of Cam Clay model and modified Cam Clay model even the yield curve acts as the or is the representative state boundary surface.

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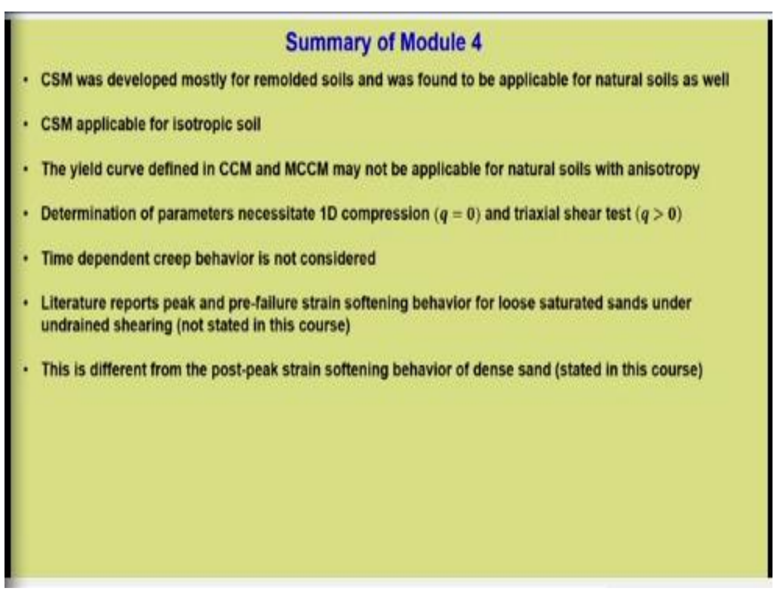

Now let us discuss there are a few things in addition to what we have learned. Critical state model was developed mostly for remolded soils which we have already discussed. And it was found to be applicable for natural soils as well. It closely relates in most of the cases but there are cases where it deviates as well. Now we need to understand critical state model is basically applicable for isotropic soil.

The yield curve defined in CCM and MCCM may not be applicable for natural soils with anisotropy. Now here is the point in natural soils we tend to have anisotropy because of the way in which it is formed. Most of the soils are formed by sedimentation, so sedimentation means layering, and when there is layering there is a possibility of anisotropy. So, this anisotropy it creates some issues in interpreting the Cam Clay and the modified Cam Clay, because the yield curve which has been idealized may not be representative.

So, there will be a clear deviation in the shape of the yield curve, and that is how the modified Cam Clay model was also modified further to account for these, so this we are not discussing in this course. Determination of parameters necessitate 1D compression where we say $q = 0$ and triaxial shear test where q is greater than 0. So, these are the 2 concepts one with respect to $q = 0$, and the other one with respect to q greater than 0.

A time dependent creep behaviour is not considered in this course, rather it is not captured in critical state. Then one important aspect which I thought I should share with you, you can see that in some literature it reports peak and pre-failure strain softening for loose saturated sands under undrained shearing, this is not stated in this course. Now we have always gone by the notion that the peak is always related to a dense state of the sand or over consolidated soil.

But there are results which are there in the literature wherein the peak is also reported for loose saturated sand and that too under undrained condition. Why we did not discuss this? is that, for sense generally the undrained condition is not that prominent, unless otherwise we talk about liquefaction. So, that is why we have not chosen to explain this, and what important difference is that this peak is considered to be due to pre-failure strain softening, where the trend which we have discussed is post failure strain softening.

This is different from the post peak strain softening behaviour of dense sand which is stated in this course. So, that is how, in fact we should not say it is post peak it is like post yielding. If you see the lecture you will see that this is based on the post peak yielding. So, that after yielding it start exhibiting, so that is how we have interpreted. But then it is more or less once the yielding starts we know that it is towards failure.

And there is a very small kind of differences between these terminologies, so this is all for module 4. And now in all sense we have completed the course, we are left with one lecture where we will basically discuss about the closure of this course, so that is all for now, thank you.