Pavement Materials
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Lecture – 9
Strength Properties of Soil (Part-4)

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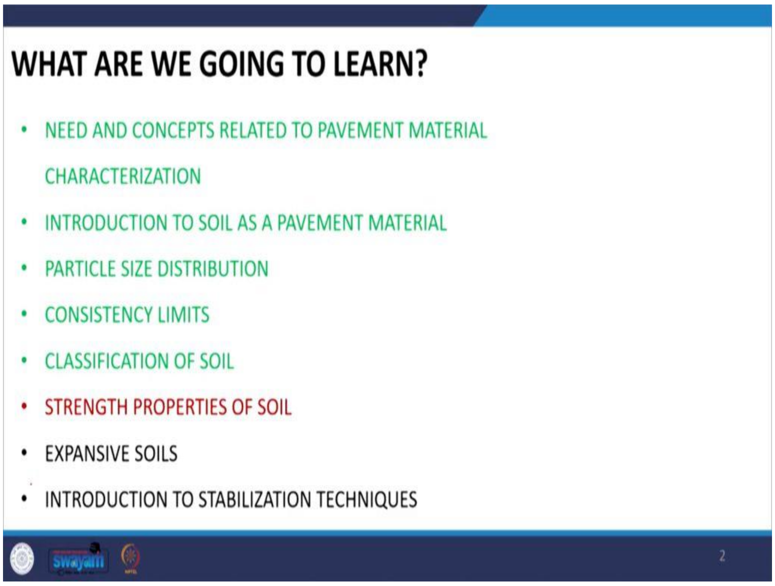

Hello friends, in the last lecture we were talking about the CBR test of the soil. Today, we will continue our discussion on the strength properties of soil and will start discussing with the dynamic cone penetrometer test.

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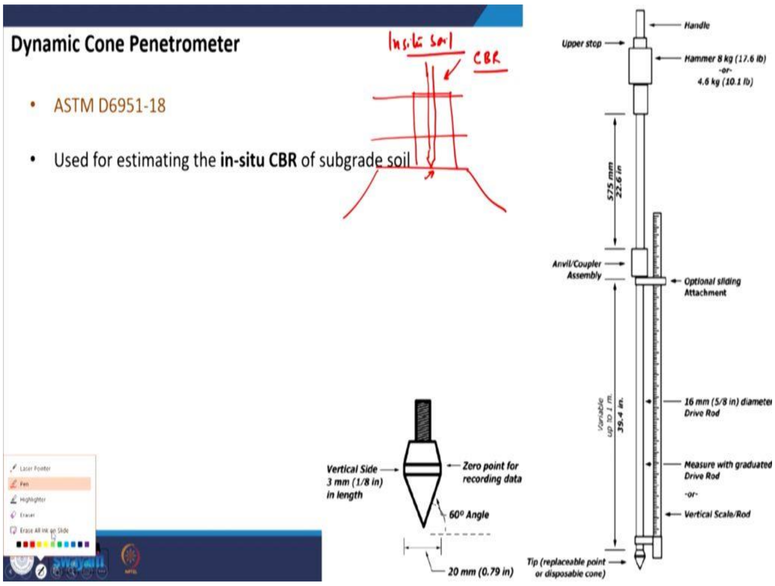
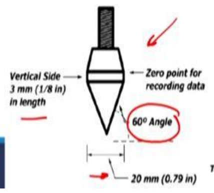
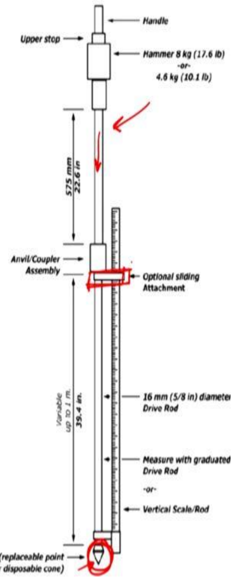
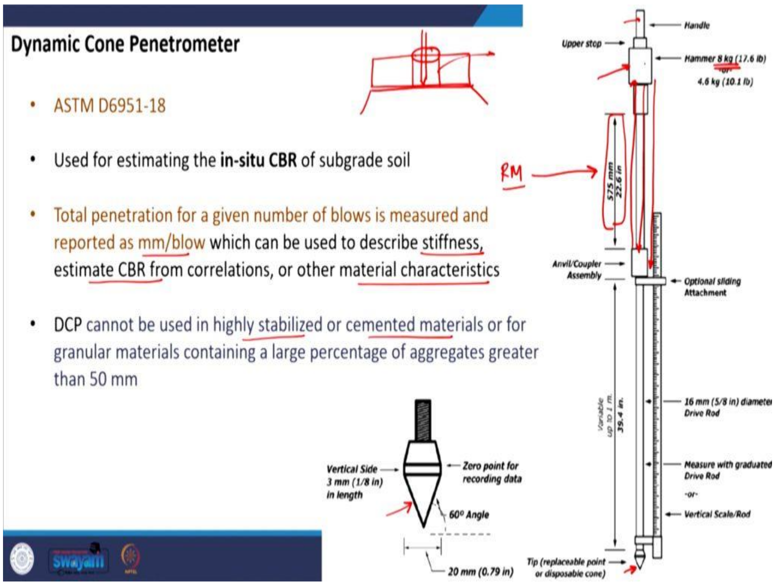


Dynamic Cone Penetrometer

- ASTM D6951-18
- Used for estimating the **in-situ CBR** of subgrade soil
- Total penetration for a given number of blows is measured and reported as mm/blow which can be used to describe stiffness, estimate CBR from correlations, or other material characteristics







So, the standard method for dynamic cone penetrometer test is ASTM D6951, you can look at it. So, why are we doing a dynamic cone penetrometer test? So, dynamic cone penetrometer test is usually adopted for testing in-situ soil. Let us say you have already constructed a pavement and after few months or after a few years, you are going to visit that pavement to see or to analyze the in-situ properties. So, in the pavement you have let us say this is the subgrade soil, we usually cut a pit here.

We will expose this soil and then we will put this penetrometer here, and we will do the specific test as per the procedure. And using the results we will be able to tell about the stiffness of the material. Here we will be able to predict the CBR of the soil of this particular subgrade material and so on. So, in pavement engineering, typically DCP test is used to estimate the value of CBR of the existing subgrade soil. So, let us see that how this test is done. Again, this is an empirical test.

A simple test to be performed in the field, if we do not have much time to take the sample, go to the lab to the testing, so, this will be a quick test for us. So, this is used in as for estimating the in-situ CBR of subgrade soil as I mentioned. In this test what we do? We measure the total penetration for a given number of blows, and then the result is reported in terms of mm per blow. So, you see we have a standard cone here, which is basically you know, which is attached to the lower part of the penetrometer. So, this is the penetrometer, it is basically a vertical rod in very simple terms.

So, this vertical rod which you are seeing is the penetrometer. On the lower part we have the cone attached. This cone is a very specific cone, usually we take the cone having an angle of 60 degree. So, 60-degree cone we take and you can see the other dimensions of the standard cone. And then you have a sliding attachment here to hold the load, which we will be using for the penetration, and you see this is the load. So, in the DCP test, the standard load which is used for penetrating this particular cone on the surface of the soil is 8 kg. So, we usually hold the handle here and then manually we will lift this load, and we will allow a free drop to this particular point.

So, the standard drop height is 575. So, we will move the load upward, we will allow a free drop. It will again drop here and we will keep on doing this reputation until the completion of the test method or the test process. So, this value of penetration in terms of mm per blow as I said is used can be used to describe the stiffness of the material, it can be used to estimate the CBR from existing correlations. It can also be used to assess other material characteristics. And talking about correlations not only CBR, there are correlations available that will give us the value of resilient modulus directly from the values of the dynamic cone penetrometer test.

DCP test cannot be used in highly stabilized or cemented materials because this can harm the cone also. And it will not the weight which we are using is also not sufficient for the penetration of the cone inside such stiff material. So, usually let us say you are interested to analyze a subgrade soil, over this you have a stiff material, let us say you have a cement concrete slab. Then, typically you have to drill a hole here, remove this material, and then you will put your DCP cone to do the test. So, you can do the test from the surface also by drilling the hole.

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TABLE 1 DCP Data Sheet[4]

Project: Forest Service Road
Location: STA 30+50, 1 M RT of C/L
Depth of zero point below Surface:0
Material Classification: GW/CL
Pavement conditions: Not applicable

Date: 7 July 2001
Personnel: JLS & SDT
Hammer Weight: 8 kg [17.6 lb]
Weather: Overcast, 25 °C, [72 °F]
Water Table Depth: Unknown

Number of Blows[A]	Cumulative Penetration mm [in.][B]	Penetration Between Readings mm [in.][C]	Penetration per Blow mm [in.][D]	Hammer Factor[E]	DCP Index mm/blow [in./blow][F]	CBR %[G]	Moisture %[H]
0	0 [0]	. . .	. . .	. . .	. . .	. . .	
5	25 [0.98]	25 [0.98]	5 [0.196]	1	5 [0.196]	50	
5	55 [2.17]	30 [1.19]	6 [0.238]	1	6 [0.238]	40	
15	125 [4.92]	70 [2.75]	5 [0.183]	1	5 [0.183]	50	
10	175 [6.89]	50 [1.97]	5 [0.197]	1	5 [0.197]	50	
5	205 [8.07]	30 [1.18]	6 [0.236]	1	6 [0.236]	40	
5	230 [9.06]	25 [0.99]	5 [0.198]	1	5 [0.198]	50	
10	280 [11.02]	50 [1.96]	5 [0.196]	1	5 [0.196]	50	
5	310 [12.20]	30 [1.18]	6 [0.236]	1	6 [0.236]	40	
5	340 [13.39]	30 [1.19]	6 [0.238]	1	6 [0.238]	40	
5	375 [14.76]	35 [1.37]	7 [0.274]	1	7 [0.274]	35	
5	435 [17.13]	60 [2.37]	12 [0.474]	1	12 [0.474]	18	

[A] Number of hammer blows between test readings.
[B] Cumulative penetration after each set of hammer blows.
[C] Difference in cumulative penetration (Footnote B) between readings.
[D] Footnote C divided by Footnote A.
[E] Enter 1 for 8-kg [17.6-lb] hammer; 2 for 4.6-kg [10.1-lb] hammer.
[F] Footnote D × Footnote E.
[G] From CBR versus DCP index correlation.
[H] % Moisture content when available.

From ASTM D6951

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So, this is just an example taken from the ASTM code to explain you that how you are recording the reading. So, you see this is the number of blows. So, when 0 number of blows, it is at the zeroth reading, so there is nothing which is being recorded. Then, you give 5 number of blows. After 5 number of blows, you see that what is the cumulative penetration, let us say the penetration is 25 mm. So, the penetration between the reading is how much? 25-0, so this is 25. And if you want to calculate penetration per blow, you have given 5 blows, penetration is 25. So, $\frac{25}{5}$ mm per blow.

So, and this will be the reading of the DCP as well, so the DCP index is 5 for the first reading. Then, you give five additional blows here and then let us say the reading recorded was 55, but the individual rating was 55-25, so 30. And DCP value here is , $\frac{30}{5}$ that is why it is 6. Then, you record the reading after 15 more blows. So, 5 reading was after 5 blows, second reading was after 5 additional blows, and then you give 15 additional blues before recording the reading.

Let us say after 15 blows, it was 125. Then, the individual reading is how much 125 – 55=70. And the DCP value becomes $\frac{70}{15}$ = 5. So, likewise you do all the further calculations until you complete the test, so you see that you will complete the test. Usually the test is completed once the entire length of the DCP machine is penetrated in the soil sample, so, you get the DCP index. So, this is how you do the test. And then based on these results, there are correlations available.

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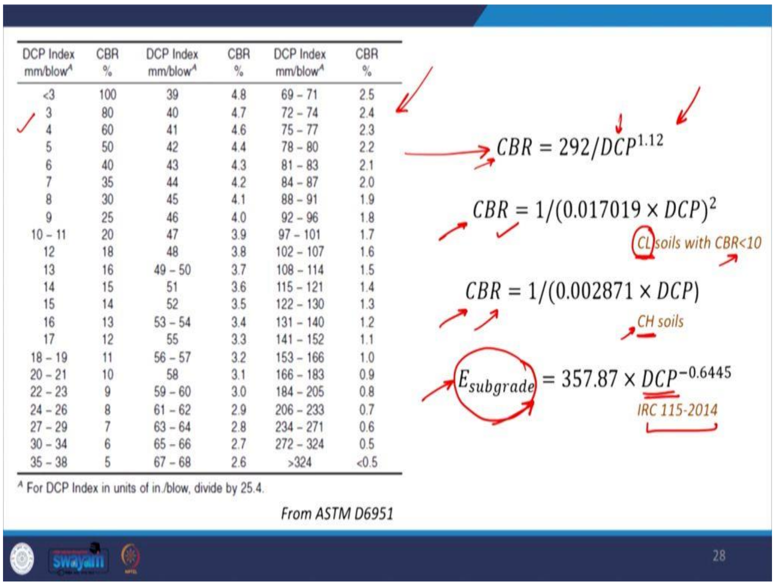

DCP Index mm/blow[A]	CBR %	DCP Index mm/blow[A]	CBR %	DCP Index mm/blow[A]	CBR %
<3	100	39	4.8	69 – 71	2.5
3	80	40	4.7	72 – 74	2.4
4	60	41	4.6	75 – 77	2.3
5	50	42	4.4	78 – 80	2.2
6	40	43	4.3	81 – 83	2.1
7	35	44	4.2	84 – 87	2.0
8	30	45	4.1	88 – 91	1.9
9	25	46	4.0	92 – 96	1.8
10 – 11	20	47	3.9	97 – 101	1.7
12	18	48	3.8	102 – 107	1.6
13	16	49 – 50	3.7	108 – 114	1.5
14	15	51	3.6	115 – 121	1.4
15	14	52	3.5	122 – 130	1.3
16	13	53 – 54	3.4	131 – 140	1.2
17	12	55	3.3	141 – 152	1.1
18 – 19	11	56 – 57	3.2	153 – 166	1.0
20 – 21	10	58	3.1	166 – 183	0.9
22 – 23	9	59 – 60	3.0	184 – 205	0.8
24 – 26	8	61 – 62	2.9	206 – 233	0.7
27 – 29	7	63 – 64	2.8	234 – 271	0.6
30 – 34	6	65 – 66	2.7	272 – 324	0.5
35 – 38	5	67 – 68	2.6	>324	<0.5

[A] For DCP Index in units of in./blow, divide by 25.4.

From ASTM D6951

For example, you see this is one table which has been created using this particular correlation. So, using the DCP value, you can calculate the value of the CBR in percentage. So, the first equation which means this particular table is applicable to most of the soils, except the soils which falls under the category of CL with CBR less than 10 percent, and also the soil which falls under the category of CH. So, they have given two separate correlations for these soils, so, this is the general equation for all types of soil. But, if it is a soil which is a clay soil with low compressibility and the CBR value is less than 10 percent, then, this equation you can use.

If it is a clay soil with high compressibility, then this particular equation can be used. In India, to analyze the in-situ soil when we are doing pavement evaluation let us say using IRC 115 for flexible pavement evaluation, then this is the correlation which has been suggested here that if you know the value of DCP, then you can use this equation to calculate the resilient modulus of the subgrade which is used in the pavement design.

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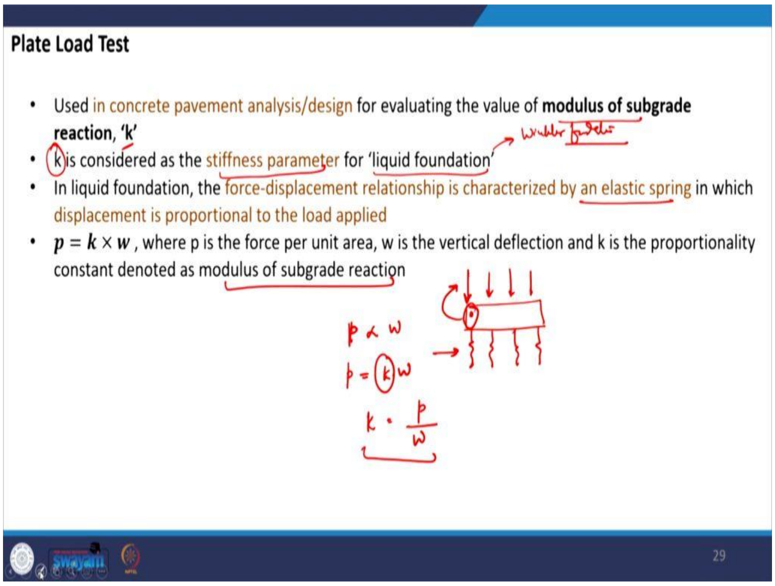

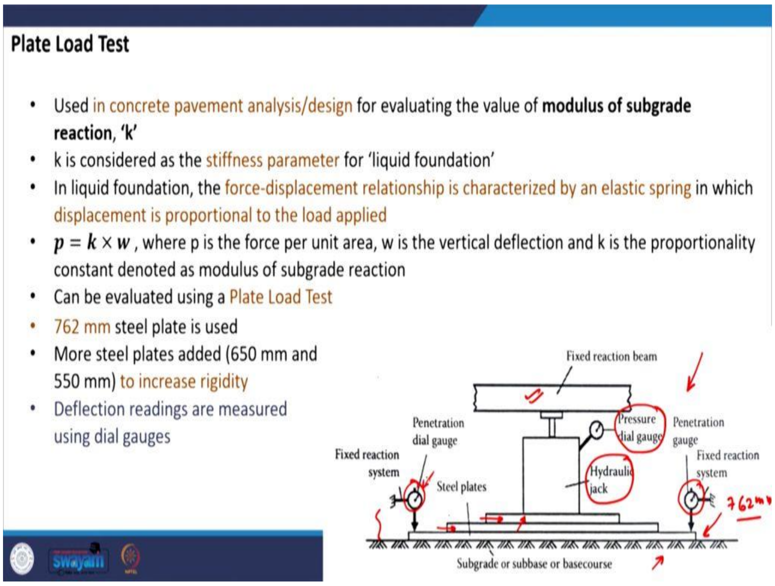

Now, we talk about last common test which is used typically in pavement design, that is the plate load test. Plate load test is basically used in concrete pavement analysis and design, and this value we need for evaluating the modulus of subgrade reaction k. I mean the test we need to evaluate the modulus of subgrade reaction k. And what is k? k is actually a stiffness parameter for the liquid foundation. So, liquid foundation is the Winkler Foundation which we assume in the concrete pavement design.

So, what is the liquid foundation? It is basically can be considered that your slab concrete slab is resting on a set of spring here. So, this foundation is characterized by elastic spring. And the assumption here is that the displacement at any particular point is proportional to the load at that particular point only, and is not affected by the load at other points. So, the displacement of this point will be a function of the load which is applied to this point. So, which means that if I know the what is the load pressure, this will be proportional to the deflection at that particular point.

So, p = k ×w, and this k which is the proportionality constant is nothing but the modulus of subgrade reaction k, which means k is the load pressure per unit deflection. So, this is the definition of k and this k is used in the analysis and design of concrete pavement, and that is why we are interested for its to evaluate it using the plate load test. So, this is a representation of the plate load test which you can see here. So, here what we have? We put the assembly on the subgrade or the material over which we are trying to find out the value of k. You can see that this is the arrangement of the plate load test.

Here we keep the machine over the layer on which we are interested to find out the value of modulus of subgrade reaction. This comprises of a set of plates, the dia of the plate which rest on the particular layer is 762 mm, so, this is the standard dia. We have more plates which are kept here, this is done to increase the rigidity of this particular setup. These plates are kept in decreasing diameter. So, the diameter of this plate is around 650 mm, whereas, the diameter of the top plate is around 550 mm.

Then, we have dial gauges, we can have two to four dial gauges which are kept to continuously record the penetration of the plate once we start applying the load. So, the load is applied using the hydraulic jack here and the amount of load or the pressure can be monitored using a pressure dial gauge. So, what we do in this test using the reaction frame? We continuously apply the load and we see that how the penetration changes with increase in load.

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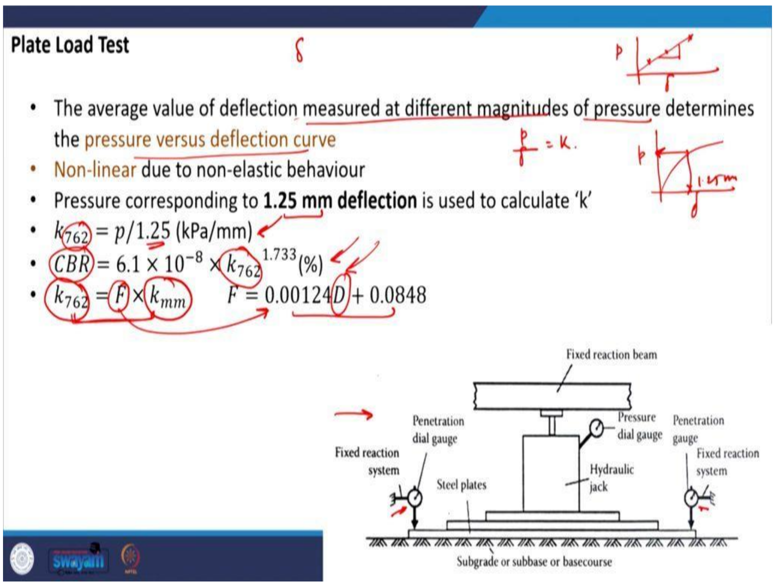

So, since we have let us say two to four dial gauges, we will take the average of those dial gauge reading to see the average value of deflection. So, the average value of deflection measured at different magnitudes of pressure, it determines the pressure versus deflection curve. So, this is what we draw here pressure versus deflection. If it would have been a elastic material, then you would have got a straight line. But, typically soils are not elastic in nature, so, we will get a nonlinear relationship between the value of p and delta (δ). And then since if the slope is not constant, so, which means we cannot use all the points to define the value of k.

So, the standard is that we will see the pressure corresponding to a deflection of 1.25mm. So, will note down the pressure here and this pressure divided by deflection is the value of k. So, this is the value which you get and as I said deflection is 1.25 mm, so, this is fixed. This plate load test is basically a very cumbersome test to do in the actual field. It comprises the size of the machine is huge and it is not always feasible to carry this machine at the field and carry out the test on the soil we are interested in.

So, again researchers have tried to develop correlation for the value of k with respect to some easier test which can be conducted. And as we have discussed, CBR is one of those easier tests which we can perform in the laboratory. So, with respect to CBR, we can find out the value of k 762, and this is one of the correlation which is available you can see here. So, if you know the CBR of the soil, you can calculate the value of k also. As I said that the 762 mm is the standard dia of the plate which is used, and this correlation is also applicable for 762 mm dia plate.

But, if the test is done using some other dia, some some other plate with some different diameter. So, we can use this particular equation which is shown here to calculate the value of k corresponding to 762 mm, if the value of k corresponding to any other dia is available with us. So, you can see that it is just a multiplication of a constant and this constant is defined as this. So, this F you can see that it is a simple equation, where D is the dia of the plate with which we are doing the testing. So, I hope again this process is clear to you and it is clear that why we use the plate load test.

It is basically used in the concrete pavement design and we have correlations available, because conducting plate load test is not always very practically possible. Therefore, we have correlations available. So, if you know the CBR of the soil, you can also estimate the value of k to be used in concrete pavement design. Well with this week, we have completed most of the strength tests that are used typically in the area of pavement engineering, concerning soils. And in the next lecture we will take up a new topic, we will start discussing about expensive soils.

And we will also see that what are the techniques available to stabilize expensive soils, if we encounter it at the site. So, we will see what are the problems with the expensive soils and then how they can be stabilized. Thank you.