Advanced Soil Mechanics
Prof. Sreedeep Sekharan
Department of Civil Engineering
Indian Institute of Technology-Guwahati

Lecture-47
Peak State

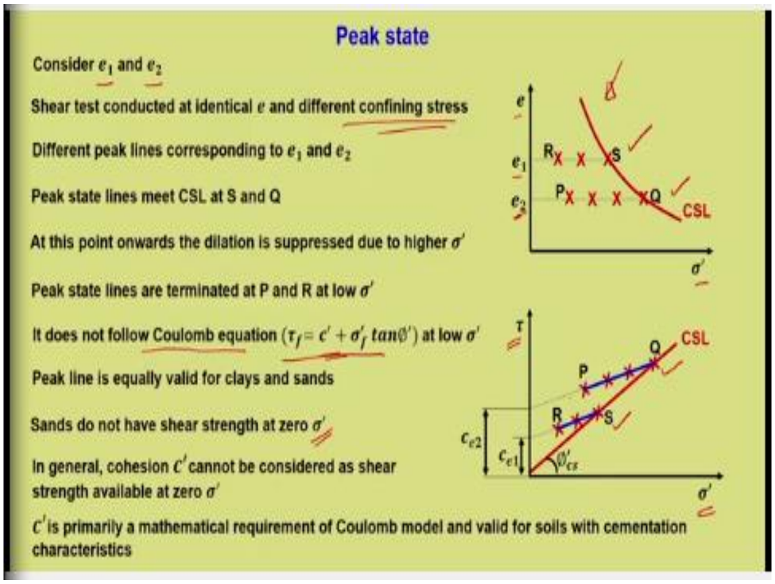
A warm welcome to all of you, in the past few lectures we were discussing about critical state soil mechanics. We have already seen the basics, we have also seen the two dimensional representation in the last lecture. While discussing the two dimensional representation, you might have noticed that we discussed about the right most boundary for the soil to exist and that was isotropic consolidation line or normally consolidated line which forms the right boundary.

In the last lecture we have also seen a tension cut off zone which appears on the left side beyond which the soil cannot sustain. And bottom part we have the axis itself, where shear stress is equal to 0, where q or the deviatoric stress is equal to 0 that forms the bottom boundary. But what is the top boundary? One can conveniently say that it can be a critical state line; you remember there is a line in q p' or τ σ' plot.

And that can be considered as the boundary provided why? Because the soil ultimately fails on it, but in fact for those soils which dilates, we know that it has to first hit the peak and then come back to the critical state line. So, the top proportion, if you want to really consider the boundary it has to be the peak state. Because peak state is above the critical state even though the final failure happens at critical state.

So, today's lecture we will see more specifically about peak state which happens to be another boundary for the soil to exist. And finally what we are trying to do? Through critical state framework; we are just trying to understand the bounds within which the soil can be loaded that is where the soil can actually exist during shearing.

(Refer Slide Time: 03:02)



So, with this we will now start with what is known as peak state? Now let us consider 2 reference void ratios e $_1$ and e $_2$. Let us say we are considering e σ' plot, and the critical state line is marked in this. Since we are considering the peak state, we do not have to really bother about normally consolidation line. Because we know that peak state is relevant to over consolidated or dense sand and which lies on the wet side of the critical state, mostly.

So, we will discuss about e σ', now there are different ways of representation all majority of them we have already discussed, it can be on log σ' plot as well. But here specifically it is on a linear scale. Now this is the reference void ratio e $_1$ and e $_2$, it is noted you can note that e $_2$ is less than e $_1$ that means this is a more dense state. Now shear strain test is conducted at identical e and different confining stress, and that is what we do.

If you want to determine the strength of the soil, we need to have at least 3 identical samples. And these identical samples means, the initial state has to be comparable for all the 3 states. And that means that the void ratio has to be same or the water content has to be same, the initial state. And then we choose 3 different confining pressure, whether it is in direct shear test or whether it is in triaxial test.

We need to conduct it at 3 different confining stress, that is what is written here, at least 3, so three confining stress. So, this is what at e $_2$, these are the locations at which or these are the σ' at which the shear test is performed and the last point being on the critical state line. So, let this be PQ and for e_1 the same void ratio but with different effective stress or the confining stress, so it can be denoted as RS.

So, there is a PQ series and there is an RS series. Now different peak lines corresponding to e_1 and e_2. I hope you remember or rather you can refer back to module 2 wherein we have discussed this particular aspect where for a peak you can have three different points and there will be a peak line. And this peak line when it is fitted using Coulomb's equation will give the cohesion and peak friction angle.

So, let us try to do the same thing here τ versus σ', this is the critical state line. And for e_2 that is at a smaller void ratio we get the 4 points here, the last point being on the critical state line. So, the peak line is PQ which meets the critical state line at point Q. Now if we extend this or rather if we fit a Mohr Coulomb or a Coulomb's envelope we end up with a cohesion value and the inclination will be peak friction angle, similarly for RS.

Now we can note that void ratio e_1 is greater than e_2 obviously the strength of e_1 will be less than PQ, and that is very legibly shown in this particular figure. So, that gives C_{e1}, so cohesion for void ratio series e_1 is C_{e1} and cohesion for void ratio series e_2 is C_{e2}. Peak state lines meet critical state line at S and Q; we have also discussed this aspect. As we go on increasing the effective stress it reaches a point where the effective stress suppresses all the dilation.

At that point the peak state line becomes same as the critical state line, this aspect we discussed. But now there is a lot more clarity in those discussions, why? Because when we integrate the explanation with respect to e σ' plot, this gets quite comfortable and it is very easy to understand. Because we know that as you go on increasing σ', there exists a condition where it will meet the critical state line, when you project that down that will give Q and S.

At this point onwards the dilation is suppressed due to higher σ', this aspect we have clearly discussed. Now from this point onwards it will be on the critical state line. Peak state lines are terminated at P and R at low σ'. Now you can see here that it does not extend beyond this, because it is very difficult to find out or to simulate a condition of low stress lower than this particular point P or R, so it gets terminated, peak lines are terminated at P and R at low σ'.

Now beyond this it does not follow the Coulomb's equation $\tau = c' + \sigma'_f \tan \varphi'$ at low σ'. Now I do not know whether you will be able to really appreciate this particular point or not. Because we never bothered about this particular aspect, when we conducted the test may be for finding out peak friction angle and cohesion. So, cohesion would exist only if we are dealing in terms of peak friction, so both goes hand in hand.

Now when we discuss this or when we have already determined this in the lab, we have got 3 points and we have just fitted. How low stress value we have considered, we have not bothered about it. In fact the authenticity of the stress points towards the lower end is restricted because of certain factors. One important factor is the tension cut off zone and the other one is what we are going to discuss now.

So, this particular equation for the time being is more like a mathematical fitting parameters. How sound or how much physically relevant these parameters are? Definitely φ' has got it is own physical significance. But then whether c' is always justifiable or not, that is what we will just see now. Peak line is equally valid for clays and sands, this also we know because when we say clays we talk in terms of over consolidated or normally consolidated.

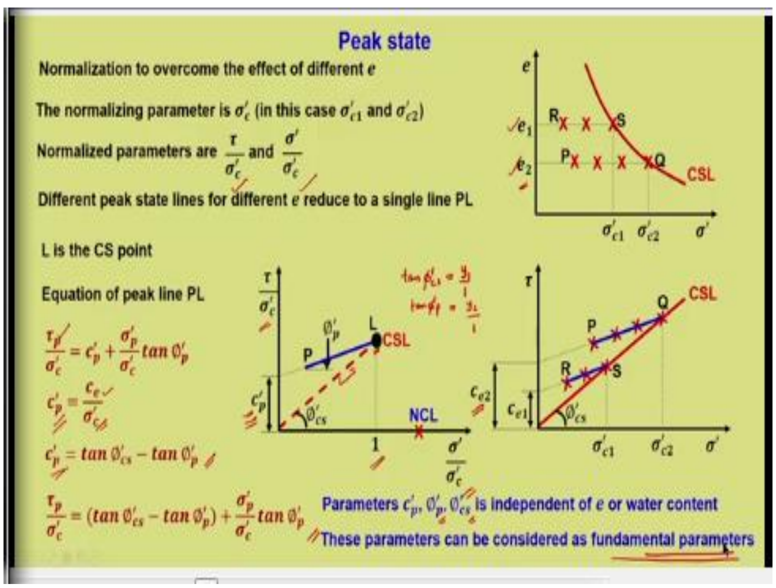
And if it is over consolidated we say that there will be dilation, there will be peak and there will be c' which is associated. And in the case of sand we say that for dense condition it will be exhibiting a peak friction angle. But what about the condition close to 0 confinement, can it have cohesion? Definitely not, so that is the reason that is another reason why we say that in general the Coulomb's envelope or Coulomb's equation may not be valid for lower stress condition.

Sands do not have shear strength at 0 σ', at 0 confinement sands do not have any shear strength. So, in general cohesion C' cannot be considered as shear strength available at 0 σ'. So, we cannot generalize stating that σ' is always the shear strength at 0 confinement, because that is not valid for at least sandy kind of soils. So, where it will be applicable?

C’ is primarily a mathematical requirement of Coulomb's model and it is valid for soils with cementation characteristics. Definitely one can always say that those soil which exhibits a kind of cementation characteristi$_{cs}$, it can hold on it is own even if there is no confinement. So, in those cases and that can be also due to apparent cohesion. An apparent question may not be available all the time, so that also we need to be careful about.

So, we are basically discussing about in depth the understanding of peak and the cohesion behavior of the soil. Definitely if there is a kind of cementation, it is bound to exhibit cohesion, and for that particular reason we can always extrapolate the results. So, that intercept can be considered as cohesion.

(Refer Slide Time: 13:28)



We have seen that different e $_1$ and e $_2$ will result in different C and φ’ characteristics for peak line. Now let us try to make it unified by the process of normalization, in the last lecture we have already seen how to normalize a given plot. So, the normalizing parameter is σ’ $_c$ that is the stress condition or the confinement which corresponds to the critical state line. So, σ’ $_c$ is the normalizing parameter and in this case there will be σ’ $_{c\,1}$ and σ’ $_{c\,2}$.

So, σ’ $_{c\,1}$ for e $_1$ series and σ’ $_{c\,2}$ for e $_2$ series, this will be the normalizing parameter. And what we will normalize? We will normalize τ and σ’, so the normalized parameters are τ / σ’ $_c$, σ’ / σ’

$_c$. We have done this in the previous lecture and we have seen that critical state line and normal consolidated line comes to a particular point.

The line is represented by a point how this is so? Please refer back to those lectures. So, this is the normalized plot. Here different peak state lines for different e, it reduces to a single line PL, do not think that this is a critical state line, this is done with a specific purpose, that is why it is drawn in dashed line, this dashed line is not critical state line. Critical state line is represented by this particular point and this line is only meant to show the slope.

So, PL becomes the peak line which is normalized, now the effect of e_1 and e_2 goes away whatever we have got as PQ and RS, it all merges to PL. All the data points will be on this line because of the normalization. We have seen that this is 1 and NCL is a point on the x axis. So, this parameter c'_p is a normalized parameter and φ'_p is the inclination of the normalized plot rather φ'_p will be same as this plot as well, because it is only a division by σ'_c.

So, L is the critical state point where it merges on the critical state line. Now we can always write the equation of the peak line PL which is the normalized plot as τ / σ'. Now I have added τ_p here just to make sure that it is the point on the peak line PL. So, $\tau_p / \sigma'_c = c'_p + \sigma'_p / \sigma'_c \tan \varphi'_p$. In which C'_p can be written as C_e / σ'_c, C_e is the cohesion corresponding to a given void ratio, so it can be C_{e1} or C_{e2}.

Now that will be getting reduced by or that will be getting factored by σ'_c, so C e_1 upon σ'1 C or C e 2 upon σ' C 2, whatever. So, that normalized value of cohesion is c' p as you can note from this figure. We can also write $c'_p = \tan \varphi'_{cs} - \tan \varphi'_p$, how this is possible? Now this expression is possible only on the normalized plot, why?

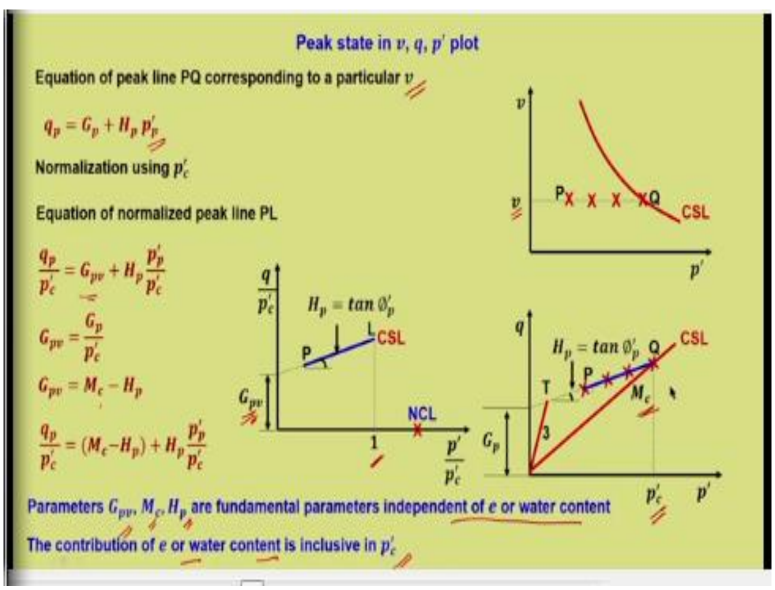
Let us consider $\tan \varphi'_{cs}$, this is the triangle, inclination $\tan \varphi'_{cs}$, so $\tan \varphi'_{cs}$ is equal to let us take this distance as y upon 1, because this is 1. And similarly if you consider this particular triangle, we can write tan φ' p, let us call this as y_1 and this will be $y_2 / 1$, so $y_1 = \tan \varphi'_{cs}$ $y_2 = \tan \varphi'_p$. So, in short we what we are writing is $c'_p = y_1 - y_2$, that means that is $\tan \varphi'_{cs} - \tan \varphi'_p$.

So, substituting this in this particular equation, we can write $\tau_p / \sigma'_c = \tan \varphi'_{cs} - \tan \varphi'_p$ + the same $\sigma'_p / \sigma'_c \tan \varphi'_p$. So, now the parameters c'_p that is the normalized parameter, φ'_p φ'_{cs} is independent of e or w which is the initial condition. Because now we have normalized it and hence the effect of e_1 e_2 or it can be told in terms of water content for a saturated sample, the effect goes away, so it is normalized now.

So, this parameter it is independent of the initial condition that is e. Hence these parameters can be considered as fundamental parameters, only after normalization. But there is a catch here, can it be really considered as a fundamental parameter under certain condition? If we consider another parameter that is the confining stress, then you will see that the things will be different and this we will explain in the slides to come.

For the time being if you are referring only to the initial state, that is the void ratio or w, we can consider this to be still a fundamental parameter after normalization.

(Refer Slide Time: 20:04)



Now let us try to repeat this in v, q, p' plot, because this is important. Finally we will be explaining all these aspects on v, q, p' plot. So, I am not going to spend much time, it is the same explanation, we have a reference v for which four tests has been conducted PQ. And the same has been shown on q p' plot, where M_c is the slope and G_p is the intercept on q axis, p'_c corresponds to critical state.

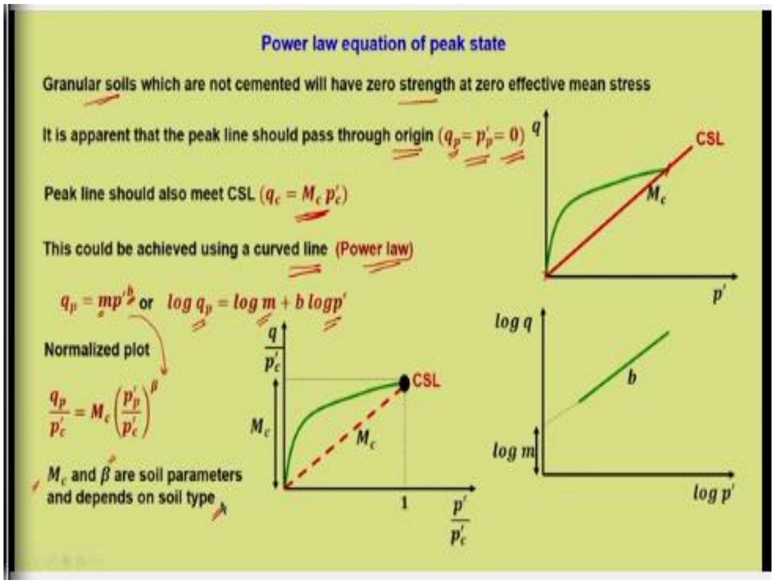
Here we can also add the tension cut off zone with an inclination of 3, let this slope be H_p which is given as tan φ'_p, where φ'_p is the inclination of PQ line. Equation of line PQ corresponding to a particular v, please note it is for a specific volume q p, that is q on peak line $p_q = G_p + H_p$ into p'_p, p'_p means p' on the peak line PQ, so this is the equation and that is very state forward.

And if we normalize using p'_c which is the point on the critical state line, we get the normalized plot where $H_p = \tan \varphi'_p$ that remains same G_{pv} is the normalized G parameter with respect to specific volume v, this is 1 again. Equation of normalized peak line can be written, this is normal consolidated line point $q_p / p'_c = G_{pv}$ which is from here + H_p into p'_p upon p'_c, a same exercise as we have done before.

And this $G_{pv} = G_p / p'_c$, G_{pv} can also be written as $M_c - H_p$, where M_c is the slope of this line or this particular line. And here this distance as we have done in the previous case it will be $M_c - H_p$. So, q_p / p'_c from here is $M_c - H_p + H_p * p'_p$ upon p'_c. As like before parameters G_{pv} that is normalized parameter M_c, H_p are fundamental parameters independent of e or w, it is fundamental parameter.

Only because it is not dependent on initial state, it is independent of the state variable e or w. As I told there is another hidden part here which may violate this fundamental nature that we will see a bit later. The contribution of e or water gets included in p'_c in this particular parameter. The effect of e and w is inclusive in the normalizing parameter p'_c that is why it gets normalized.

(Refer Slide Time: 23:21)



Now let us see something what is known as power law equation of peak state. Now we have represented the linear representation of peak line in a normalized parameter. We would also like to see if we actually consider the real behaviour, how it would look like? When I say real behaviour what I mean is we have told that peak line cannot be extended beyond a certain point on the left side or towards the low confinement stress region.

So, if that is the case, is there a better model to represent peak state which is even more general than the linear representation. Granular soils which are not cemented will have zero strength at zero effective mean stress. Now this aspect is not considered in the linear representation for peak state, so that is very important. So, when we represent the peak state using a linear fitting it is bound to give an intercept, and this is not valid for soils which do not have cementation characteristics. So, let us see this in detail.

It is apparent that the peak line should pass through origin for this particular case, where there is zero strength then it has to pass through the origin where q p = p', that q_p means q on the peak line, p'_p, p' on the peak line that will be equal to 0. So, it has to move through the origin. We also know that on the right hand side peak line would also meet critical state line, it cannot go on and on, so it will meet at critical state line where the dilation gets suppressed.

And the peak behaviour is no more possible, a peak gets suppressed, when that is $q_c = M_c p'_c$ when where it meets the critical state line. Now this could be achieved only using a curved line, if we want to meet this condition and this condition, it has to be a curved line. Now please understand, we are slightly breaking certain rules which we felt it is actually the case when we studied during our undergraduate.

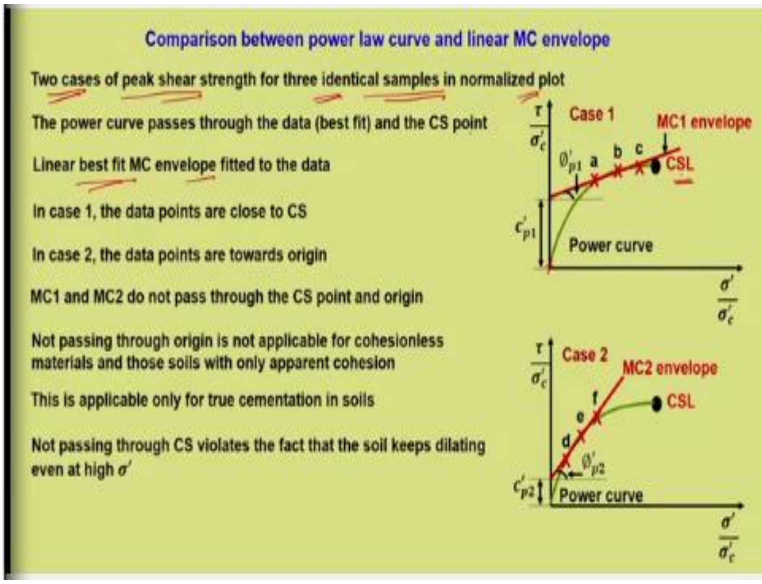
So, as we move forward we have to add more and more details to what we have already learned. And in the process we may have to break certain rules with which we have understood the shear strength concept, and this is one. The speak behaviour is very, very critical and which we have not discussed in detail during our undergraduate days. So, this could be achieved using a curved line, because for soils we do not discuss about this curved failure envelope to represent peak behaviour.

This is very much dealt when we discuss the behaviour for rocks, but the same is not considered when we discuss for soils. So, this curved line a very simple equation can be of that of power law. If we represent the peak state points using a curve like this which is a power curve, then this will satisfy that it goes through the origin and it meets the critical state line, so both the points are actually met.

And that can be represented as q_p = M into p'_b, where M and b are the power equation parameters. In log we can also write this as log q_p = log M + b log p', and that can be represented as a straight line because then it becomes on a log it becomes a straight line, where this log m b and in the normalized plot. We can write q / p'_c p / p'_c, we can write the power curve in this particular manner m'c.

And this particular intercept will be equal to M_c because the slope is M_c that we have seen since this is 1, this distance becomes M_c. So, we can write the equation for this curve as q_p / p' c = M_c p'_p / p'_c raise to β. So, the same equation altered in the normalized plot, where M_c and β are soil parameters and depends only on the soil type.

(Refer Slide Time: 28:41)



Now let us make a comparison. Now we have discussed the various nuances associated with peak state which we have not studied earlier. Now what is the implication of this, what is the implication of the more generalized representation of peak state using power law curve? vice-a-vice what we already know which is the Mohr Coulomb failure envelope or we can also call it as Coulomb's failure envelope.

Because we are representing in terms of τ and σ', so how do we make this comparison? Let us see, for this I am considering 2 cases of peak shear strength for three identical samples in normalized plot. So, now we will consider only normalized plot because we have discussed in detail about how e and w is going to affect, the initial state how it is going to influence.

Now the other aspect which is the role of confining stress that is what we are going to see in this particular slide. Now for that what we are doing is, we are considering three identical samples the way we use it for shear strength determination. And we are representing it in normalized plot and there are 2 cases which we need to consider. Now the first case, case 1 on the normalized plot, this is the power curve which has the more general representation of the peak state.

Let us consider these three identical samples are a, b and c, now why this is case 1? In case 1 the three identical samples are close to critical state line that is towards the critical state line or the right most portion of the peak curve. Now in normal practice what we do, we fit a best fit line and we call it as Mohr Coulomb failure envelope or Coulomb's envelope and we get the cohesion and the friction angle, that is φ'_{p1}, because it is case 1.

So, the peak friction angle is φ'_{p1} and the cohesion given is c'_{p1} and 1 represents that it is case 1. The power curve passes through the data, that is best fit and the critical state point. So, the power curve passes through even origin through the data and the critical state point. Now we are best fitting a linear envelope or Mohr Coulomb envelope to the data, so what we see?

In case 1, the data points are close to critical state and this is the best split curve, and we can see that it gives a cohesion and friction. Now what is case 2? Now case 2, the data points are towards origin, that is towards this or lower σ'. So, this is case 2, same power curve, same identical state but we have chosen d, e, f that is the three normal stress or effective stress towards left side or towards origin, now what we do?

We have to again fit the Mohr Coulomb failure envelope, so this is represented as MC2 envelope. And given by the friction angle φ'_{p2} and c'_{p2}, so this is what we do for peak envelope. Now we can see, we can compare the power curve which is general in both the cases case 1 and case 2, whereas MC1 and MC2 there are marked differences between case 1 and 2. So, MC1 and MC2 do not pass through the critical state point and origin.

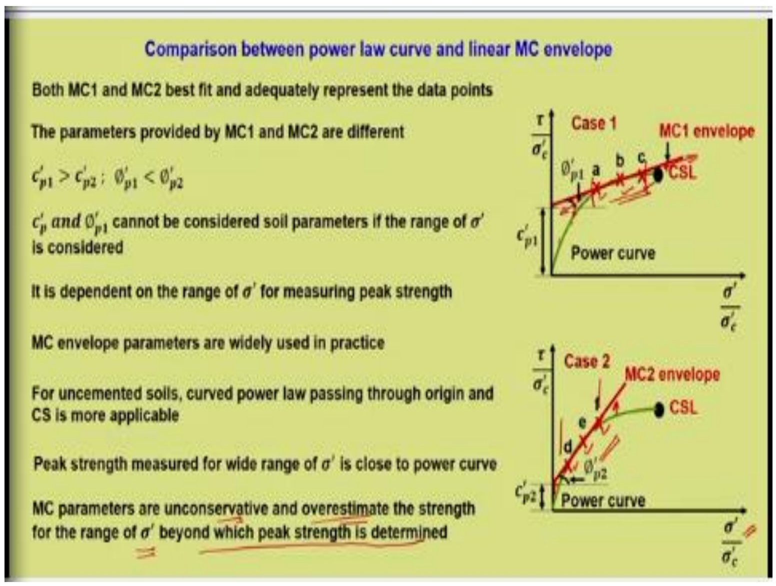
So, for peak we know that it has to pass through origin, because to satisfy the lower end and it has to pass through the critical state to meet to satisfy the upper end. Now both the Mohr Coulomb failure envelope best fit line will not pass through these 2 points. So, you can see that the Mohr Coulomb is a kind of violation for representing the peak behaviour. But still it is valid, we will see how?

Now not passing through origin is not applicable for cohesionless materials and those soils with only apparent cohesion. So, what is the implication of not passing through origin? If it is Mohr Coulomb is not passing through origin means, it is not applicable for a cohesionless situation or for the soil where there is no proper cementation it cannot hold on it is own, because, in apparent cohesion we cannot consider it as a true cohesion.

So, those soils which cannot sustain on it is own, it may not be able to represent the lower stress conditions, this is applicable only for true cementation in soils. Not passing through critical state violates the fact that the soil keeps dilating even at high σ'. So, the contribution of suppression by σ' is not accounted, if the Mohr Coulomb is not passing through the critical state point.

So, these are some of the violations which we have to keep in mind when we use Mohr Coulomb failure envelope for representing peak behaviour.

(Refer Slide Time: 34:58)



So, both MC1 and MC2 best fit and it adequately represent the data points; there is nothing wrong in representing this particular line. Because it adequately represents this particular range of data, it also represent this particular range of data, but what matters? The range of σ' considered matters that is why MC1 is practically different from MC2. The parameters provided by MC1 and MC2 are different, c'_{p1} is greater than c'_{p2} and φ'_{p1} less than φ'_{p2}.

Now c'_{p} and φ'_{p1} cannot be considered soil parameters if the range of σ' is considered. Now we are just going against what we have told in the previous slide where these normalized parameters c'_{p} and φ'_{p} can be considered as a fundamental parameter. Provided, we are referring only to the initial state, then it is correct, but if we are considering the range of σ' as you can see here, this is one particular range and this is another particular range.

If the range of determination of σ' comes into picture then you can see that both c' and φ' peak changes. So, it is dependent on the range of σ' for measuring peak strength. So, MC envelope parameters are widely used in practice because we never look at the power curve, what we are interested in is the representation using Coulomb's envelope. All the numerical evaluation even all the programs that we use it is all basically based on Mohr Coulomb failure envelope.

So, for uncemented soils, curved power law passing through origin and critical state is more applicable or it is more general in nature than Mohr Coulomb failure envelope. Peak strength measured for wide range of σ' is close to power curve. Now if we include different range or during the determination then that particular Mohr Coulomb envelope will be a more generalized and close to what we represent using peak.

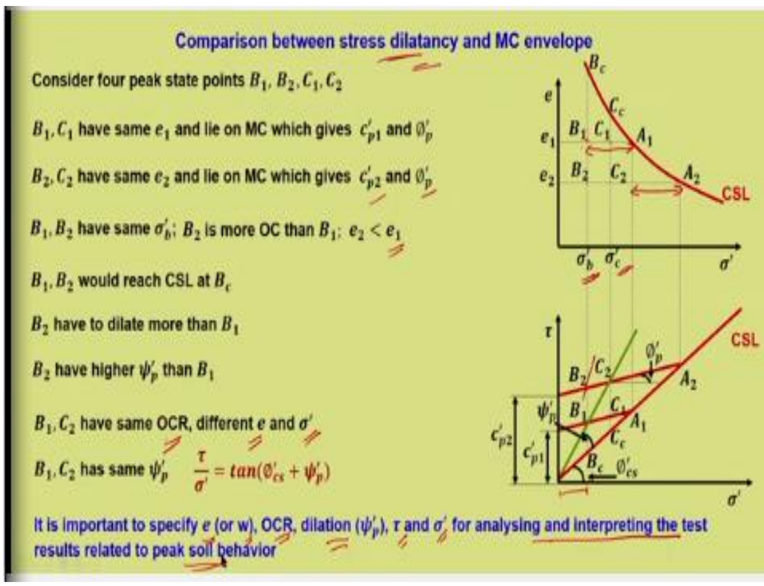
Now we can see another important aspect, Mohr Coulomb parameters are unconservative and overestimate the strength for the range of σ', please understand this, beyond which peak strength is determined. Let us take the example here, now for these three data points it fits very well, so if this is the range considered nothing wrong it goes hand in hand with the power curve. But the moment it exceeds the range that is towards this side and towards this side we can see that Mohr Coulomb failure envelope is above the power curve.

If this is the actual strength available the predicted strength based on Mohr Coulomb towards the lower end is this, similarly in the upper end it is this. So, it is an overestimation, and whenever we overestimate strength it becomes more unconservative. Whether that much strength is available or not, that is a kind of debatable subject. But then according to the mathematical framework what we need to understand is that the Mohr Coulomb beyond the range for which the strength is determined.

Now it is same for this also, this is the range, so beyond this there is an overestimation of strength by Mohr Coulomb failure envelope. We are basically working with higher strength, for a designer this is not good. So, for the range for which the σ' is determine, if the same confinement is there in the field then whatever we are telling is correct. So, that is why we have not discussed these aspects in detail during our UG learning.

There it is presumed that whatever peak strength values that we are determining, it corresponds to the given confinement in the field. So, σ' that we use for strength determination, it adequately represents what is there in the field. Hence there is no dispute, otherwise there are a lot of loopholes when we consider Mohr Coulomb failure envelope, which we need to keep in mind at least we should be knowing and we should appreciate this better.

(Refer Slide Time: 39:49)



Another aspect which we need to discuss is the stress dilatancy and Mohr Coulomb envelope. Let us consider four peak state points B_1, B_2, C_1, C_2 that is e corresponding to e1 we have A_1 and e_2 which is A_2 which is the point on the critical state line. Corresponding to σ' b we have B_1 and B_2. And corresponding to another reference effective stress σ'_c we have C_1 and C_2 and B_c is the point on the critical state line and CC is the point on the critical state line.

The same is shown all the critical state points are mapped that is B, C, BC, CC, A 1 and A 2. Now, this four points represents many different aspects B_1 and C_1 same e_1, B_2 C_2 same e_2, where e_2 is less than e_1. Now the points B_2 and B_1 corresponds to same initial effective stress, that is σ' b, but e_1 is greater than e_2. So, this and the over consolidation ratio will be different for B_1 and B_2, the amount by which B_1 is over consolidated or B_2 is over consolidate it differs.

So, there this four points represents adequately different aspects of stress dilatancy. So, let us consider peak which is represented by B_1 C_1, now this has same e1. So, this B_1 and C_1 will lie on the same peak line and B_2 and C_2 will lie on the other peak line. And you can see that e_1 is greater hence the strength is lower. And the corresponding cohesion is c'_{p1} and c'_{p2}. Now let us consider there is a given line here which is drawn to show Ψ'_p, what is Ψ'_p?

You can refer back to module 2, it is the dilation angle which is over and above the critical state angle, and summation of these 2 gives the peak friction angle. So, φ'_p, if this is the peak line φ'_p is the critical state plus the dilation. Now B_1 C_1 have same e_1 and lie on Mohr Coulomb failure envelope which gives c'_{p1} and φ'_p, we have already seen that. B_2, C_2 have same e_2 and it lie on Mohr Coulomb failure envelope which gives c'_{p2} and φ'_p.

B_1, B_2 have same σ'_b, now these 2 points we are referring it has same initial stress condition. But B_2 is more OC than B_1, you can see that it goes down and has come so this much allowance is there. So, B_2 is more OC than B_1, and e_2 is less than e_1, so these are the 2 important conditions. Now if you refer to this B_2 is more OC than B_1 means if we draw a line through B_2, you can see that the dilation angle is more for B_2 which is a good indication that, it is more over consolidated.

If it is more over consolidated, it is bound to exhibit more dilation towards the lower stress region. So, the dilation caused in B_2 will definitely be more than B_1 and hence the dilation angle is more. And if you draw this line through origin you can see that Ψ'_p for B_2 is more than Ψ'_b at B_1 and obviously the e_2 is less than e_1. B_1 and B_2 would reach $_{CSL}$ at BC, that is already there, now B_2 have to dilate more than B_1.

Accordingly B_2 dilates more, now even though the initial stress condition is same; it does not mean that the dilation is going to be same. We also need to consider how much over consolidated the given sample is? Definitely B_2 is has to dilate more and hence the dilation angle will be more, so B_2 have higher dilation angle Ψ'_p than B_1. Now let us consider B_1 and C_2, that is B_1 and C_2.

Now this point B_1 and C_2 has got same over consolidation ratio. Now if you see B_1 from here and C_2 these are same over consolidation or the over consolidation ratio at B_1 and C_2 are same. And that is very clear from here, because this particular line passes through B_1 and C_2, and the dilation angle is Ψ'_p. So, both B_1 and C_2 has the same dilation angle, now this is possible only if the over consolidation for B_1 and C_2 is same.

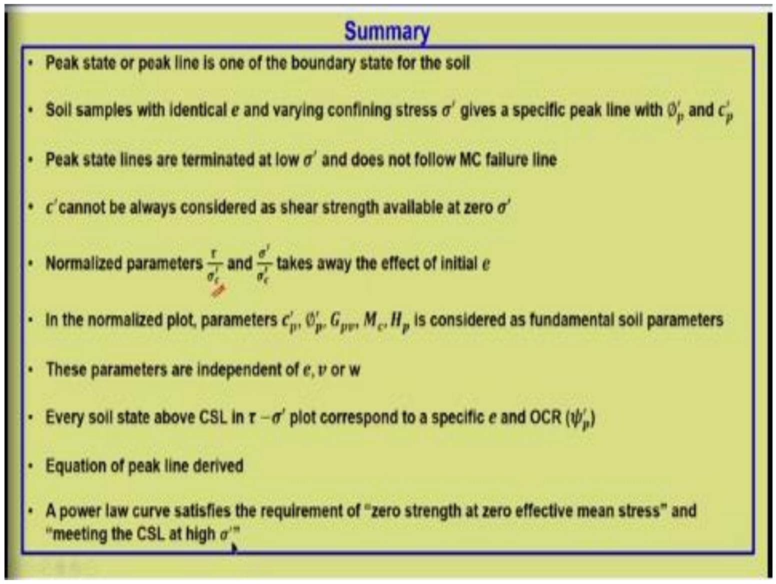
And that is why we say that the B_1 and C_2 has same OCR, but it has different e and different σ'. Earlier case we discussed for the same σ', now here we have different e and different σ' but OCR remains same. Now B_1 and C_2 has same Ψ'_p, which can be represented by $\tau / \sigma' = \tan \varphi'_{cs} + \Psi'_p$. Because this τ / σ' that ratio remains same for both B_1 and C_2 because the dilation angle Ψ'_p is same for both.

What it indicates is that for peak points both the stress dilatancy also need to be considered and it is important to specify e, that is the initial state parameter e or it can be in terms of w. The over consolidation ratio as we have shown here, dilation Ψ'_p, τ and σ' for analyzing and interpreting the test results related to peak soil behaviour. So, interpreting peak is slightly more complex than what we generally do for critical state.

So, we need to keep in mind these parameters, not to confuse, but to understand that these parameters also significantly contribute towards the peak characteristics. So, that is why in certain design we see that the cohesion characteristics is ignored, why because we do not know whether it is going to mobilize that much of friction actually in the field. So, the safe way is to nullify cohesion and only consider the frictional characteristics.

So, here what it means is that, it is not only the over consolidation or a single parameter that need to be considered while interpreting the peak behaviour. We need to take into consideration, the state parameters, OCR, this what range of σ' we are talking about and so on.

(Refer Slide Time: 47:47)

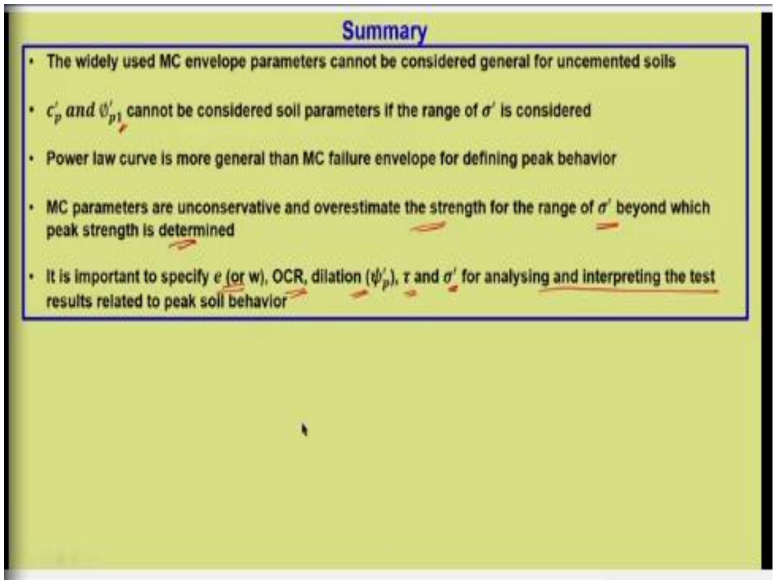


So, let us summarize today's lecture. Peak state or peak line is one of the boundary state for the soil. So, that is where we started off with NCL forms right boundary, tension cut off zone on the left bottom we have the axis, and the top instead of critical state we have the peak line as the boundary. Soil samples with identical e and varying confining stress σ' gives a specific peak line with φ'_p and c'_p.

Peak state lines are terminated at low σ' and does not follow the Mohr Coulomb failure line, we have shown this. c' cannot be always considered as shear strength available at zero σ'. The normalized parameters τ / σ'_c and σ' / σ'_c takes away the effect of initial e and because it is inclusive in σ'_c. In the normalized plot parameters c'_p, φ'_p, G_{pv}, M_c, H_p is considered as fundamental soil parameters provided the range of σ' is fixed.

These parameters are independent of e, v or w. Every soil state above critical state line in τ σ' plot correspond to a specific e and OCR, that is Ψ'_p. Equation of peak line is derived, a power lock curve satisfies the requirement of zero strength at zero effective mean stress and meeting the critical state line at high σ', that we have shown, because this is the most adequate representation and the more generalized aspect.

(Refer Slide Time: 49:31)



The widely used Mohr Coulomb envelope parameters cannot be considered general for uncemented soils. c'_p and φ'_{p1} or rather φ'_p cannot be considered soil parameters if the range of σ' is considered. Power law curve is more general than Mohr Coulomb failure envelope for defining peak behaviour. So, Mohr Coulomb parameters are unconservative and it overestimate the strength for the range of σ' beyond which the peak strength is determined.

So, so long as it remains within the range it is fine. So, it is important to specify the state parameter e, OCR, dilation angle, τ and σ' for analyzing and interpreting the test results related to peak soil behaviour. So, we have discussed a very important aspect of peak behaviour which you will see later in the state boundary surface. So, this information is valid when we consider it there, so that is all for this lecture, thank you.