Earthquake Geotechnical Engineering

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Lecture 35

Initiation of Liquefaction (Conti.)

I welcome you again in this 35th lecture on earthquake geotechnical engineering. So, today we are going to discuss the liquefaction and we are continuing with the module number 4, Liquefaction of Soils and we are under chapter number 3rd which is on initiation of liquefaction. As we discussed in the last lecture that the topics which are going to be covered in this chapter, flow liquefaction surface which is FLS. FLS we just discussed in the last lecture, lecture number 34 and today in lecture number 35 we are going to discuss that what is the influence of excess pore pressure. In fact, this is the pore pressure which is the hallmark of the liquefaction and when the excess pore pressure increases, so what is the influence we are going to talk before we talk evaluation of initiation of liquefaction in the next lecture.

So, today's topic is influence of excess pore pressure and we are going to cover this into two part, one is related to flow liquefaction, and another is related to cyclic mobility and most of the part of the liquefaction is from the Kramer and particularly the figures and we are going to discuss, but I am going to explain each one by one. So, when we talk about excess pore pressure, the generation of excess pore pressure is the key to the initiation of liquefaction. For changes in pore pressure and changes in effective stress neither flow liquefaction nor cyclic mobility can occur. So, naturally the first point is this one for liquefaction of course, you have decided to let us say my soil is susceptible to liquefaction, but until the pore pressure develops then there will be no change in the effective stress and neither of the flow liquefaction or cyclic mobility can occur and there these different phenomena require different level of pore pressure to occur.

Now, because there are two different phenomena one is flow liquefaction and another is cyclic mobility. The level of the generation of pore water pressure required for both the phenomena are different, which we are going to discuss in detail. Flow liquefaction can be initiated by cyclic loading only when the shear stress required for static equilibrium is greater than the steady state shear strength. So, this is one of the condition for flow liquefaction that is the stresses which is generated should be more than the shear strength of the soil. I think we are discussing this point from since the beginning of the first lecture on liquefaction.

In the field the shear stresses are caused by gravity and remain essentially constant until large deformation develop. Therefore, initial states that plot in the shaded region of figure are susceptible to flow liquefaction. So, here what is this? FLS flow liquefaction surface and FLS line we have already discussed in the last lecture, that is lecture number 34. Now, suppose if your initial soil condition falls under the shaded region, anywhere at the shaded region then and you increase the excess pore pressure due to shaking what will happen? There will be increase in pore pressure which we called excess pore pressure. When Epp will increase then p prime will decrease because there is as we discussed p effective like you know this pressure will be p minus u and when there is u increases this will decrease.

So, what will happen? You start moving this side and naturally when I move from any point to this side then you are going to hit this line FLS line and once you hit this FLS what happens which we are going to discuss. So, here there is a zone of substantive flow liquefaction if initial condition is within the shaded zone flow liquefaction will occur if an undisturbed undrained disturbance bring the effective state path from the point to the initial condition to the FLS. So, if initial condition of the to the FLS will be described by this line like you have the line here. So, if it touches this one then this the flow liquefaction will start. The occurrence of flow liquefaction requires an undrained disturbance strong enough to move the effective path from the initial point to the FLS.

So, here like issue is you may be somewhere in the shaded region, but ultimately you need to touch this line this line. So, when you touch this line then only what you call the flow liquefaction will takes place. If the initial stress conditions float near the FLS as they would be in and then in that case large shear stress under drain condition flow liquefaction can be triggered by small EPP. So, if you are already near this FLS line for example, in this region then even small excess pore pressure will lead to the flow liquefaction. The liquefaction resistance will be greater if the initial stress conditions are further from the flow liquefaction.

So, that is the opposite of that. The FLS can be used to estimate the pore pressure ratio at the initiation of flow liquefaction and excess pore it decreases sufficiently with increasing initial stress ratio for soils at a particular void ratio. So, this pore pressure ratio, what is the pore pressure ratio? We already discussed pore pressure ratio which is Ru is basically U excess divided by that EPP divided by sigma 3 effective. So, this is the excess pore pressure. Now when EPP increases that is this numerator increases naturally the value of Ru will increase.

So, the excess estimate the pore pressure ratio at the initiation of flow liquefaction, and this will decrease substantially with increasing initial stress ratio for soils at a particular void ratio. At high initial stress ratio, the flow liquefaction will be triggered by very small static or dynamic disturbances which is shown in this slide. So, you have the relation between excess pore pressure ratio and the value of principal effective stress ratio. When the principal effective ratio is 1 then you have the Ru also 1, but when the principal effective ratio decreases the value of Ru will be. So, this is the variation of pore pressure ratio Ru which is required to trigger flow liquefaction in triaxial specimen of this Sacramento River fine sand with initial principal effective stress ratio.

So, the Kc, so here the value of Ru required to trigger the liquefaction will be high when this value Kc is small, but when you increase the value of Kc effective stress then the liquefaction may takes place even lower value of Ru. So, that is the case here. So, this variation of required to trigger flow liquefaction. So, the value of Ru can be read at what value of Ru the liquefaction will be triggered even the liquefaction may be triggered when the Ru is less than 1 when you have the higher value of principal effective stress ratio. Although flow liquefaction cannot occur cyclic mobility can develop when the static shear stress is smaller than the steady state shear strength.

So, this is also what we discussed earlier. In the case of cyclic mobility where number of cycles are applied that means free or like you know that it is done in a number of loading cycles are increased even the liquefaction may takes place when the shear stress develop is less than the or like the shear strength. So, steady state shear strength. Therefore, initial states that float in the shaded region of figure are susceptible to cyclic mobility. So, for the what this was the condition, or this was the condition for the flow liquefaction that means you should lie in this triangular shaded region, but for the cyclic mobility you even lying below this triangular region like in the shadowed region then cyclic mobility may take place.

That means because your stresses are less than SSU this is the point you have steady state shear strength, and your stresses are even below then still cyclic mobility may take place. So, zone of susceptibility to cyclic mobility if initial condition float within this shaded zone cyclic mobility can occur. So, the cyclic mobility can occur in both loose as well as dense soils which we already discussed this it could be happen it is not necessary. Flow liquefaction is normally happens only in case of loose sand or loose soils, but the cyclic mobility may take place in both loose and dense soil. The shaded region of figure extend from very low to very high effective confining pressure and corresponding to states that would float both above and below the SSR.

The development of cyclic mobility can be illustrated by the response of soils in cyclic triaxial test. So, when you have the cyclic triaxial test then the cyclic mobility can be illustrated. Three combination of initial conditions and cyclic loading conditions generally produce cyclic mobility and these conditions we are going to discuss in detail. So, the first condition which is illustrated we will discuss the figure also. The first condition when toe static minus toe cycles is greater than 0 that means, the value of toe static shear strength is greater than the cyclic shear stress we apply and in that case no shear stress reversal will take place.

And another condition with this toe static plus the combination of the these two are less than the steady state strength that is no accidents of steady state strength. In this case, the effective stress path move to the left until reaches the drain failure envelope. Since it cannot cross the drain failure envelope additional loading cycles simply cause it to move up and down along the envelope. So, this is the case here. So, what we have discussed in the last slide was the A case.

In A case your point of initiation is here this is shown from the solid circle. Now when you apply the cyclic loading at this point toe static is given by this shown here toe cycle cyclic is less than this. So, as a result even when the reversal takes place that when the cyclic stress goes up then it add to the toe static plus toe cyclic and this addition is less than the this value this addition combination of these two is less than the SSU value. Here but when it go down toe cyclic then even this the toe cyclic toe static minus toe cyclic is not it is greater than 0. So, that means there is no in fact, so this is maximum value, and this is minimum value.

So, both maximum and minimum value are positive. So, that means no stress reversal is taking place. So, this was the case in the first case. So, no stress reversal and no accidents of the steady state system takes place. So, this was the case which we discussed in the last slide.

And in this case as a result the effective stress conditions stabilize; flow type deformation cannot develop because any unidirectional straining would induce dilation. The effective confining pressure has decreased significantly and the resulting low stiffness can allow significant permanent strain to develop within each loading cycle. So, this is the case here. So, here this all these was for case a. The second condition which belong to the figure b which is this figure, the second case is this case.

In this case this occurs when the difference between toe static and toe cyclic is greater than 0 and still no stress reversal takes place. So, this is the similar stress reversal is not there in the this is similar to case a, but the sum in this case is greater than SSU. Earlier it was less than SSU steady state strength is exceeded momentarily and again this is cyclic loading will cause the effective stress part to move to the left side when it touches the FLS momentary periods of instability will occur. So, here what happens because now because the sum of these two stresses toe cyclic and toe static is less than this value or this more than this value. In this case even the high sum this point was less than it was below this line.

So, there was no issue, but here what happens no stress reversal is taking place no negative values, but on the positive side the peak values touches this FLS. Once it touches this FLS now it cannot cross this one. So, what will happen here your peak have truncated because you cannot cross this FLS line. So, as a result when the next cycle you this side is okay, but on this side the maximum value is terminated here. So, which was said here when it touches the FLS momentary period of instability will occur.

These are the points where the instability will occur here. So, significant permanent strain may develop during these periods particularly when toe static is greater than the quasi-static shear strength, but the straining will generally cease at the end of cyclic loading when the shear stress return to toe static. Now, coming to the third case, the final condition in which case there is a stress reversal that is the difference between toe static and toe cyclic is less than 0 that means your toe or another word this toe cycle is greater than toe static. So, stress reversal will take place and the sum of these stresses is less than SSU. So, this is steady stress strength is not exceeded.

So, this is the third case. In third case you see here because toe cyclic now is greater than toe static. So, it was not the case between A and B. So, as a result when you go to the negative side there is a stress reversal it is not positive. So, it will have gone to the negative all these peaks that is one difference. On another side because the sum of these two are still less than SSL. It will not touch this line. This is the case here. So, what happens in all the three cases when excess pore pressure increases EPP increases then EPP will increase then p prime that is this is the difference between p minus u that is the effective that is p and u is excess pore pressure. So, p prime will decrease because pore pressure is increasing and when it decrease you will move from right hand side to the left hand side. So, you will move towards this condition. So, in all the cases now in this case when you move towards this it is not touching this line, but after this point, it will start touching here and then you continue to be and finally, you end up here.

So, in this case third case figure c the direction of the shear stress changes. So, each cycle includes both compression and extension loading. Experimental evidence have shown that the rate of EPP generation where EPP is nothing but excess pore pressure generation increases with increasing degree of stress reversal. So, the rate of excess pore pressure generation will be higher when increasing degrees of stress reversal and stress reversal is taking place here in this case.

So, this is the stress reversal here. This is stress reversal and when the stress reversal takes place the rate of generation of excess pore pressure is also increased as a result this p will decrease at a faster rate compared to in a or b cases. Hence, the effective stress path moves relatively quickly as I said to the left because it will be built up as quickly and eventually oscillate along the compression and extension portion of the drain failure involved. Each time the effective stress pass passes through the origin it does twice during each loading cycle. The specimen is in the instantaneous state of 0 effective stress that is R u equal to 100 percent. So, what is the case here? For the one cycle stress reversal will take place two times. For example, it started from here then it goes to peak value and then it becomes 0 here. But before the cycle get completed it go to the maximum value in the negative side and then again bounce back. So, you have two stress reversal for one cycle here and then as well as here two stress reversal. Same is for the next cycle. So, the stress reversal is two stress reversals you takes place.

Hence the effective stress path moves relatively quickly to the left because excess pore pressure built up quickly and eventually oscillate along the compression and extension portion of the drain failure involved. So, this was about that. Now, each time the effective stress path crosses through the origin it does twice during each loading cycle and in that case the 0 effective stress that is the R u value is 100 percent. Although this state of 0 effective stress is referred to as initial liquefaction it should not be taken to imply that the soil has no shear strength. This is important here. That means it passes two times here that q is 0 and then but it does not mean the soil does not because it is cyclic loading. So, one time it is going up and it is reversed. So, it does not mean that there is no shear strength here. Continue with this. If monotonic loading is applied at the state of initial liquefaction the specimen will dilate until the steady strength is mobilized.

So, this is the case here. Let us see that here. Now, in like let us both figures are in different form. One is for deviatoric stress versus axial strain another is like you have q versus p. What is done? Let me discuss the second one first. What happens? You apply the cyclic loading and the cyclic loading with the stress reversal, and this goes.

When this stretches the steady state line it goes here and finally, it comes here. But when it reaches this point then it will follow like this and then it is going like this and then it move to monotonic loading. So, here you have the cyclic loading and on the top of it you have the monotonic loading. So, here in this case the specimen will start from this point and go towards the left. While in this case on the figure A your cyclic loading point starts from this point and it will move towards right side and after this monotonic loading starts from this point.

So, this should be treated like this cyclic loading here first and then monotonic loading. Here cyclic loading and then monotonic. So, here what it shows? The figure shows dilative behavior of specimen loaded monotonically after occurrence of cyclic mobility. So, first cyclic mobility is there and then after cyclic mobility after cyclic loading you have the monotonic loading. Cyclic loading with stress reversal causes the effective confining pressure to decrease rapidly.

Eventually reaching momentary values of 0, subsequent monotonic loading causes dilation as the steady state strength mobilized. So, what happens after this monotonic loading?

Again, it reaches to this point, steady state point. When it reaches the steady state point then dilation will due to this dilation because dilation will take place and it is fine. So, here in contrast to the flow equation there is no clear point, at least the cyclic mobility is initiated.

So, that is the difference. We cannot say that this is the point from where the cyclic mobility will start. Now for influence, continue with the influence of excess power pressure which is related to cyclic mobility, permanent strains and the permanent deformation which has produced also accumulate incrementally. That means, the time they will keep increasing. The magnitude depends on the static shear stress and the duration of the ground motion and for ground motions of short duration of nearly level sides permanent deformations may be small. If you have them for moderately sloping sides or gently sloping sides which are subjected to ground motion of long duration, cyclic mobility can produce damaging levels of soil deformations.

So, the levels of soil deformations will also depend whether you have gentle slope or sloping sides. For the sloping sides this is dangerous, but for gently sloping sides or for like with moderate then if it is subjected to long ground motion of long duration, then if duration is large then cyclic mobility will able to produce damaging levels of soil deformations. So, this was all about, and this was all about influence of excess pore pressure and we discussed in two parts, one was related to flow liquefaction, and another was related to cyclic mobility. So, with this the first part of initiation of liquefaction is over and then in the next lecture we are going to talk about two of the approaches which is cyclic stress ratio approach and cyclic strain ratio approach for determination of what we call the liquefaction potential. So, and that is and then you can determine by that analysis whether liquefaction will occur on one of the side or it will not occur.

So, with this I end this lecture here because this topic is over and then the next lecture, we are going to start the another like related to liquefaction only, but we are going to discuss what is the cyclic stress approach and which is like consist of what is typically popularly known seed and Idriss analysis. So, where we are going to discuss that how to characterize the earthquake loading or and how to characterize the liquefaction resistance of the soils. Thank you very much for your kind attention. Thank you.