Geology and Soil Mechanics
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Lecture - 25
In-situ Stresses - B

Welcome back. So, in the last lecture we have seen the concept of effective stress, total stress, and pore water pressure under static condition as well as under seepage when the seepage is occurring right. So, under that situation also we have discussed or we have derived the different stress components and we have seen that there may be a possibility okay when you get the limiting condition when the effective stress is becoming simply zero and for that you will be getting some critical hydraulic gradient right.

So, you I mean for any kind of hydraulic structure or hydraulic design you should avoid this critical hydraulic gradient otherwise what will happen, the soil will lose its effective strength or the effective stress or the actual say grain to grain contacts and then basically you will be having the problem of boiling right or the quick condition. So, now we will be seeing that how we can find out the seepage force.

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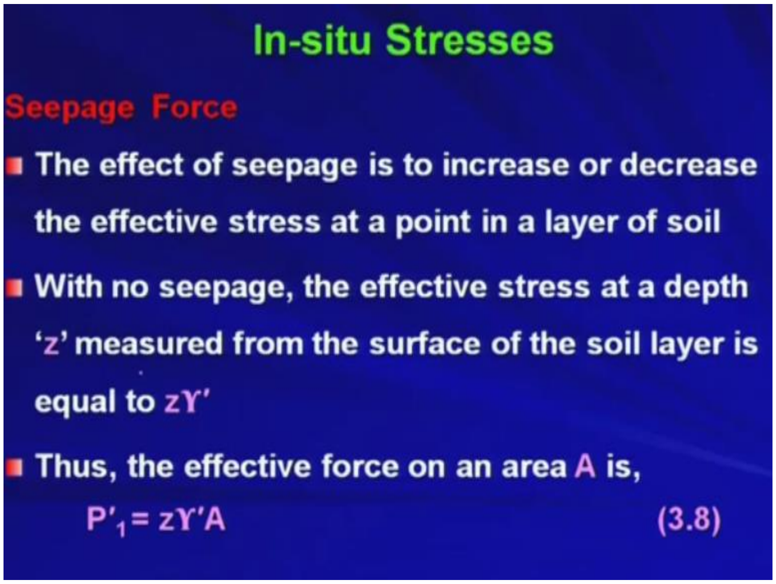

Now the effect of seepage is to increase or decrease the effective stress at a point in a layer of soil as already we have seen that if you consider the upward flow the effective stress was decreasing. If you consider the downward flow effective stress will be increasing. So, based on the seepage direction basically you will be getting enhancement or reduction in the effective stress. Now with no seepage that means under static condition the effective stress at a depth z measured from the surface of the soil layer is z into gamma prime.

It is as simple as that, already we have seen in the last lecture that the effective stress at any depth z under static condition say there are no seepage is happening really. So, in that situation your effective stress will be z into gamma prime. Thus, the effective force on an area on any cross sectional area say A so the P 1 prime will be nothing but z into gamma prime that is the effective stress multiplied by the area on which the effective stress is acting. So, that will give me the effective force under no seepage condition.

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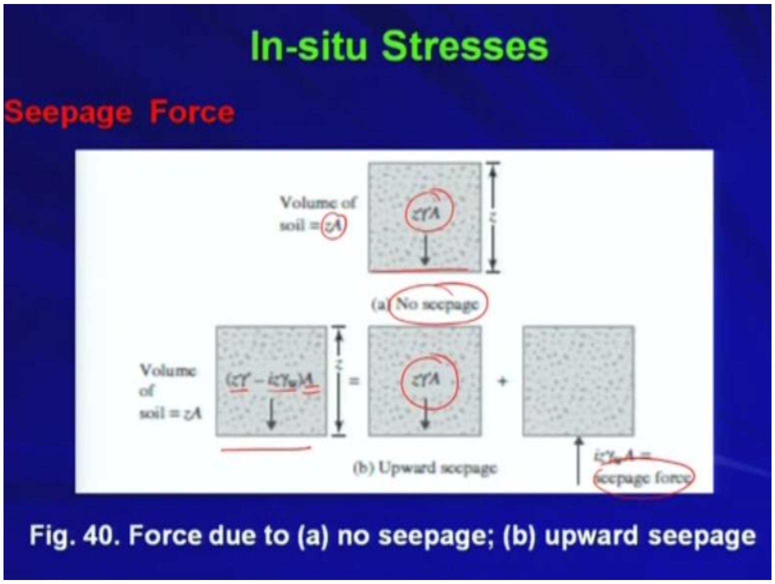

Fig. 40. Force due to (a) no seepage; (b) upward seepage

So, that can be seen from this figure that can be elaborated or I mean say explained through this figure say if you do not have any seepage right so under static condition your effective stress on any area say on any area so total volume of the soil is say z into A so on any area, A is nothing but this is the force happening on this area so that is z into gamma prime into A right. Now if you consider the upward seepage at that time what is happening? Effective stress is getting reduced by some amount due to the seepage force right.

So, that is nothing but z into gamma prime into A - iz into gamma w into A. So, that is the seepage force which is causing the reduction in the effective force right or the actual force. So, that can be divided or that can be separated or that can be decomposed basically in 2, 2 components one is the force when no seepage was happening so z into gamma prime into A plus some upward force which is caused by the seepage force that is nothing but iz into gamma w into

A and then if you add them together algebraically then you will be actually getting this condition right.

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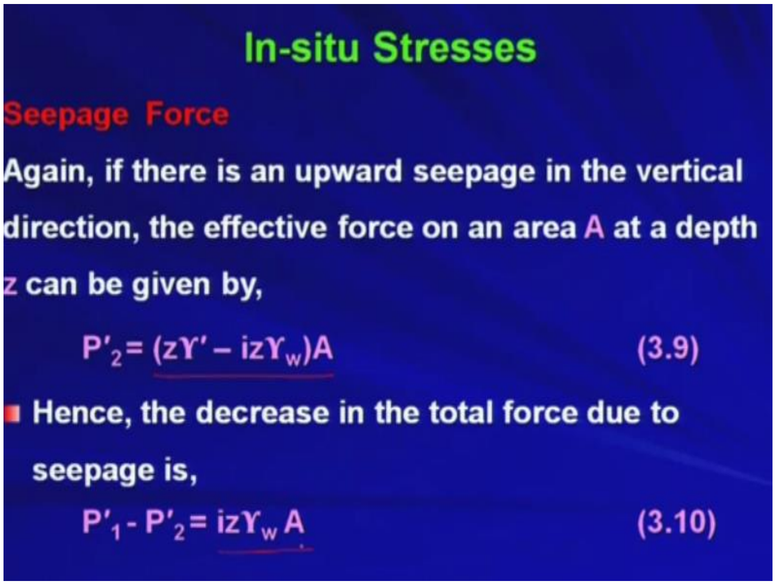

So, basically if there is an upward seepage in the vertical direction, the effective force on an area A at a depth z can be given by this, already we have seen it. Just now we have explained that figure and we have seen it right. Therefore, the decrease in the total force due to seepage is P 1 prime - P 2 prime. So, P 1 prime was the force under no seepage condition under static condition and P 2 prime is the force when the seepage is really happening, really occurring in the upward direction. So, P 1 prime - P 2 prime is nothing but iz into gamma w into A. So, this much is the I mean decrease, this much is the force which is getting deducted from the actual effective force right.

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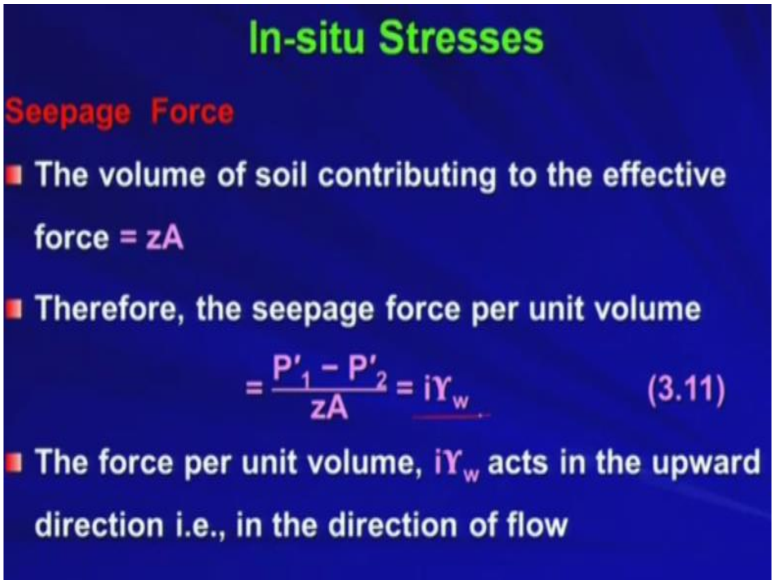

So, the volume of soil contributing to the effective force is z into A because z is the depth and A is the cross-sectional area so that much of volume is participating or contributing to this effective force. Therefore, the seepage force per unit volume will be P 1 prime - P 2 prime by z into A that is the volume. So, that comes as i into gamma w. So, that is the force, that is the seepage force per unit volume of the soil.

The force per unit volume igamma w acts in the upward direction that is in the direction of flow okay. So, whatever it may be the direction okay, depending on the direction of flow your force seepage I mean seepage force per unit volume will be i into gamma w. Now whether it will be I mean this thing additive or I mean it will cause the reduction or cause the enhancement so that depends on the flow direction.

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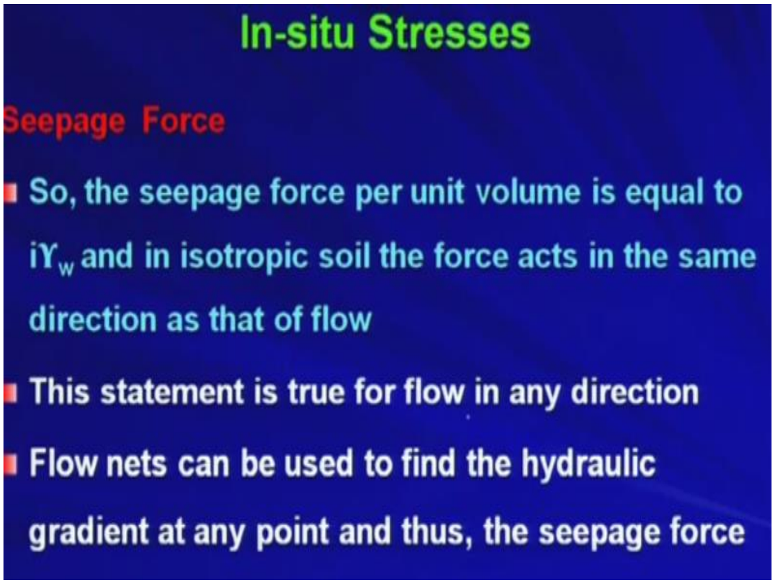

So, the seepage force per unit volume is equal to i gamma w and in isotropic soil the force acts in the same direction as that of flow, already we have seen it. This statement is true for flow in any direction right. Flow nets can be used to find the hydraulic gradient at any point and thus the seepage force. So, that means basically what you are getting you know how to I mean already we have seen that you can construct the flow net okay by using equipotential lines and flow lines and then from each and every point you can find out the hydraulic gradient.

Once you know the hydraulic gradient then basically you multiply the hydraulic gradient with gamma w that will give you the seepage force at that particular location or that particular point. So, if you know the seepage force then at each and every point you can find if you know the total stress you can find out the effective stress under seepage condition okay.

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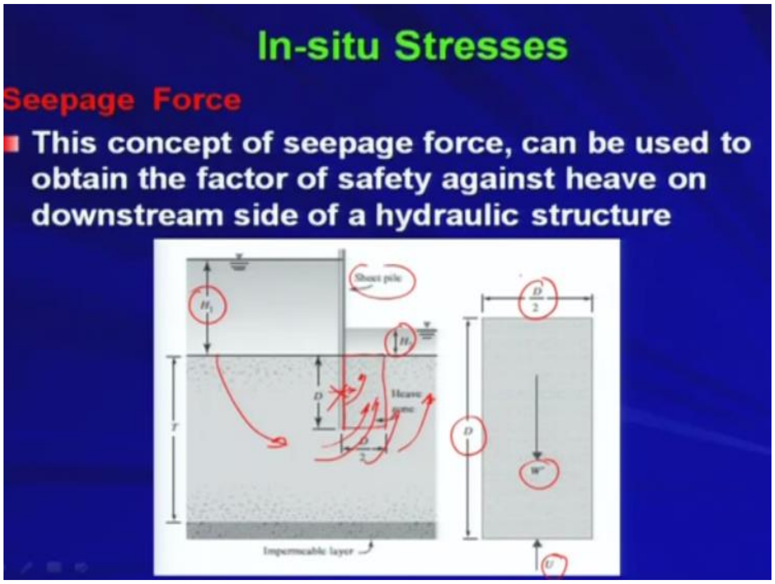

This concept of seepage force can be used to obtain the factor of safety against heave okay on downstream side of a hydraulic structure. Now what is heave? Let us see that thing and let us find out how to find out that kind of factor of safety. So, basically what generally happens? Suppose you have the sheet pile. So, this is your sheet pile say which is protecting the water from the upstream side to downstream side. Say this is the upstream side water depth. This is the downstream side water depth. Now water will be allowed to flow in this direction and it will go in this direction right. So, something like that okay.

So, I mean the water will not flow across, this is not possible because you have the sheet pile but you have the flow like this I mean you know from your flow net right. Now you may have the situation when I mean this is this soil which is very near to the sheet plié, this block of soil, basically heaving will occur at that location okay. That rectangular element can be taken out and can be enlarged blown up and it can be seen that say d is the total depth of that block which is nothing but the depth of embedment of the sheet pile and then w prime is the weight of the heave zone that is actually heave zone.

Now why it is heave zone? We will come to that point later on. So, w prime is the weight of the heave zone and capital U is the force, seepage force is acting in that direction because the flow is happening in the upward direction so the seepage force will be also acting in the upward direction rather not seepage force this is basically your pore water pressure or the water pressure or the water force okay. So, now D by 2 is basically the width of the heave zone and that was proposed by Terzaghi.

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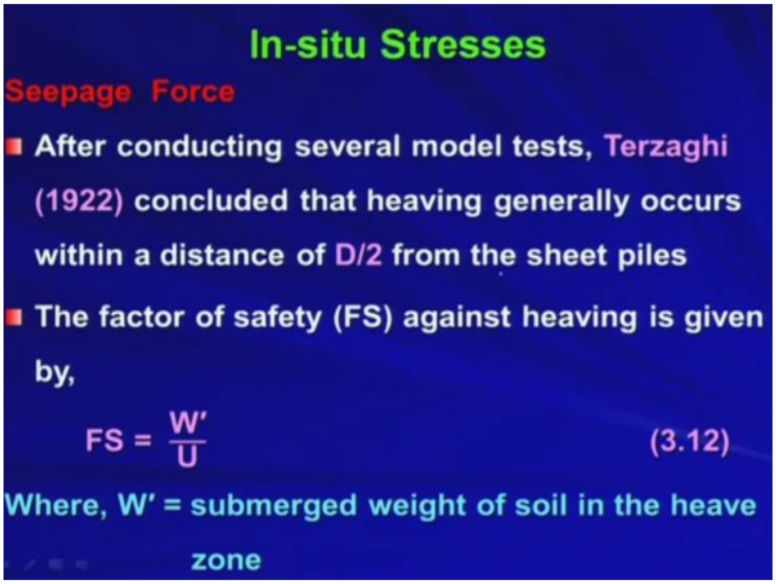

So, after conducting several model tests Terzaghi in 1922 concluded that the heaving generally occurs within a distance of D by 2 as I told you from the sheet piles okay. Now the factor of safety against heaving is given by W prime by U. Now why it is like that? W prime is the weight of heaving zone and U is the upward force acting in the heaving zone. Now if W prime is getting equal to U right that means it is win-win situation that means whatever weight of the heave zone you have and the same amount of upward force the heaving zone is experiencing.

Now if you increase the I mean upward force little bit then the material will flow or will move in the upward direction right. That is that is the meaning of that. So, your factor of safety should be more than 1 so that your weight of the material okay weight of the heaving zone should be more than the upward force which is acting on the heaving zone. So, W prime is nothing but the submerged weight of soil in the heave zone.

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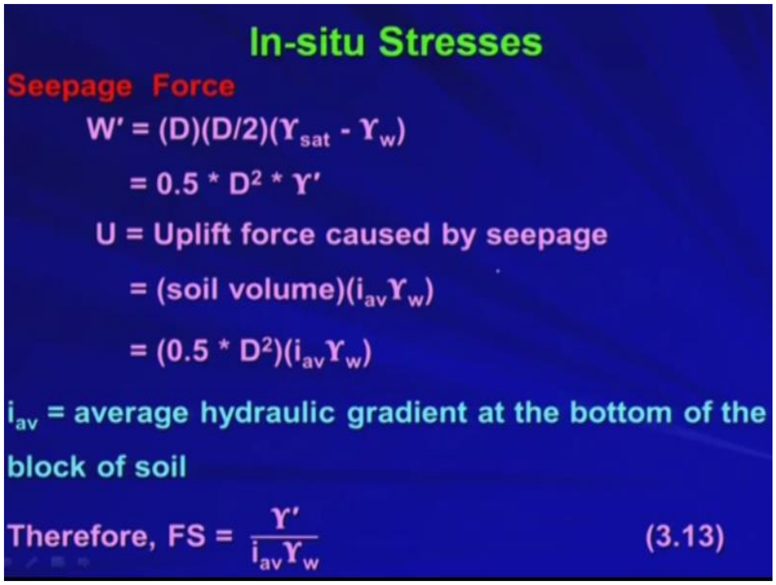

Now W prime is given by D into D by 2 into gamma saturated - gamma w that is nothing but the gamma submerged. So, 0.5 D square gamma prime is nothing but the weight of the heaving zone okay whereas the U that is the uplift force caused by seepage right so that is equal to soil volume multiplied by the seepage force. Already we have seen in the just I mean previous to that, that i into gamma w is nothing but the nothing but the seepage force.

So, that if you multiply that thing with the soil volume you will be getting the total force. So, this uplift force is nothing but the soil volume into i average that is the average hydraulic gradient at the bottom of the block of soil that is the heave zone into gamma w right. So, that is that comes to 0.5 D square into i av into gamma w. Therefore, factor of safety is nothing but w prime by U which gives me gamma prime by i av into gamma w okay so that is your factor of safety.

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Now coming to a new concept, so this we have seen, that heaving zone basically you will be having some heave right. So, now basically there will be always some tendency when the weight of the heaving zone will be lesser than the upward or the uplift force generated by seepage. Now under that situation what will happen? Soil will try to move in the upward direction.

Now if you want to arrest that condition you need to put some filter and the filter will allow the water to pass through but it will not allow the soil particles to move inside or pass through the filter material right. So, that is the actual say function of the filter. Now we are going to discuss about that filter condition.

In practice, a minimum factor safety of about 4 to 5 is required for the safety of the structure in the heaving zone right whatever factor safety you just calculated so minimum 4 to 5 factor safety is required in the practice okay for any kind of structure, hydraulic structure. Now one way to increase factor of safety against heave is to use a filter in the downstream side. Now we will see that how we can find out or how we can get extra factor of safety.

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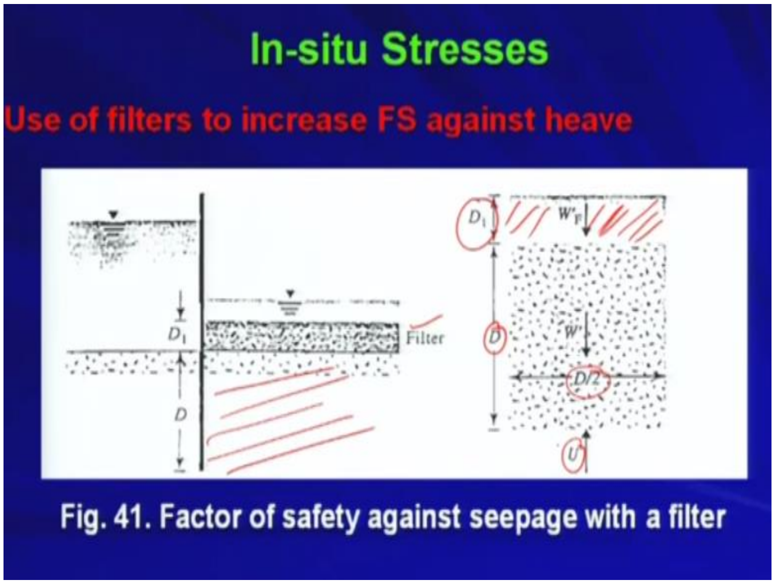

Now this is a typical picture which will show the placement, also the filter details right. So, suppose this is your heaving zone okay. So, this is your heaving zone so this is your heaving zone okay. On top of that you are putting the filter okay. Now what exactly you are getting? So, you just take out that thing so as we have seen that the width of the heaving zone is D by 2 and depth of heaving zone is D right as proposed by Terzaghi. Now we are putting some filter material, so this is your filter material on top of that say of depth D 1 and the weight of the filter bed is W F prime and weight of the heaving zone is W prime and this is the upward seepage force acting on this whole assembly.

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Now a filter, what is a filter basically. As I told you, a filter is a granular material with openings small enough to prevent the movement of the soil particles upon which it is placed and at the same time it is previous is pervious enough to offer little resistance to seepage through it. So, that means it will allow the water to pass through but it will not allow the soil grains to pass through or pass across the material okay.

So, that is the function of the filter. Now the submerged weight of the soil as well as filter in the heave zone is W prime + W F prime, already we have seen is W prime is the weight of the heave zone and the W F prime is nothing but the weight of the filter bed.

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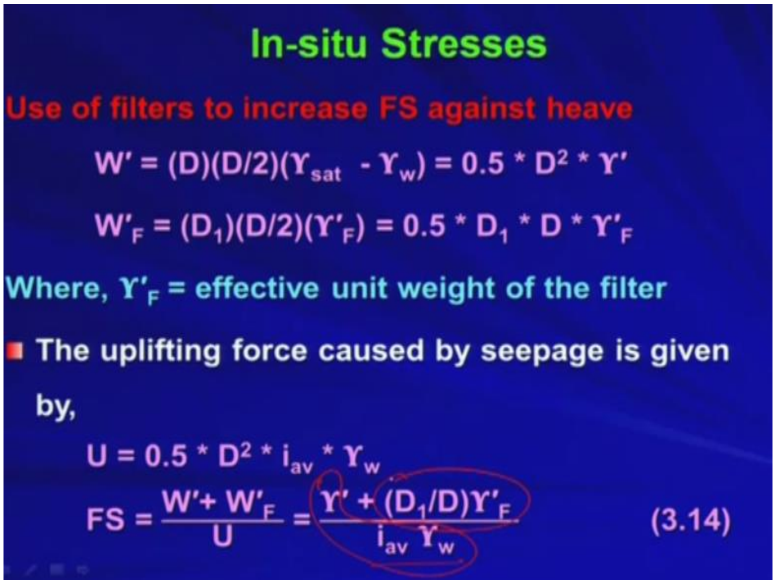

So, W prime can be calculated like that D into D by 2 that is the total volume okay because we are considering the unit length along the normal to the board or normal to the plane okay. So, D into D by 2 into gamma sat - gamma w that is gamma submerged so 0.5 D square gamma prime is your W prime. Already we have calculated that thing previously. Now W F prime is nothing but the weight of the filter bed so that is the volume of the filter bed is D 1 into 0.5 D into 1 of course.

So, that comes to the normal to the plane so into gamma F prime. So, gamma F prime is nothing but the effective unit weight of the filter okay. So, that comes to 0.5 into D 1 into D into gamma F prime. Now the uplifting force caused by the seepage is given by the same already we have seen 0.5 gamma 0.5 D square i av into gamma w. Therefore, factor of safety will be nothing but

W prime + W F prime divided by U which comes to gamma prime + D by D D 1 by D into gamma F prime by i av into gamma w.

Now in if you recall without the filter material this was your expression of factor of safety. Now this is the additional part which you are getting due to the use of your filter. So, that means your numerator of the factor of safety is getting enhanced by application of filter which will eventually cause or which eventually increase the factor of safety. So, in that way basically you can use filter to increase or to enhance the factor of safety.

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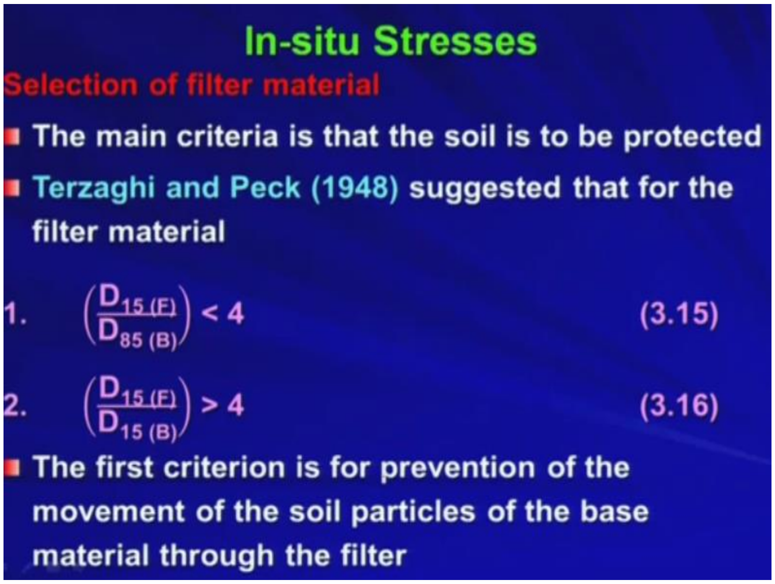

Now the selection of filter material. So, basically how you can select the filter material okay. So, the main criteria is that the soil is to be protected. So, basically the if the heaving zone is getting instable so still the soil particles cannot move through the filter bed okay, water can pass through. So, that is the main criteria. So, to satisfy that criteria Terzaghi and Peck in 1948 suggested that for the filter material D 15 of filter I hope that you still remember what is D 15 and what is D 85 those things, already we have discussed that thing.

So, D 15 of filter by D 85 of base material should be less than 4. Base material means the heave zone material or the soil in the heave zone and the second criteria is that D 15 filter divided by D 15 base material should be greater than 4 okay. So, these 2 ratios must be satisfied. The first criteria if you see is for prevention of movement of the soil particles of the base material through the filter.

Now we will see we will establish the grain size distribution probable grain size distribution curve okay by which I mean to for the filter material because filter material you are selecting right. you are selecting. You have the soil deposit the heave zone and all those things. That is not in your hand right. That is the natural deposit. But the filter material you can select okay and which will satisfy these 2 criteria and based on that you select the grain size distribution for the filter material and ultimately you can put that filter to serve the purpose. Now let us see how we can establish that.

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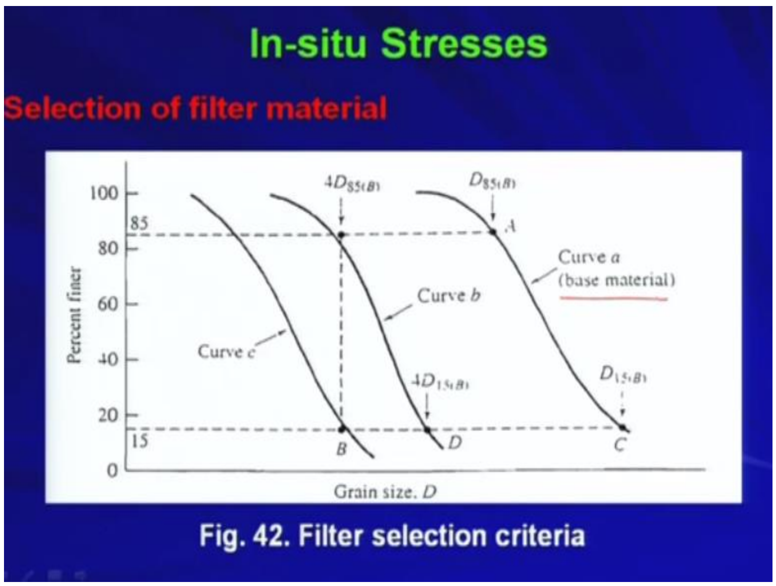

Now this is the filter selection criteria. We will see that one by one. So, curve a is basically for the base material that means that is the grain size distribution for the heave zone material and curve b and curve c we can establish by following some steps. So, we will come to that point.

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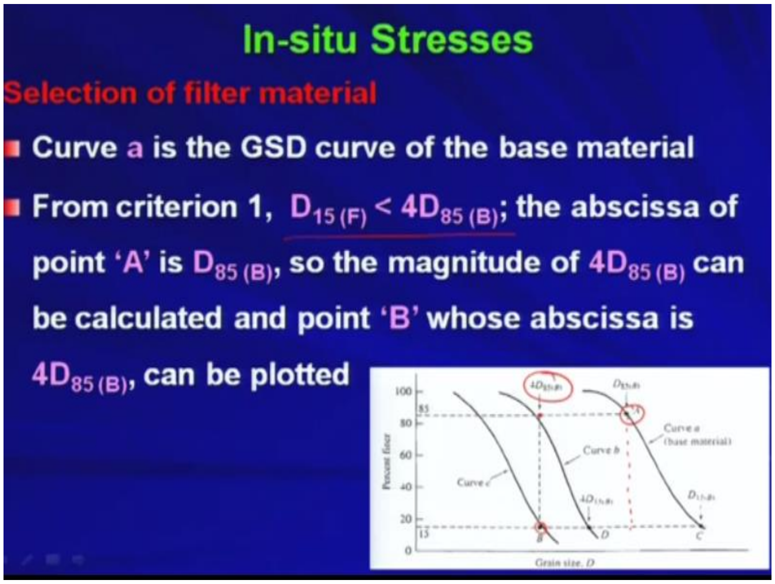

Now curve a is the grain size distribution curve for the base material as already we have discussed okay. Now from criterion 1, what is criterion 1? D 15 of filter material should be less than 4 times of D 85 of the base material. So, that was your criterion 1 okay agreed? So, now the abscissa of point A, the abscissa of point A okay is D 85 agreed?

This is the D 85 of the base material. So, the magnitude of 4 times D 85 base material can be calculated and point B capital B whose abscissa is 4 times of D 85 B can be plotted. So, this point B okay this is the point which is 4 times of D 85 base material and we are we can locate one point B okay which will be corresponding to 4 times D 85 whose abscissa is 4 times of D 85 B okay.

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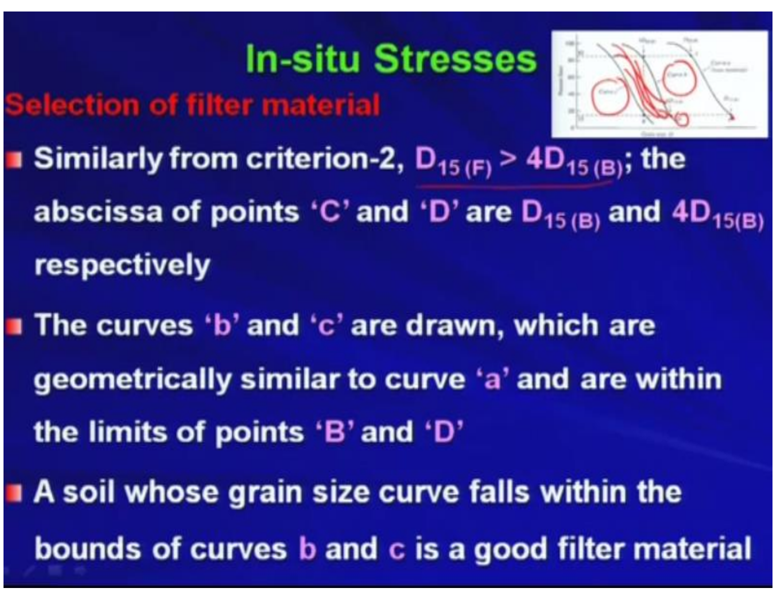

Now similarly from criterion 2, the criterion 2 says D 15 of filter should be greater than 4 times of D 15 of base material. So, the abscissa of point C and D so abscissa of point C and D so D is here okay and C, C is here okay are D 15 B and 4 times of D 15 B respectively. So, because point A and C they are known from the grain size distribution of the base material. That means the material which is lying in the heave zone right.

So, from A we can get point B which is nothing but 4 times of D 80 D 85 of base material. Similarly, from point C we can get point D which is nothing but 4 times of D 15 B right. So, we can establish 2 points B and D by following I mean 4 times rule. Now the curves small b and small c are drawn okay which are geometrically similar same as the base material or the grain size distribution for the base material that is curve a and are within the limits of points B and D okay.

So, we can obtain curve C and curve B which will be within the point capital B and capital D which has been established okay. Now a soil whose grain size curve falls within the bounds of curves b and c is a good filter material. Now any grain size curve which is coming within this zone or within this range basically that will serve my purpose as filter material. Now if you see if you get any curve in between, all those curves will satisfy those 2 criterion criteria which had been proposed by Terzaghi and Peck right.

Okay, so I will stop here today. So, in the next class we will take the capillary rise and other issues okay which will be based on the seepage criteria and then we will conclude this chapter and then we will take some numerical problems. Thank you very much.