Advanced Soil Mechanics
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Lecture-41
Stress Pathfield Cases-II

Welcome back all of you, in the last lecture we were discussing about the stress path related to field cases. We will continue on that there are some more cases which we need to discuss. So, in the last lecture we essentially focused on slopes. So, in this lecture we will see some more examples relevant to field cases.

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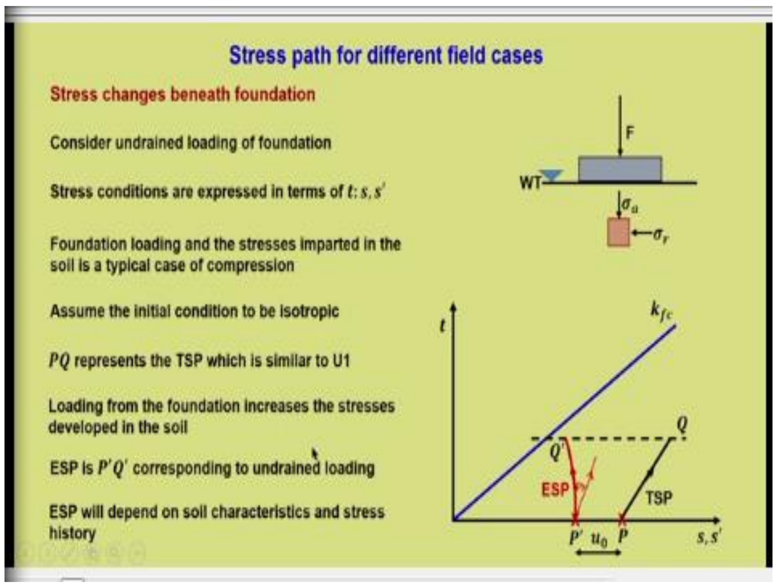

First is the stress changes beneath foundation, a very common case which that we encounter. Let us say let us consider the undrained loading of foundation, now is a typical foundation where it is the soil is under a submerged state because the water table is at the ground surface. This is a case where the foundation is resting on the ground for an example. Now the foundation transfers the load onto the soil.

So, there will be these the soil element beneath the foundation is stressed because of this load. Earlier it was stressed under it is own weight, now because of the placement of foundation some additional stresses are imparted onto the soil. Stress conditions we will see again in terms of t-s, s', we can study the stress path in any form the most common forms are t-s, s', and q-p, p' because those are in terms of invariance. So, generally q-p, p' is also preferred but since t-s, s' and q-p, p' plots are more or less similar because one this is a very marginal difference in terms of slope.

The procedure remains the same, so we will discuss in terms of t-s, s'. You can try doing all these and plot it on q-p, p' plot as well. Foundation loading and the stresses imparted in the soil. It is a typical case of compression and we have seen very specific stress paths in our previous lectures where we discussed about compression, extension and different manner in which this compression and extension can be created.

So, here we are discussing whatever is the foundation loading that is acting is a typical case of compression. Assume the initial condition to be isotropic for simplicity. So, this t-s, s'plot, since this condition is invoked we know that the starting point will be on s, s', so let p be the total stress point and if there is an initial pore water pressure of u_0. So, the effective stress point will be at p'.

Now we will have the total stress path from p, now the same total stress path when you draw at p' that we have seen in one of the examples earlier, so that is total stress path minus the initial pore water pressure. So, it is one other same, it is a parallel shift that is happening and sometimes that helps us to understand the pore water pressure and effective stress path difference better. PQ represents the total stress path which is similar to U1.

Now U1 we have already discussed previously, so PQ is the total stress path. And loading from the foundation increases the stresses developed in the soil. Effective stress path is from P' it will start P'Q' corresponding to undrained loading. So, how it will look like? So, it will be P'Q' and this essentially would depend upon the slope of effective stress path and the A value. This is how it will look like and if we draw this parallel total stress path here, so this total stress path is TSP - u_0 plot, this is u_0 and this is the actual increase in the pore water pressure, this one.

I think this we have already discussed in the previous lecture. Now how this ESP would look like, it will depend upon the soil characteristics and stress history. You will see that, this sentence is getting repeated in all the examples, this is intentional because we should not forget that ESP is essentially governed by A value and as well as the soil characteristics.

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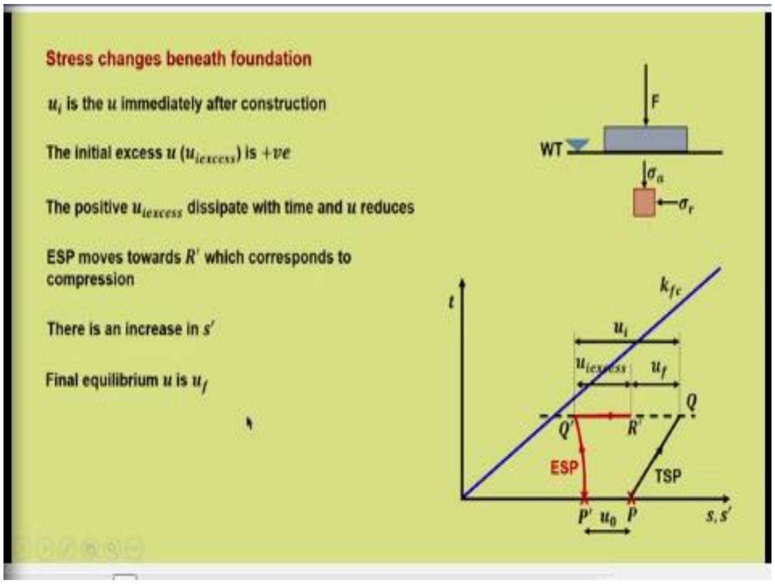

Now stress changes beneath the foundation again the remaining aspects. Let us say that u_i is the u immediately after construction. Now there are 2, 3 types of pore water pressure that we are discussing; one is the initial pore water pressure that is u_0. The other one is since it is an undrained loading at the end of construction there will be an pore water pressure that pore water pressure is initial pore water pressure that is u_i, that is immediately after construction.

So, that is what is shown here u_i. Now the initial excess pore water pressure which is denoted as u_i excess is positive because this is a case of compression. And hence we know that the excess pore water pressure that gets generated in the beginning will be always positive. The positive u_i excess dissipate with time and then u reduces. So, the total u_i comprises of this excess pore water pressure as well as the initial pore water pressure.

Now what it says is that as the time progresses we know that the positive pore water pressure has to dissipate. Now after dissipation the u starts reducing, so it will no longer be u_i, it starts reducing. So, what is the implication of this reduction in u on ESP, this ESP moves towards R dash which corresponds to compression of the soil mass. As the soil gets compressed because of dissipation of pore water pressure, it moves towards R'.

And that is in towards this direction that is given by R’. Because there is no more shear stress getting added because the foundation load has been fixed, that is the maximum that is Q’. But because of reduction in pore water pressure that gets affected in s’. So, now you can see that why this pore water pressure? That is initial power pressure at the end of construction period why it comes down?

It comes down because this much component is the excess pore water pressure that gets generated because of the foundation load. So, that gets dissipated and then the stress path is Q’ R’. And Q’ R’gives the idea about the compression that is taking place within the soil mass. So, what is this then left out that will be more or less equal to u_0 that is the final equilibrium pore water pressure?

So, there is an increase in s’, final equilibrium pore water pressure is u_f, now this is the final value that is where the effective stress path stops. So, u_f is the equilibrium pore water pressure which happens after the dissipation of excess pore water pressure.

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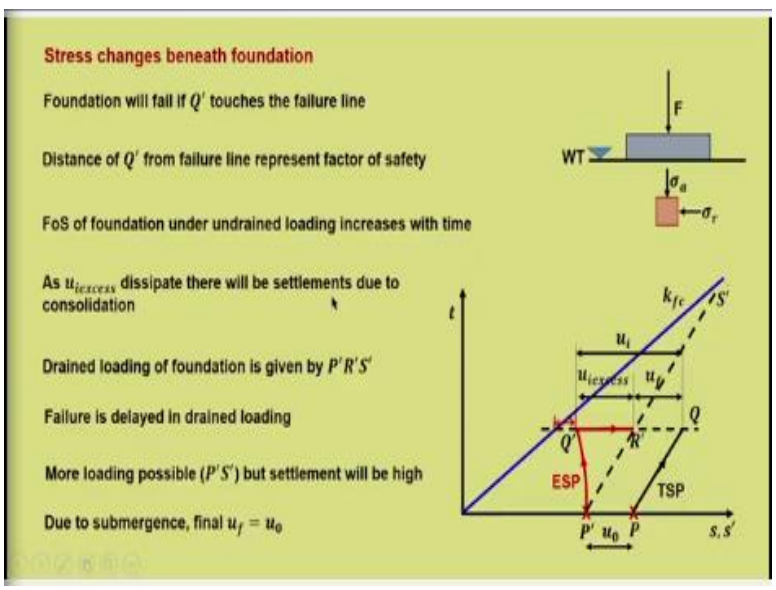

Foundation will fail; we know that if Q’ touches the failure line, what does that mean? Because up to Q’ it represents the undrained loading condition. So, if the foundation has to fail, it has to fail during this short term undrained period, why? I am talking with respect to a specific loading condition, because if Q' touches the failure line then only it is bound to fail, I am talking specifically with respect to undrained condition.

And if the foundation crosses this period like undrained condition and the pore water pressure starts dissipating you can see that the effective stress is moving right wards, that is away from the failure line, so does it fail? No, it can fail only when it touches the failure line. So, in long term condition a foundation which is subjected to compressive load and for a specific load will not fail, if it does not fail in the initial period that is during undrained condition.

But definitely it can fail under drained condition if the stress becomes more and more. So, at drained condition the slope of the effective stress path is I mean to say effective stress path and total stress path both are same, that slope is different and that will be at an inclination of 3. So, distance of Q' from the failure line, so this distance, I mean to say this distance represents the fact of safety.

That is, it gives the margin by which this foundation is safe. So, factor of safety of foundation under undrained loading increases with time as you can see here. So, this distance goes on increasing, so it is moving away and hence factor of safety increases with time. As u_i excess dissipate there will be settlements due to consolidations. Now it is moving away, why? Because it is progressively densifying and the strength is getting enhanced.

So, that is the reason why it is moving away, but what is the cost we have to pay? The cost is the excessive consolidation, because this densification happens because of the excess pore water pressure dissipation and void ratio getting reduced. Void ratio getting reduced means settlement is more, so it is not that the foundation is performing absolutely well. In certain cases it can go wrong because the settlements may increase even though it is moving away from the failure line.

The soil may not fail but foundation will undergo distress because of this settlement. So, drained loading of foundation is given by P', R', S'. Now if suppose that we have discussed about undrained loading where pore water pressure is there. Now from P' if there is a drained loading that is happening then it will follow P', R', S'. Now this is the slope which I talked about.

You can see that the margin towards the failure line is this much, that is a huge margin. So, lot of load can get added up to the soil before the actual failure takes place, but what is the cost? From here to here it will densify. Now failure is delayed in drained loading, yes fine, that is fine and that is good also the soil is not going to fail but then it is at the expense of the settlement. So, more loading possible from P' to S' but settlement will be high.

Now due to submergence, now we are considering this it to be submerged condition. Now since there is submerged condition the pore water pressure change is not going to take place. Now because of this assumption of submergence the final equilibrium pore water pressure will become equal to the initial power pressure u_0.

Now let us say that it is not submerged condition, then there is a possibility that the final pore water of pressure is not actually equal to u_0, it can be even less than that**.** And that is generally governed by in what manner the pore water pressure got dissipated, how it sieved out**.**

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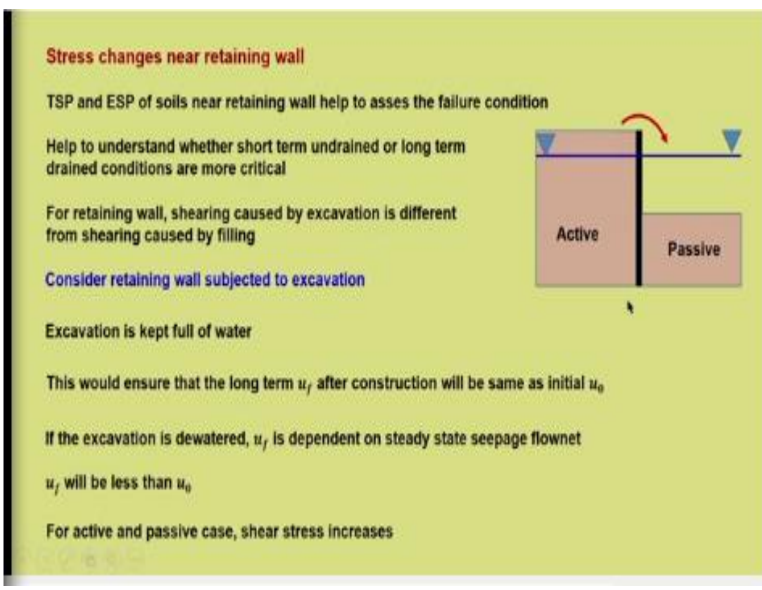

So, that is all about the condition or the stress variations that happens beneath a foundation. Now let us see another example wherein we talk about stress changes near the retaining wall. Now retaining wall all of us know, it can generate movement and because of this movement there can be failure due to active or passive condition. Please refer back to the undergraduate portion for understanding this better.

Now TSP and ESP of soils near retaining wall, it will help to assess the failure condition. Help to understand whether short term undrained or long term drained conditions are more critical. Now by discussing these stress paths in the last lecture and just the previous slide. It is very clear that there is a kind of stability is determined either under short term or at long term. Now plotting stress path helps us to understand this much better, why?

In the previous cases, in the previous lecture we have seen that with time the effective stress path moved towards the failure line. In the last example that we have seen the foundation we have seen that effective stress path moves away from the failure line after construction. So, then that determines whether it is moving towards or away. That determines whether the given structure or the given condition will be safe during short term or at long term.

Now what determines this? Essentially during undrained condition the kind of pore water pressure that gets generated determines this. It can be positive pore water pressure or it can be negative pore water pressure. Now that determines in what direction the effective stress path would move further. For retaining wall, shearing caused by excavation is different from shearing caused by filling.

Now when you say retaining wall, there are 2 possibilities, they are in one case it can get excavated and in the other case you can have progressive filling of the backfill. So, in both the cases the kind of stress path will be different. So, let us first consider retaining wall subjected to excavation. Now we have already seen an example of slope excavation, so it is more or less very similar to that.

Excavation is kept full of water, now this is what it means, to make sure that the final equilibrium pore water pressure is comparable to the initial pore water pressure u_0 So, that is what this same statement u_f, the final equilibrium value will be equal to initial u_0. If the excavation is dewatered, that is during construction of a retaining wall if there is a high ground water level; definitely the water has to be pumped out.

So, this condition what we have assumed is no longer valid when it comes to actual field implementation. So, but what is the implication of that? If the water is drained out then what happens is the pore water pressure that is the equilibrium pore water pressure it is dependent on steady state seepage flow net. We have already seen what happens if water is pumped out, so there will be seepage from higher water level to lower water level.

Now this will be governed basically by the flow net under this structure. Now this will determine what will be the equilibrium final water pressure. Now to avoid that complication for this example we are considering this water level to be unchanged, so it remains the same. So, u_f will be less than u_0, if this condition happens I mean to say the steady state seepage is happening then definitely the final part of pressure will be less than the initial pore water pressure u_0.

For active and passive cases irrespective of in what direction the retaining wall is moving that in both the cases the shear stress increase would be there, whether it is active or passive it is bound to fail at some point of time.

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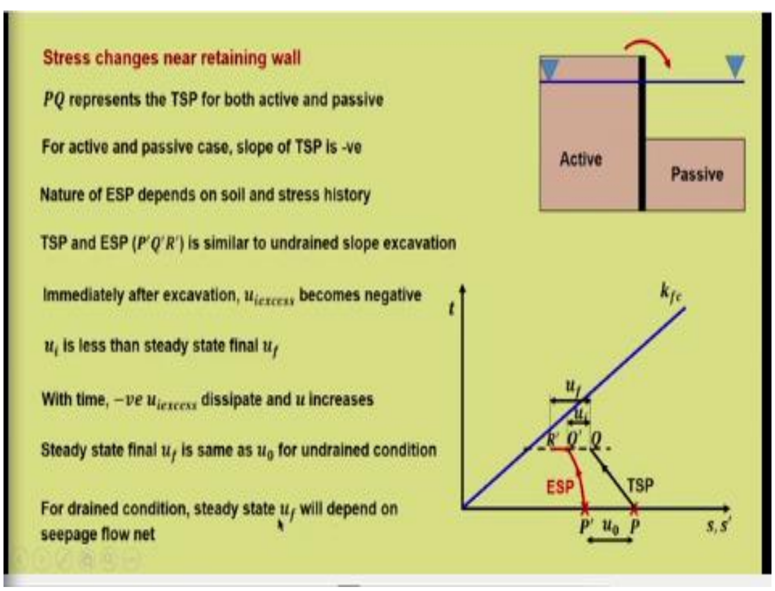

Now PQ represents the total stress path for both active and passive cases, why is it so? For active and passive case slope of TSP is negative, you can see that if you substitute for active and passive conditions, that is how $\Delta\sigma_a$ $\Delta\sigma_r$ changes. You will see that in both the cases you will get the total stress path to be negative, please verify yourself. Because this we have already explained in our previous lecture while considering one is constant the other is increasing.

So, P this is the starting point and there is an initial pore water pressure of u_0. Now this is the manner in which the total stress path changes, why? Because the total stress path the slope is negative, so that is why it is moving in this direction. The shear stress component is increasing but s' or s component is decreasing. Now nature of ESP will depend upon soil type and soil behavior and stress history, this again I am repeating.

TSP and ESP, that is ESP is represented by P', Q', R' is similar to undrained slope excavation, which I have already told. Now this is the typical response of the effective stress path where this is P', Q', R'. Now P' to Q' it represents the construction stage where Q' is at the end of construction, where there will be an initial pore water pressure of u_i, and with time the excess part dissipates and then achieves a final equilibrium value.

So, this is the point Q', so this is the initial pore water pressure at the end of construction period and this is the final pore water of pressure. Now what is happening here, immediately after excavation the excess pore water pressure because of the excavation that gets it becomes it achieves a negative value. So, the initial excess pore water pressure is negative, what was the kind of water pressure in the case of compression for foundation?

Initially it was positive, here initially it was negative, so it looks fine, since it is negative power pressure we know that it will improve the strength. But with time what will happen? This initial negative excess pore water pressure would dissipate. So, u_i is less than steady state final u_f, here you can see that, why u_f is becoming more than u_i ? Because initially the excess pore water of pressure was negative and that will dissipate.

And in the process pore water pressure has to increase from the initial u_i value. With time the negative pore water pressure excess pore water pressure dissipate and that is why u has to increase from the value of u_i to a given value. So, let u_f be the equilibrium final value that is the steady state u_f. And this steady state u_f, since we have assumed a condition of submergence will be equal to initial pore water pressure u_0. For drained condition u_f will be less than u_0, and that will depend upon the seepage flow net.

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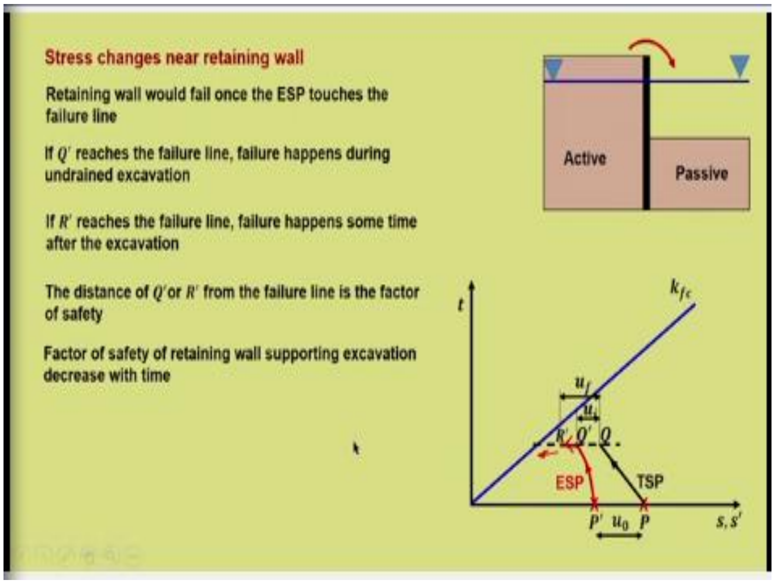

Now retaining wall for this particular case of excavation it would fail once the effective stress path touches the failure line. Now this is moving in this direction, you can see that it moves up to here and Q' to R'. Now if R', it extends towards the failure line then once it reaches the failure line it would fail. If Q' reaches the failure line, now there is another possibility that is from P' to Q', it is the construction phase that is at the end of construction.

Now it can also fail during the construction that is at the end of construction when Q' it goes and touches the failure line. So, then we say that the failure happens during undrained excavation, so it has not started dissipating, so it fails at the short term undrained condition. If R' reaches the failure line, now if this portion reaches the failure line then failure happens sometimes after the excavation that is as the negative pore water pressure dissipates.

Now why there is negative pore water pressure? Because here it is a kind of excavation that is happening and there is a release that is happening. The distance of Q' or R' from the failure line is the safety margin or the factor of safety. Now the factor of safety of retaining wall supporting excavation decreases with time. So, in the case of this particular retaining wall, which is supporting the excavation, then the factor of safety decreases with time why because effective stress path is moving towards the failure line with time.

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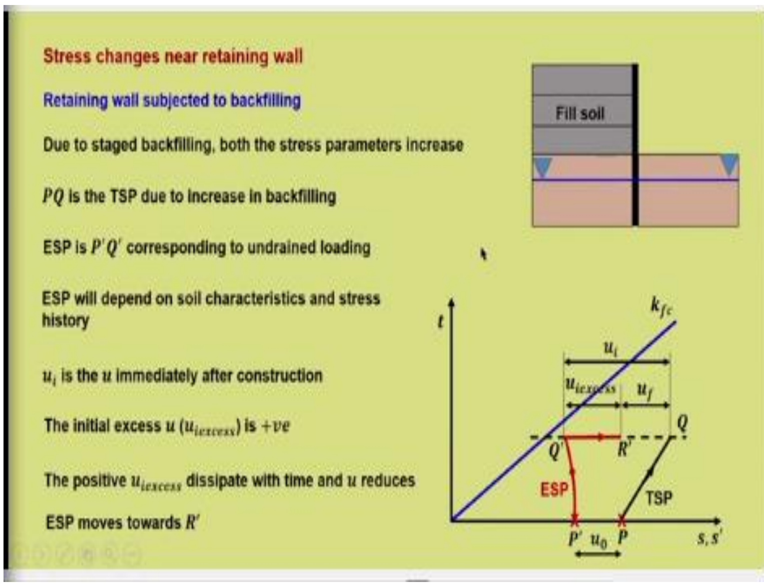

Now let us see what is the case of retaining wall subjected to backfilling or filling? Due to staged backfilling both the stress parameters increase. Now it is more like a compression, so here it is the starting and the filling takes place, so this is the fill soil. Now PQ is the total stress path due to increase in backfilling. So, now P, P' and with a difference of initial pore water pressure u_0, you can see that it increases and it was positive slope, so PQ is the total stress path.

Now ESP is given by P' Q', and it will depend upon soil characteristics and stress history. So, P' Q' is the effective stress path, u_i is the pore water pressure immediately after construction. Now in this case since it is getting loaded, it is a more like a compressive load, so the initial excess pore water pressure will be positive, so that is the difference. So, this will be positive and this positive pore water pressure dissipates with time and u reduces.

Now here it is just the opposite than the case that we discussed before, u excess which is positive when it dissipates then the u_i starts reducing. So, ESP will move away from the failure line and it moves in the direction of R'. So, you can see that it is departing away from the failure line and this is similar to the case that we discussed for foundation imparting compressive load. So, u_i excess, so this much excess pore water of pressure gets dissipated and then it reaches a final equilibrium pore water pressure which corresponds to this value.

So, that u_f is the final equilibrium pore water pressure which is equal to u_0, because we have considered a submergence condition.

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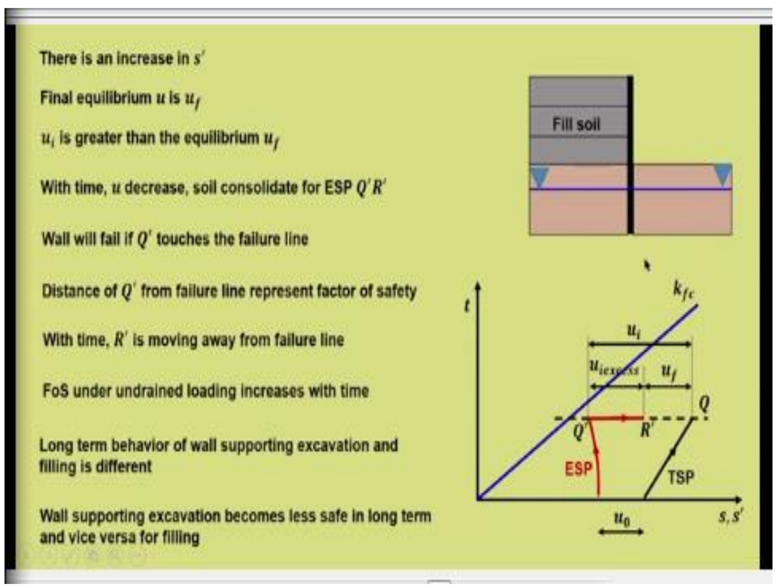

There is an increase in s', s it is increasing, so final equilibrium is u pore water pressure is u_f, u_i you can see that it is greater than u_f because it is excess pore water pressure is positive. With time u decrease, soil consolidate for ESP Q' R', so from Q' to R' definitely the soil will undergo consolidation under this load of the fill soil. Wall will fail if Q' touches the failure line.

So, definitely in this particular case where we have backfilling we know that the soil will fail in when it is under undrained condition, that is immediately after the construction only under undrained condition. With time as the pore water pressure dissipates it moves away, so it is not going to fail in long term. So, distance of Q' from the failure line represents the factor of safety, with time R' is moving away from the failure line, so factor of safety increases with time.

So, long term behavior of wall supporting excavation and filling these are different. So, wall supporting excavation it becomes less safe in long term and vice versa for filling, so that is what we have seen. In this case factor of safety increases, so safety is increasing which is reverse in the case of excavation.

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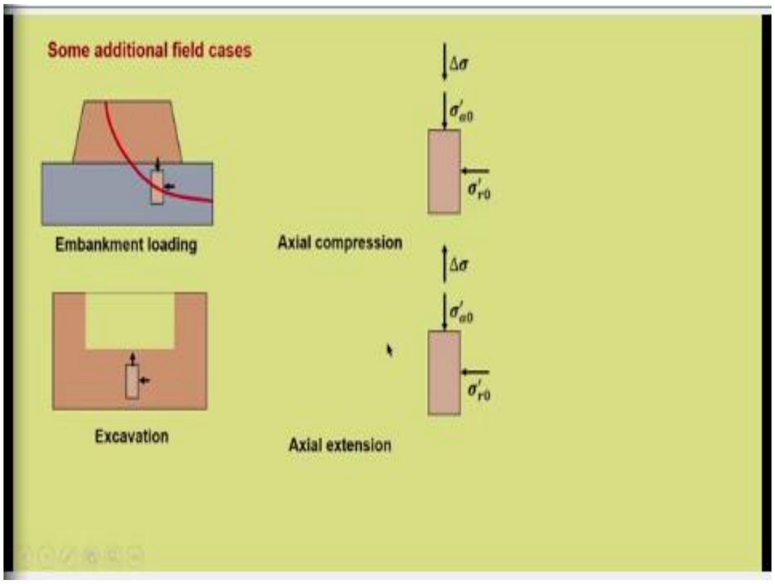

So, these are some of the additional cases which we will see in the field, there is an embankment load which is acting on the soil. And there is a possibility of slip failure that can take place; it is a typical case of compression. So, it is an axial compression, this is the initial stress σ'_{a0} and σ'_{r0} before the construction of embankment. And when the embankment is constructed, we have an additional $\Delta\sigma$ in the axial direction.

So, this is the case of axial compression and we have discussed how the total stress path effective stress path would look like in the case of axial compression. So, these are cases which we have already seen because we have seen if σ_r is constant σ_a increases, those type of cases we have already discussed, we are just correlating these field cases to those cases. Now in the case of excavation what is happening?

You can see that it the actual stress is getting released, so in this, this is the initial condition when the axial stress is getting released. So, that results in axial extension, so this is another case which we have already seen. So, I am not going into the details of stress path, because that will be then repetition.

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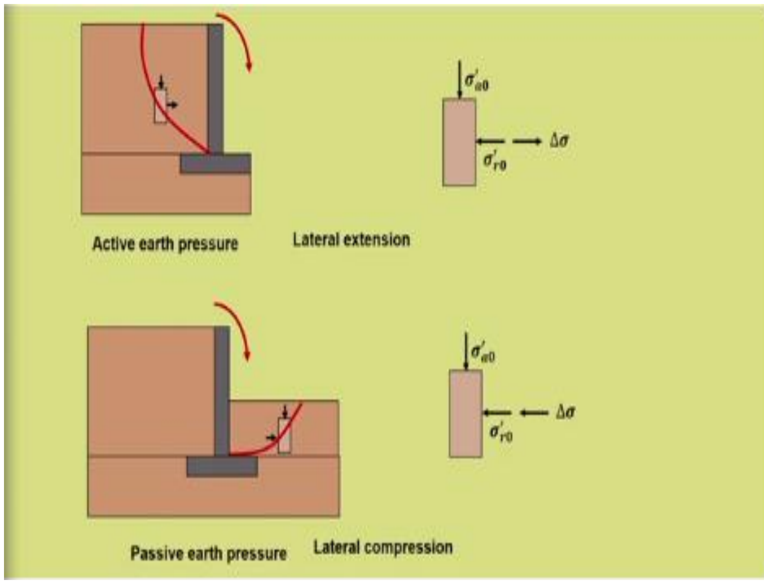

Now this is the retaining wall which undergoes an active condition and active failure. So, in this particular case is active pressure which comes into play. And here we can see that because of the excavation there is a release in the lateral stress that is happening. So, this is the initial condition under it is own weight and because of the excavation there is a release that is happening in radially. So, this is a case of lateral extension that is it is moving in this direction.

Now just the reverse of it that is a typical case of passive earth pressure that is when the retaining wall is rotating this mass will undergo a passive condition. So, hence what is happening? There is a more compressive condition which is getting added up, that is lateral stress is increasing**,** so that is the case of lateral compression. So, these are some of the cases, field cases which we have already completed. Now let us try to summarize what we have learnt in this particular lecture.

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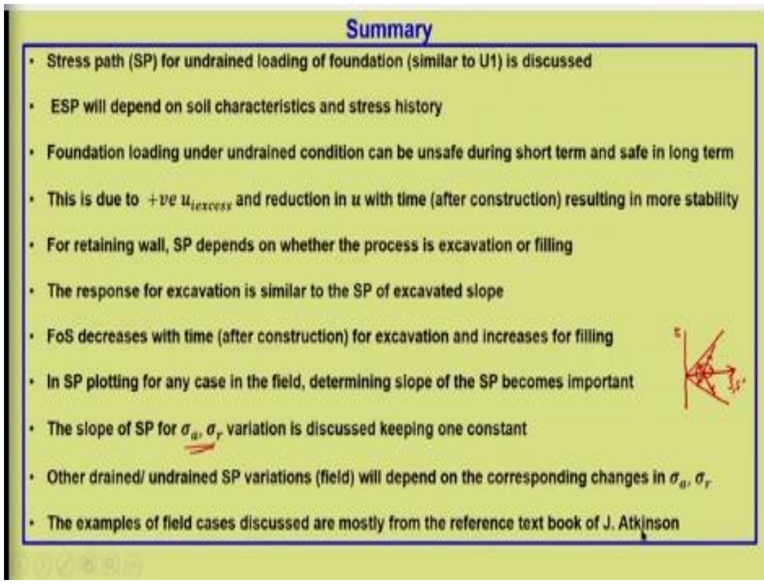

The stress path for undrained loading of foundation which is similar to U1 is discussed. Effective stress path will depend on soil characteristics and stress history, which we have already seen in couple of examples before. Foundation loading under undrained condition can be unsafe during short term and it becomes safe in long term. We have very clearly seen this how the stress path departs away from the failure line.

Now this is basically due to the positive pore water pressure that gets developed. And reduction in u with time that is after construction and that results in more stability. But I would like to underline here it is progressively densifying and hence becoming more stable in terms of stress path. But what is happening to the deformation or the settlement response of the foundation? So, this densification is at the expense of settlement, so we need to also look into the serviceability part of the foundation.

For retaining wall, stress path depends on whether the process is excavation or filling the response is totally different in both the cases. The response for excavation is similar to the stress path of excavated slope. Factor of safety decreases with time, that is after construction for excavation and it increases for filling. In stress path plotting for any case in the field determining the slope of the stress path becomes important, now what does all these means?

We need to identify or we need to determine the correct slope of stress path. And for that what we have done the slope of stress path for σ_a σ_r variation is discussed keeping one constant. So, we have discussed the very critical cases, what are they? We first kept σ_r constant and σ_a increased, and all other similar there are 4 cases, now accordingly what we have got?

We have got if this is the failure line, we have got a response something like this, so we have 4 stress path. Now in the field depending upon how σ_a and σ_r varies? The slope of the stress path would change and that can change in any direction in this 360 degree. So, what we have discussed is a critical case where one is constant the other one is changing, this we have done for simplicity.

But it can so happen that σ_a and σ_r changes in a particular manner, and for that we will have different slope of the stress path**.** And this is relevant for both drained as well as undrained stress paths. So, other drained and undrained stress path variations in the field, it will depend on the corresponding changes in σ_a and σ_r. So, depending upon this variation the slope of the stress path would change.

It can be in this or it can be in this direction, so the actual magnitude of the changes would determine the stress path slope. So, whenever we get a field problem what we need to understand is, how the stress path is moving depending upon the relative changes in σ_a and σ_r. Now most of the examples that the cases in the field that we have discussed, it is mostly from the reference textbook of Atkinson.

So, you can refer to this textbook if you get access to it because most of these examples have been taken from that and also from the book by Parry. So, you may refer to it for further reading. So, that is all for this lecture, so we have completed the stress path for various field cases. Now in the next lecture we will see some worked out examples related to stress path, thank you.