Advanced Foundation Engineering
Prof. Kousik Deb
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

Lecture - 33
Soil - Foundation Interaction

Hello. Now, this class I will explain about the various soil foundation interaction or soil structure interaction. So, basically the meaning of this soil foundation or soil structure interaction is the interaction between the soil with various foundation or structural components like beam plate, which is resting on the elastic half space medium. Now, this basically this soil which is represented by the elastic medium in in the half space and these soils are idealized by various modulus like mechanical model, mathematical model or numerical model. Now, I will explain of various this type of model special in this class. I will explain various type of mechanical model to represent the soil condition and how the interaction is working between the soil and the various structural components like beam and plate.

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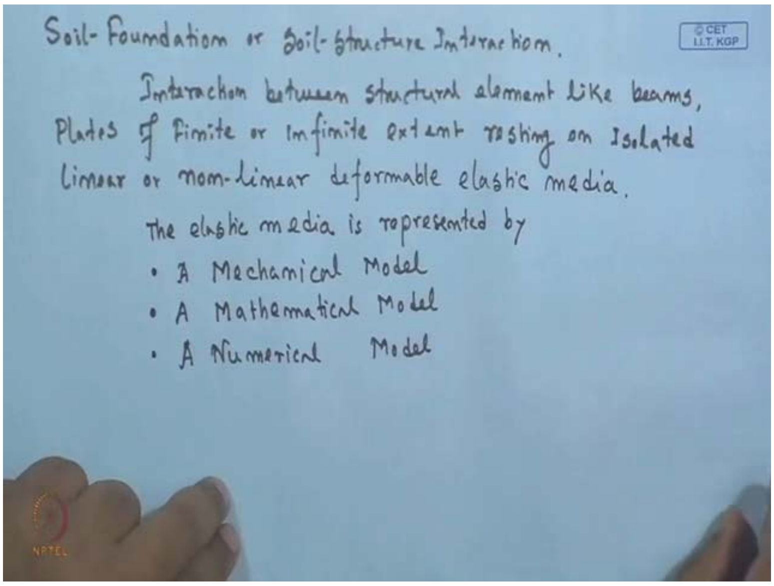

Now, first if I go for this soil foundation interaction or soil structure interaction, so you when this, we can say that interaction between the various element of structure side side such as interaction between structural element, like beams plates of finite or infinite extent resting on isolated linear or non-linear deformable deformable media. So, that is the interaction between structural element like beams plates or finite or infinite extent resting on isolated linear or non-linear deformable elastic medium. Now, in the in the analysis generally the soils are assume medium assume that represented by the elastic medium and a half space region.

So, that is a soil elastic medium of the soil is represented by represented by one, we can say that a mechanical model, so again a mathematical model or by a numerical model. So, here so next section I will explain about various type of this mechanical model.

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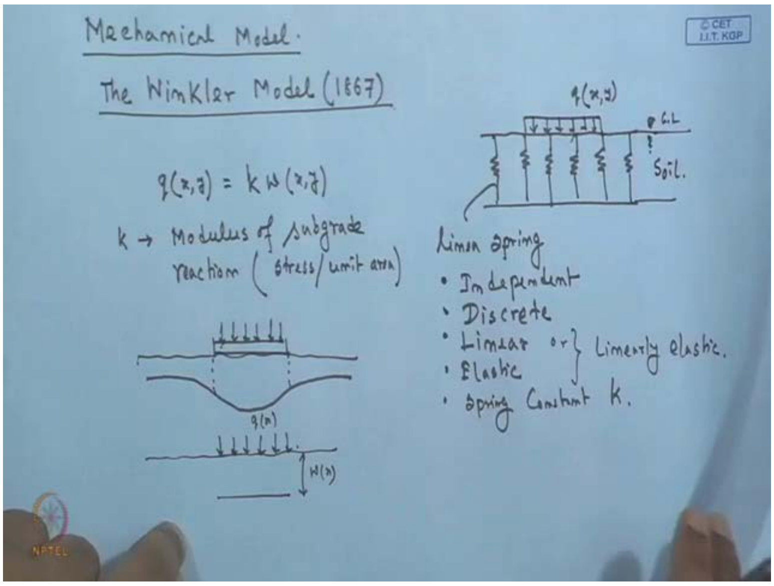

So, now first if I go for different mechanical model. So, first type of mechanical model which is given by this soil representation is the Winkler model. So, first type of mechanical model that we will explain that is Winkler model. Now, Winkler model basically, that we can say that the load which is applied on a foundation system. Suppose, this is the soil medium which is represented by several linear spring. This is linear springs. So, here these are the soil which is idealized by linear spring and if we apply a load here so this is the uniformly distributed load which is applied on this soil.

Then this load is proportional to the displacement of the spring. and where so that means this load or stress that is applied on this plane or over the soil medium, which is directly proportional to the deformation of the spring. So, where k is, small k is called modulus of sub grade reaction. Whose unit is stress per unit area or if it is a two dimensional problem then stress per unit length. So, that means we can write that that we can say that

that the settlement at any point within the soil medium is directly proportional to the stress which is applied on that point.

So, that means settlement or at any point or the spring is directly proportional to the stress which is applied on that particular point. So, here k is defined as modulus of sub grade reaction. Now, physically this Winkler's idealization that it is a system of multiple in so that means here the soil idealization it is system of multiple, independent, discrete, linearly, elastic spring with spring constant k. So, we can say that this is this springs are this springs are independent. So, there is no connection between these springs. So, these springs are independent. So, there is no connection between this springs and this spring. So, this is the soil ground surface and these are the soils, which is represented by a spring so that means that springs are independent, this springs are discrete, this is linear and this is elastic or linearly elastic. We can say or so with a spring constant.

So, this modulus of sub grade reaction is nothing but the spring constant of this spring. Now. So, that means here we can say that these deformation is for a idea is concentrated on a particular zone. As we can say there is no connection between these springs and the deformation is proportional to the load or a states which is applied to that particular point. Now, if any spring which has not loaded that means there will be no deformation. So, now the limitation of this model is that, when we apply load suppose, this is our ground surface and then we apply load on this surface. So, there will be a deformation pattern is like this.

So, that means we will get a deformation beyond the loaded region also. But if according to a Winkler model then this this spins are not connected to each other. When there is the deformation is proportional to the load. So, directly so that means if there is no deformation no load there will be no deformation. So, that means if we consider the Winkler model so beyond the loaded region we will not get any deformation. So, actually in the field that will not happen. In the field or actual case we will get a deformation beyond the loaded region, but but in the Winkler spring we will get the deformation only within the loaded region and even another case that as, if it is a u d l.

We applied up to this zone and then as, the, if we consider a spring constant or module of sub grade reaction is same for this entire soil then every point there will be a equal amount of the settlement because as if it is q is the load then there will be equal amount of the settlement at every point. So, that is another limitation of this Winkler model. So, we will not get settlement beyond the loaded region and the we will get the enough amount of settlement within that loaded region also. So, that means this model is in common use in the analysis of foundation problem. So, that means so that means now, the next stage is how to determine this sub grade reaction. So, that means here terzaghi in 1955 is proposed that how this plate reaction modulus sub grade reaction is calculated. So, that means here we will get that how this k value modulus of sub grade reaction or determination of.

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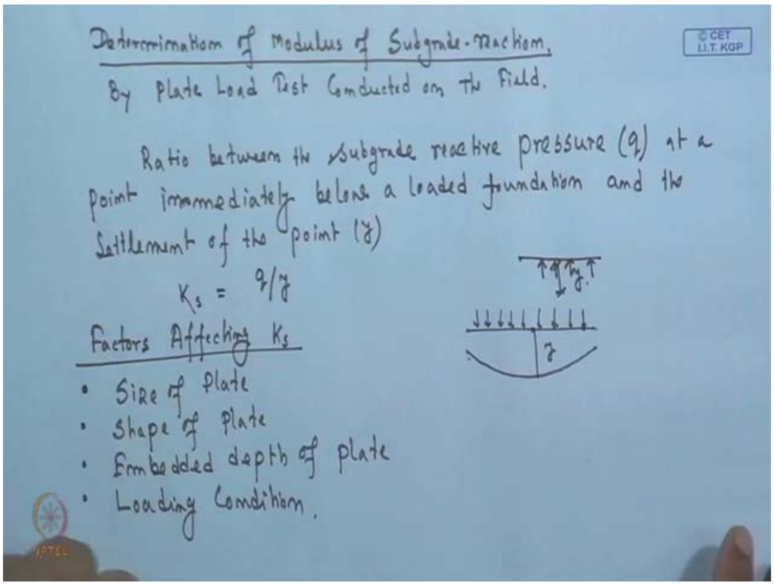

So, this modulus of sub grade reaction is determined by plate load test, conducted on the field. So, this plate load test about this plate load test I have already explained how this plate load test are conducted. What are the limitation of this plate load test. What are the plate size is generally used. So, based on that plate load test we can determine this modulus of sub grade reaction. So, that means the definition of this modulus of sub grade reaction is that that is a ratio between between the sub grade reactive pressure q at a point immediately below a loaded foundation and the settlement of the point y.

So, that means the definition of this modulus of sub grade reaction based on this plate load test that, the ratio between the sub grade reactive pressure q at a point immediately below the loaded foundation and the settlement of that point. Suppose, if this is the plate that we have used and the immediately below the foundation that is the settlement y. If this is the settlement y then the reactive pressure at this point that ratio that means the, k s sub grade reaction or k that is equal to q by y. So, that means the reactive pressure here is that is mean the soil reaction. So, that is q and the settlement at that point is y.

So, now these k is not constant throughout the soil because as we know that for a flexible foundation uniformly loaded that there is a non-linear uniformity because as we know that this k value, if we apply the load there will be a this type of deformation of the soil. So, as I have we have mentioned that the k value is if this is y and if this is uniformly distributed load which is applied over the foundation. So, that means this y deformation is not same in all the points. So, as that if if our loading reaction is load load is constant then the deformation if is not same then obviously this k s value will change and if this because of that we have, there is a several factor which the k value depends on that.

So, this factors k s so this factor first one is the size of plate shape of plate. Then embedded depth of the plate, then loading condition. So, these are the factors nearly on that k s depends. So, now as I have mentioned that the size of a plate will play a very important role in the plate load test because in the actual condition the field if, the soil is homogeneous then the representation or the plate load test will be very good, but if the soil is not homogeneous and if the some Winkler is existing below the after certain depth. Then plate load test we cannot find that layer or if it is the layered soil then we cannot find the exact value of the bearing pressure, which which we are getting in the actual field. Because in the pressure bulb or the zone of influence for a small size plate is concentrated within the shallow region of the foundation or foundation soil, but actually k s if there is a actual side the influence zone or pressure bulb will go up to a great extent.

So, in that case these are the limitations of the plate load test. So, even though if the plate load test the size that will also effect. The plate size will also effect on the behavior of the foundation and then then how this this modulus of sub grade reaction for the actual footing size and the is correlated with the plate size, then those things can be explained in this form.

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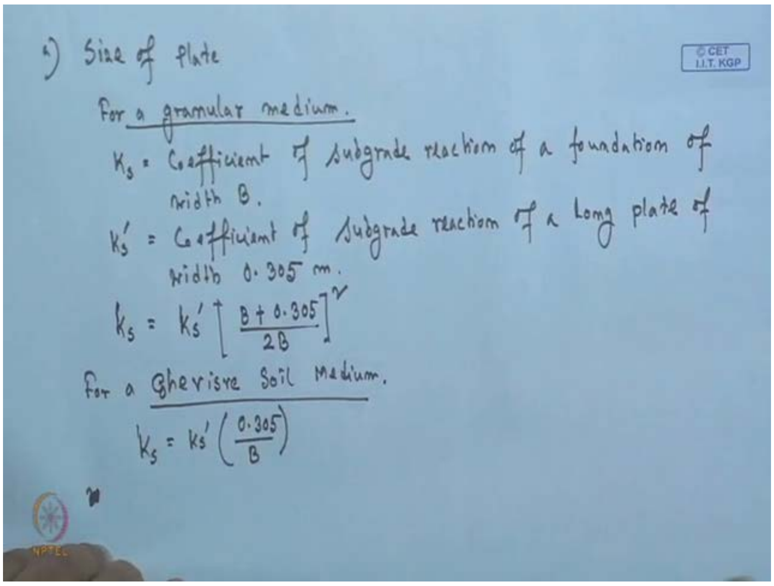

So, suppose the if I write that the size of the plate, the first factor. Now, for a granular granular soil or medium if k s is equal to coefficient of this coefficient of sub grade reaction is same as the modulus of sub grade reaction. So, those things are two things are same of a foundation of width b. So, if the coefficient sub grade reaction k s with the actual foundation of width b and k s dash is coefficient of reaction of a long plate of width 0.305 meter. So, here plate site is taken as 0.305 meter and that in the test, we will get the value of coefficient of sub grade reaction if we used a width of plate 0.305 five meter that is k s dash.

So, that means the actual k s that will be equal to k s dash to B plus 0.305 divided by 2 B whole square. So, that is the relation, correlation between the actual k s with the k s which is obtained with the plate load test with the plate size of 0.305 meter for a long plate of width 0.305 So, that is valid for the, these things is valid for the granular soil. Now, similarly for the clayey soil also we will get a similar type of correlation for cohesion less or cohesive soil soil medium. So, there also we will get k s that is equal to k s dash into point 0.305 by B.

So, now when. So, this is these two relation. For the, this is for the cohesive soil and this is for the granular soil. So, we will get these two type of relation which is related to the actual plate load test and the actual foundation. Now the next thing is the shape of plate.

The shape of plate will also effects the value of k s. Now one thing that if k s one is determined by using a square plate of 0.305 into 0.305 meter in size.

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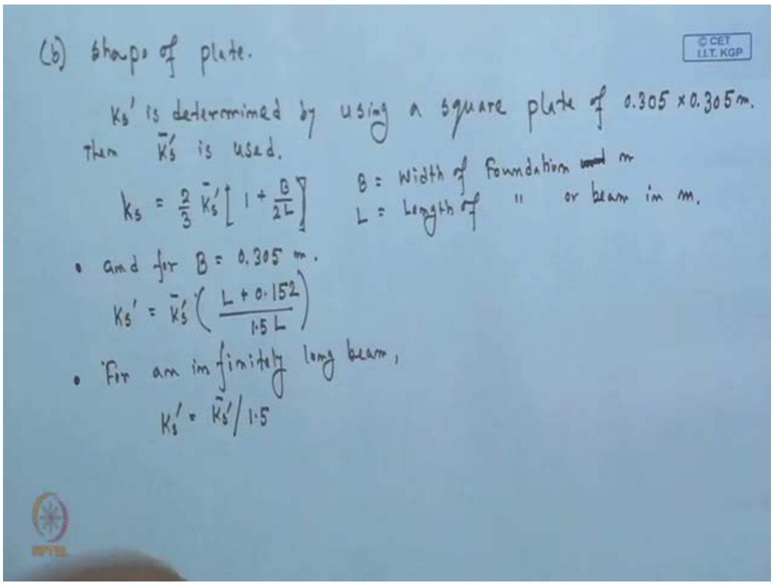

So, then k s dash bar is used. So, that is is used. So, as I mentioned that k s dash is determined by a long plate of width 0.305 meter. Now, if k s dash is determined by using a square plate of 0.305 cross 0.305, then we can use k s dash bar. I n that case k s is equal to two third of k s dash bar into one plus B into 2 L. Where B is the width of foundation, L is the length of foundation. So, in that case and for B is equal to 0.305 meter k s now k s dash can be related with k s dash bar by L into 0.152 divided by 1.5 L, where that is the length of the foundation or beam in meter. Width of the foundation or it is a foundation that is also in meter.

So, now we can say that here we consider B equal to 0.305. Then k s dash is also related by k s dash bar by this expression. Now for n this is for B equal to 0.305 and for and infinitely long beam, this k s dash that is equal to k s dash bar divided by 1.5, so these two relations. This is one relation. This is another relation. This is for a finite beam of width 0.305 meter and this is where L is the length of the beam and B is the 0.305 meter then k s dash is related to k s dash bar into l plus 0.152 divided by 15, 1.5 L Then if it is infinite long beam then this k s dash is k s dash bar divided by 1.5 and others this k is determined by this is k s for the actual footing, which is determined by two third k s dash I by 2 L.

Now, first we will determine this k s dash bar. If it is determine using this plate then that value you can use to determine these k s and now, this k s and k s dash also related correlated by these two condition. One is finite beam another is infinite beam condition in this way, so next one that we will get for this. So, this is the shape of the plate, then next one is the embedded depth of the plate.

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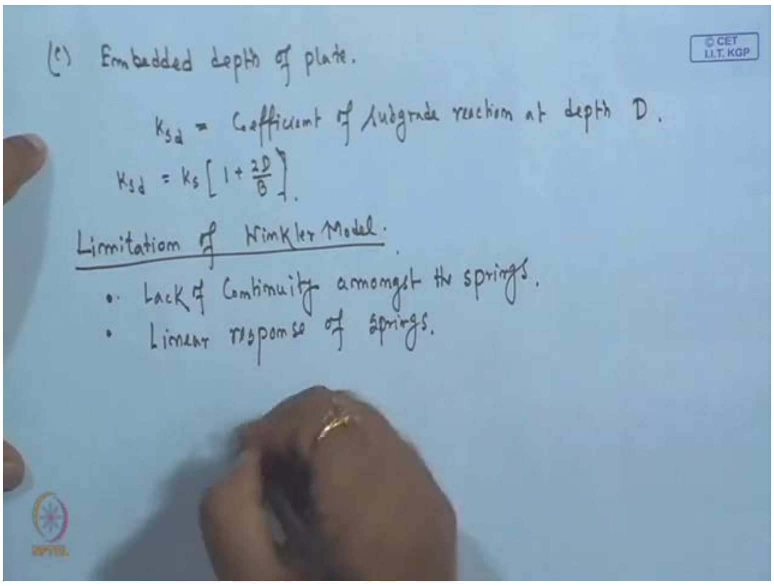

So, now third factor that is, now, here if k s d, is the coefficient of sub grade reaction at depth d, then k s d is equal to k s 1 plus 2 D by B. Now, if D is equal to 0 then k is d is equal to k s. So, that means the k s value that you are using for previous two cases. So, that is determined at the ground surface. So, where depth of the foundation is 0.So, now if there is a depth and definitely the foundation will be placed at a certain depth. So, in that way we can place this k s is k s d is the coefficient of sub grade reaction at a depth. Now, generally the elastic that modulus of elasticity for a granular soil medium is increases approximately linearly with the depth. So, in that way that our k value is also will increase with depth.

So, now there are few comments that actually as which is common for any plate load test, that when you have to conduct the plate load test we have to place the plate exactly at the foundation level, so where the foundation has to be placed. Now, the plate side the limitation as I have already mentioned that because of these small size the influence zone is small. So, we will not be able to cover more soil layer. If there is a soil layer then the result will not give the exact one. So, these are the things that we have to keep in mind when we do the plate load test. Now, another very important thing that the area of the load test should be tend to 15 percent of the loaded, actual loaded area covered.

So, that means the in the actual foundation area area that is that will be covered in the field, the plate area that should cover at least 10 to 15 percent of the loaded area. So, on the determination of this k k k sub grade reaction we need to conduct the plate load test. So, these are the factor that means the shape of the plates size of the plate and the embedded depth that will effect this k s value. So, this way we can determine the k s value based on different size, different shape and different depth condition and you we conduct the plate load test, we have to keep all these factors in mind that how where we have to place the plate and what are the area it should cover during the load test.

So, now these are the k value determination. The next part is the limitation of the Winkler model. So, the… As I have mentioned that the limitation of the Winkler model, that, what are the that the most two very common limitation or the important limitation of this model, the one is the the springs are not connected. So, that means the that is a lack of continuity between the springs. So, so that because of this as I have already discussed because of this reason we will not get any deformation beyond the loaded region because there is no continuity between the springs. So, when the load up to the loaded region if there is no load you will not get any deformation. Where this up to the loaded region, we will get only deformation.

So, that is the lack of continuity this is the major limitation of this Winkler spring and second one is it is the linear. So, this Winkler spring springs are considered as a linear spring, but actual case soil here is not a linear one. It may be it it will follow non-linear pattern, so that is another limitation of the Winkler spring. So, that means one first limitation that we will see, that is the lack of.

So, one is the lack of continuity among the springs another the linear response of the spring, so how to improve this limitation. So, next thing is this we have to improve this limitation. So, how we will improve this limitations? So, in the next model that I will explain where these limitations are inputs, so one of the major limitation as I mentioned that the lack of continuity. So, now we have to provide some things so that the springs are connected to each other. So, that is in the next model that is the improved model for this spring.

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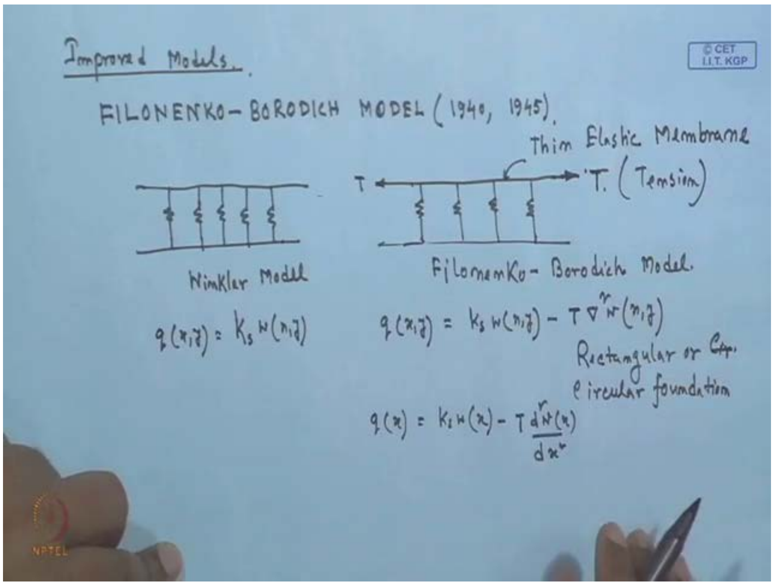

That is improved model, where this lack of continuity that can be taken care. So, that to model first model that we will explain that is FILONENKO and BORODICH model. So, next model is Filonenko and Borodich model. So, where this spring's? Suppose, in the Winkler model. These are the springs, which springs constants clay that is Winkler model and in the Filonenko and Borodich model this spring's are connected by a elastic membrane. So, here this spring's are connected which tension T. So, this is.

So, that means here this spring's are connected by a theme elastic membrane under a constant tension T. So, now the in the Winkler model as we mention that our q was equal to k or k s into w x y. That was the expression for the Winkler model. So, in the Winkler model the parameter that was involved is only k s that is the modulus of sub grade reaction. So, if we know the spring constant or modulus of sub grade reaction of the soil. Then if we apply the load how much settlement we will get we can determine by using the Winkler model because if we know the load that much load will apply if I know the modulus of sub grade reaction of the soil, then we will get the deformation of that point.

So, now in the Filonenko Borodich model, Filonenko Borodich model we will get the this is our load that is applied and then that is equal to k s into w x y. Then another thing that is T to del square w x y. So, that is for rectangular or circular foundation.

Rectangular or circular, so this is rectangular or circular foundation So, here we can see and if it is a strip routine then we will get k q x that is equal to k s into w into x minus T d square w x by d x square. So, here T is the uniform applied tension. So, here we will get this is the two parameter model. So, one parameter is the k s modulus of sub grade reaction another parameter is T that is the tension which is applied into the soil into the membrane which is used to connect the spring.

Now, this lack of continuity themes is removed because here we are applying the these springs are connected to each other. Now, if we apply the load on these springs and then we will get the deformation beyond the loaded area also because here now, because of this connectivity all the springs are now connected with each other. So, this springs are connected and with the help of a membrane with the uniform tension T which is applied here. So, we will get the loaded deformation beyond the loaded region also. So, that is way, the lack of connectivity things is removed. So, this is our improved model and this is two parameter model where two parameters here one is modulus of sub grade reaction another is the constant tension T which is applied. This is the tension applied in the membrane.

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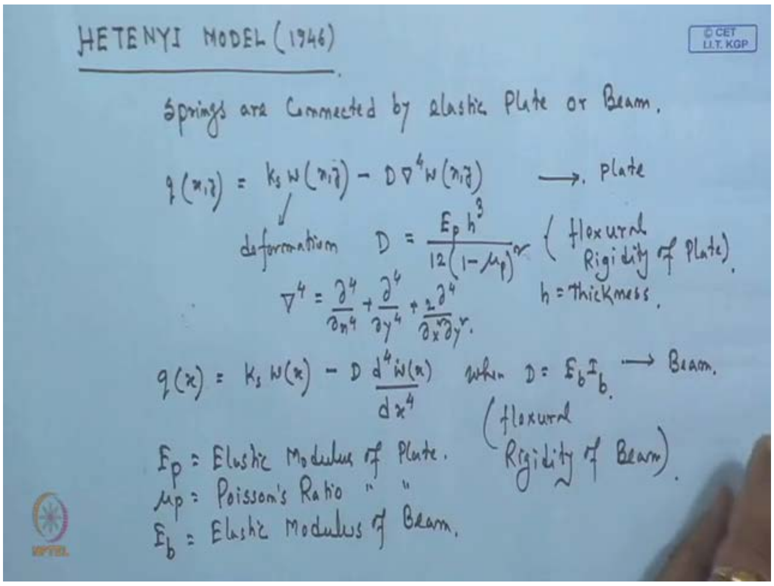

So, this is a Thin Elastic membrane. So, these are connected with the Thin Elastic membrane which is under constant tension. So, this model is proposed by Filonenko and

Borodich. So, next model the similar type of improved model or two parameter model that is proposed by HETENYI model or Hetenyi.

So, that the next model is Hetenyi model, where with the help of this model also that lack of continuity will be removed here the springs in the Filonenko and Borodich model springs are connected with thin elastic membrane here springs are connected with by a beam. So, now if with the springs are connected by an elastic plate or elastic beams. springs are connected by plate or beam Now if similarly, we will get the expression q u that is equal to k s w x y, w is the deformation, then minus D del to the power four w x y, where D is the flexural rigidity of the plate. E p h cube by 12 1 minus mu p to the power square. And del 4 is equal to del 4 x four plus del 4 y 4 plus 2 del four del x square del y square. And this is for the x y condition similarly, q x that will be equal to k s x minus D D four D w D x to the power four where D will be E b i i b.

So, now here these are the connected by plate or beam so we will have the expression q equal to k s into w D to the power delta x. So, this is x y direction. So, this is this here first expression this is connected by plate and here second expression this is connected by beam. So, here we will get the, this is D is the flexural rigidity of the plate. That is flexural rigidity of the plate and here d is flexural rigidity of the beam flexural beam. So, here we will get the this is full of D is the flexural rigidity of the plate, here D is the flexural rigidity of the beam, here D is equal to E b elastic modulus of the beam and the i of the beam and here also we will get D is the E p esteem modulus of the plate and mu is the Poisson ratio of the plate and h is the thickness of the plate. So, here we will get these expressions.

So, here h is the thickness and E p is the elastic modulus p then mu p is the Poisson ratio plate. Similarly, E b is the elastic modulus of beam. So, this is another improved model where this similarly, this spring’s are connected with beam or plates so that we will get the deformation beyond the loaded region. So, lack of continuity concept here also it is improved. So, next model that is a similar type of model that is proposed where this here also the lack of continuity concept is removed. That is our Pasternak model where the springs are connected by the shear layer.

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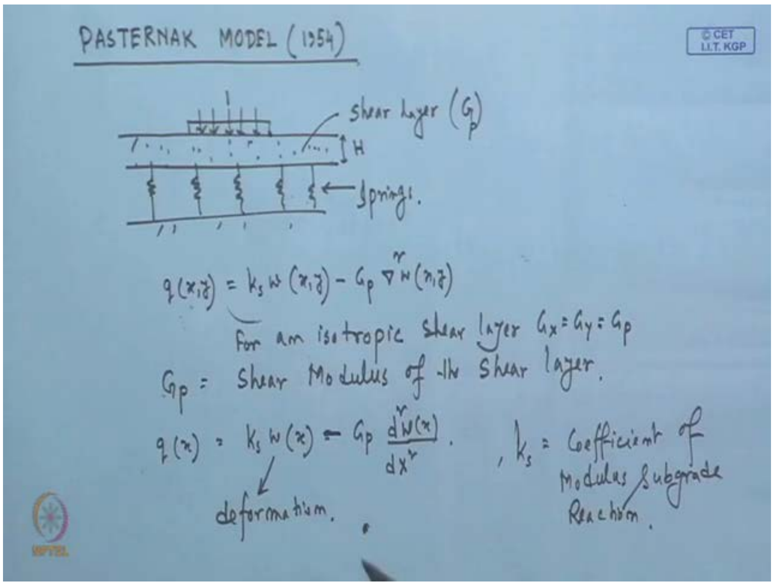

So, now the next model that is the Pasternak model, so here this model, suppose these are the springs. So, these springs are connected by a shear layer. This is springs and this is shear layer, with a shear modulus G. So, this is shear layer. Now, these springs are connected. Now, that we can apply the load so we can apply the load or uniform distributed load. So, we will get the now these springs are connected with the shear layer of thickness say H and then we can get the deformation beyond the total region so there is lack of continuity concept will also be improved. So, now here if we the response function we will get q x y that is equal to k s into w x y that is G p into del square w x y.

So, now for a isotropic shear layer G x is equal to G y is equal to G p, so now where G p is the shear modulus of the shear layer. Now, the G p which is mention at the that is the shear modulus of the shear layer. Now similarly, for the one D k s that is q into k s w into x minus G p D square w D x square D square w x. So, this is in x y direction and this is is only in the x direction. So, we will get this is the deformation again or settlement and k s is the coefficient of.

So, here also we can see this is two parameters. That is one is k s is one parameter that is coefficient sub grade reaction and G p is the another parameter. So, we have to know the parameter two parameter; one is the shear modulus of the shear layer another is the modulus of sub grade reaction of this soil or the spring constant of this spring. So, that if I know these two things, then we can find the deformation at any region within the loaded region or beyond the loaded region both we we can determine the how much settlement we will get for a particular point. So, here the boundary condition will be within that loaded region there, loaded region there will be q and if beyond the loaded region this q will be 0.

So, this q dash boundary condition will apply here up to the age of the foundation q dash will be equal to that q value and beyond that this q x will be 0. So, now with this way we can solve and we will get the deformation even beyond the loaded region also. So, these are the we have explained what is this solid structure interaction then what are the different types of modules of mainly we have discussed, I have discussed about the various type of mechanical model. So, first Winkler model how to idealize the soil. In the Winkler model soil is idealized by the spring. Then in the limitation of the Winkler model the lack of continuity is one major limitation another is the linear spring that is considered here.

So now to improve this lack of continuity the improved models are suggested one is I have discussed three of them. One is Filonenko Borodich model, then the retaining model and then the Pasternak shear model. So, and then how to calculate a determine the k s. What are the factor effecting this k s. In the next class I will discuss about the various other types of improved models and then how to incorporate the non-linear response within the spring which is considered linear here. So, those things I will explain in the next class.

Thank you