Geosynthetics Engineering: In Theory and Practices
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Lecture - 35
Geosynthetics for Reinforced Soil Retaining Walls

Dear student warm welcome to NPTEL phase 2 video course on geosynthetics engineering in theory and practice. My name is Professor J. N Mandal, department of civil engineering, Indian institute of technology, Bombay, Mumbai, India, this lecture number 35, name of the course geosynthetics engineering in theory and practice. This module 6, lecture number 35 geosynthetics for reinforced soil retaining wall.

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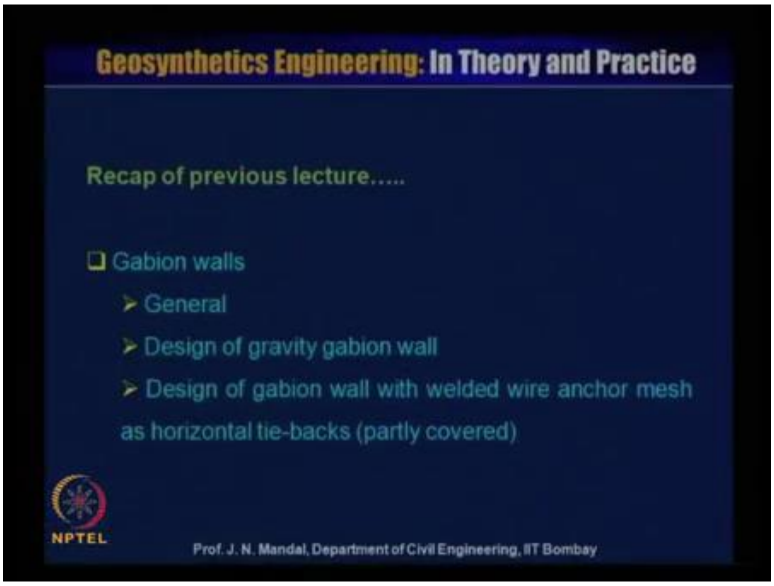

I will now show the recap of the previous lecture. We covered the gabion wall, general, design of gravity gabion wall and design of gabion wall with welded wire anchor mesh as a horizontal tie-backs that partially covered. Now, I will now continue with the remaining part of this example.

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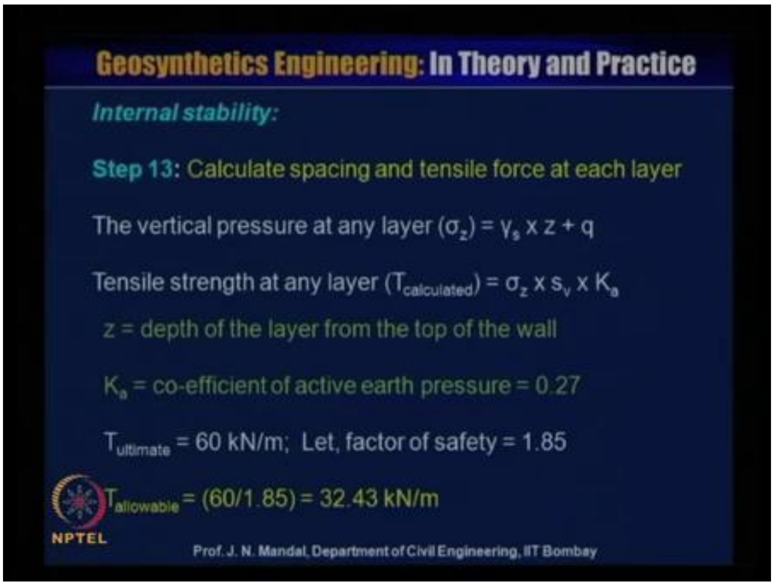

So, we have covered this external stability now, I will address the internal stability, that is step 13. You have to calculate the spacing and the tensile force at each layer, the vertical pressure at any layer, if it is a sigma z will be equal to gamma s into z plus q. Where q is the surcharge load, gamma s is the unit weight of the soil and z at any depth of the layer from the top of the wall. Now, tensile strength at any layer T calculated will be equal to sigma z into Sv into K of a. So, where K a is coefficient of active earth pressure that we have calculated earlier, that is 0.27 and Sv is the spacing between the two reinforcement. Now, T ultimate we know say, about 60 kilo Newton per meter, let the factor of safety 1.85. So, T allowable will be equal to 60 divided by 1.85 is 32.43 kilo Newton per meter.

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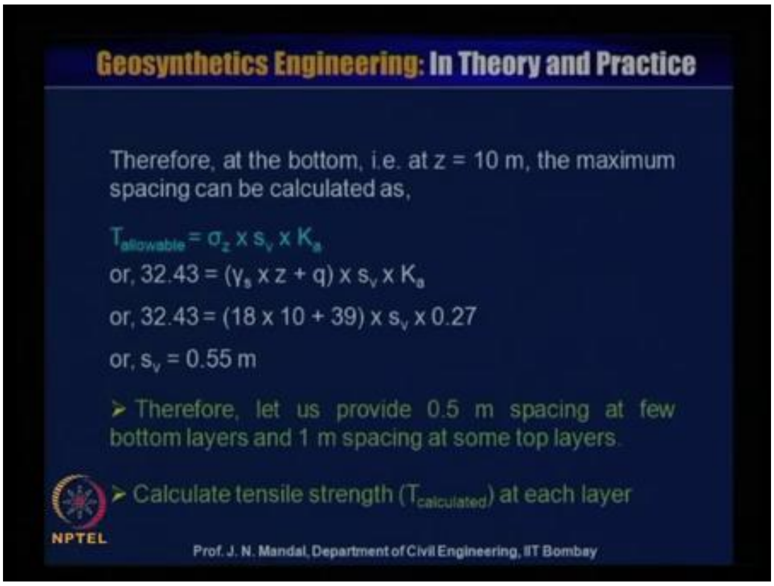

Therefore, at the bottom that is at z is equal to 10 meter because this is the 10 meter height of the wall. So, maximum spacing can be calculated as T allowable is equal to sigma z into Sv into K a. We know what is T allowable we calculated 32.43, we already knows this value and then sigma z is equal to gamma s into z. And this plus, this is the surcharge load q into Sv into K a so this gamma s is 13, z is at the base of the wall, that is 10 meter and surcharge load q is 39 into Sv and K a is 0.27. So, from this equation you have to calculate that what will be the Sv, spacing between the two reinforcement. So, Sv can be calculated as 0.55 meter therefore, let us provide 0.5 meter spacing at few bottom layer. And then, the 1 meter spacing at some top layer, calculate tensile strength T calculated at each layer.

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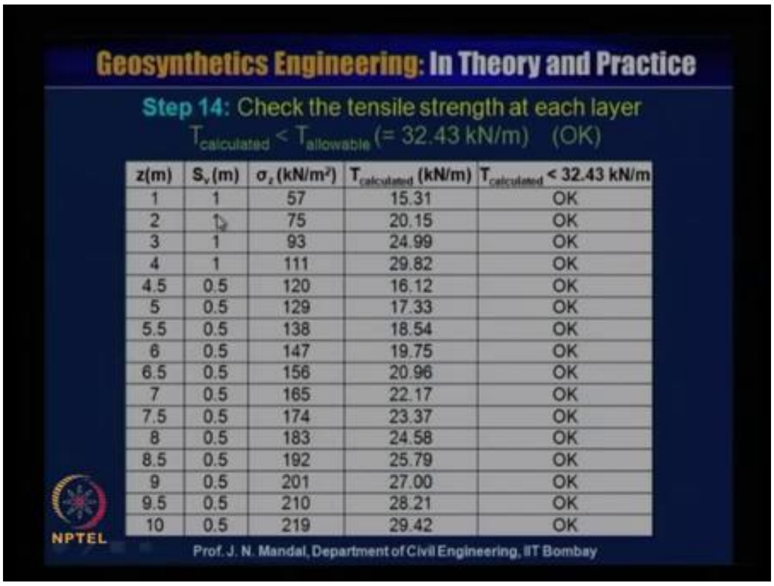

z(m)	S_v(m)	σ_z (kN/m²)	$T_{calculated}$ (kN/m)	$T_{calculated}$ < 32.43 kN/m
1	1	57	15.31	OK
2	1	75	20.15	OK
3	1	93	24.99	OK
4	1	111	29.82	OK
4.5	0.5	120	16.12	OK
5	0.5	129	17.33	OK
5.5	0.5	138	18.54	OK
6	0.5	147	19.75	OK
6.5	0.5	156	20.96	OK
7	0.5	165	22.17	OK
7.5	0.5	174	23.37	OK
8	0.5	183	24.58	OK
8.5	0.5	192	25.79	OK
9	0.5	201	27.00	OK
9.5	0.5	210	28.21	OK
10	0.5	219	29.42	OK

So, you can see from the step 14 that, you check the tensile strength at each layer. So, T calculated should be less than, T allowable that is 32.43 kilo Newton per meter. In this table, you can see here, this is the 10 meter height of the wall and up to this depth 4.5 meter, we are keeping the spacing between the two reinforcement 0.5 meter. And the remaining, we are keeping 1 1 1 1 1 meter spacing, so this gabion type of wall facing it may be that, 1 meter or it may be the 0.5 meter in a half of the gabion, as a facing in the, in this zone.

Now, sigma z we have calculated at different that depth so these are the value 57 and then it is gradually increasing and then, up to the 10 meter depth is 219 kilo Newton per meter square. Now you have calculated, T calculated kilo Newton per meter it is starting from 15.31 and then, we can see that it is increasing and 29.42, so T calculated value is 29.42.

So, this T calculated value it should be less than T allowable value, that means 32.43 kilo Newton per meter. If it is less than the allowable value 32.43 that means, it is okay so that means T calculated less than 32.43 kilo Newton, that is why it is okay so this design is okay. Sometimes when you will change this spacing between the reinforcement, suddenly 0.5 to the 1 meter or like that, if you can do that sometimes, it may not be satisfied, this T calculated value. So, you are to the, select the spacing also, sometimes depending upon that what will be the strength of this material. So, you can, you can go 1 meter you can see which can be satisfy this criteria.

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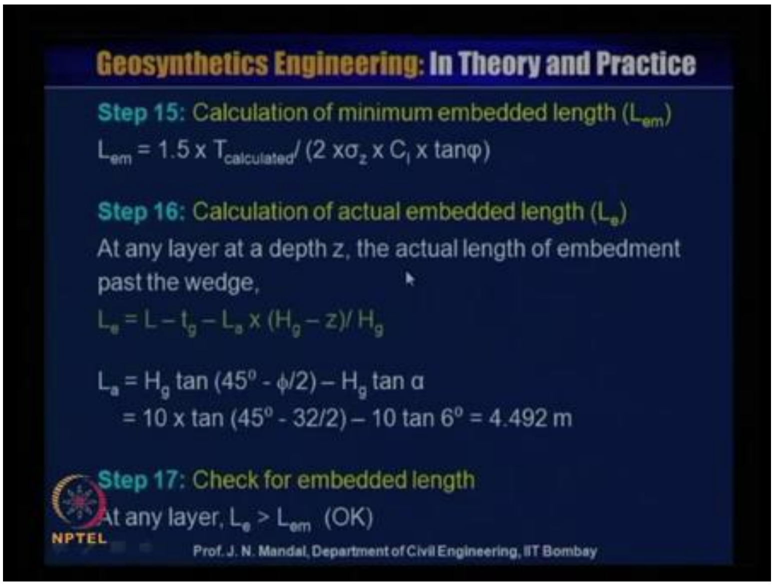

Now, step 15 calculation of minimum embedment length that is L em, L em is equal to 1.5 into T calculated divided by 2 into sigma z into C of i into tan of phi. Step 16, you have to calculate the actual embedment length L e. So, at any layer at a depth of z, the actual length of the embedment past the wedge, that is L e is equal to L minus t g minus L a into H g minus z divided by H g. We have already explained this embedment length now, you L a would be also H g into tan 45 degree minus phi by 2 minus H g into tan alpha. So, this is L of e and this is L of a.

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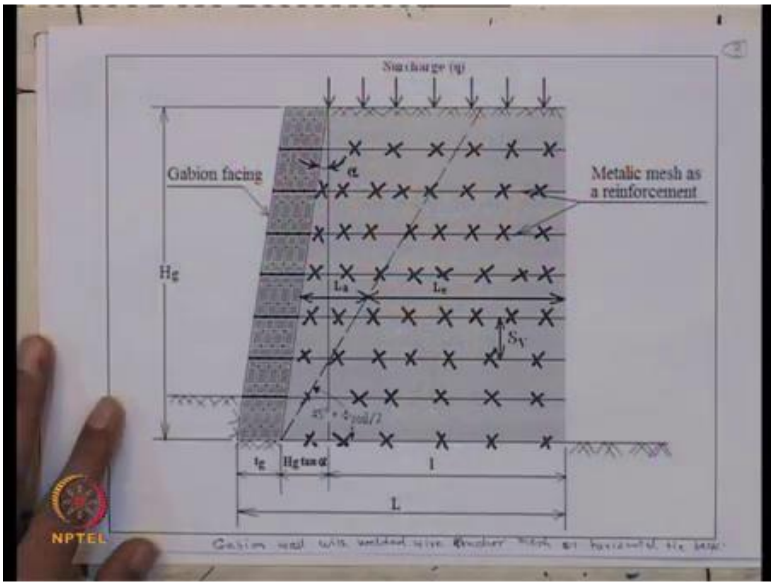

So, that means that this part, this part is the L e that means which is the L, this is minus T g and then this minus L a and into L a into H 0 at any depth. So, that is why L a into H g minus z divided by H g, H g is the height of the wall and L a is this part, L a. So, L a this angle is 45 degree phi by 2, so this angle will be 45 degree minus phi by 2.

So, L a will be equal to H g into tan 45 degree minus phi by 2 minus H g of tan of alpha so you can calculate it from this. So, we can obtain that H of L a, H g is equal to 10 tan 45 degree, phi 32 minus H g 10 tan alpha value 6 so 4.492 meter. Step 17, check the embedment length, at any layer this L e that means actual embedment length, should be greater than this minimum embedment length, L em is minimum then if it can satisfy then it is ok.

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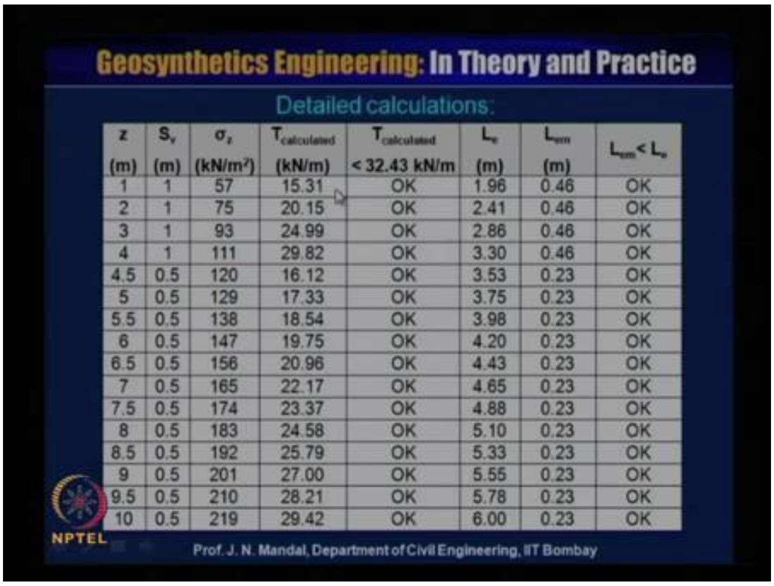

z (m)	S_v (m)	σ_z (kN/m²)	$T_{calculated}$ (kN/m)	$T_{calculated}$ < 32.43 kN/m	L_e (m)	L_{em} (m)	$L_{em} < L_e$
1	1	57	15.31	OK	1.96	0.46	OK
2	1	75	20.15	OK	2.41	0.46	OK
3	1	93	24.99	OK	2.86	0.46	OK
4	1	111	29.82	OK	3.30	0.46	OK
4.5	0.5	120	16.12	OK	3.53	0.23	OK
5	0.5	129	17.33	OK	3.75	0.23	OK
5.5	0.5	138	18.54	OK	3.98	0.23	OK
6	0.5	147	19.75	OK	4.20	0.23	OK
6.5	0.5	156	20.96	OK	4.43	0.23	OK
7	0.5	165	22.17	OK	4.65	0.23	OK
7.5	0.5	174	23.37	OK	4.88	0.23	OK
8	0.5	183	24.58	OK	5.10	0.23	OK
8.5	0.5	192	25.79	OK	5.33	0.23	OK
9	0.5	201	27.00	OK	5.55	0.23	OK
9.5	0.5	210	28.21	OK	5.78	0.23	OK
10	0.5	219	29.42	OK	6.00	0.23	OK

So, here detailed calculations have been shown, this is the depth z. We know the spacing, we have kept up to the 4, this is 1 meter spacing and then after that remaining portion is 0.5 meter fitting. We calculated sigma of z is 57 to 219 kilo Newton per meter square, we calculated T, whatever the calculated is 15.3 one kilo Newton per meter to 29.42. Now, we also calculated, T calculated which is less than 32.43 kilo Newton, that means it is ok. Now, the other part is that, this is L e, this is L em and L em always should be less than L e.

So, you can see that, this is the L of e embedment length that is it is starting from 1.96 meter and then, gradually increasing it goes to about 6 meter. So, this is the L of e and if you calculate that L of em that is a minimum embedment length, it should be 0.46 to going down to 0.23. So, you can see this L em value is always less than the L e, that means it is okay.

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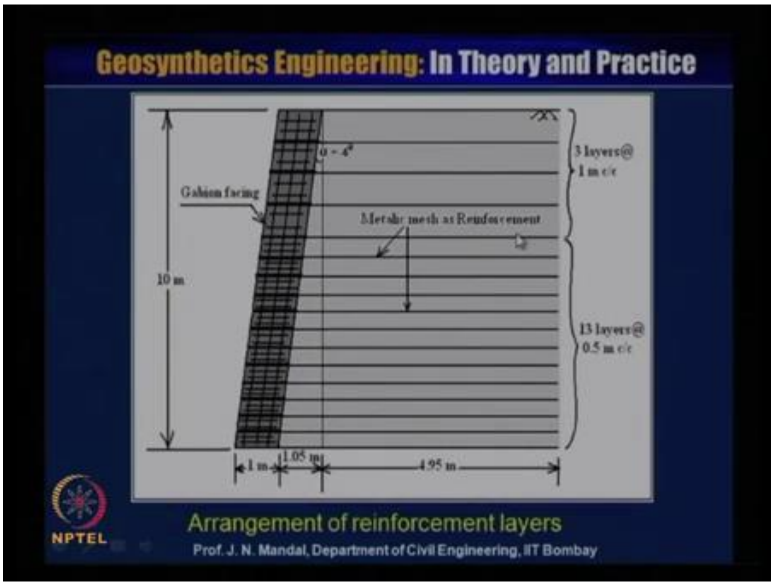

So, like that you can make the design so this is the arrangement of the reinforcement in different layer and we know, this is the height of the reinforced soil wall. And this is the gabion as a spacing, gabion as a spacing. So, here you can see that 0.5 millimeter spacing so up to 13 layer you have given 0.5 millimeter spacing, that means 13 layer into 0.5 millimeter means, you are giving up to this is 13 layer. And after that, the remaining three layer at a spacing of 1 meter so we are giving 1 meter interval. And this angle you know, that alpha 60 degree and this is given the T g, what we call 1 meter, this you know is minus T g, this is 1.05 meter and this L is 4.95 meter.

So, you need also proper connection with the gabion, with this reinforcement, metallic reinforcement you should, proper strip is to be connected. So, gabion wall generally the 1 meter q so in the bottom part you have to make half-half, that means 0.5 meter then, place the reinforcement then, 0.5 meter then you place on it. Like this up to that 13 layer and after that, this is 1 meter length. So, like this you can also design the gabion wall so this kind of the structure also has been implemented in India.

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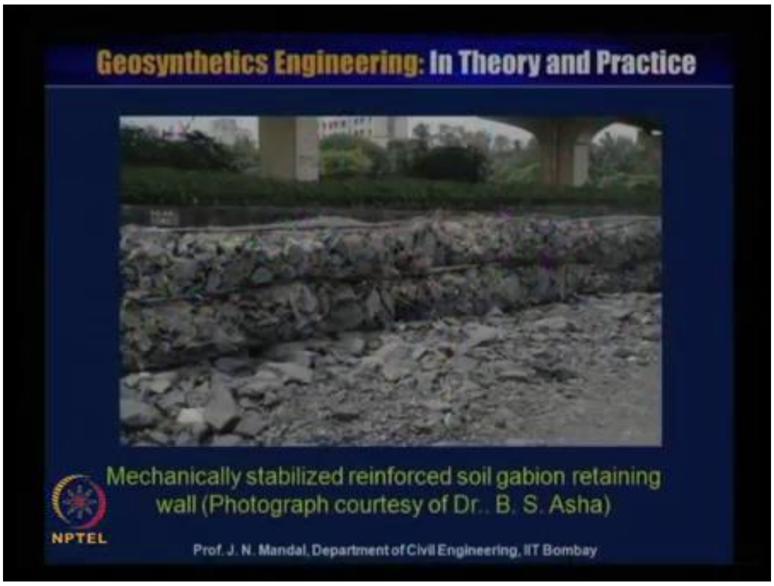

So, this is one that is small that mechanically stabilized reinforced soil, this gabion retaining wall, this is courtesy to doctor Asha.

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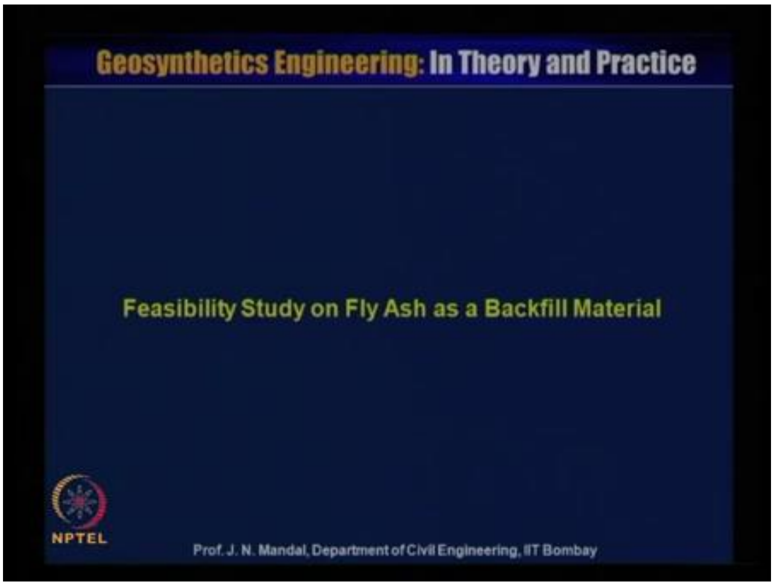

Now, we will discuss the feasibility study on fly ash, as a backfill material. This is the part of the work from our research scholar Rathan lal. And most of the time that, when we will use this fly ash for any reinforced soil retaining wall, the selection of the fly ash is very important. We cannot use that, any fly ash as you like it, there may be the different types of the fly ash is available whether, it is a bottom ash or from coal industry or from any other industry, steel industry. So, you have to be careful that, what kind of the fly ash material you should use as a backfill, for the reinforced soil retaining wall.

So, you have to find out, exact the properties of the fly ash which will suit the criteria or specification for this retaining wall. So, that is why some feasibility study on the fly ash as a backfill material, has been considered and it found that this material may be the suitable. And then, this material also has been used for the constructing of cellular reinforcement as a retaining wall.

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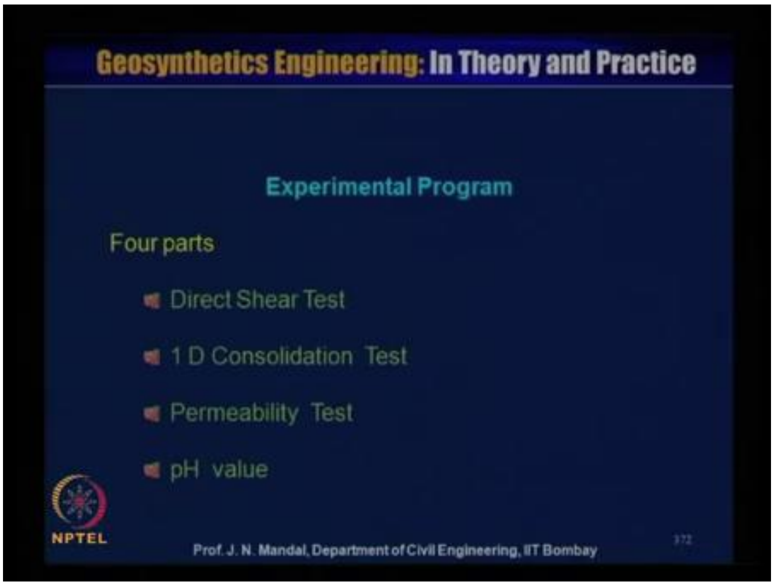

So, some experimental programs have been performed in this institute and this is a four parts this is direct shear test and one dimension consolidation test, permeability test and also pH value.

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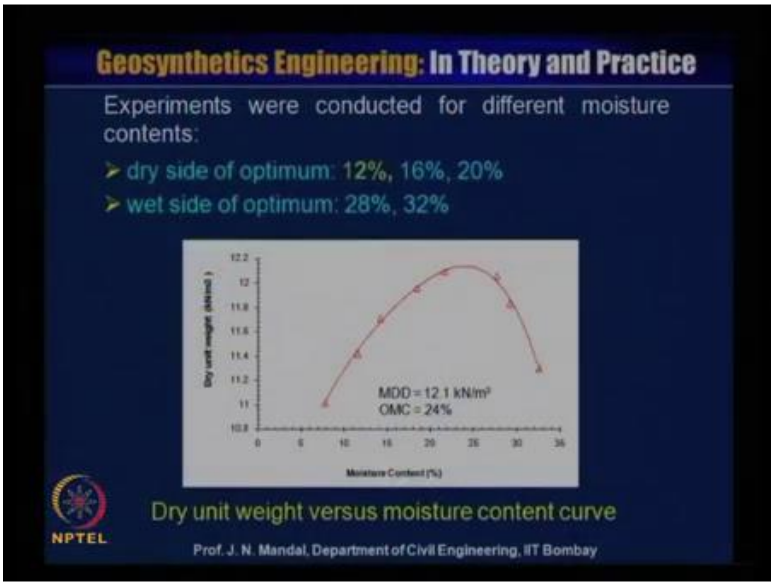

So experimental, experiment was conducted on the different moisture content, that is dry side of the optimum moisture content and wet side of the optimum moisture content. So, this figure shows the relationship between the moisture content and the dry unit weight. This is a compaction curve and from the compaction curve, you have determined what is maximum, dry density is 12.1 kilo Newton per meter cube and optimum moisture content is about 24 percentage. Now, you have selected the, some moisture content on the dry side you can see dry side moisture content.

So, this is for 12 percent moisture content selected then, the 16 percent moisture content selected then, the 20 percent moisture content, when a dry side of the optimum moisture content selected 3. And similarly, this is the optimum moisture content similarly, wet side of the optimum moisture content also selected, that is 28 as well as 30 of 2. So, this, the moisture content dry side and wet side of optimum has been selected for performing the test.

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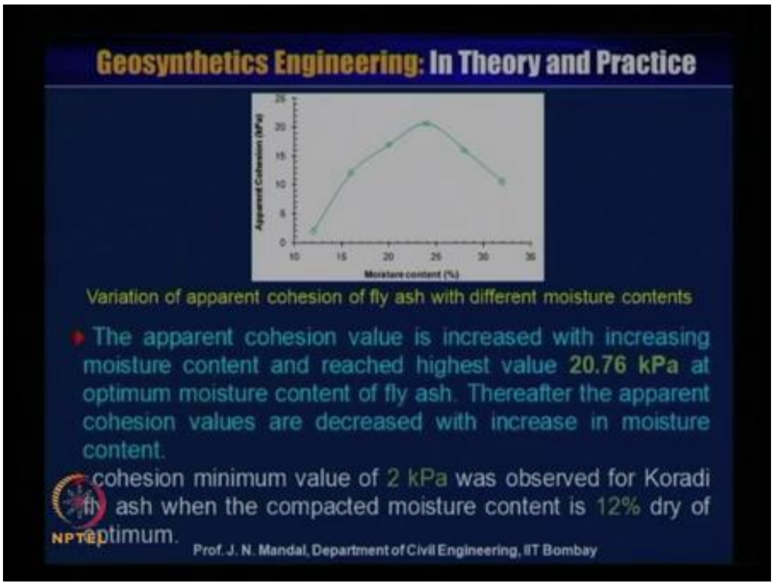

Now, this side show that variation of apparent cohesion on the fly ash with different moisture content. This x axis is the different moisture content and this is the apparent cohesion in kilopascal. So, you can see that apparent cohesion value is increasing, with increasing the moisture content and reached to the highest value that means, it may be 20.76 kilopascal. When it is reached to the 20.76 kilopascal, at the optimum moisture content of the fly ash and thereafter, this apparent cohesion value are decreasing with increasing the moisture content.

This cohesion of minimum value of 2 kilopascal was observed for Koradi fly ash when the compacted moisture content is 12 percent dry of optimum. So, when we take that 12 percent dry of optimum, and then you can find that cohesion value is minimum value that is, 2 kilopascal. So, this kind of result has been observed for Koradi fly ash when, it is compacted with the optimum moisture content 12 percent of the dry of optimum.

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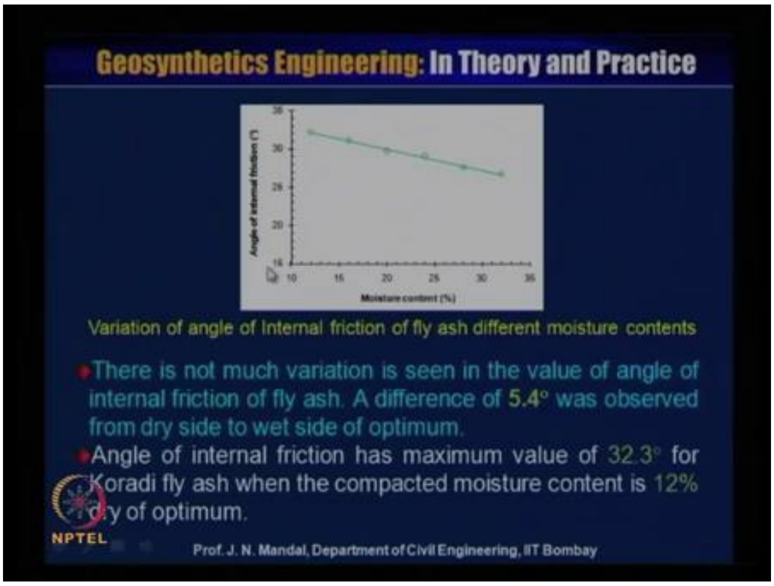

Now, this shows the relationship between the moisture content versus angle of internal friction. So, this is the variation of angle of internal friction of fly ash, with different moisture content. You can note that, there is no such variation is seen in the value of angle of internal friction of fly ash. So, you can see that this angle of internal friction is reducing, but increasing the moisture content, but no significant development of the internal friction angle of the fly ash. So, only difference you can have that 5.4 degree, which is observed from the dry side to wet side of the optimum. So, angle of internal friction has the maximum value of 32.3 degree for the Koradi fly ash when, the compacted moisture content is 12 percent dry of optimum. So, when 12 percent dry of optimum you are having the good value of friction angle that is 32.3 whereas, you are having that cohesion value is very less.

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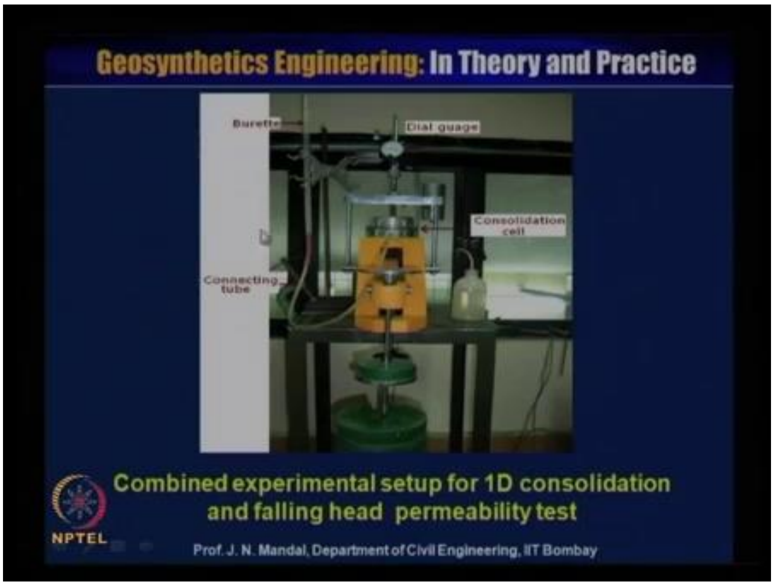

So, this is the combined experiment set up for one dimensional consolidation and falling head permeability test. So, we can also indirectly determine the coefficient of permeability from the consolidation test. So, this is the consolidation that is the cell and this is the connecting tube and this is the burette here and then this is the dial gauge.

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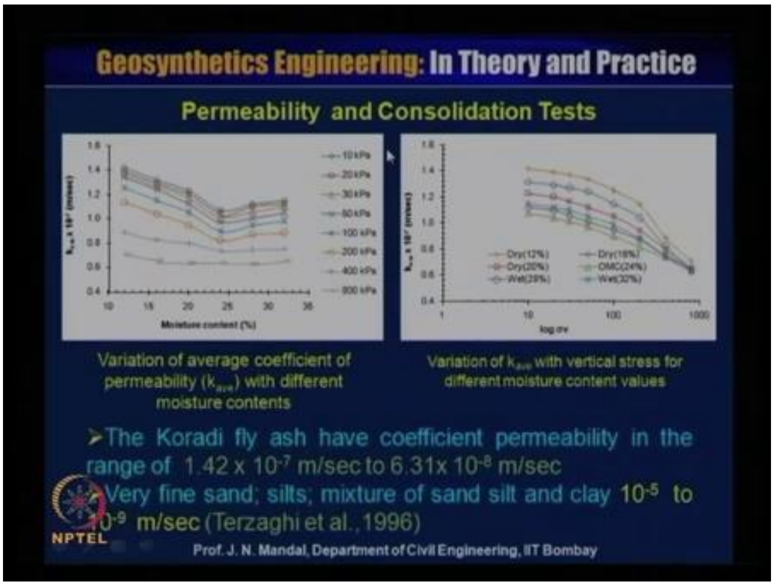

So, number of test has been performed from the permeability and the consolidation test. So, this figure shows the variation of the average coefficient of permeability K ave with the different moisture content, under different pressure. So, on the different pressure starting from 10, 20, 30 kilopascal, 50 kilopascal, 100, 200, 400 and also 800 kilopascal. And see the relationship that average coefficient of permeability value, this value is decreasing you can see here, with increasing this moisture content and then, here it is dropped.

And then it is increasing and you find that Koradi fly ash have coefficient of permeability in the range of 1.42 into 10 to the power minus 7 meters per second to, 6.31 10 to the power minus 8 meter per second. It is also observed by Terzaghi et al 1996, that very fine sand and silt mixture of sand and silt and clay, this coefficient of permeability value lies between 10 to the power minus 5 to 10 to the power minus 9 meter per second, as per Terzaghi's et al 1996.

So, it satisfies this criteria here, this figure, this variation of coefficient of permeability with the vertical stress for different moisture content. So, here the dry side moisture content 12 percent, this is 16 percent then, dry side of 20 percent, when the OMC is 24 percent, wet side 28 percent and the wet is 32 percent. So, you can see that what is the variation of the average coefficient of permeability for the vertical stress, various vertical stress at different moisture content.

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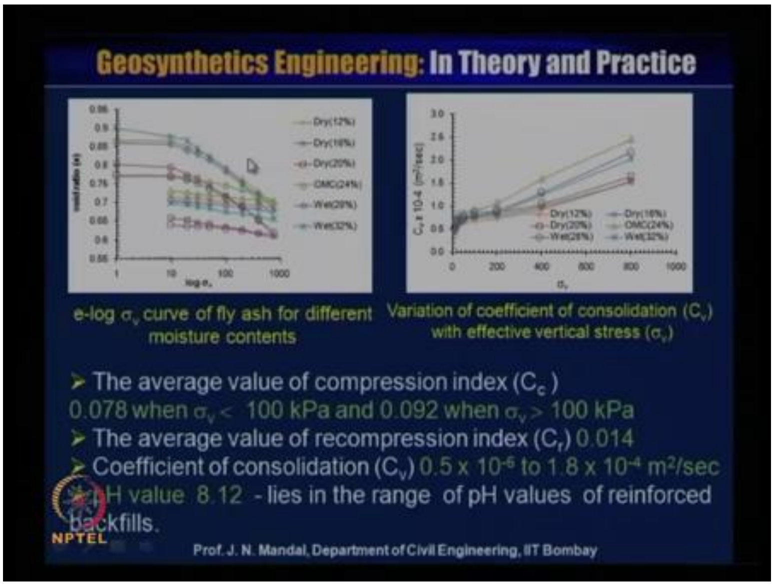

So, next this is the e log of sigma v curve for fly ash, for different moisture content this x axis in log scale sigma v, this is the void ratio. We know that direct consolidation test, this is under the different dry it is 12 percent, 16 percent and 20 percent. And we know the OMC is about 24 percent then, wet side we have selected 28 percent and the wet side you have selected 32 percent.

So, we can see that nature of the relationship between the void ratio and also the sigma of v and this, the curve, which is the variation of coefficient of consolidation C v with the effective vertical stress. That is sigma v, this also the dry 12 percent, 16 percent and the 20 percent you know, OMC is 24 percent and the wet side also we have taken that 28 percent and 32 percent.

We can see nature of the curve is the same, it is increasing then little bit constant and then, it is the increasing that means, this is coefficient of consolidation increasing with increasing the stress, vertical stress. So, here we can calculate that what will be the average value of compression index, which is called Cc. So, this compression index is 0.078 where, sigma v is less than, 100 kilopascal and 0.092 when, the sigma v is greater than 100 kilopascal, so the average value of recompression Cr that is 0.014. So, coefficient of consolidation also lies between 0.5 into 10 to the power minus 6 to 1.8 into 10 to the power minus 4 meter square per second. Also we check the pH value, which is 8.12, this is lies in the range of pH value, for reinforced backfill, so you check the pH value also.

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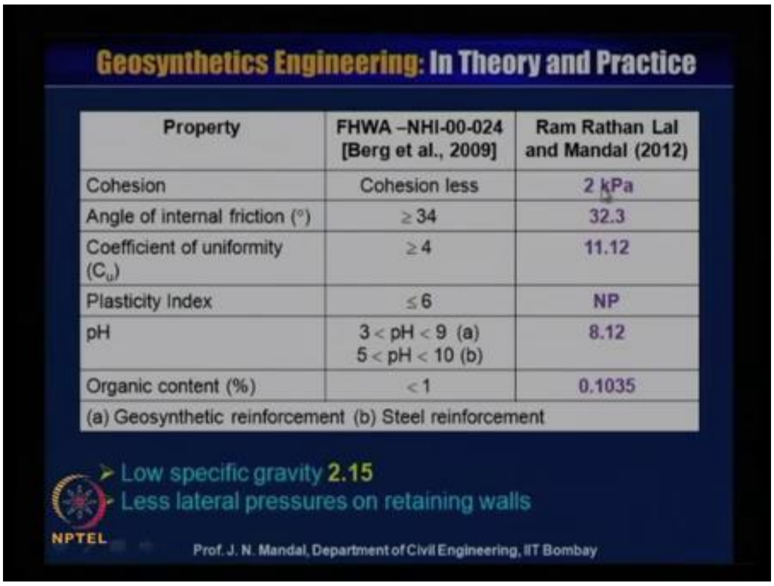

Property	FHWA –NHI-00-024 [Berg et al., 2009]	Ram Rathan Lal and Mandal (2012)
Cohesion	Cohesion less	2 kPa
Angle of internal friction (°)	≥ 34	32.3
Coefficient of uniformity (C_u)	≥ 4	11.12
Plasticity Index	≤ 6	NP
pH	$3 < pH < 9$ (a) $5 < pH < 10$ (b)	8.12
Organic content (%)	< 1	0.1035
(a) Geosynthetic reinforcement (b) Steel reinforcement		

So, this is the table given that, different property, this is cohesion angle of internal friction coefficient of uniformity that is Cu, plasticity index, pH value, organic content.

So, here what is the result that obtained by Ram Rathan lal and Mandal 2012, that cohesion value, we can see less 2 kilopascal. Angle of internal friction is 32.3 degree, coefficient of uniformity it is 11.12, plasticity index it is a non-plastic and pH value 8.12 and organic content is 0.1035.

Now, this value has been compared with the FHWA-NHI-00-024 of Berg et al, 2009. So, this cohesion value, this is cohesion less almost, cohesion value angle of friction value greater than equal to 34. You are having about 32.3, coefficient of uniformity greater than equal to 4, where it is 11.12, plasticity index less than 6, is non-plastic.

And pH value which is also important, it should be greater than 3, less than 9 or pH value greater than 5 or less than 10, in case of a, if it is a geosynthetics as a reinforcement, in case of b, where there steel reinforcement is used. So, we use this geosynthetics as a reinforcement and which, that value here we obtained pH is 8.12. So, it satisfies the criteria and organic content in the fly ash is less than 1 and we have obtained 0.1035 so it is 1.

So, this kind of the fly ash you can see, that satisfy the specification and this low specific gravity that is 2.15. So, less lateral pressure on the retaining wall because fly ash is light material with respect to, but we use for the conventional specified backfill material. So, that was another reason that, it is a good that, it can reduce the lateral pressure on the retaining wall.

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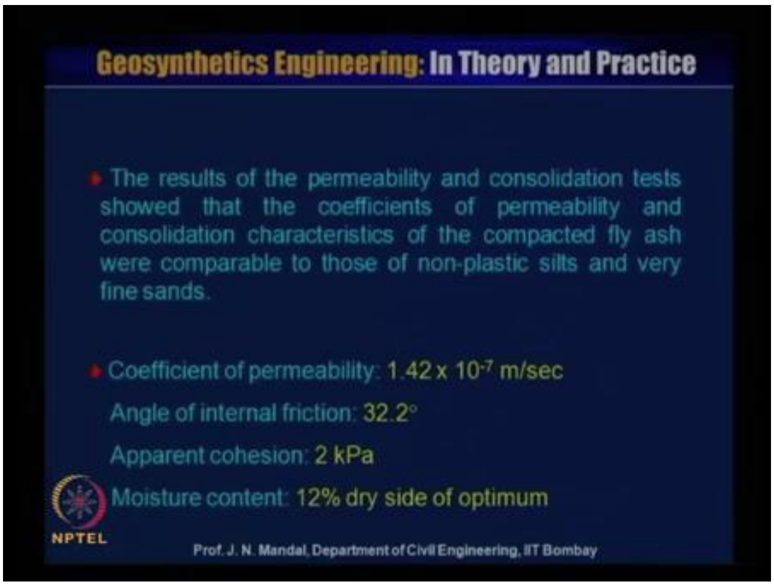

The result of the permeability and consolidation test shows that, the coefficient of permeability and the consolidation characteristics of the compacted fly ash were, comparable to those non plastic silt and very fine sand. As you observe that, what has mentioned and what we obtain. So, this is quite comparable we find that, coefficient of permeability is 1.42 into 10 to the power minus 7 meter per second, angle of internal friction is 32.2 degree and apparent cohesion is 2 kilopascal and moisture content is 12 percent of dry side of optimum. So, we have to select that, proper kind of the parameter.

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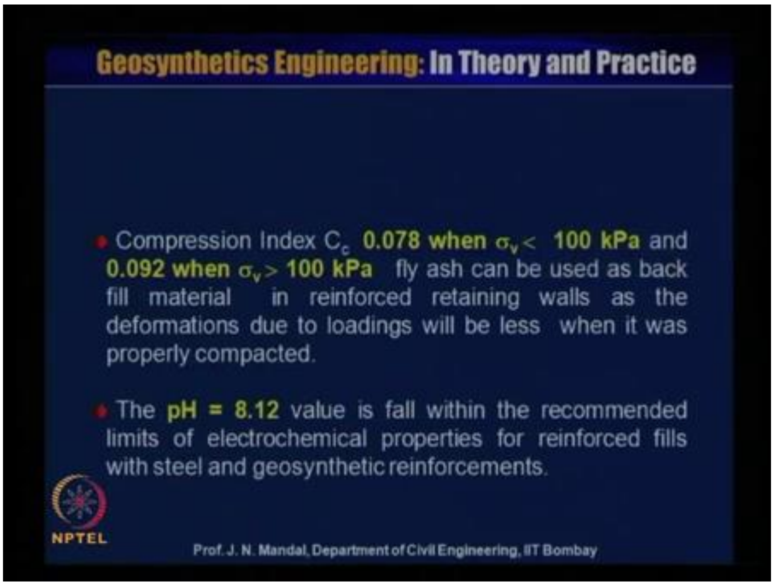

Now, compression index Cc is 0.078 when the sigma v value less than, 100 kilopascal and 0.092 when sigma v is greater than 100 kilopascal. Fly ash can be used as a backfill material in reinforced retaining wall, as the deformation due to loading will be less when it was properly compacted. The pH value is 8.12 is fall within the recommendation limit of electrochemical properties for reinforced fill, with steel and the geosynthetics reinforcement. So, it satisfy the all the criteria. So, this is the, how we talk about that, how the fly ash can be used as a backfill material for the construction of the mechanically stabilized reinforced soil retaining wall. So, it must check the property of the fly ash whether, it satisfy the specification or not if it satisfy then, you can use it.

So, what we find that the fly ash, what we have been used and we perform the number of the tests, consolidation test, permeability test and the compaction curve and find that, what moisture content is suitable for the compaction. So, the another greatest problem that moisture content, what moisture content sometimes, you can find that optimum moisture content may not be the suitable for the compaction, in case of the fly ash.

Most of the time in general, we use the optimum moisture content as a compression and achieve to that degree of relative density. But it is not necessary in case of the fly ash so we have to be careful for selection of the moisture content in order that, where cohesion value can be reduced. And angle of friction value also can be increased and material can satisfy, the all other criteria pH etcetera. So, this kind of the fly ash can be used for the mechanically stabilized reinforced soil wall.

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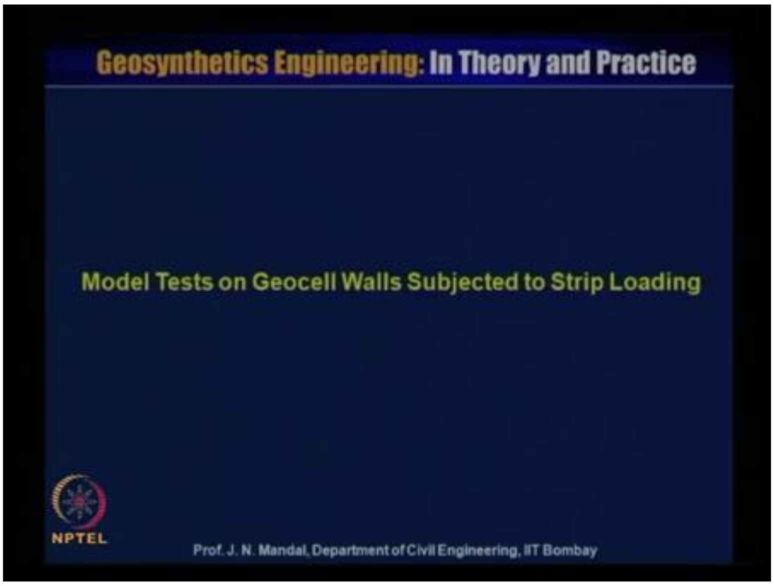

Now, also I have performed some test on the, model test on Geocell wall subjected to the strip loading.

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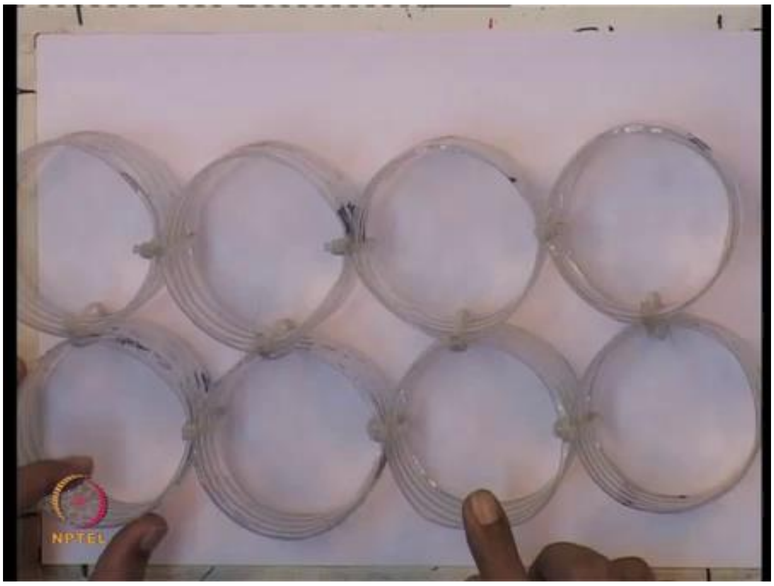

Now, geocell wall it is like, this is the, this you can say the geocell because we have cut from the waste bottle and we have prepared the geocell and it has a particular diameter and also the height. So, this we also call the geocell or the cellular reinforcement so you can construct this in the form of the mat and then, it can be jointed. And we find that this kind of joint it is suitable, there is no problem and then, you can fill up with the filling material into the cell and you can compact it.

So, this is one that, in the mat form we can use it also, you can use this geocell in the strip form. So, you can give the spacing and then you can ((Refer time: 35:38)) the another of the strip geocell and this geocell also, you can fill up with the fly ash and can be compacted. So, this kind of the system is adopted in this experimental program, this is a kind of new innovative system where, it has been, it has been performed, in this wrap. And here, part of this the experimental wall is presenting that is on model test, on geocell wall subjected to strip loading.

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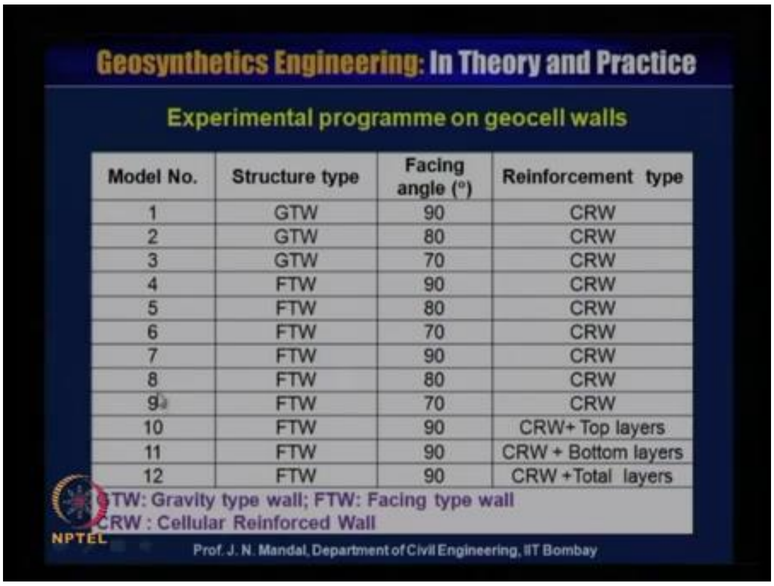

Model No.	Structure type	Facing angle (°)	Reinforcement type
1	GTW	90	CRW
2	GTW	80	CRW
3	GTW	70	CRW
4	FTW	90	CRW
5	FTW	80	CRW
6	FTW	70	CRW
7	FTW	90	CRW
8	FTW	80	CRW
9	FTW	70	CRW
10	FTW	90	CRW+ Top layers
11	FTW	90	CRW + Bottom layers
12	FTW	90	CRW +Total layers

So, experimental program geocell wall there are 12 models. So, this is GTW indicate, gravity type of wall when, the facing angle 90 degree and reinforcement side CRW mean, cellular reinforced wall. Then, this gravity type wall also the angle change 80 degree 70 degree, but all cases we use the cellular reinforced wall. And the model number 4 FTW that is, facing type wall so from model 4 to 11, we have used the facing type of wall. But angle also change, it may be 80, 70, 90, etcetera and also the, some cases we have used that cellular type of the reinforced wall or some cases, that cellular reinforced wall plus, top layer cellular reinforced wall for bottom layer, cellular reinforced layer, total layer.

What I want to mean is that, sometimes that if this is the facing, this is the cellular reinforcement, so you can construct the gravity wall only with this cellular kind of reinforcement. We can, we can place like a gabion, you can place one then, you can place another one here then, we can place another one here. So, then you can construct a gravity type of the wall so that is gravity type of the wall also, you can place this, only this or like this. This part so this will act as a facing element so this is facing type of wall, facing element and then, you can add the reinforcement also.

It can be connected reinforcement also like this, it can be connected and that, also that, you can sometimes use this as a reinforcement, cellular as a reinforcement. Facing element you can use this cellular as reinforcement, at a particular spacing. So, you can use this kind of cellular reinforcement as a gravity retaining wall or you can use as a facing element, and also the cellular reinforcement you can use as a strip. So, these are the model different and experimental wall have been carried out.

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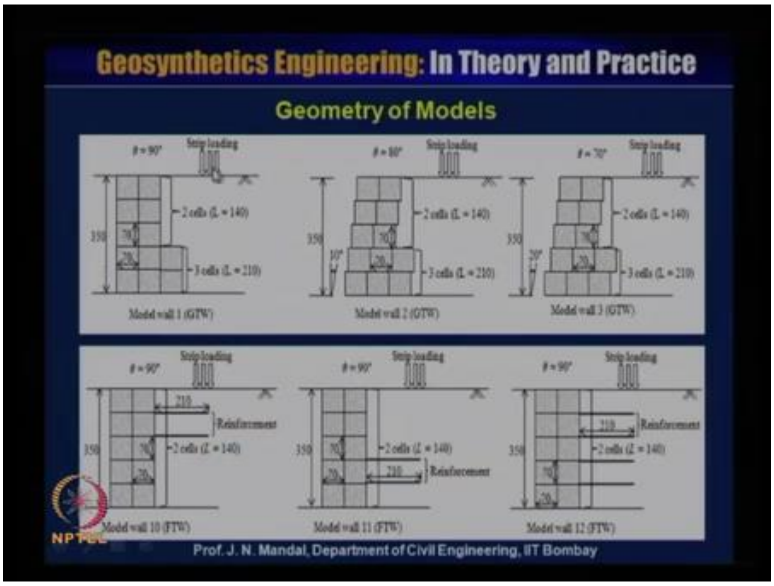

You can see that, different types of the geometry of the model has been considered. So, this is let us say module 1 and I mention that what is GTW that is, gravity type wall so this is gravity type wall we can see that, cell and this theta angle is 90 degree. This is gravity level this is 1 model, this is 2 cell whose length is 140 and here is the 1 2 3 cell whose length is 210 and each cell is 70 and this theta 90 degree then, you are applying the strip load here.

Then, this is another type, here is a better is 10 is given and this is height of the wall 350 and here theta 80, here 2 cell, L is 140 here, 3 cell where L is 210. So, similarly here theta 70 degree angle is changing here, 2 cell here again, the 3 cell here, better angle change to 20 degree then, this model wall 10, this is as a that FTW, FTW means facing type wall. So, this is facing type wall, so only facing you can see this as a facing 1 2 1 2 this is cell as a facing and this is the reinforcement, this is the reinforcement. Here is the reinforcement, 210 and this is only 2 cell as a facing element.

Similarly, this as a model wall 11 this act as a facing element and this as a length of the reinforcement and then, you are changing the length of this is, I put at the top this, you place at the bottom and this you place then, theta is equal to 90 degree is all case theta 90 degree. And here place the number of the layer of the cellular reinforcement and this cellular act as a, facing element and then you are applying the strip loading in all cases. So, different types of the model have been selected and optimized.

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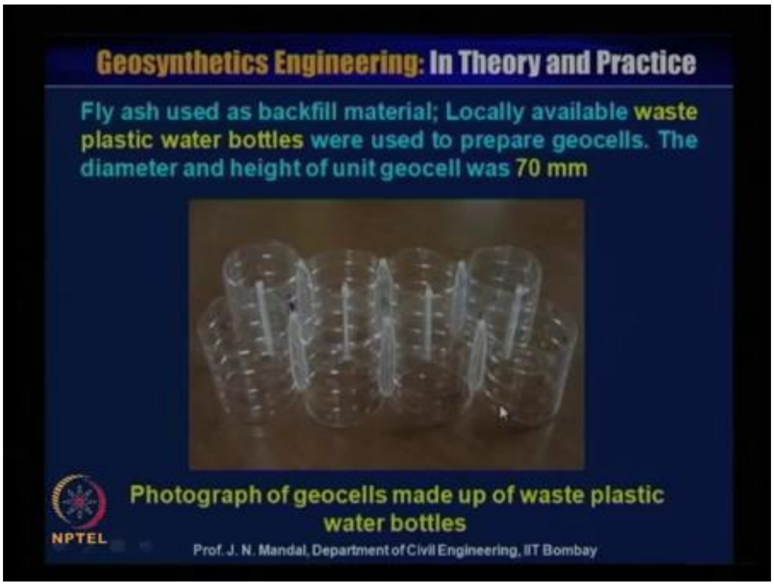

So, this is the, that what you call, that photograph of geocell which is made up of the plastic waste bottle and fly ash has been used as a backfill material. What we have discussed earlier about the fly ash, the same fly ash has been used as a backfill material, which is locally available, this plastic bottle have used to prepare the geocell. And this diameter and the height of the unit geocell was 70 millimeter.

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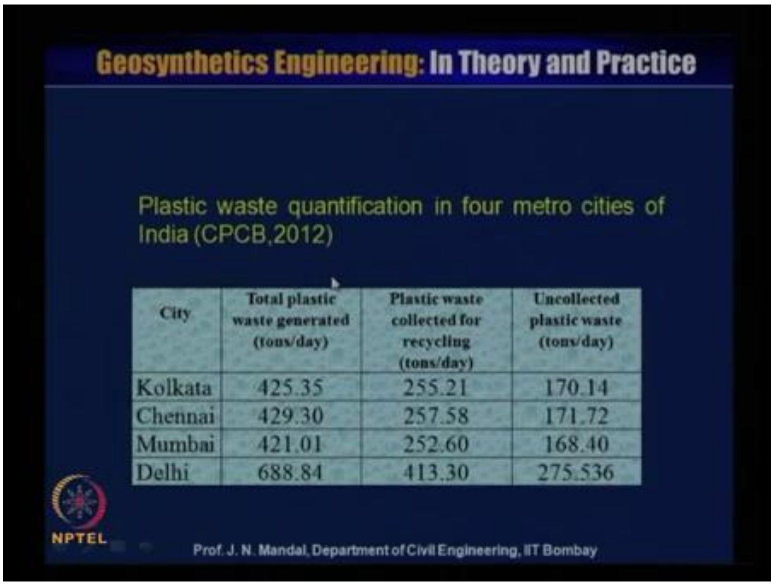

City	Total plastic waste generated (tons/day)	Plastic waste collected for recycling (tons/day)	Uncollected plastic waste (tons/day)
Kolkata	425.35	255.21	170.14
Chennai	429.30	257.58	171.72
Mumbai	421.01	252.60	168.40
Delhi	688.84	413.30	275.536

Now what, you know the why we have also interested to study you can see lot of the plastic bottle, it is very difficult to control. And here you see that, plastic waste quantification in 4 metro cities of India CPCB 2012, reported that city in Kolkata, it is total plastic waste generated about 425.35. And plastic which collected from the recycling, the 255.21 tons per day, uncontrolled plastic waste about 170.14 ton per day. Similarly, Chennai 429.30 ton per day this is total plastic generated, 257.58 is the plastic which collected for the recycling and 171.72 uncollected plastic waste this ton per day. Mumbai, 421.01 total plastic waste generated and 252.60 plastic waste collected from recycling and 168.40 uncollected plastic waste.

And Delhi, 688.84 total plastic waste generated and 413.30 ton per day plastic waste collected for recycling and 275.536 uncontrolled plastic waste ton per day. So, you look that what will be the kind of the plastic waste is uncontrolled so it is almost that 40 percentage. So, we can make use of this kind of the plastic waste bottle for, the construction of the reinforced soil retaining wall. And also, it can be used for the road construction.

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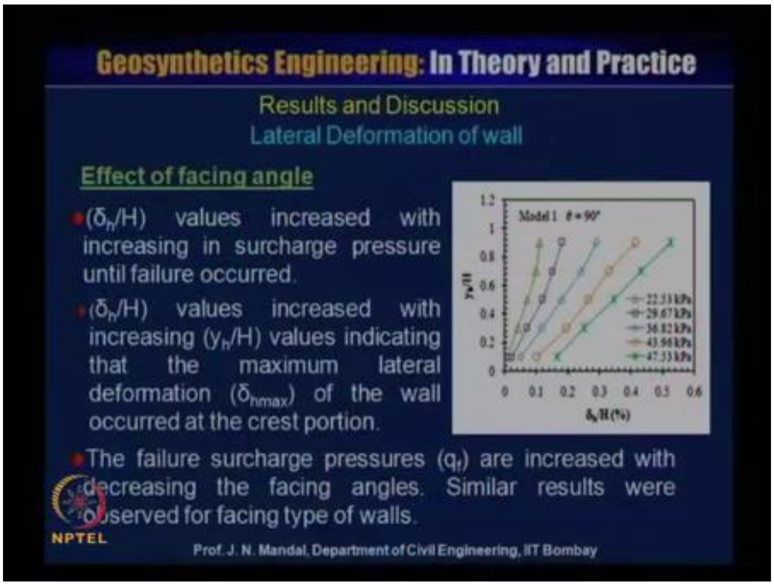

So, number of the test has been conducted here, you can see that what will be the lateral deformation of the wall. So, this curve shows with the relationship y h by H, H is the height of the wall and this is delta h by H in percentage, this is under the different load. This is 22.6 to 47.55, this is model number 1 theta 90 three degree so effect of the facing angle.

So, delta h by H value increase with increasing in surcharge pressure, until failure occur even delta h by H value increase, with increase in the delta h by H value. Indicating that, indicating that, indicating that maximum lateral deformation delta h maximum of the wall occur, the crest portion. The failure surcharge pressure q f are increased with decreasing the facing angle, similar result was observed for the facing type of wall.

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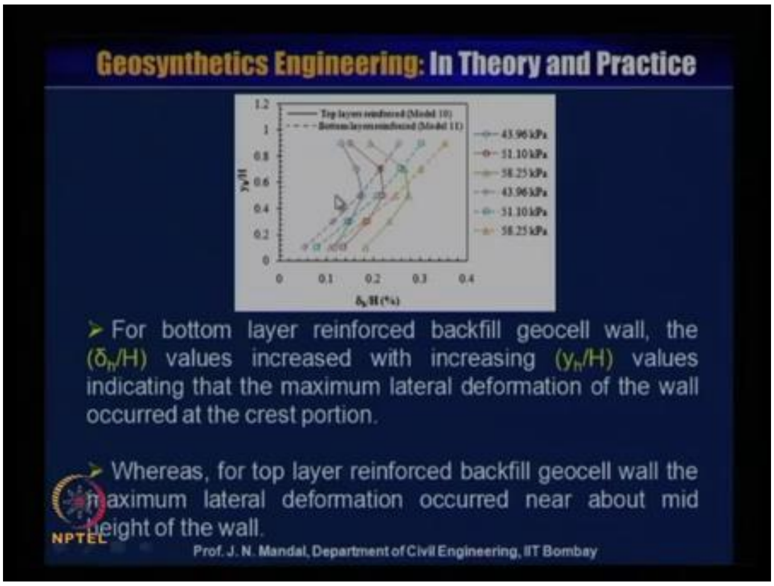

Now here also, that y h by H to delta h by H in percentage, this relationship for the top layer of the reinforcement model 10 and bottom layer of reinforcement 11, under this is load. So, from the bottom layer of the reinforcement, reinforcement backfill, geocell wall, the delta h by H value increase with increasing y h by H value, indicating that the maximum lateral deformation of the wall occur, at the crest portion. Whereas, for top layer of the reinforced backfill, the geocell wall, the maximum lateral deformation occur near, about the mid height of the wall. You can see somewhere mid height of the wall also occurring.

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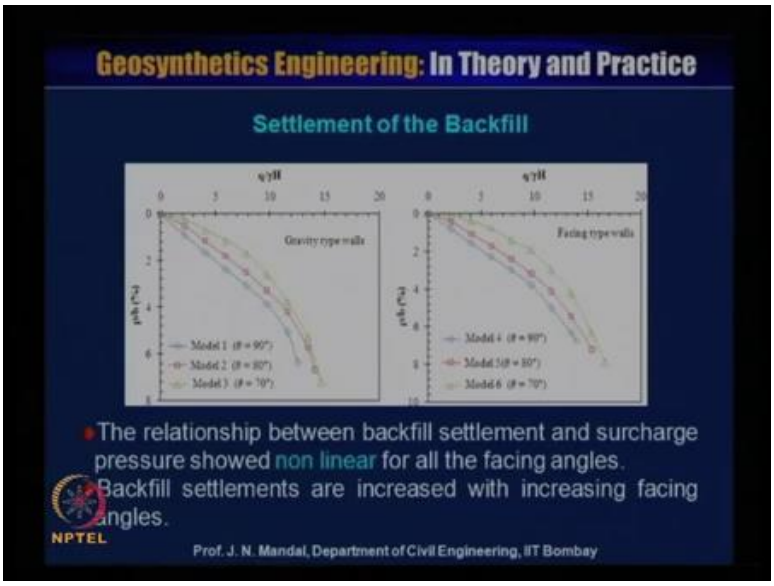

Now settlement of the backfill, this is the relationship between the q y, q y delta H versus this is p by b, this is percentage, this is for model number 1 2 and 3, theta is 90 degree, 80 degree and 70 degree, this is the gravity type wall. So, you can see the relationship here so similarly this one also facing type wall. So, this is gravity type wall, this is facing type wall and this is q by gamma H, x axis and p by b, this is percentage.

This is for model number 4, model number 5, model number 6 and theta is 90 degree, 80 degree and 70 degree. So, we can see that nature of the curve be the same so relationship between the backfill settlement and the surcharge pressure shows non-linear for, all facing angle. Whether it is 70, 80 or 90 degree, this is all non-linear, the backfill settlement had increased with increase in the facing angle.

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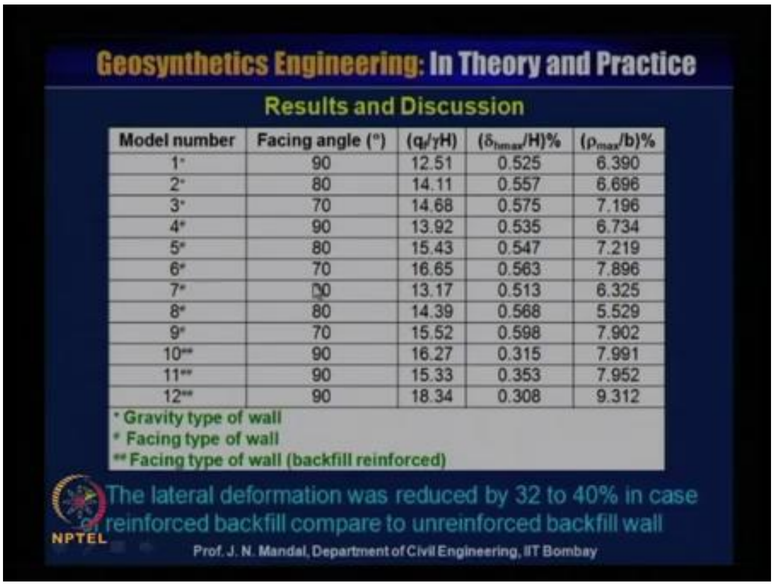

Model number	Facing angle (°)	$(q_f/\gamma H)$	$(\delta_{hmax}/H)\%$	$(\rho_{max}/b)\%$
1*	90	12.51	0.525	6.390
2*	80	14.11	0.557	6.696
3*	70	14.68	0.575	7.196
4*	90	13.92	0.535	6.734
5*	80	15.43	0.547	7.219
6*	70	16.65	0.563	7.896
7*	90	13.17	0.513	6.325
8*	80	14.39	0.568	5.529
9*	70	15.52	0.598	7.902
10**	90	16.27	0.315	7.991
11**	90	15.33	0.353	7.952
12**	90	18.34	0.308	9.312

So, result and the discussion so here we have shown that model number 1 to 12, this facing angle degree 90, 80, 70, 90, 80, 70, 90, 80, 70, 90, 90, 90. Here this star, you can see here this star, 1 and 2 and 3 which is gravity type wall so this is all gravity type wall. What the facing angle is 90 degree, 80 degree and 70 degree and you are having q f by gamma H, value 12.51, 14.11, 14.68 and delta h maximum by H percentage 0.525, 0.557 and 0.576, and rho max by b percentage 6.390, 6.696 and 7.196.

Now in case of model number 4, 5, 6, 7, 8 and 9, this star indicate facing type of wall. So, these are the facing type of wall, whose facing angle also change 90, 80, 79, 90, 80 and these are the q f by gamma H value. And these are the delta max by H percentage value so rho max by b value we can see here. Similarly, for 10, 11 and 12 that is, it is facing type wall that is, backfill reinforcement. So, that means facing and the reinforcement is provided this is facing angle 90, 90 and 90.

So, we are having that q f by delta is 16.27, 15.33, 18.35 and this delta is maximum value 0.315, 0353 and 0.308 and rho max by b percentage 7.991, 7.952, 9.312. So, we can see that different types of the model, different types of the facing angle and it is gravity wall and only facing type of wall and facing type with the backfill. So, lateral deformation it can be of observed that, is reduced by 30 to 40 percentage in case of the reinforced backfill, compare to the unreinforced backfill soil. So, how the lateral deformation have drastically make use so what are the major finding from this experiment.

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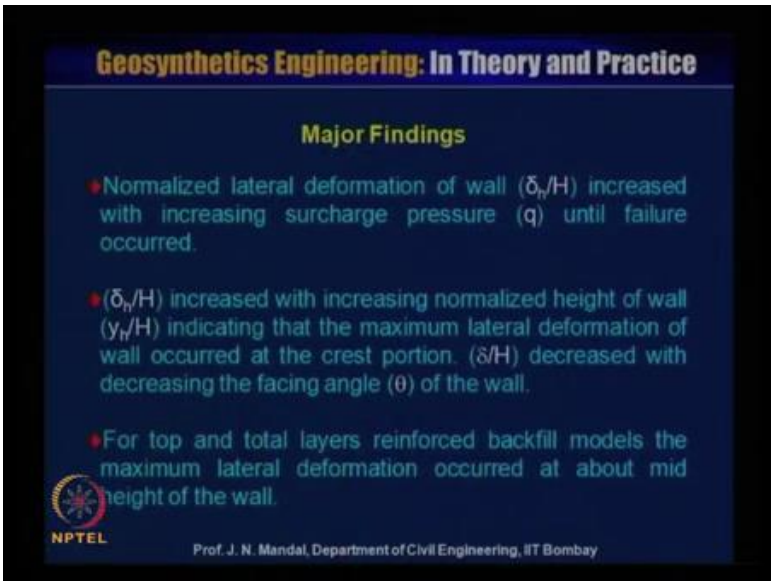

The normalized lateral deformation of the wall delta h by H, increase with increasing the surcharge pressure q until, the failure occur delta h by H increase, with increasing the normalized height of the wall. That is y h by H indicating that maximum lateral deformation of the wall occur, at the crest portion, that is delta by h decreased, with decreasing the facing angle of the wall. Now, for the top and total layer of reinforced backfill model the maximum lateral deformation occur at about mid height of the wall.

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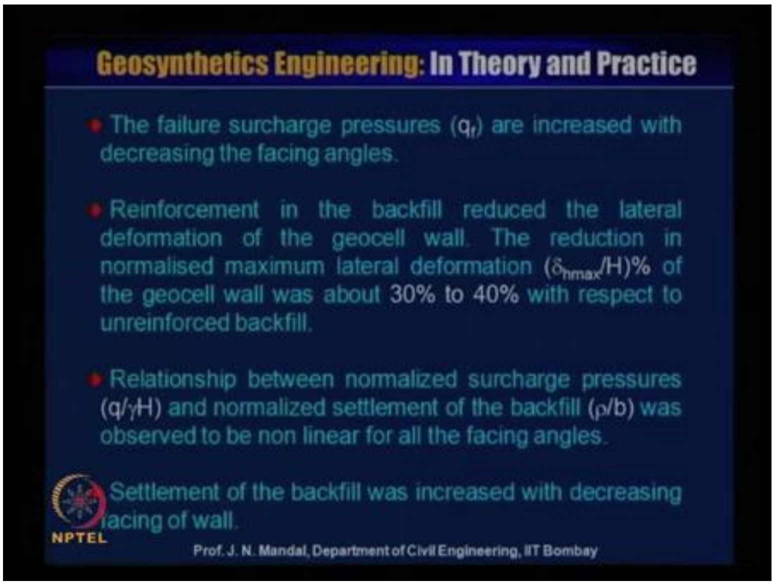

The failure surcharge pressure q f are increased with, decreasing the facing angle reinforcement in the backfill reduced the, lateral deformation of the geocell wall. The reduction in normalized maximum lateral deformation delta h max by H percentage, of the geocell wall was about 30 to 40 percentage with respect to, unreinforced backfill. The relationship between the normalized surcharge pressure q by gamma H and normalized settlement of the backfill rho by b was, observed to be non-linear for all the facing angle. Settlement of the backfill was increased, with decreasing the facing of the wall.

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You can see here also that, cellular type of the reinforcement and has been used this is the cell type of reinforcement and filled up with the compacted backfill material. So, this type of the wall also can be constructed and also you can print the green colour. So, it looks like a greenery also, sometimes you can make, you can make a hole on the, on the cellular reinforcement and the grass also can grow. So, you can make a greenery reinforced soil retaining structure.

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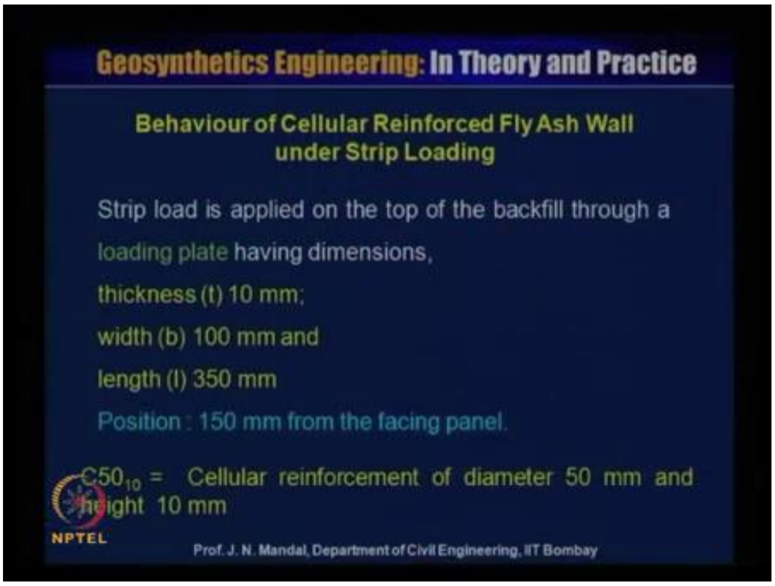

So, behaviour of cellular reinforced fly ash wall under strip loading, strip load applied to the top of the backfill through a loading plate, having the dimension thickness 10 millimeter, width 100 millimeter, length 350 millimeter, and position 150 millimeter from the facing panel. Here c d 10 is the cellular reinforced of diameter 50 millimeter and 10 millimeter.

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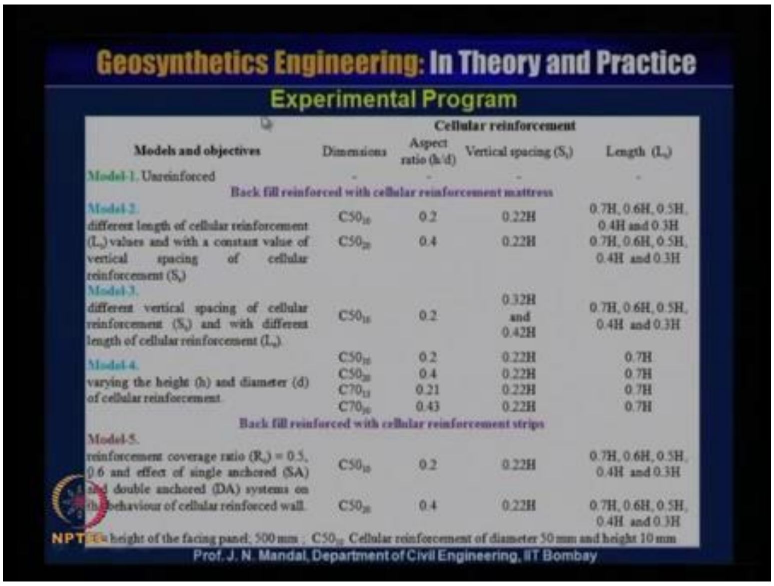

Models and objectives	Cellular reinforcement: Dimensions	Aspect ratio (h/d)	Vertical spacing (S_v)	Length (L_r)
Model-1. Unreinforced	-	-	-	-
Back fill reinforced with cellular reinforcement mattress				
Model-2. different length of cellular reinforcement (L_r) values and with a constant value of vertical spacing of cellular reinforcement (S_v)	$C50_{10}$	0.2	0.22H	0.7H, 0.6H, 0.5H, 0.4H and 0.3H
	$C50_{20}$	0.4	0.22H	0.7H, 0.6H, 0.5H, 0.4H and 0.3H
Model-3. different vertical spacing of cellular reinforcement (S_v) and with different length of cellular reinforcement (L_r)	$C50_{10}$	0.2	0.32H and 0.42H	0.7H, 0.6H, 0.5H, 0.4H and 0.3H
Model-4. varying the height (h) and diameter (d) of cellular reinforcement	$C50_{10}$	0.2	0.22H	0.7H
	$C50_{20}$	0.4	0.22H	0.7H
	$C70_{15}$	0.21	0.22H	0.7H
	$C70_{30}$	0.43	0.22H	0.7H
Back fill reinforced with cellular reinforcement strips				
Model-5. reinforcement coverage ratio (R_c) = 0.5, 0.6 and effect of single anchored (SA) and double anchored (DA) systems on the behaviour of cellular reinforced wall	$C50_{10}$	0.2	0.22H	0.7H, 0.6H, 0.5H, 0.4H and 0.3H
	$C50_{20}$	0.4	0.22H	0.7H, 0.6H, 0.5H, 0.4H and 0.3H

H = height of the facing panel: 500 mm ; $C50_{10}$ Cellular reinforcement of diameter 50 mm and height 10 mm

So, these are the different types of the model 1, 2, 3, 4, 5 with the different aspect ratio this h by d. So, this is aspect ratio h by d 0.2, 0.4 and this is the vertical spacing 0.22H and this is the different length has been considered, where here that c and d 15 indicate that, d is the diameter, that is d 50 diameter. And this is the height h of the cellular reinforcement and number of the experiment also has been occurred, performed. So, this is the, h is the height of the facing panel 500 millimeter and this is the cellular reinforcement diameter also, varying and height also, varying so this is the aspect ratio.

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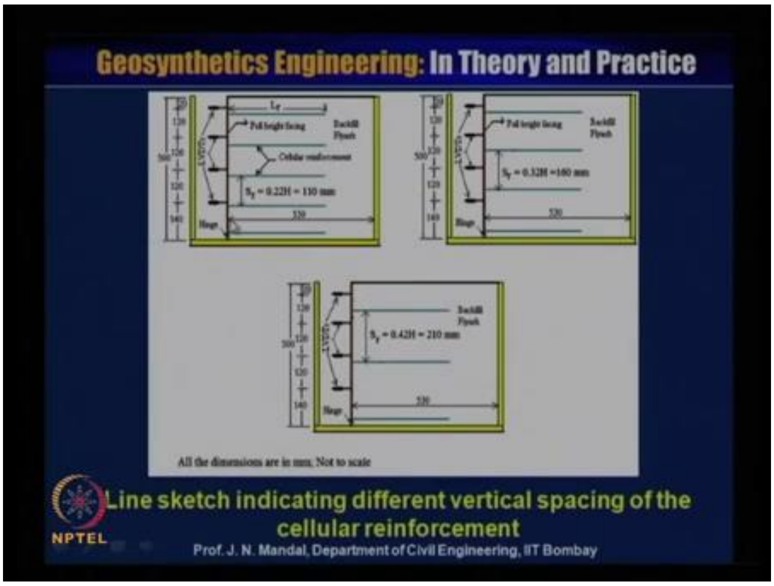

So, these are the experimental program has been performed and this is the fly ash model.

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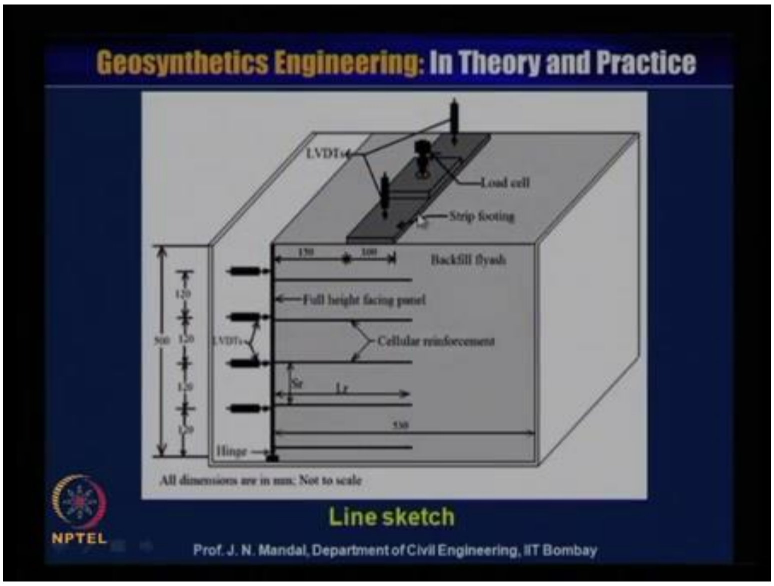

This is the line sketch has been shown, how the strip load has been applied and here is the LPTT.

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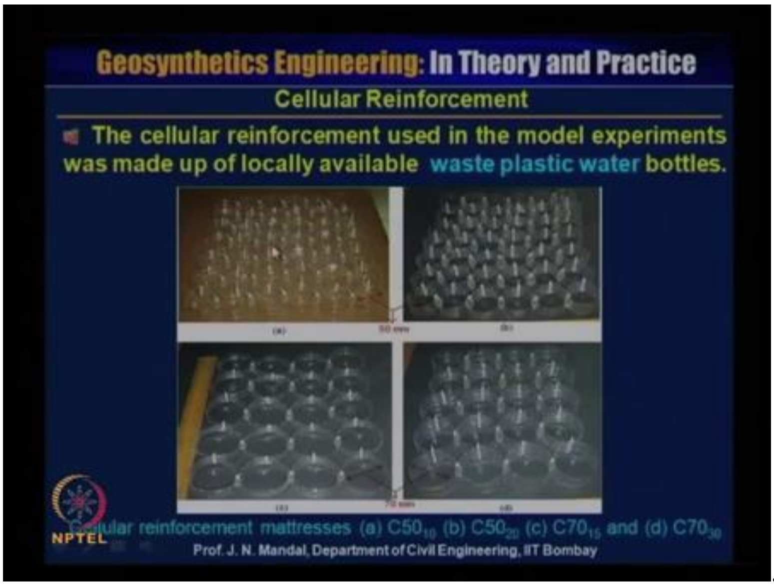

So, this is the cellular reinforced used in the model, experiment was made up locally available, that plastic waste bottle. And I say that C50 10 mean this is the diameter, this is the height, this is the diameter of the plastic bottle and this is the height 20, this is the diameter 70, this is 15, C70 30, then this is diameter and this is the height.

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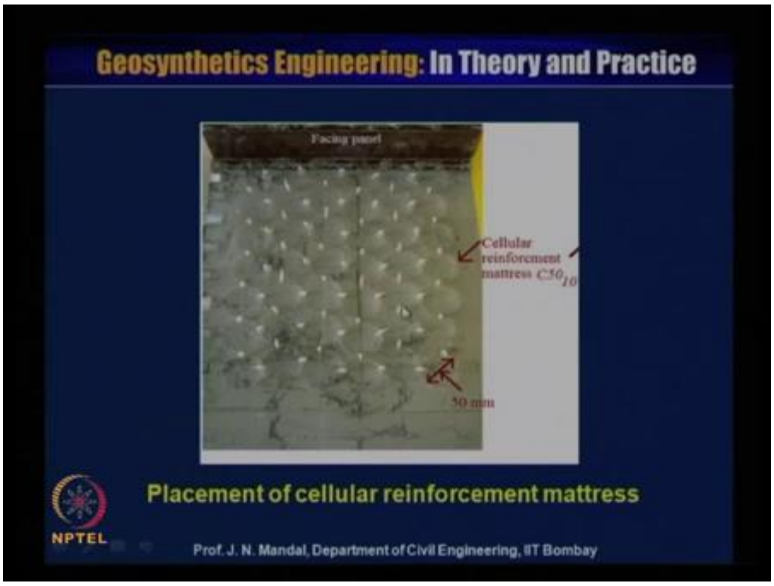

So, these different types of the placement and it has been placed in the mattresses form.

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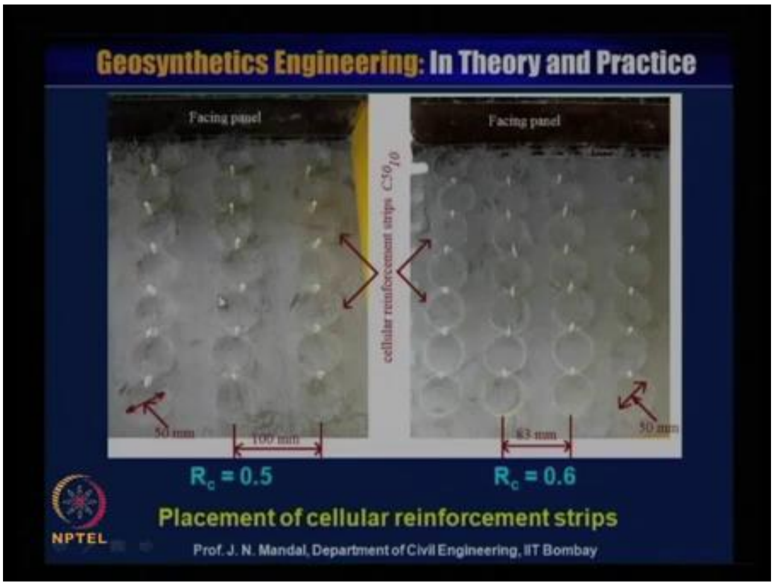

It has been placed also in a Rc value, Rc I mean are coverage ratio. This is 0.5 and this is 0.6, this placement of cellular reinforcement strip it is in the form of strip, also has been used.

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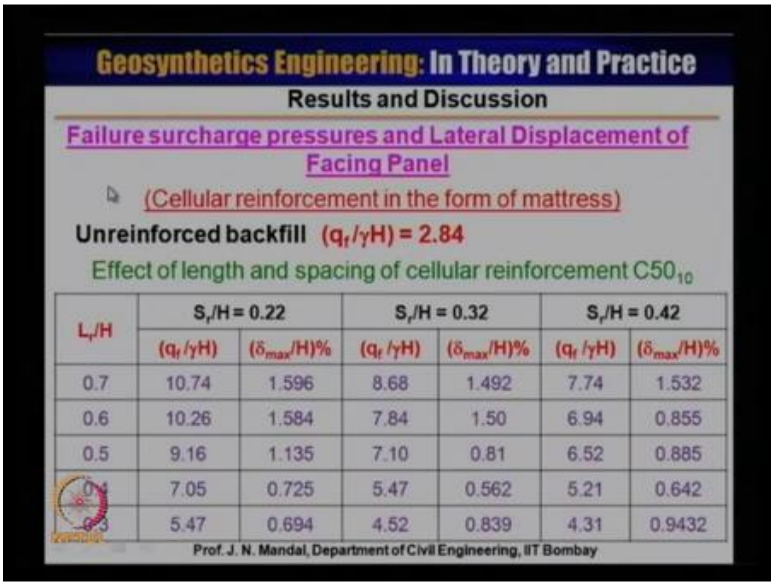

So, this is the failure surcharge pressure and the lateral deformation of the facing panel. So, cellular reinforcement in the form of the mattresses unreinforced case q by gamma H is 2.84, effect of length of spacing cellular reinforcement C50 10. So, you can see different value of L r by H, the length of the reinforcement by height of the wall and S r by H 0.22, 0.32 and 0.42.

So, you will have that q f by gamma H value for the S r by H is equal to 0.2, S r by H 0.30, you can have q r by gamma H. And delta max by H value and S r by H 0.42, you can have q f by gamma H value and S r by H value. So, you can see that how the difference in the value of, because for different value of S r by H and length by H.

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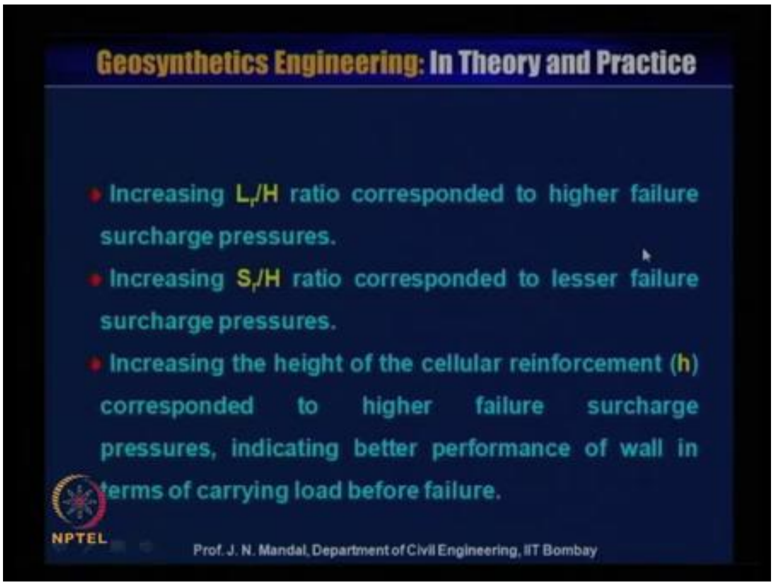

So, what we can say that increasing L r by H ratio, corresponding the higher value of surcharge pressure. Increasing S r by H ratio, corresponding to the lesser failure of surcharge pressure, increasing the height of the cellular reinforcement height H, correspond to the higher failure surcharge pressure, indicating the better performance of the wall, in terms of carrying the load before failure.

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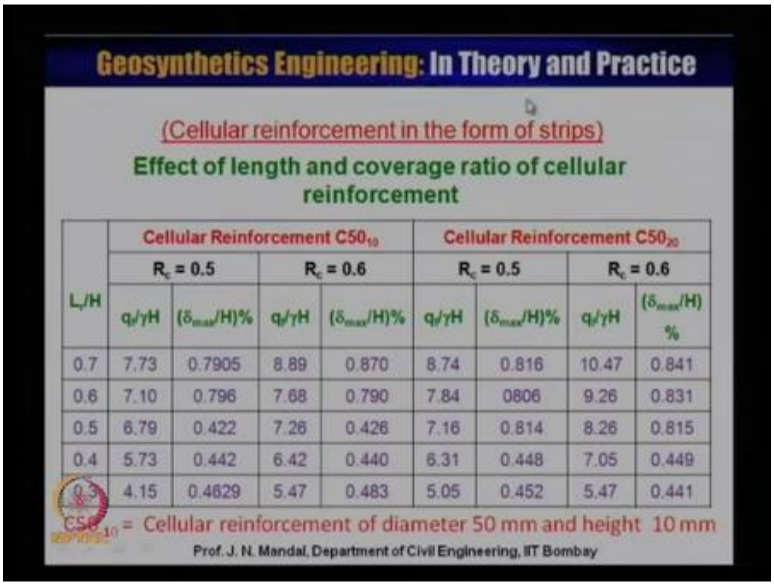

L_r/H	Cellular Reinforcement $C50_{10}$				Cellular Reinforcement $C50_{20}$			
	R_c = 0.5		R_c = 0.6		R_c = 0.5		R_c = 0.6	
	$q_f/\gamma H$	$(\delta_{max}/H)\%$	$q_f/\gamma H$	$(\delta_{max}/H)\%$	$q_f/\gamma H$	$(\delta_{max}/H)\%$	$q_f/\gamma H$	$(\delta_{max}/H)\%$
0.7	7.73	0.7905	8.89	0.870	8.74	0.816	10.47	0.841
0.6	7.10	0.796	7.68	0.790	7.84	0806	9.26	0.831
0.5	6.79	0.422	7.26	0.426	7.16	0.814	8.26	0.815
0.4	5.73	0.442	6.42	0.440	6.31	0.448	7.05	0.449
0.3	4.15	0.4629	5.47	0.483	5.05	0.452	5.47	0.441

So, this is the cellular reinforcement in the form of strip so where you can see R c value that, cellular reinforcement for C50 10 used for R c value 0.5, 0.6 and for cellular reinforcement C50 20 diameter same, but height is different. So, R c value 0.5 and 0.6 so for the different value of L by r H value, so you are obtaining the different value. So, here you can see that when R c value 0.5 is 7.73, when R c value is 0.6 this value is 8.89.

That means, it is increasing this value you can see when the C r, cellular reinforcement when the diameter is 50, but height is 50, R c is 0.5 this is 8.75. But, when the R c is 0.6 then, you can see that 10.47 so it is observed that when R c is 0.6, this value is increasing, when R c is 0.6 this value is increasing. So, this may be the most suitable and what we have also performed this kind of, this kind of the coverage ratio in case of the geogrid material.

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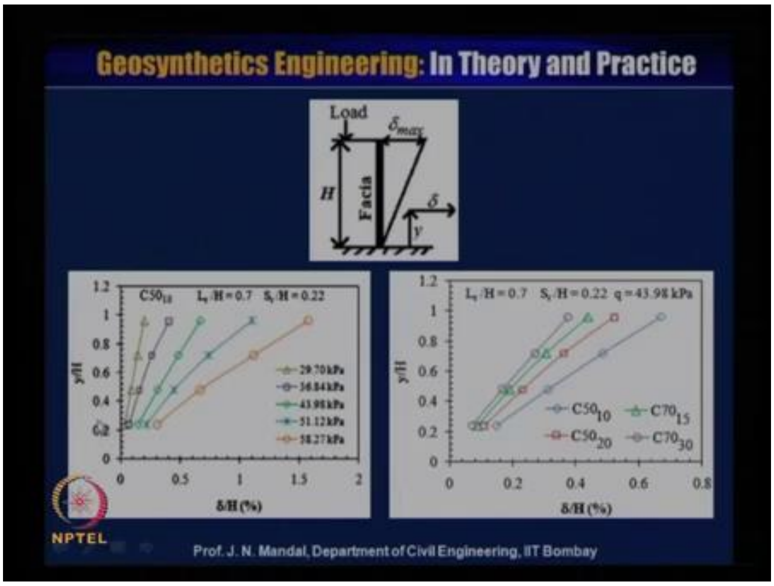

So, these are the same result, you can see under the different load with different height and you can see that, how this is, this is increasing this value like this.

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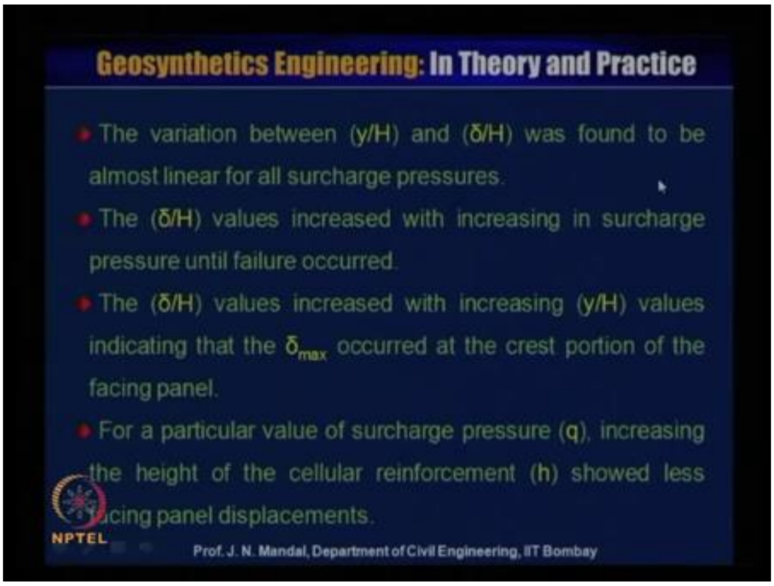

So, what is that the variation of between the y by H and delta by H was found to be almost the linear for all surcharge pressure, the delta by H value increase, with increasing in surcharge pressure until, the failure occur. The delta by H value increase, with increasing the y by H value indicating that, the delta maximum occur at the crest portion of the facing panel. For a particular value of surcharge pressure q, increase the height of the cellular reinforcement h, so less facing panel displacement.

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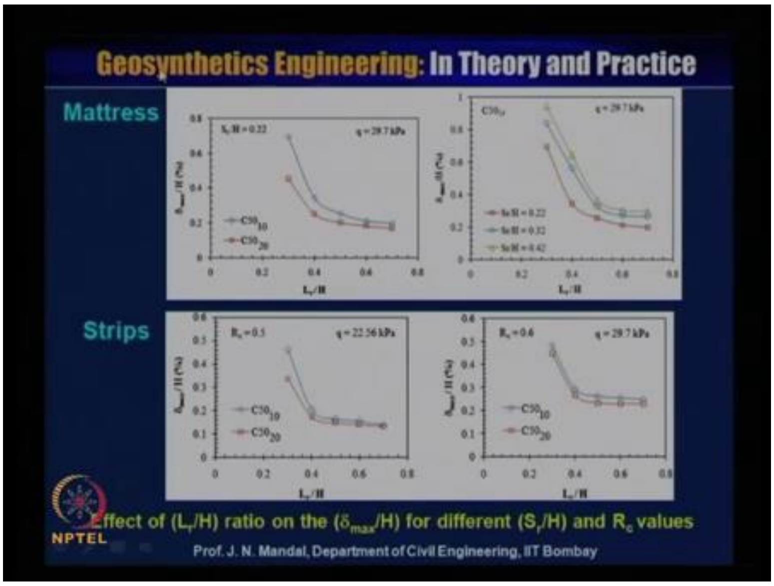

So, this is the, for the mattress case you can see delta h by Lr by H value and it is decreasing. And almost left constant also, for strip case it gave the same nature of the curve.

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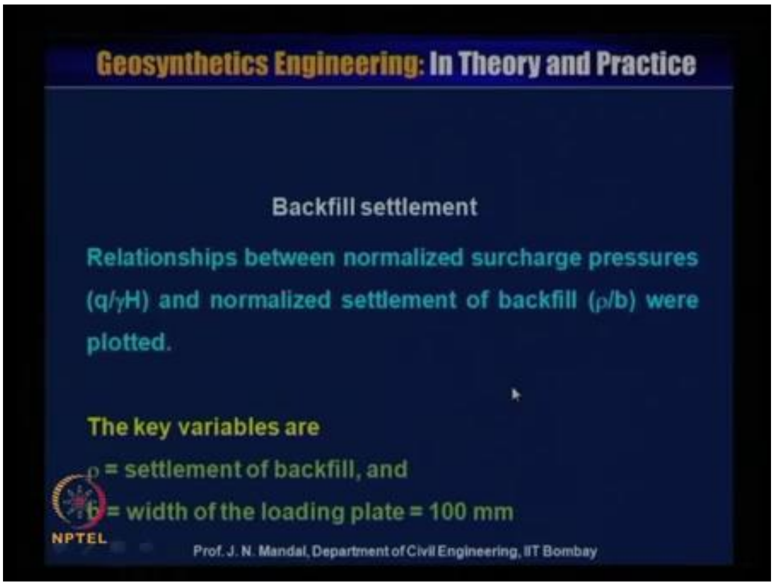

So, for backfill settlement relationship between normalized surcharge pressure q by gamma H and the normalized settlement of the backfill rho by b, were plotted. So, here key variable rho is the settlement of the backfill material and b is the width of the loading plate, that is 100 millimeter.

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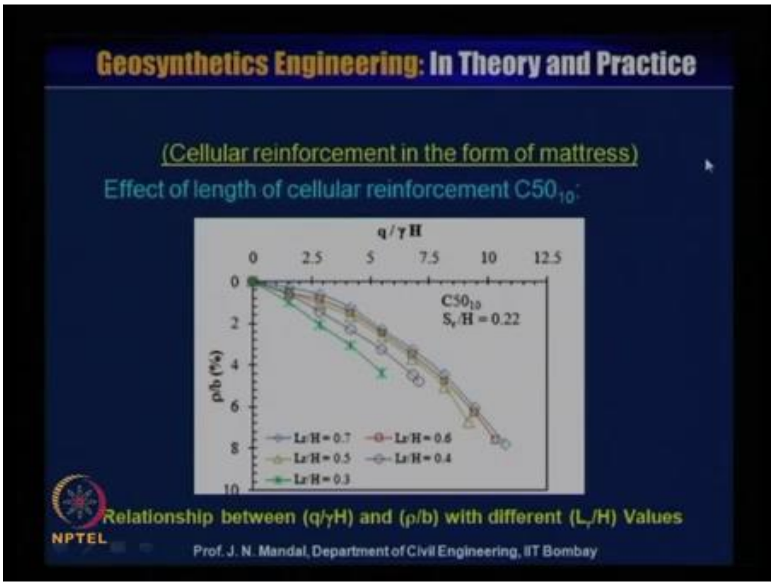

So, this is the cellular reinforcement form of mattresses, effect of length with the cellular reinforcement C50 10, so this relationship between the q by gamma H and rho by b with different L by r ratio.

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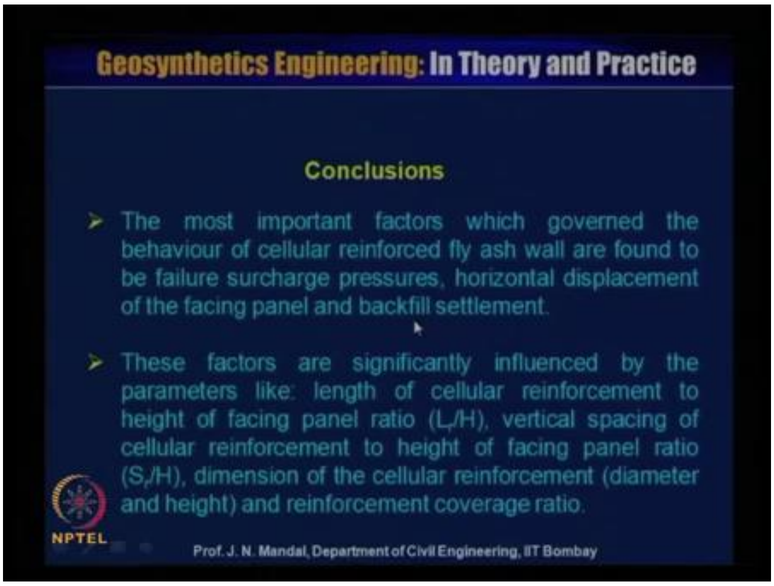

You can see that, then, what conclusion we can draw, most important factor which govern the behaviour of the cellular reinforced fly ash wall, are found to be failure surcharge pressure, horizontal displacement of the facing panel and backfill settlement. These factor are significantly influenced by the parameter like length of the cellular reinforcement to height of the facing panel ratio Lr by H, vertical spacing of the cellular reinforcement to the height of the facing panel ratio that is, Sr by H. And dimension of cellular reinforcement that means, diameter and height and the reinforcement coverage ratio.

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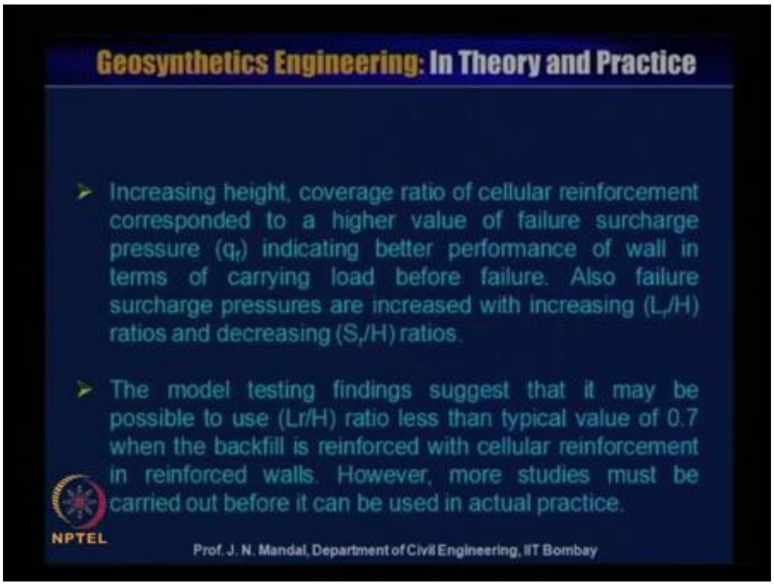

The increasing the height of the coverage ratio of cellular reinforcement corresponding to, higher value of failure surcharge pressure q f indicating, better performance of the wall in terms of the carrying load, before failure. Also failure surcharge pressure are increased, with increasing the L r by H ratio and decreasing the S r by H ratio. The model testing findings suggest that, it may be possible to use L r by H ratio less than, typical value of 0.7. When, the backfill is reinforced with cellular reinforcement, in reinforced wall however, more studies must be carried out before it can be used in the actual project.

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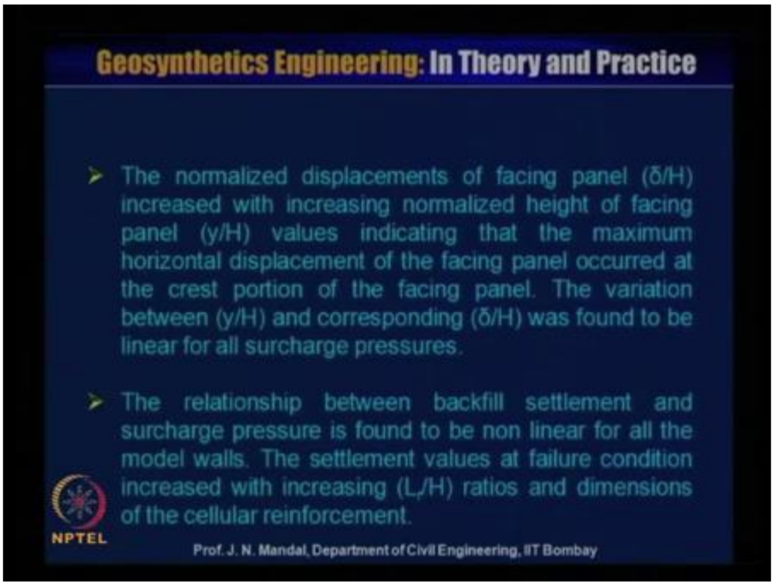

The normalized displacement of the facing panel delta by H increase, with increasing normalized height of the facing panel y by H value indicating that, maximum horizontal displacement of the facing panel occurred at the crest portion of the facing panel. The variation between y by H corresponding to delta by H, was found to be linear for all surcharge pressure. The relationship between the backfill settlement and the surcharge pressure is found to be, non-linear for all the model wall, the settlement value at failure condition increased with increasing the L r by H ratio and dimension of the cellular reinforcement.

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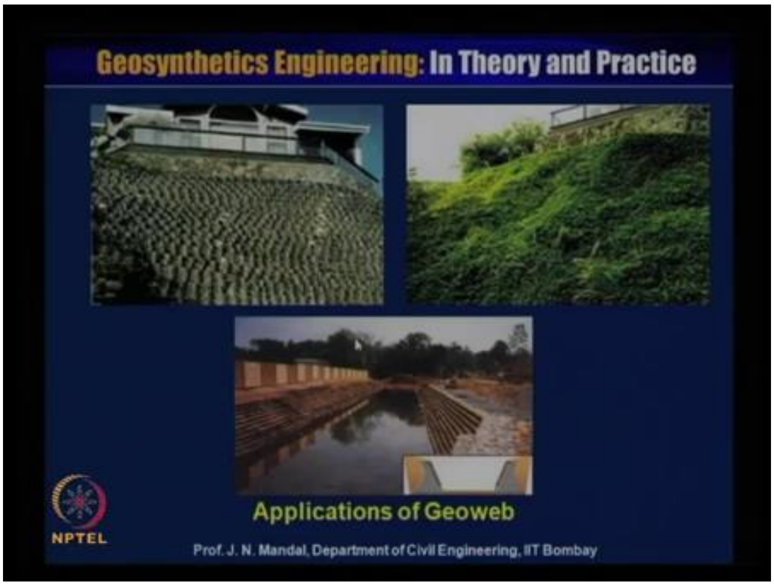

You can see some kind of the, application of the Geoweb where, this here is the building, where is the geocell has been used and then the grass can grow. Here also in the canal where, the geocell also has been used. Please let us hear from you, any question.

Thanks for listening.