Advanced Foundation Engineering
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Lecture - 38
Soil - Foundation Interaction (Contd.)

In the last few classes I have discussed about what will be the expression of shear force, settlement bending moment, deflection for infinite beam, then semi-infinite beam. Now today we will discuss initial part about the finite beam, what be the expression, how to solve those expressions. Then we will discuss some field application of this for the structure introduction or soil foundation introduction theories that I have discussed. Then first we will go for that how that beams on semi-finite beam.

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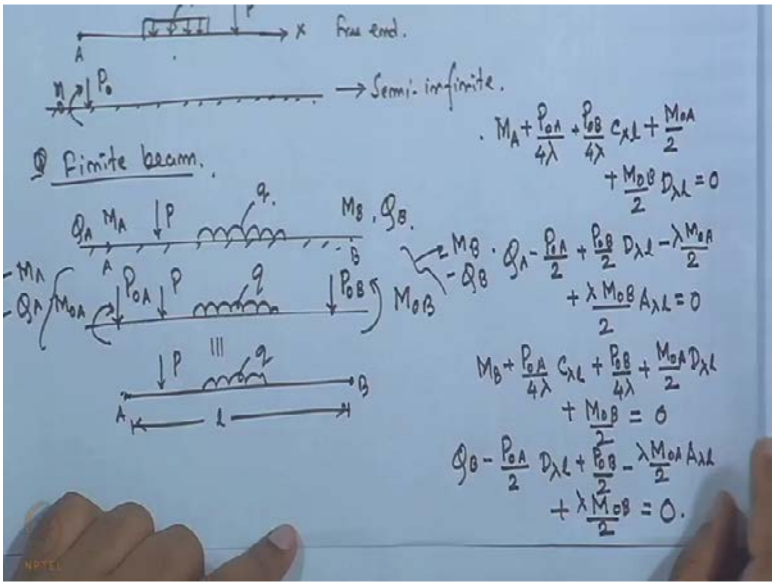

So, if beam it is a finite length**;** so in the semi-infinite beam that I have discussed that suppose this is end A, which is the starting point and this end X. So, beam is extended in one direction only. So, there the solution technique was that; so suppose we are applying any udl or any concentrated load there and because of these concentrated load and udl, there would be a moment and shear force will generate at point A.

So, now to make this point; so, if it is a say free end, then we consider one infinite beam and then we apply a moment and a shear force M 0 and P 0 such that it will produce a minus M G M A and minus Q A shear force and minus M A bending moment at this point. Because at this A point, because of this udl and p, there will be a M A moment and Q A shear force will develop. Now to make this point as an infinite beam, then we can apply this moment P 0, moment M 0, and load P 0, such that it will produce moment minus M A and minus Q A shear force, so that the net moment and net shear force of this infinite beam at this point A is zero; such that we can make it is a equivalent to a semi-infinite beam and then we can derive the expression.

Those things I have explained in the last class; we derived those expression. Then from this expression, we can calculate what would be the amount of the P 0 and M 0 we have to apply, so that the net moment and net shear force will be at point p will be zero. So then we will get, we can then convert this infinite beam to a semi-infinite beam with the net moment in shear force zero at this point p and because it is a free end beam. So, that was for the semi-infinite beam. Now, if it is an infinite beam. So, suppose you have an infinite beam and then we have to apply basically two forces and two moments; one is at for the semi-infinite beam, next for the finite beam.

So we will consider this infinite beam, then we will apply; then because of this loading and the shear force here p and udl q here will be a moment M A and Q A will develop. So, M at this point A and this is B. These are the 2 points of this finite beam and then now we convert; this is infinite beam and then the moment M A and Q A. Similarly moment M B and shear force Q B will develop at point A and B respectively. So, at point A shear force Q A and moment M A. Now we convert it to and then to avoid this thing, what we have to do for this finite beam.

So, you have to apply a moment M 0 at A and force P 0 at A; similarly force P 0 at B and moment M 0 at B; such that it will produce. So, this will produce minus M B and minus Q B and this will produce minus M A and minus Q A. So, in this; so that means this, as we know that P 0 M 0 and P 0 B M 0 B or P 0 A M 0 A, these are the end conditioning force. So, that must produce these two moments and two shear forces. So, such that ultimately this can be converted into a finite beam of length l with same force q is applied and p applied at any point on this beam.

Now we have to make sure then, once you do this exercise like the semi-infinite beam, then we can derive this expression for the finite beam also. So, this expression is M A plus similar to the semi-infinite beam that I have already derived; so, similar to semi-infinite beam. So, for the finite beam also we can derive these expression that is M A. Similar way P 0 A by 4 lambda plus P 0 B by four lambda c lambda l; it is a length of the beam plus M 0 A by 2 plus M 0 B by 2 D lambda l, that is equal to 0. So, this is the expression, one expression.

Then the next expression that we will get, this is one expression. Another expression Q A minus P 0 A divided by 2 plus P 0 B divided by 2 D lambda l minus lambda M 0 A divided by 2 plus lambda M 0 B divided by 2 A lambda l; that is also equal to 0. Now for the third expression in terms of M B; also M B plus p 0 A divided by 4 lambda c lambda l plus P 0 B divided by 4 lambda plus M 0 A divided by 2 D lambda l plus M 0 B divided by 2 equal to 0. And the fourth expression that will be Q B minus P 0 A divided by 2 D lambda l plus P 0 B divided by 2 minus lambda M 0 A divided by 2 A lambda l plus lambda M 0 B divided by 2; that is equal to 0. So, we have these four expressions.

So from here, from these four expressions we have to determine four unknowns that is P A 0, M 0 A, P 0 B, M 0 B; so, P 0 A, M 0 A, P 0 B M 0 B. So, these four unknowns we have to determine such that this amount of load or moment we have to apply these two ends, so that we will get a finite length condition. So, now how to solve this four expressions? Now to solve this expressions, we have to use two bound condition at least for example, that if it is a hinged beams. So, hinged beam with finite length. So, one boundary condition will be deflection at both end is zero; another moment at both end is also zero. So, similar to other end condition also we will get boundary condition. So, these boundary conditions we have to apply here. So, that is y equal to 0 M equal to 0.

Another thing is that apart from these things, we have to; suppose we have two loading condition that we have this type of loading condition; this is hinged beam both end. So, one boundary condition is y equal to 0; another boundary condition is moment at both end are also 0. So, in this condition if we apply p, then we can convert this thing into two parts; one is symmetric loading. Suppose this is p by 2, similarly from the same distance from this side that is also p by 2.

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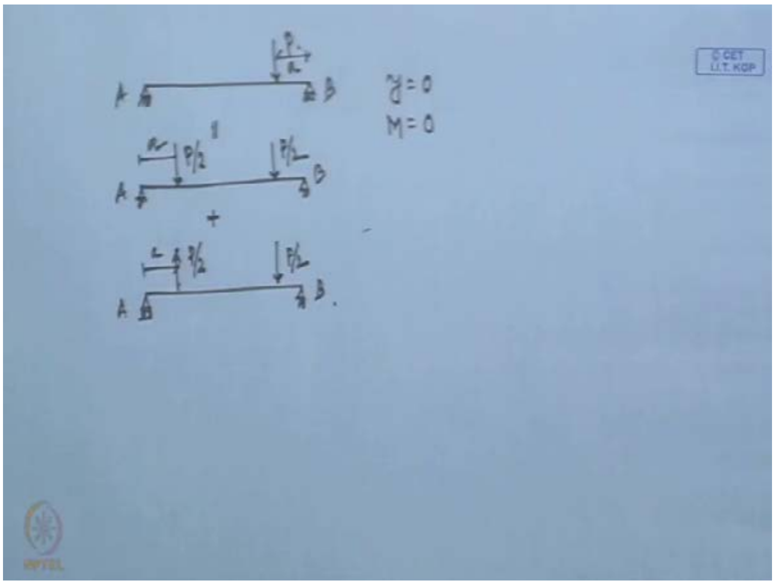

So, this is at a distance some a. So this all be also a, and this will be also a. So, that is symmetric. Then plus antisymmetric behavior also that is here p by 2 and here it is direction is opposite p by 2. So, this is the distance is same. So ultimately, this is symmetric condition, we can get the expression. This is symmetric condition p by 2, p by 2; both are acting downwards to the same distance from this edge or end condition A and B. Another one we will get the antisymmetric loading condition; this p by 2 acting downward direction, p by 2 minus acting on the upward direction. So, net force is zero at this point and this is p which is the original force.

So, you have to apply this loading condition; then we can and as well as you have to apply these boundary condition and then we derive this expressions. So, this portion also, this symmetric condition also we will get moment and the shear force expression and this antisymmetric condition also we will get moment and shear force. Then the net expression we will get if we add this two things. So, form the net expression we will get the moment and the shear force and that amount of shear force and moment, we have to apply in this two ends, so that we will get this end condition; this finite beam condition you can achieve and as well as we have to apply this boundary condition. Here this is the boundary condition. Depending upon the end condition also you have to change the boundary condition.

So, these are the solution techniques or the expression which are available for the finite beam or beam with finite length. Now on the next section; now we know that what is the Pasternak-Winkler model, then what is the Pasternak model, and what is the limitation of Winkler model, what are the limitation and how to overcome those limitations. So, those things we have discussed. Then we know that how to expression of the beam resting on elastic foundation, it is a infinite beam, finite beam, or semi-infinite beam and what is a general expression of the beam; those things we have already discussed.

Now, how we will apply those things to solve our field problems. So now, in the next section that I will discuss that we will apply these all theories and then we will solve a critical field problem and then we will determine the expression and the solving technique of those problems and that is the idea of this all soil structure introduction expressions or the models. Now, the expression that I will discuss a problem; that problem is a field problem which is very important in geotechnical engineering application.

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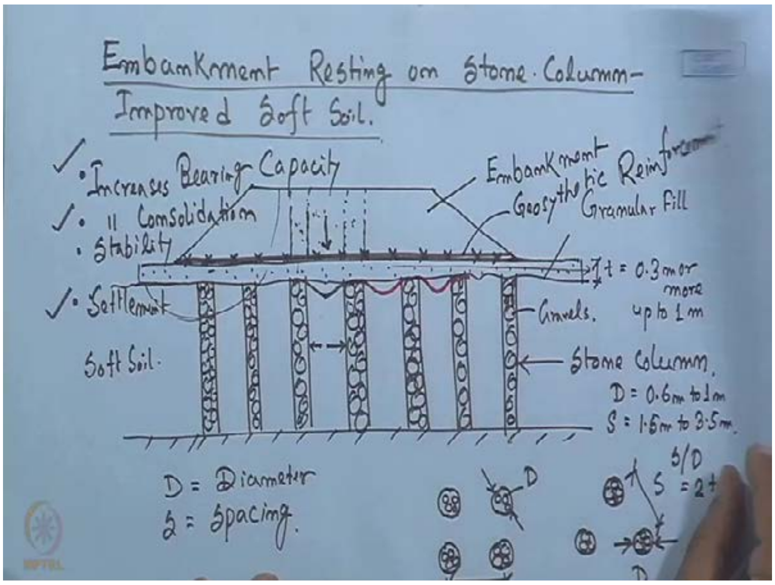

So, that problem is a problem where suppose we will solve the problem that is embankment resting on stone column-improved soft soil. Now we will solve, we will derive the expression for this type of problem. Suppose if an embankment which is resting on the stone column improved soft soil. Now this problem is important, so that it is very important for the high way construction, it is very important for the railway construction also. Because suppose if we have an embankment which have that, this is the embankment which is resting.

So, this is the existing soft soil, say, this is existing soft soil. Now on this existing soft soil, we have to construct an embankment, so that here we can construct the road, we can construct the railways. So, it is very important for the railway and roadway or the traffic engineering. So now, suppose if this is the embankment, then first we will place one granular layer on this embankment. So, suppose this is the granular layer. So, that the idea of this granular layer replacing is, so that we can make this ground workable; so that the machinery which we will use to construct the embankment which can easily stand on this soil, because this soil is very soft. So now, this thickness of this layer; it can be 0.3 meter or more. Generally up to one meter and so.

So, before we place this. So now, this soil we have to improve. So now, this soil can be improved by the application of the. So, this is say bedrock. So, this soil can be improved by the application of the stone columns. So, we can install stone columns here. So, these are the stone columns which are installed here. So, this is granular layer granular fill, this is embankment, this is stone column. So once this ground is improved, then you can instruct the embankment over this ground. So that mean first, this soil are improved; this soil is improved using stone column, we can use the granular fill also and then above this granular fill layer, then we can construct this embankment.

Now, what is the stone column and what is the purpose of this stone columns? The stone columns, other columns because here, these columns are inserted; the stones are inserted into the soil. So that means, we have to remove one method. So, this we can remove or replace this soil and then we insert stone into that replace ground. Another we can make; we can insert the stones within the ground and that is called this vibro replacement. That means here we can remove this soil or replace this soil by either using the dry method or wet method.

So, these are methodologies available to construct this stone column. So, that thing we are not going in detail; we are just giving the idea what is stone column. Basically this is a column which has a specific diameter. So, this is the diameter of these columns and then based on this desired diameter, we insert the stone into the ground. So, that is the stone or basically this stones are gravels. So, generally these are gravels which are inserted into the ground and these columns are placed into the ground by square pattern or we can place it into triangular pattern also; this is a triangular pattern. So, this is the diameter of the stone and this will be the spacing of the column. So here also, this is the spacing of the column and this is the diameter of the column So, D is the diameter, S is equal to spacing

Now, so that means first these columns are placed into square pattern; this is square pattern or triangular pattern or sometime it can be used by hexagonal pattern also. But this triangular and square are most common pattern of the installation. So, we will install the stone into the ground. Now what is the purpose of these stone columns into the ground? So, first as we know these are the gravels and these are the very soft soil. So, the stiffness of this soft soil or the strength of the soft soil is very less compared to the strength of the stone column. So, it will act as a composite ground. So, what will happen is that this stone and this composite or stiffness of the overall ground will improve. So, once the stiffness of the overall ground improve, then the strength of the ground will also improve

So that means this way, it will increase the bearing capacity and reduce the settlement of the foundation; so that means this embankment bearing capacity it will increase, it will increase the settlement of this embankment and sometimes also the stability problem. If the embankment is not stable, then this slope line is passing through this soft soil zone; then also if we install this stone column, the stability will also be increased due to the installation of the stone column because here we will get the more strength. So, now that is the three purposes that are explained. One is the improving the bearing capacity; one is the reduction of the settlement; another one is the stability problem, increase the stability of the structure or the embankment here, and fourth one that is also very important that we know that soft soil it has very low permeability. So, consolidation it will take huge time to consulate the total ground.

So, if we use the stone column. So, then basically these columns are stones and made up with stones and the width between the stones are very high. So, what will happen is the water will try to enter into this column or this path and then it will go upward direction, and then we can collect this water from here and we can remove this water; so that the consolidation, that is called the radial consolidation. So that means there will be the radial consolidation as well as there will be the vertical consolidation, but radial consolidation is much faster than the vertical consolidation. So, overall consolidation is merely because of this radial consolidation or this stone column.

So that means it will increase the consolidation rate. So, it will fasten the consolidation of the soil. So, soil we will get consolidated at very early stage of the construction. So, that the future is problem; if there is a consolidation process is going on for few years, then future will get some problems because of the settlement. So, the most of the settlement if we get within a very short period time, so that in feature we can avoid that type of problem and once the consolidation is over, then we will get more strength into the soil. So, that is the idea.

So, basically four purpose these stone columns are serving. One is to increase the bearing capacity; reducing the settlement; one is the increasing the stability; another increasing the consolidation. So that means here for this methodology that we will discuss, we will not consider on their stability purpose; there we assume that column is stable. So that means the stability there is no problem; only other three things that we will discuss here. So that means one problem is here. Solving is increasing the bearing capacity, then increase the consolidation, then make stability, another is improve the settlement.

So that means the stone column increases, bearing capacity increases, consolidation rate improve the stability, and improve the settlement. So from these things, we will discuss the bearing capacity improvement, consolidation improvement, and settlement improvement. So, these three things we will discuss and how to model these things, incorporate all this behavior here. So now the diameter, typical diameter of the stone column varies from 0.6 meter to 1 meter and spacing generally it varies from 1.5 meter to 3 to 3.5 meter. So, the S by D ratio that varies from 2 to 6.

So, these are the general ideas; what is the diameter of the stone column, what is the spacing between the stone columns; S by D ratio is generally 2 to 6. So now, another very important thing we will come into picture that, when we will construct this type of embankment on soft soil where we can use the stone columns here, then what will happen to that soil above this. So that means this portion is very soft and this portion is stiff; stiffer than this portion. So, that means there is a zone above this two portion.

So, as the center portion between this columns; this is a very soft zone and soil within that centre portion will deform more compared to the column. So, that means we have this type of settlement pattern. So, we will get this type of settlement pattern here. So, that means the soil within this zone that will deform more compared to the column. So, what will happen? The soil above the center zone that will also deform more compared to this two zones. So in the soil deformation within this zone will be more compared to these two zones.

So, what will happen in that interface? This is the interface, this is the one zone, this is another zone, this is another interface, this is another interface, this is interface. So, at this interface, there will be shear and this shear is because of this differential settlement; differential settlement means difference of the settlement between this point and then this point. So, that the top of the column and the middle of the column and the center of this two columns. So, because of this differential settlement, there will be differential settlement on the embankment soil also. So, this embankment soil; there will be differential settlement and then shear will develop at the interface.

Now because of this shear resistance the soil has its own resistance. So, because of this shear resistance what will happen? This soil of this zone will try to hold some portion of this soil of this zone of the center zone. So, that means what will happen. So because of this reason, some stress because these soil above the stone column region; this embankment soil because of the soil resistance, shear resistance it is not allowing the soil within this region to settle down. So, what will happen? There are some stress on this region will be transferred on the stone column because of this shear resistance. Now this phenomena is called soil arching.

So now, if I go further that what is soil arching? So, that means if we have stone column here, this is embankment. So, suppose with including this embankment and this granular layer, the thickness of the embankment or height of the embankment is H and the density is also H. So, that means one stress that will act here. So, that is q s soft soil and another one we can consider q c or the stone column.

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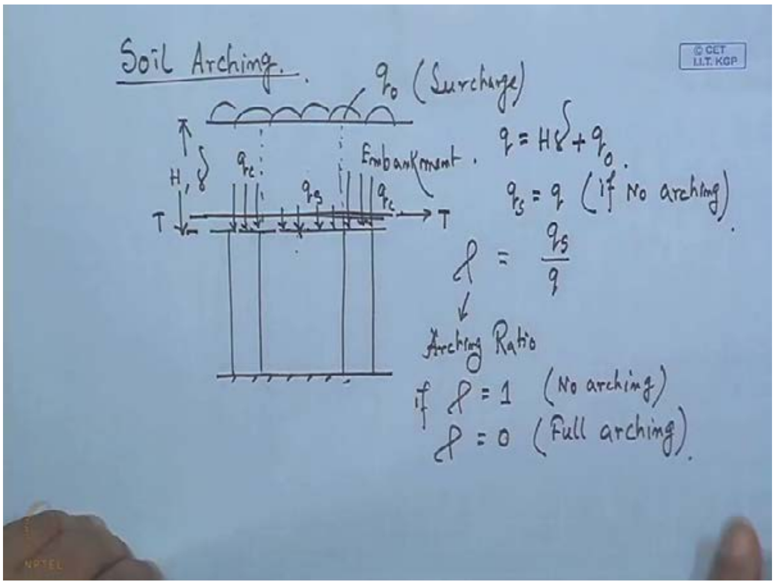

So, that means here the soil within this zone, the total soil pressure; suppose at this zone, the total at the base of the soft soil, the ideal load is gamma into H; that is the q which is acting here. If there is no soil arching nothing, so that means the total force is acting here q into H. But because of this soil arching and if it is there is a surcharge over this zone and that value is q 0. So, this will be q plus q 0 if there is a surcharge; q 0 is surcharge.

So, if there is no soil arching; that means the q s will be equal to q if no arching. So now, if I write one arching ratio; that is q s divided by q. So that means, if rho is equal to 1 then we can write no arching and if rho is equal to 0 means q is equal to 0 and then no stress is coming on the soft soil; all the stresses are going to the q c for this embankment, that is called full arching. So, it is clear that if q s equal to q; that means the all the load which is applied above the soft soil is equal to all the stress which is coming on the soft soil, then it is no arching; no arching has been occurred.

So, the stress at the every point is same, on the stone column as well on the soft soil. But because of this soil arching, because there is a differential settlement, then the shear stress will develop; so that means the soil above this soft soil region, the embankments material, above the soft soil were that will also settle more compared to the soil above the stone column region. So, there will be a differential settlement. Once the differential settlement, there will be a shearing between this two soil of this two zone. One is for the zone above the stone column; another is zone above the soft soil and because of this shear resistance of the embankment soil again in the material, the stress on this region will transfer. Stress on the soft soil above the soft soil region is transferred on the stone column region because of the shear resistance.

So, that phenomenon is call soil arching and if I expressed it in the soil arching ratio, then this is the if rho is equal to 1, there is no soil arching; all the stress are coming on the soft soil and if it is 0, then full arching; no stress is coming on the soft soil, all the stress are transferred on to the stone column. So, that mean the stress on the stone column and stress on the soil are not same because of this arching phenomenon. So now, sometimes in this stone column also embankment we can place a reinforcement layer; geosynthetic reinforcement layer here at the base of the embankment, so that we can provide geosynthetic reinforcement. Now because of application of geosynthetic reinforcement, the settlement is further reduced; all the total settlement and the differences settlement will further reduce and the bearing capacity will be further increased. So, another thing that will add here is the geosynthetic reinforcement tension t; there is a tension t.

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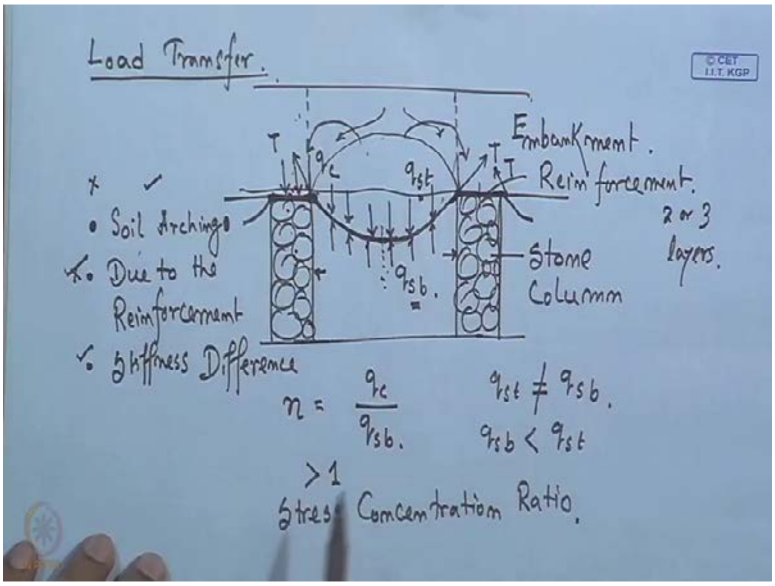

So now, if I go for the load transfer mechanism of these things; that is the load or stress transfer mechanism. So, there is three ways by which the stresses are transferred on to the stone column from the soft soil region. So, this is the stone column, this is another stone column. So, if I consider the reinforcement layer; so if we provide the reinforcement, so that will deform in this form. So, deformation on this region; consider as this is the steep, the reinforcement deformation will be almost same here and here reinforcement deformation is not same. So, there will be a tension that will induce at both the end and this is embankment soil; this is embankment

So, stress on the stone column if I consider q c and stress on the soft soil or above the stone column or then the stress below the stone column, they will not be same. So, if I consider this is q s top, q s bottom. Now q s top is not equal to q s bottom. Generally q s bottom is less than q s t. So, why it is less than? So, that thing we have to explain that because of this, once there will be the settlement of the reinforcement. So, this is reinforcement. So, once there is a settlement of the reinforcement in this form, because of this shear between the reinforcement and soil, that tension will develop within the reinforcement. So, that I have explained that one is string effect another is confinement effect. So, tension is developed, equal amount of the compression is developed in the soil. So, the soil will get compressed, we will get the reduction.

Another one is that the tension will develop and this tension component if I take the sin theta, t sin theta and t cos theta. So, t sin theta component will balance this some stress. So, that means ultimately the stress below the reinforcement layer is less compared to the stress above the reinforcement layer. So now, what are the stress transfer mechanisms? Here one is due to the soil arching. So now, the q c and q s are that of the stress and here the reinforcement deformation is almost same. So, there will not be too much of this stress variation. So, here we assume the stress acting on above the reinforcement and below the reinforcement is same, because we will not get this type of deformation. Once we will not get this type of deformation; this huge deformation, they will not be shear or they will not be any tension. If there will not be any mobilized tension, then we will not get any reduction on the stress

So, that means the q c is considered to be same above and below the reinforcement layer. Then the stress on the stone column and the stress on the soft soil, they are not same. So, if I go in for one ratio; that is the stress on the stone column and stress on the soft soil or here we can layer it as b. So, this is always greater than one. So, that is called stress concentration ratio; this is called stress concentration ratio. Now so that means, the reason why this q c is greater than q s b; one reason is due to soil arching. Because due to soil arching, the stress in this region will transfer on to the stone column region because of the differential settlement and that is due to the stiffness difference between the soil and the stone column. Because there is stiff, it will deform less; it is lesser. It will deform more because this soil is very soft.

So, that is then because of that region, the soil arching will occur. So, that is one region is soil arching and second region is stress transfer due to the reinforcement. So, that means that this reinforcement layer also enhance the stress transfer process from soft soil to the stone column and that is reason is that because we will get this t component here at the edge of the column. So, if this is the t component, tension component. Now if I take the two components of this tension, then this horizontal component; this will produce and this will release the stress because this t component. Because of this t component, some stress will act on the stone columns.

So, that means this is the stress which is coming due to this shear interaction between the soil and the reinforcement. This t will develop and this t will release or this because of this tension, reinforcement will release the stress on this stone column. Because here the tension will develop within the reinforcement layer and at this point this end or edge of the stone column; that is t and if we take the two components from this side, so that vertical one is balancing these stresses. This horizontal one has release the stress on the stone column.

So, what will happen? Thus this reinforcement layer will basically transfer the stress which is coming from the soft soil region and then it will transfer the stress from soft soil region, it is carrying the stress and then release it on the stone column because here there is a zone; from here also, it will again deform in this one. So, again you will get another t here. So, from here also we will get some tension or we will get some stress. So, that may lead to release this stress which is taking this stress and this component will get one t sin theta and one t cos theta. So, if we get t cos theta; so, that t cos theta part is released on the stone column.

So, that is due to this forces it will enhance the stress transfer mechanism; that means stress is transferred from this region and it is released on the stone column region and the reason is the t tension which is developed at the edge of this column and this tension some part, this horizontal part is actually resting on this soil. So, that will release here and the next one is very important thing. Suppose here we can use the single reinforcement. Now we can use n number of multilayer of reinforcement; say two or three layer of reinforcement, two or three layers. Then means what will happen? Once we increase the number of reinforcement layer, the differential settlement will also reduce.

So, that means if we increase the three layers here. So, this zone if I increase and if we provide the three layers, this zone act as a stiff region. So, it will not deform. So, once there is n number of 3 numbers of layers. So, this zone deformation will be less. So, if the deformation of the soft soil region is less and that is the differential; so that means the differential settlement will also be very less. So, if the differential settlement is very less and the settlement pattern is almost same, then if there is no differential settlement, no soil arching. So, there will not be any soil arching. If that happens and another thing, if there is no deformation settlement, we will not get this type of deformed shape of the reinforcement.

So, once we not get deformed type of reinforcement shape, then what will happen? There will not be any shear between the reinforcement and the soil. So once there is no shear, no tension will develop. Once no tension will develop, no stress will be transferred on to the stone column. So then the first two will not act in that case if there is no differential settlement. So to have sufficient benefit of the reinforcement layer, there should be much differential sufficient amount of the differential settlement. Differential settlement means settlement difference between the settlement of the center of the stone columns and the middle of the stone columns. And if there is no differential settlement, no soil arching. Still in that case also, we will get more stress on the stone column compared to the soft soil and that is due to the third reason that is stiffness difference.

So because of the stiffness difference, more stress will be coming on the stone column compared to the soft soil. As the stiffness of the soft soil a stone column is more compared to the stiffness of the soft soil. So, what will happen? The most stress will come on the stone column. So, that is the properties of the composite material. If we have a composite material and we have a stiffen material and we have a very soft material, then stiffen material will take more load compared to the soft material. Here also at the stone column is stiffer material compared to the soft soil, then it will take more load. So ultimately, the stress on the soft soil is less compared to the stiff stress which is coming on the stone column.

So, if there is single reinforcement because of three reasons. One is soil arching, one is reinforcement layer, and one is stiffness difference. So, there will be more stress on the stone column. If it is a multilayer system; there will be a very stiff system, there will be a less amount of the differential settlement. Then it will transfer because of the third reason only, that is stiffness difference. So, ultimately we will get the stress concentration ratio which is always greater than one in a stone column in to soil. So now in these things, now we have to model this total mechanism which is a complicated mechanism, load transfer mechanism. Now we have to model this total system by using this soil foundation interactions model.

So how we will model that? That is very important because in most of the cases, these models are available for the pile supported embankment. So, there is very few limited amount of the studies that have been done on the stone column supported embankment. So, difference of pile supported embankment and stone column supported embankment; in pile supported embankment, there will be very less amount of the deformation of the pile. But if it is a stone column supported embankment, then there will be a huge deformation of the stone column also. So, and in one case it is assumed that the soil arching will happen like a circular arch.

So, this is a circular arch and the stress above the circular arch will transfer directly to the soil. Someone has consider that arching is happened in the interface of these two zones, total arching. So, based on these assumptions it is done. But in this model that I am going to discuss, in this model no assumption is done. Here we have not assumed any shape of the arching; that is that will come by default and it will just transfer the stress and we will develop the model such that, there is no need to assume any type of arching deformation, whether it will deform circularly whether it will deform horizontal; arch will form circularly, parabolic, or straight, or vertically. So, it will form automatically. So, it is the advantage of this soil structure interaction model that we have used here.

And then the next thing is that once we model this thing with the consolidation effect as we have mentioned; thus the consolidation will play a very important role in the stone column ground because the consolidation is very important thing. So, that is also incorporated in the model. So, in the next class I will explain how this complicated problem is been modeled by using this soil foundation interaction theories and then how it is solved and then what are the expected results we have received or we have obtained. So, those things will be explained in the next class.

Thank you.