Geosynthetics and Reinforced Soil Structures

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Lecture - 28

Response of Footings Resting on Reinforced Foundation Soils

Good morning students, in today's lecture let us look at the bearing capacity of shallow foundations that are supported on reinforced soil beds.

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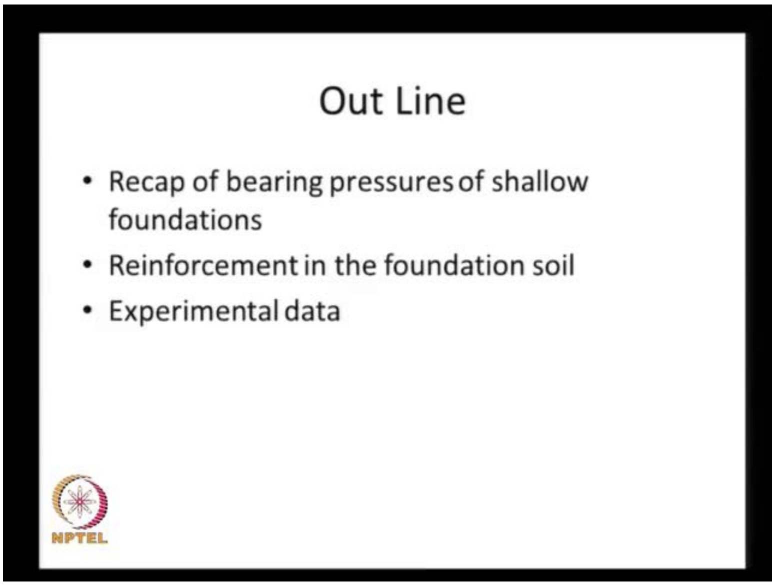

And the brief outline of this lecture is, we will have a brief recap of the bearing pressures of the shallow foundations, and then the reinforcement that is provided within the foundation soil and brief about the experimental data.

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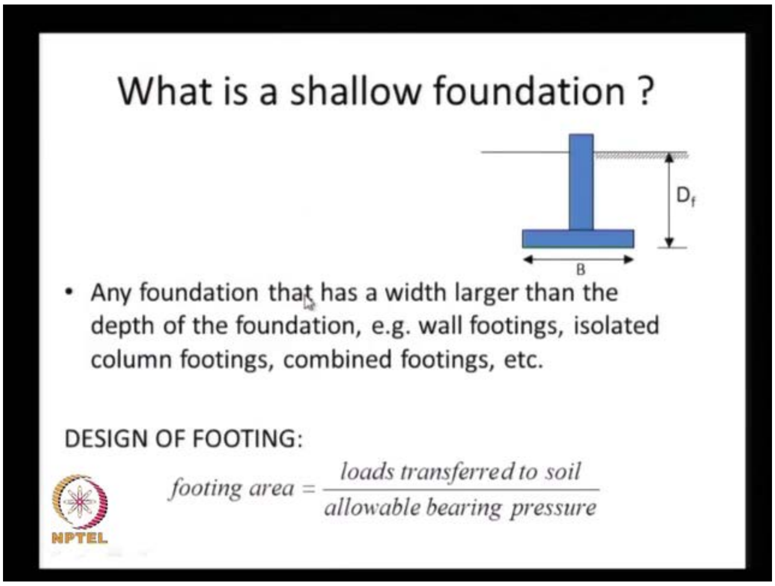

Just briefly recap, let us see what is a shallow foundations. By definition any foundation that is provided at a shallow depth compare to the width of footing is called as a shallow foundation. And here we see a typical illustration, let us say that this footing is of width B provided at a depth of D f. And if D f by D is a less than or equal to 1, we call it as a shallow foundation. And some typical examples of the shallow foundations are the wall footings. These are the footings that are provided below the load bearing walls. And that the footings that we provide below the isolated columns or combined footings and so on, even the rapt they are designed as a shallow foundations and the plan area of the footing that we require is defined as the loads that are transferred to the foundation soil divided by the allowable bearing pressure. And the allowable beating pressure itself is dependent on two different factors.

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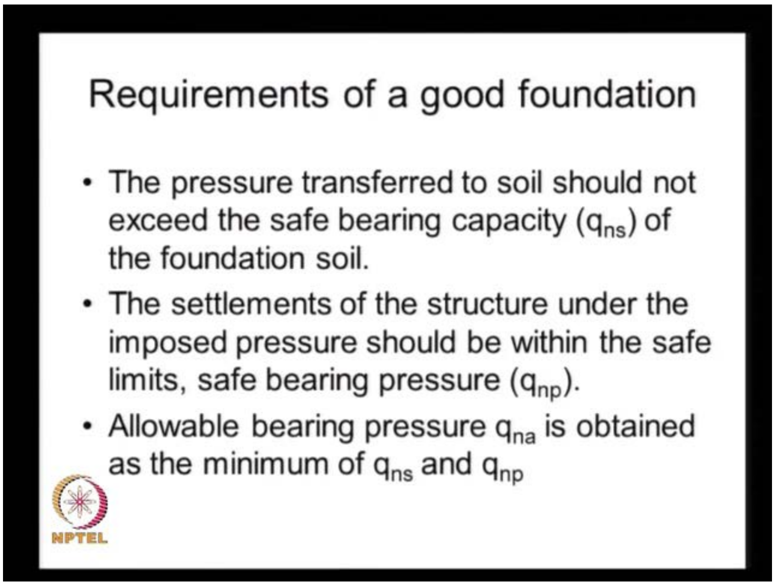

That is the bearing capacity and the settlements. And what are the requirements for a good foundation, say a foundation should a transfer the load into the soil such that the pressure that we are transferring into the soil does not exceed the safe bearing capacity Q n s of the foundation soil. And this safe bearing capacity is dependent on the shear strength properties the cohesion and then the friction angle and the shape of the foundation and so on. And another aspect that we need consider is the settlement of the structure under the imposed pressures. And these settlements they should be within a certain tolerable limits.

And this pressure is a defined as the safe bearing pressure the Q n p. And the allowable settlement are more than the allowable settlement the allowable differential settlement depends on the type of the structure, whether it is a masonry structure or whether it is a reinforced concrete structures or whiter it is steel structure. And once we are able to assess the Q n s and Q n p we define the allowable bearing pressure Q n a as the lower value of the Q n s and the Q n p. And our entire bearing capacity analysis of the shallow foundations is dependent on the this determine in the Q n s and the Q n p.

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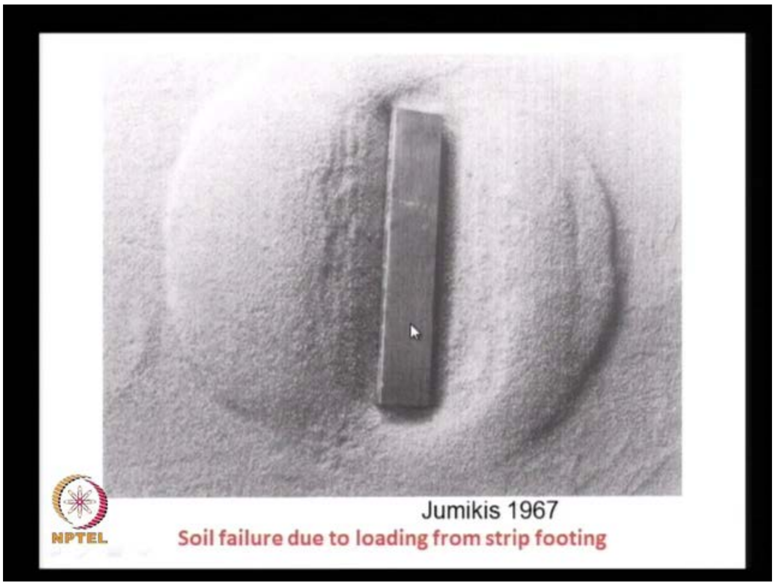

And here we see an example of one of the early pictures from the laboratory test that were performed on model footings. And this particular picture is from the text book by Jumikis that was published in 1967. And here we see an example of a very long rectangular footing that is typical of our wall footings. And if we go on loading it at some point just simply punches into the soil resulting in surface viewing, and large settlements.

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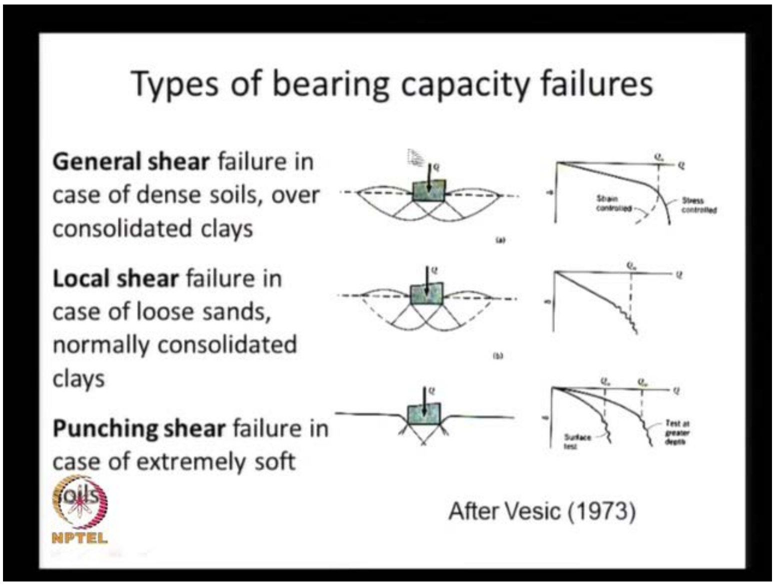

And ((Refer time: 04:24)) and later on several people like the Mehraf and finally Vesic they have define the bearing capacity failures as general shear failure, local shear failure and punching shear failure. And the general shear failure is usually associated with stiff soils dense sands or over consolidated clays, that have very nice sharp peak. And the typical rapture surface looks something like this it is a very well defined rapture surface. And this particular general shear failure is associated with surface viewing. And the other one is the local shear failure wherein there is no defined peak.

And this type of local shear failure happens in the case of loose sands, or normally consolidated clays and the rapture surface in this case, it is not fully develop it is developed only below the footing area and behind the footing area it is not develop. And there could be some small surface viewing not as much as we had in the case of general shear failure. And the other one other type of bearing capacity failure is the punching shear failure and this happens in the case of extremely soft soils. Wherein the footing the simply punches in into the soil without any lateral deformations.

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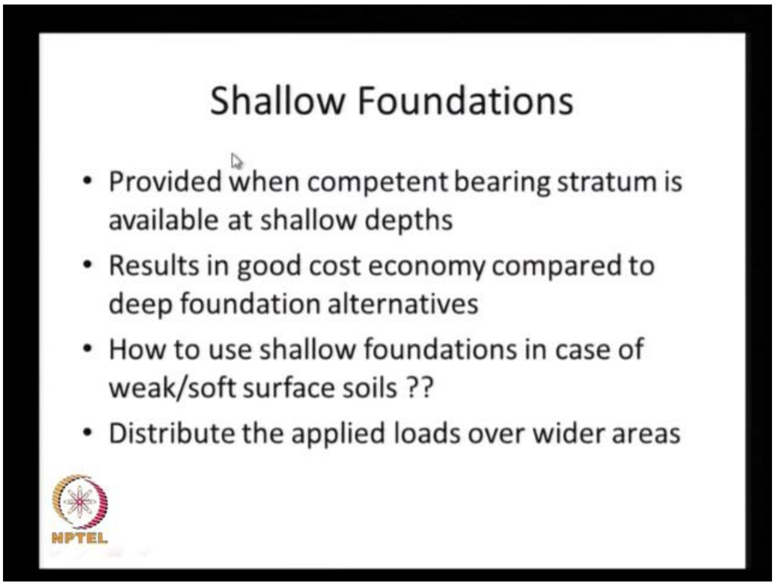

And whenever we have a good quality soil at the surface level, we can go in for shallow foundations. And the and the cost economy that we get with the shallow foundations is much better compare to other deep foundation alternatives. So, our first preference is always for shallow foundations. Whenever we can come out with a design wherein we can transfer the load at a shallow depth we prefer this, but then there could be several cases where our soil is soft that we cannot provide a shallow foundation either because of excessive settlements or excessive differential settlements or very poor bearing capacity or a combination of both. Can we do that, well we can distribute the loads over a wider area. So, that the pressure that is transferred into the soil is lesser or reduced and that could avoid all the problems.

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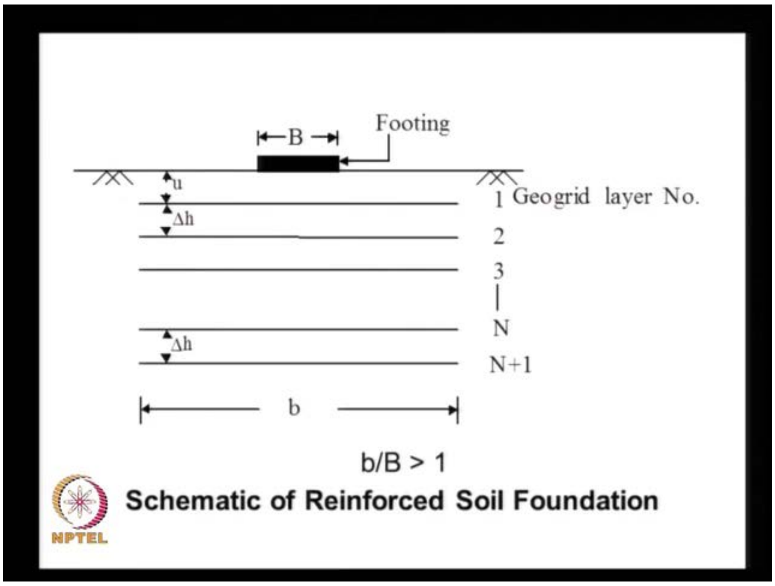

But now with the introduction of the geosynthetics, we have other options. And this particular picture shows a schematic of the reinforce soil foundation. Let us say that we have certain foundation of width b this could be a strip footing or a square footing, or a rectangular footing. And let us say that we have a certain number of reinforcement layers and the topmost one is at a depth of u. And then we have a several layers each placed at a vertical interval of delta h. And these are all the reinforcement layers.

And if we apply the pressure at the of the foundation level because these reinforcement layers there going to interrupt the formation of the rapture surface. So, the soil exhibits a higher strength and also a higher stiffness. And in this the length of the reinforcement that we have that is defined as small b and b by capital B should be much greater than one, so that we good effect from the reinforcement layers.

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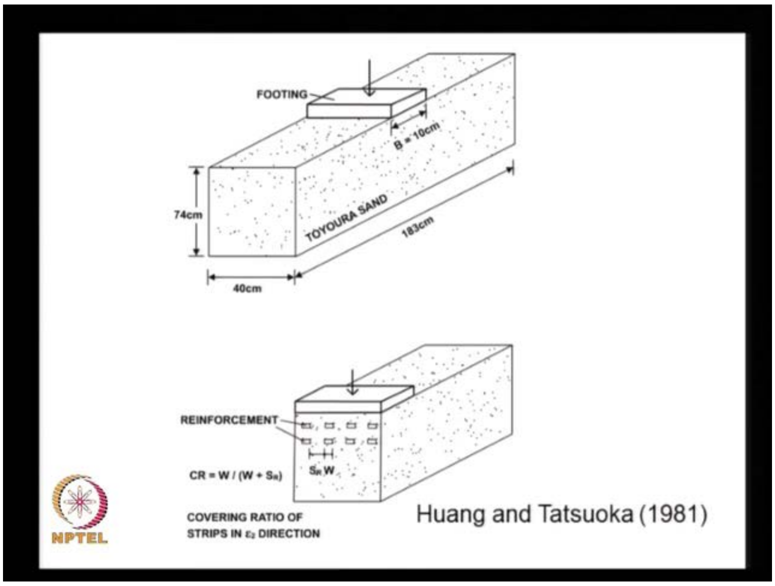

And another form of reinforcement is in provided in the form of steel strips or polymeric strips, wherein they have certain width as we have seen earlier maybe about 50 to 60 millimeters and thickness of about 5 to 6 millimeters. And these are provided at vertical spacing and horizontal spacing. And these are as we have seen earlier these are called at the desecrate type of a reinforcement materials. And this particular picture is a taken from the paper that was published by Huang and Tatsuoka in 1981.

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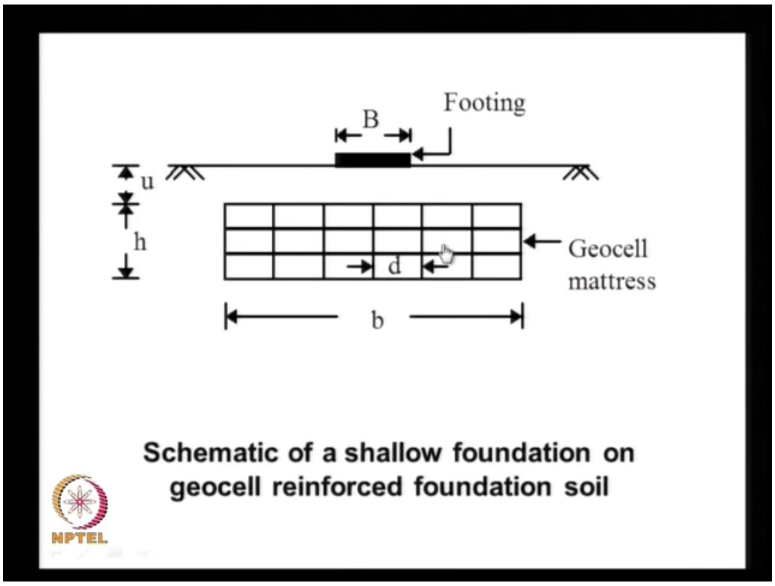

And another form of a reinforcement that we can think is the geo cell matrix that we have seen earlier. And the geo cell pockets could have pocket opening dimension of small d. And this could be provided at a say depth of a u from the foundation level. And let us say that small h is the is the height of the geo cell layer. And the type of improvement that we can get in the case of shallow foundations either reinforced with planar reinforcement strips or geo cell. They depend on the reinforcement density, and also the vertical spacing and how close we can provide reinforce to the, to the foundation and that we will illustrate through some test data.

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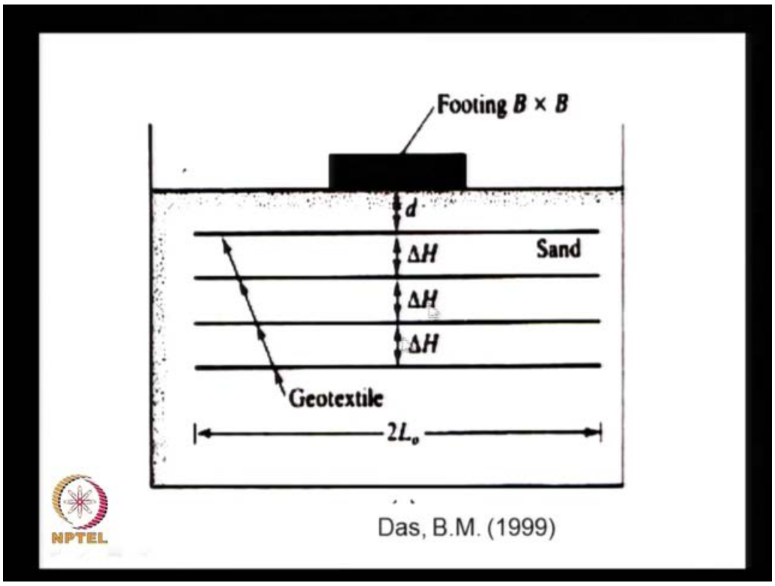

And here we see a picture of a the experimental configuration from B M Das. They have done some test and square fitting of width B by B, and they have done test with sand as infill material. And they have provided the topmost reinforcement layer of depth d and the number of these horizontal set layer reinforcement layer at a vertical spacing of delta H. And the data that is published by them is specific to the case, where the length of reinforcement is twice the twice the footing width.

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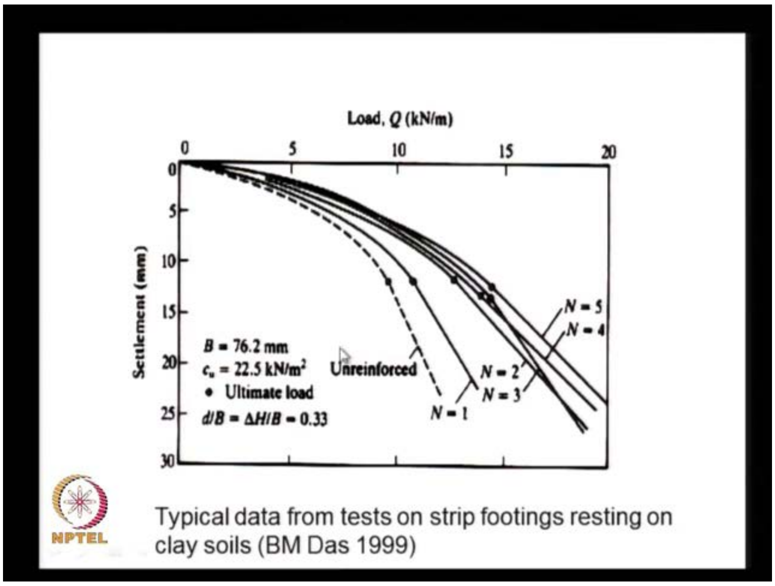

And here we see some example of the data that they have obtained on a wall footing, the load that is expressed in terms of kilo Newton per meter length. And this particular test data is from test for that perform the clay soil having a undrained a cohesive strength of 22.5k p a. And the footing width is 76 millimeters and the topmost reinforcement layer is provided at one third of the foundation width B that is d by B is 0.33.

And the vertical spacing between the different reinforcement layers is also one third of B. And the response of the unreinforced foundation bed is like this shown in the dotted lines. And then the foundation soil is reinforced with different numbers of layers the performance has improved not only the bearing capacity has increased, but also the stiffness that is shown by stiffer response, the initial levels and then even towards the ultimate load levels. And these dots they show the ultimate bearing pressures and we see that as the number of reinforcement layers is increased the bearing capacity.

And also the stiffness in increasing, with one layer the response is like this and with two layers, the response is like this and with three layers the response and with five layers the response is like this. And we see that as the number of reinforcement layers is increasing there is a conversions. So, beyond a certain depth or beyond certain number of reinforcement layers there is no point in increase in layers.

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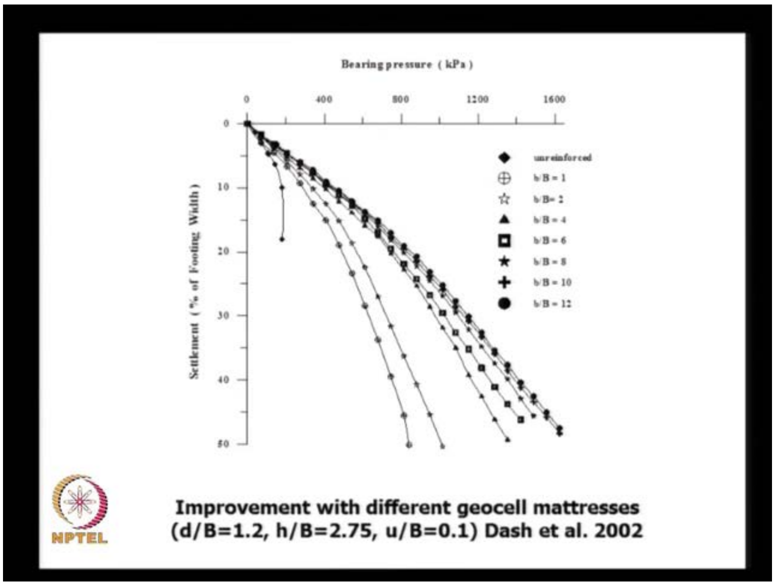

And this particular data that is that was published in 2002 by one of my own p h d student Dash. And this data is pertaining to geocell, and once again the test was performed on sandy soil and sand. And the bearing pressure versus settlement relation for the unreinforced soil is like this, it is actually it has fail about a 200 k p a and with different reinforcement configurations, we can increase the bearing pressure to as much as 1600 without really failing the foundation soil. And this particular data that we are seeing here was obtained with pocket opening size of the geocells approximately 1.1 times the foundation width.

And the height of the geocell is 2.7 times the foundation width. And the top surface of the geocell is at the depth of 0.1 b. And we see that when b by b is 1 that is a when the geocell layer is exactly width of fitting this is the type of response we get. We get almost double the bearing capacity at similar settlements levels. And as the geocell layer width is increasing we get much better performance. In all the cases you see that the stiffness is increasing that is at a given displacement at pressure developed below the reinforced foundation is much higher.

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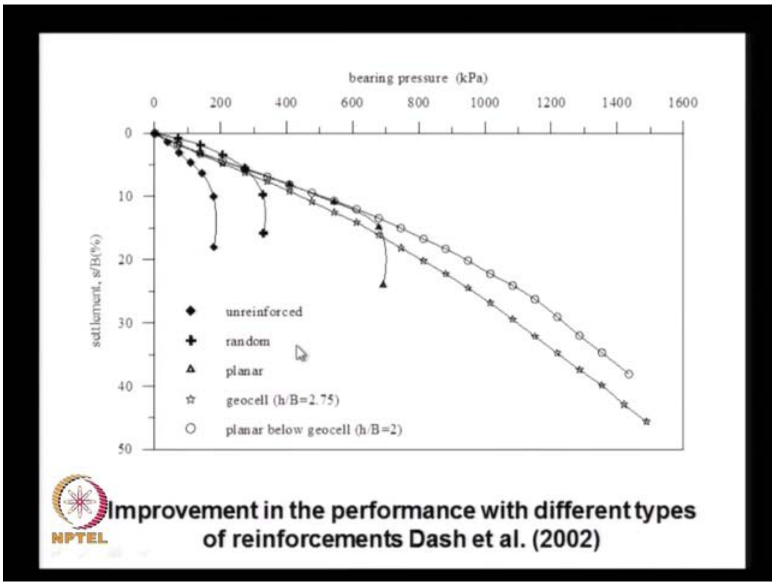

And here you see the data that was obtained by test with different types of reinforcement materials. Once again this is the pressure settlement data reinforced soil and this particular one is with random reinforcement of the foundation soil. The random one reinforcement was provided in the form of small strips, small meshes, mesh elements and they were added to the soil about 2 percent by volume. And the planar reinforcement the response is like this and geocell the response is like this. And if we provide another planer reinforcement layer below, the geocell that could act like a separate layer you get even better performance.

And this is the type of response that we get with the geocell plus planer reinforcement layer. And in all this cases we see that the foundation bearing pressure can be increased tremendously. And in the case of planer reinforcement in the ultimate bearing pressure was about 700 k p a. And with geocells you can increase it much beyond even 1200, 1400 without any sign of failure. And in all this cases what we should notice is we require very large settlements. So, that we can mobilize the reinforcement forces to have any impact on the bearing capacity on the response of the reinforced footing.

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Summary of Test data from different investigators

Series of Tests	Type of Reinforcemen	Optimum geometric parameters of reinforcement to get maximum benefit			
		u/B	Δh/B	b/B	N
Binquet and Lee (1975a)	Aluminium foil strips	0.333	0.333	20	6
Fragaszy and Lawton (1984)	Aluminium foil strips	0.334	0.334	7	3
Huang and Tatsuoka (1990)	Metallic strips (sand glued surface)	0.3	0.3	6	3
Khing et al. (1993)	PP-HDPE Geogrid	0.375	0.375	6	6
Omar et al. (1993)	PP-HDPE Geogrid	0.333	0.333	8	6
Krishnaswamy and Athavan (1994)	PP Geogrid	0.350	0.350	7	6

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And brief summary of the different test data is like this Binquet and Lee way back in 1975, they published an excellent paper on the bearing capacity of reinforced soil beds. And they have done the tests with aluminum foil strips, and they recommended that for maximum benefit, the topmost reinforcement layer should be at the depth of one third of the foundation width. And the vertical spacing between the different layers of reinforcement is once again one third. If the b and the length of the reinforcement, they recommended is at least 20 times the foundation width and the number of reinforcement layers is 6.

And Fragaszy and Lawton once again they have done with different the same similar type of aluminum foils. And they also concluded that the topmost reinforcement layer should be at a depth of one third b and the vertical spacing is the same, but they say that beyond length of reinforcement equal to 7 times the foundation width there is no further improvement.

And they also said that the number of layers could be limited to 3 because beyond that they have not seen much of an improvement. And Huang and Tatsuoka they have done the test on metallic strips mush stronger than the aluminum foil strips. And to make this metallic strip very rough they have glued sand to their surface, and they also concluded that the u by b and delta h by b is about 0.3. And they also concluded that the length of the reinforcement could be limited to 6 the number of reinforcement layers could be only 3.

And the Khing et al 1993, they have done the test with polypropylene and h d p e geogrids. And they recommend u by b of 0.375 and vertical spacing of 0.375. And the length of reinforcement is 6 and the number of reinforcement layer is 6. And Omar et al they have also done the test with polypropylene and h t p e geogrids. And they also recommend a similar thing.

The only difference is they recommend slightly longer reinforcement lengths of 8 times the foundation width. And the Krishnaswamy and Athavan they did some tests on with polypropylene geogrids, they also concluded the similar results. So, we see that it is possible to increase our bearing capacity and reduce our settlements by providing a certain length of reinforcement and certain number of reinforcement layers.

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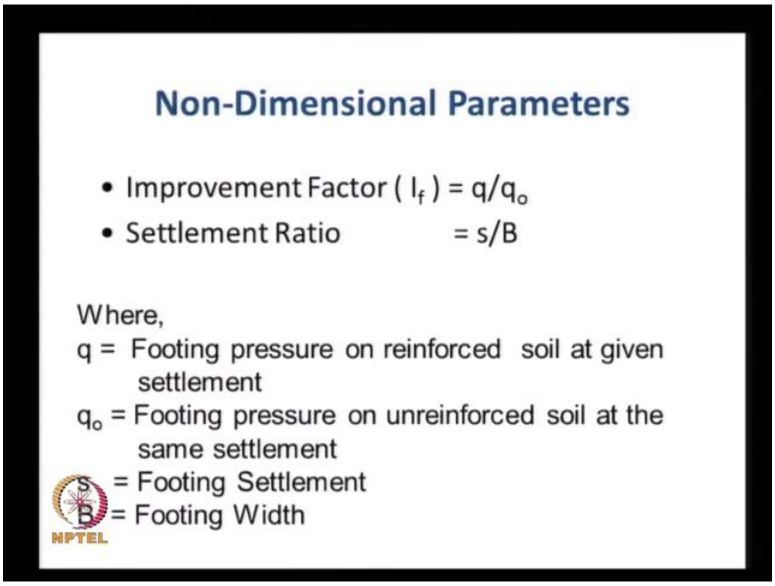

And just to present briefly on defining two non dimensional factors. One is improvement factor i f, that is defined as q by q naught. Where the q is the footing pressure at a given settlement of a reinforcement soil and the q naught is the footing pressure on unreinforced soil at the same settlement level. And the settlement ratio s by B where s is the footing settlement and B is the footing width. And I will now present brief summary of different test results.

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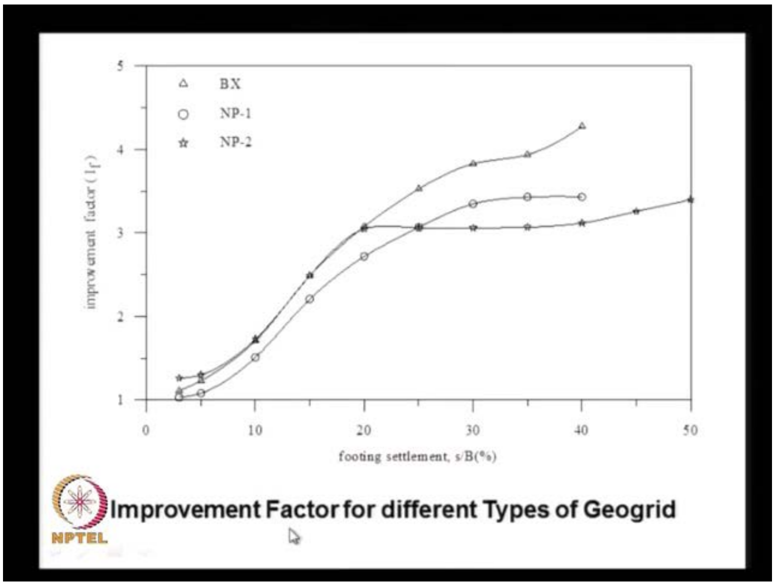

And here we see a result on the effect of the type of reinforcement on the improvement factors. Three different type of reinforcement materials for considered the B X standing for biaxial N P- 1 and N P- 2. These are very soft meshes and their load strain behavior is like this.

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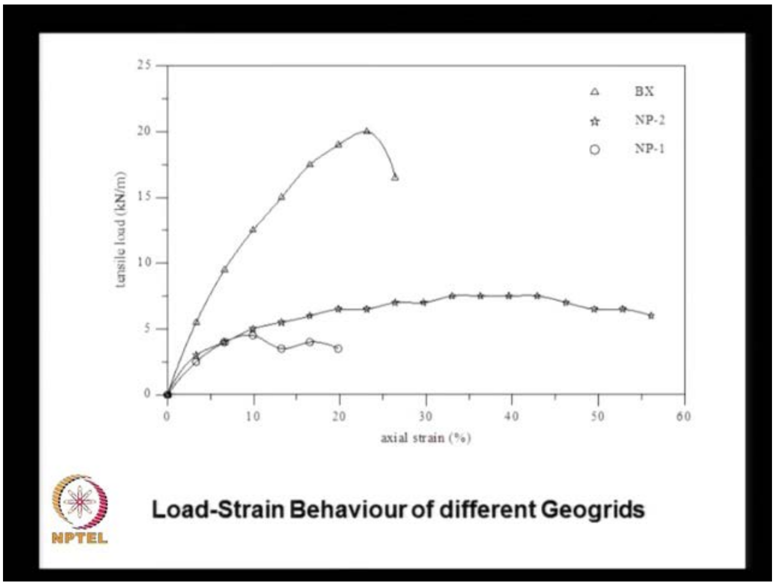

Actually B X is a polypropylene geogrid, it is it is biaxial it has a peak tensile strength of 20 kilo Newton per meter at about 20 percent strain. N P- 1 and N P- 2 they are very soft meshes and both of them they have about 5 to 7 kilo Newton per meter strength. That is developed at a very large strain levels. The improvement factor i f is the ratio between the footing pressure. In the case of reinforcement divided by the footing pressure on the unreinforced foundation bed both measured at the same settlement. And on the horizontal axis we have the settlement given in terms of the footing width.

And at a low settlement levels the as the improvement factor is nearly equal to 1, and as the settlement ratio is increasing our improvement factors increases improves. And N P-2 that is the softest mesh, beyond a settlement of about 20 it has remained flat that means that the mesh cannot mobilize any additional force. And the maximum improvement factor that we can get is about 3. And the N P-1 is slightly stiffer it has about 3.5 improvement factor. And the B X the biaxial geogrid that is much stiffer compared to these two it has shown bit more improvement. And so we can see that as the stiffness of the reinforcement increases we get better performance.

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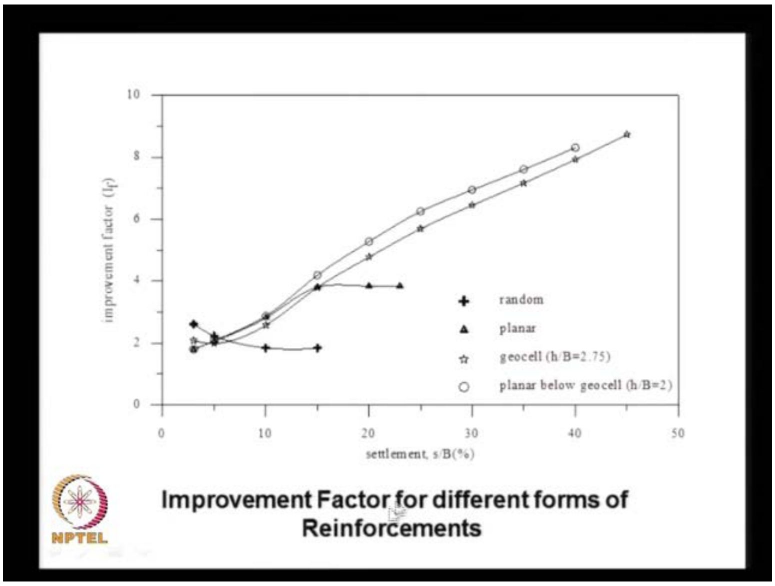

And for different types of reinforcement forms that is the random reinforcement, planer geocell and so on. So, this plus sign is with random reinforcement. Random reinforcement as I mentioned earlier it is provided in the form of small meshes. And as the settlement increases is actually it has shown a deteriorating performance at a very large settlement ratio of 15 percent. The improvement factors reduced about 2 at a lower values the improvement factor was nearly 3. And the planer reinforcement it has shown maximum improvement factor 4 that is at settlements beyond about 15 percent of the of the footing width.

And the geocell it has shown very good improvement factor almost 8, but then it happens at a very large settlement level. And if we are able to provide for planer reinforcement layer below the geocell we get even better performance. And in here we see that the result with geocell is with a height of a geocell equal to 2.75 times the footing width. Whereas if you provide a horizontal reinforcement layer even with h by b of 2, we get improved performance that is because when we have a horizontal reinforcement layer, it prevents the soil from flowing down through the geocell pockets. And it acts some addition benefit and we get slightly better performance.

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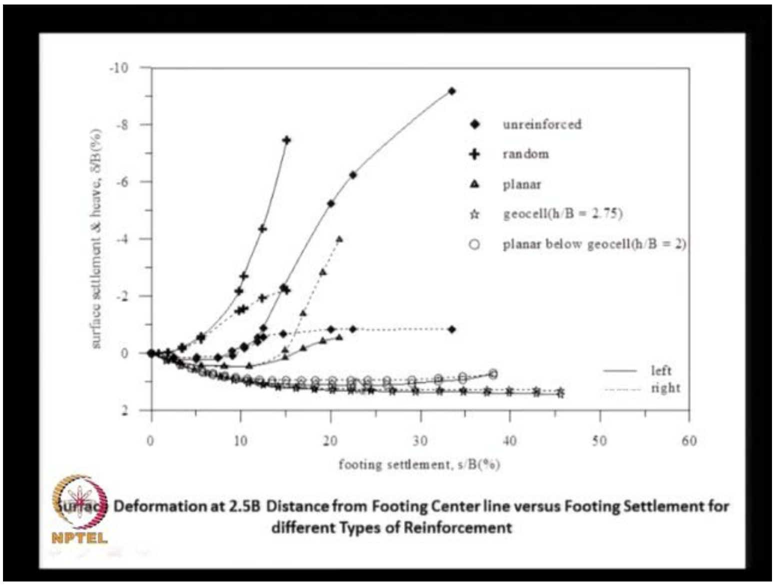

And more than the settlements we are more concerned about the differential settlements. And this particular picture we surface the difference in the settlement between the left side of the footing, and the right side of the footing for different types of reinforcements and reinforce soil random reinforcement planer the geocell with height of 2.75 times the footing width. And the planer reinforcement below the geocell with h by b of 2, and the solid lines they show the settlement on the left side. And the dotted line shows the settlement on the right hand side. I will just briefly sketch this picture.

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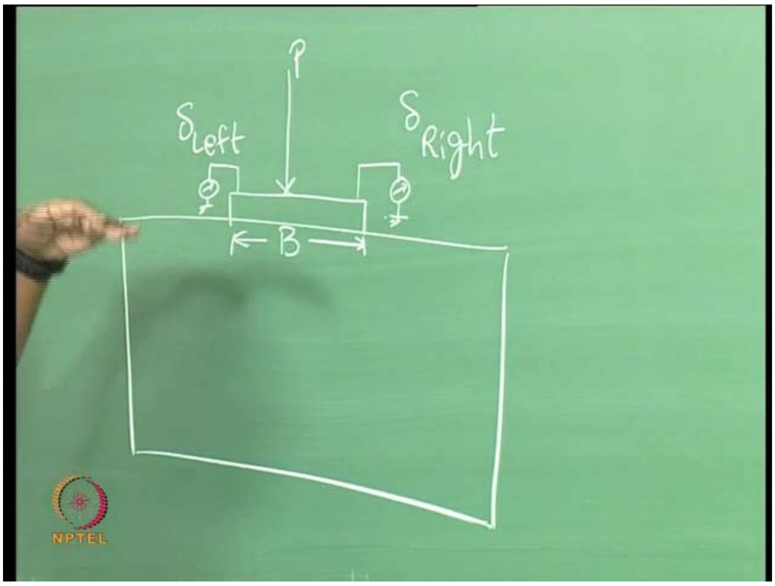

See in all our soil test we deal with soil which is not homogeneous and because of that the although, we apply a uniform pressure on footing we cannot expect uniform settlements because of the difference in the soil properties, the footing may not settle down uniformly it may undergo some differential settlements. And that differential settlement is expressed in terms of the settlement on the right hand side, and left hand side of the footings. And here we see that in the case of and reinforce footings the difference between the left and right hand side is very predominant. Here we see these two lines they show the settlement on the left and right hand side.

And there is very large difference and with random reinforcement we can control them to some extent at up to about say about 7 percent or 6 percent settlement. Both the left hand side and right hand side they have settled by the same magnitude only at a higher settlements. Say starting some about 7 or 8 percent of the difference between the left hand side and the right hand side is increasing, whereas if we see the response of the planer reinforcement material is actually it is not bad. It is up to about 12 percent settlement both the left hand side and the right hand side of the footing have settled by the same amount. And only beyond that settlement level the difference has come out and that means, that up to very large settlements once we have a reinforcement we can prevent the differential settlements. And the result with geocells is more predominant.

And actually here we see that the any displacement above this point shows the heaving, and any displacement below this point shows the settlement. And there was a too much of heaving in the case of unreinforced and random reinforcement layers, where as the because there is nothing to prevent them. Whereas in the case of planer reinforcement there was a compressional deformation, or settlements up to about 11 percent of the settlement, and beyond that only there is some soil heaving. But when we provide reinforcement in the form of three dimensional mattress, that is geocell all the settlements are compress that is the downward settlement. And we see that both the left side and the right hand side they have settled almost uniformly. That means, that the we have achieved uniform settlement and that to a very large extend it is all our structural problems because our tracking that we get in the walls, or in the beams they are all because of the differential settlements.

And see even up to about these test where performed up to about 30 to 40 percent settlements. And we see that the difference between the left hand side and the right hand side it is negligible. So, we can say that with the provision of reinforcement layers within the foundation we can reduce not only the settlements, but also the differential settlements.

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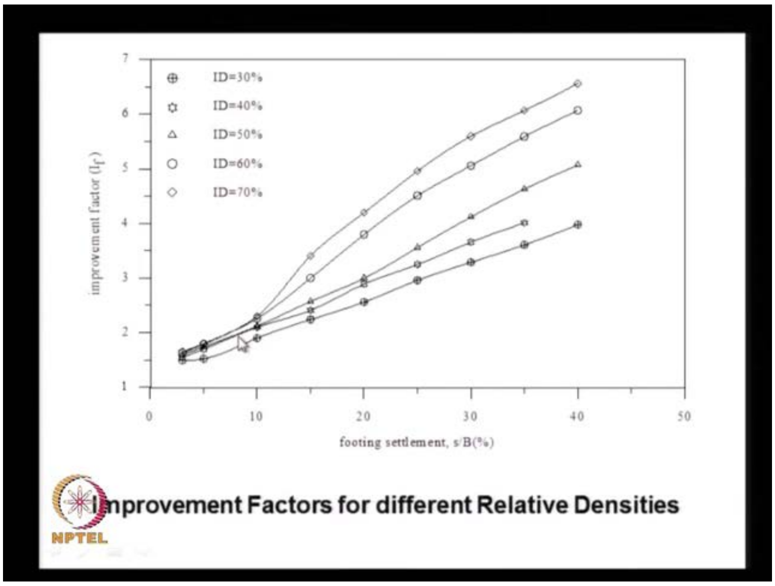

And the particular result shows the influence of the relative density of the soil because we know that the relative density place a very important role, in the friction angle of the soil. And we have seen in the early part of this course that if you have a higher friction angle, you can mobilize higher reinforcement forces because better interaction. And that result we see here, when we do the test with very low relative density of 30 percent. This is the bottom the bottommost curve is the response the improvement factor with different settlement ratios.

And when we repeat the same test at much higher relative density 70 percent this is the type of response answer all the results are with similar type of reinforcement. So, we can have 1 to 1 correspondence or 1 to 1 comparison between the between the different results. And the only variable this test is the relative density. So, we can see that say at about 20 percent footing settlement when we have a relative density of 30 percent the improvement factor is about 2.5, but at the same time if we have a relative density of 70 percent we can get a improvement factor for almost 4.5. So, that is much higher improvement factor that we can see.

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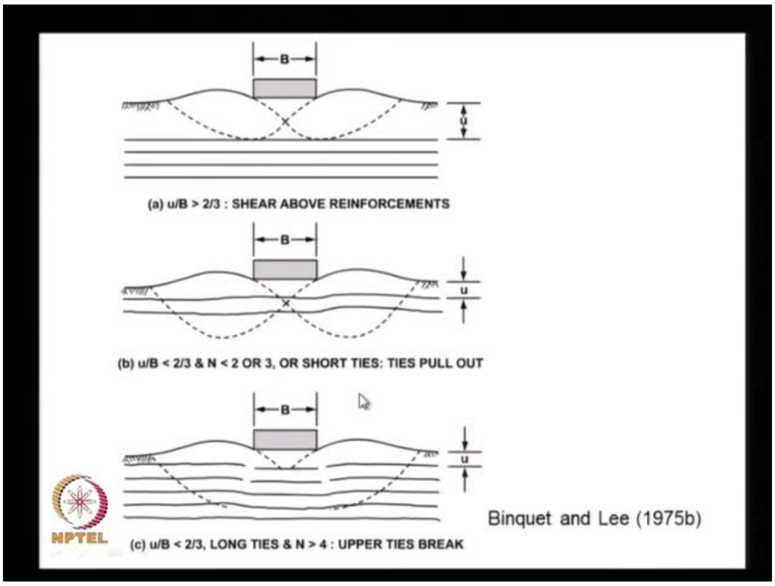

And in terms of the analysis of the bearing capacity of the reinforced soil beds Binquet and Lee, they have published an excellent paper wherein they summarized three different failure modes. The first one is if we provide very large number of reinforcement layers say starting from u by B of greater that two thirds, u is the depth to the topmost reinforcement layer because our the reinforce the soil so strong that the failure happens within the soil above the topmost reinforcement layer. And this particular case is very similar to a case, where we have a soil of limited depth compared to the foundation width in which case a bearing capacity could be very high.

And the first case assumes that the reinforcement layers they are of sufficient length, and the second mode of failure is with the u by B of less than two thirds. And number of layers is about 2 to 3 and with short ties of the short reinforcement layers. And the failure mode is more by a pull out that means, that as we are increasing the applied load the reinforcement just simply separate sort of from the soil mass by means of pullout. And the third case refers to u by B of less than two thirds and very long tires, and the number of reinforcement layers is greater than 4. And if you do not have sufficient strength in the reinforcement layers the we get a tie failure. So, we have a three modes of failure that is that was proposed by Binquet and Lee. The first one is the share happening within the unreinforced soil above the topmost reinforcement layer. And the second one is the pullout of the reinforcement layers. The third one is the rapture of the reinforcement layers.

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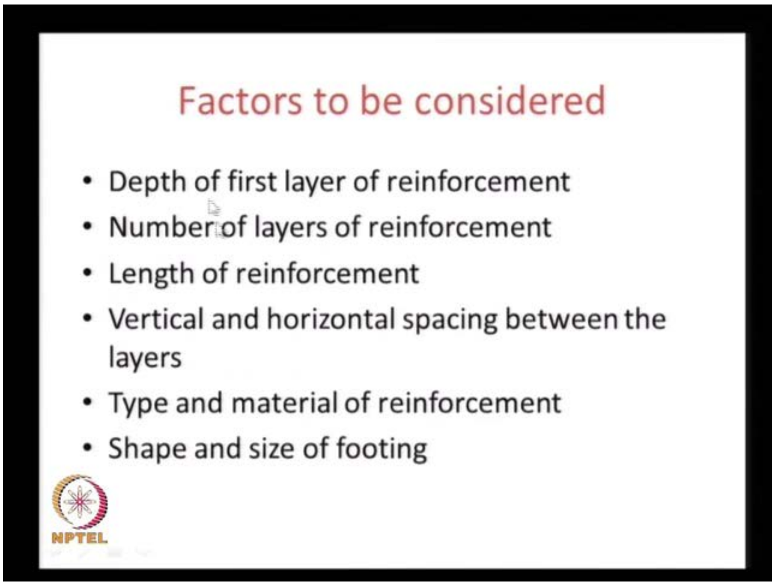

And so just to summarize the different factors that we need to considered, or the first important factor is at what depth do we provide the first reinforcement layer, and it should be provided as close to the foundation is possible. So, that we get the maximum benefit and then the number of reinforcement layers, so that we get good improvement. And different investigators they have shown different number of reinforcement layers anywhere ranging from 3 to 6. The length of the reinforcement layers anywhere from 6 to 8, then the vertical and horizontal spacing between the layers, the results very important. And we have seen that the vertical spacing should be about B by 3, that is one third of the B. And the type of reinforcement material if the reinforcement is stiffer, and stronger it can provide a much better improvement and the response that we get also depends on the shape and size of the footing.

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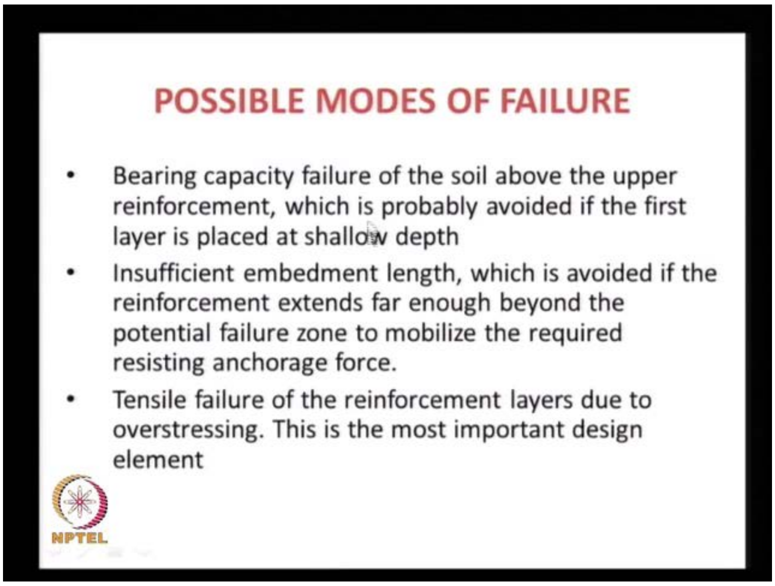

And we have seen that there are different possible failure modes. And the bearing capacity failure of the soil the upper reinforcement layer is one possible failure mode. And this could be avoided by placing the first reinforcement layer at a sufficient shallow depth, or the other mode of failure is when we provide very short reinforcement length, the failure is pullout. And the other mode of failure is detention failure or the rapture failure.

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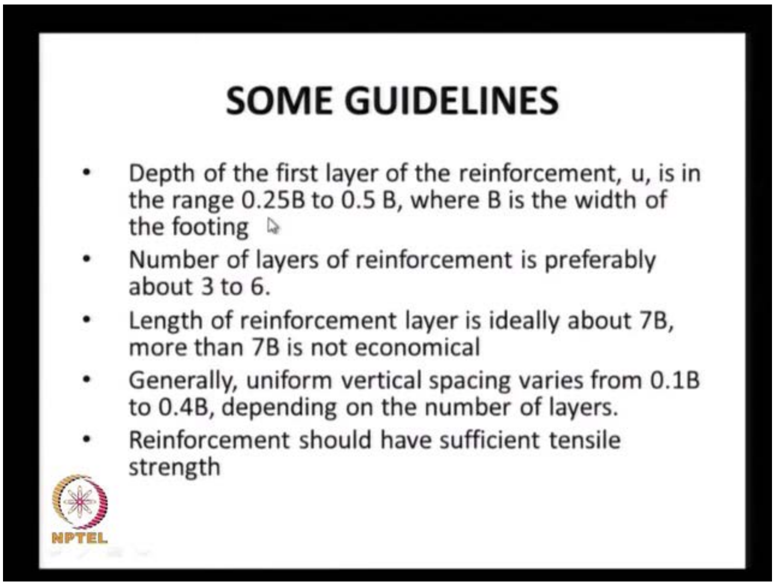

And some guidelines that we can proved based on the different experimental data is, the first reinforcement layer can be provided at a depth of about 0.25 to 0.5 B, where B is the width of the footing. The number of reinforcement layers can range anywhere from 3 to 6. And the length of the reinforcement layer should be at least about 7 times the foundation width, and vertical spacing anywhere from 0.1 to 0.4 B, depending on the number of reinforcement layers. If we provide a very few reinforcement layers then it may be preferable to space them higher so that we cover more depth. And the reinforcement layers should have a sufficient tensile strength. So, in this lecture I have briefly provided summary of the experimental data. And in the next lecture, let we will look at the theoretically analysis and how to explain the bearing capacity improvement that we can use for design.

Thank you very much.