Soil Structure Interaction
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Lecture - 11
Soil – Structure Interaction for Shallow Foundation:
Concept of Subgrade Modulus (Continued)

In the last class, the different factors affecting the modulus of subgrade reaction were discussed. Now, the discussion will be continued from that point followed by more correlations and an alternate method to determine the modulus of subgrade reaction as per IS code.

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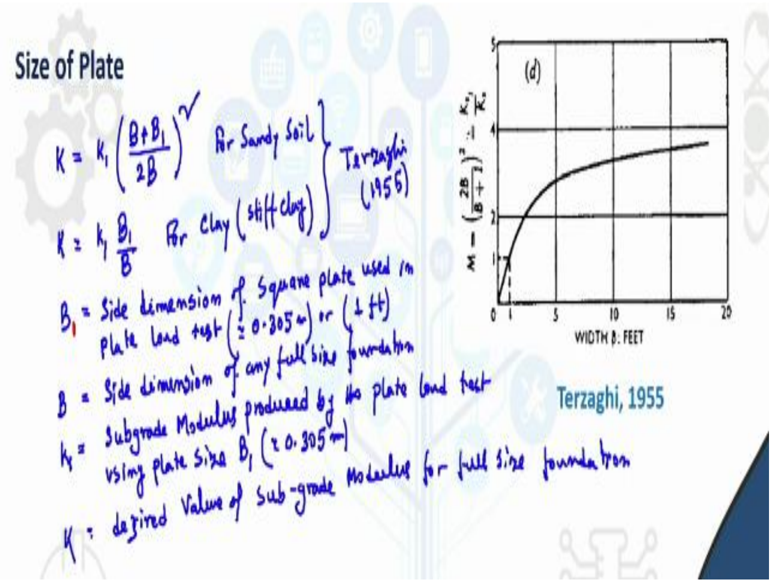

The above slide shows the equations of plate size correction in case of both sandy and clayey soils. B_1 is the side dimension of square plate used in plate load test (usually = 0.305 m) and B is the dimension of any full size foundation.

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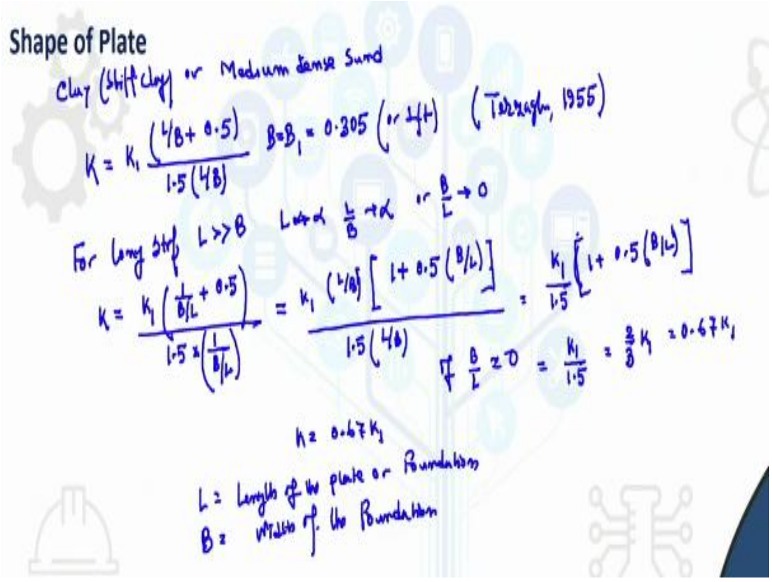

The equations involved in shape of the plate correction are shown above. So, the correction can be calculated for any given L/B ratio.

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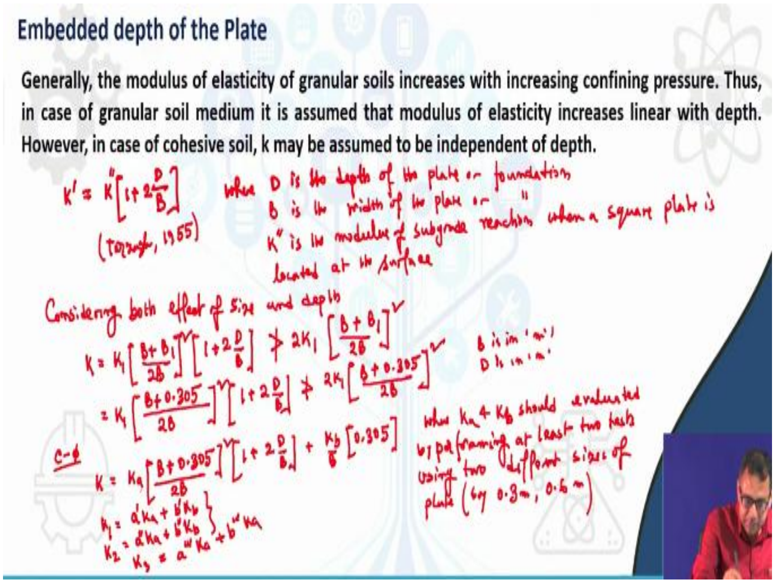

The embedded plate or depth effect was also discussed and the expression given is shown in the slide above along with that of combined correction for size and depth effect. k′ is the modulus of subgrade reaction at any depth and k″ is obtained at the surface by conducting plate load test for square plate. It should be remembered that B, D are in meter.

For a c-φ soil, the expressions involve k_a and k_b which are to be evaluated by performing at least two plate load tests or two different sizes of plate. Two expressions can be obtained from two tests that can be used to solve for two unknowns there by finding k_a and k_b.

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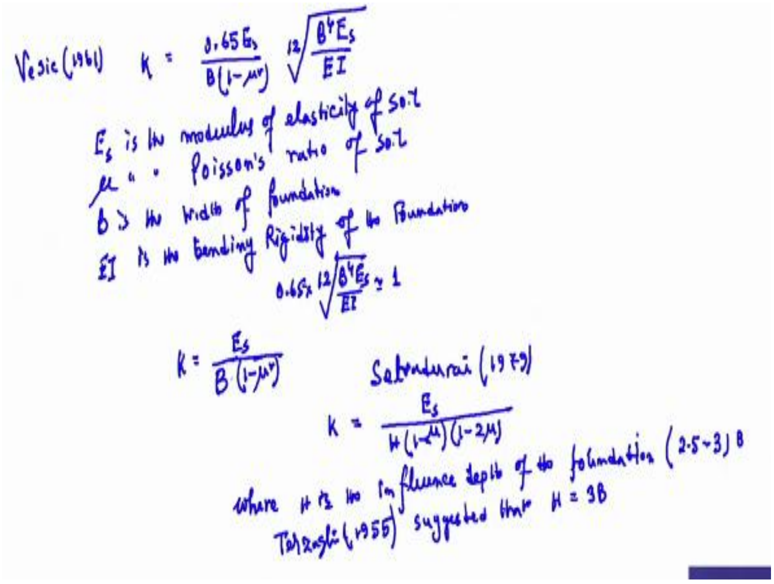

A correlation to predict the modulus of subgrade reaction of the soil considering various factors was given by Vesic (1961):

$$k = \frac{0.65E_s}{B(1-\mu^2)} \sqrt[12]{\frac{B^4 E_s}{EI}}$$

where, E_s is the modulus of elasticity of soil, μ is the Poisson's ratio of soil, B is the width of foundation and EI is the bending rigidity or flexural rigidity the foundation.

Sometimes the value, $0.65 \times \sqrt[12]{\frac{B^4 E_s}{EI}}$ may be ignored because it is close to one 1 leading to a simplified form of the equation:

$$k = \frac{E_s}{B(1-\mu^2)}$$

Similarly, Selvadurai (1979) suggested one expression:

$$k = \frac{E_s}{H(1-\mu)(1-2\mu)}$$

where, H is the influence depth or zone of the foundation which can be taken as two 2.5 to 3 times the footing width, (Terzaghi in 1955 suggested H = 3B). So if the elastic modulus of the soil and Poisson's ratio of the soil are known, for a particular footing, the k value can be calculated.

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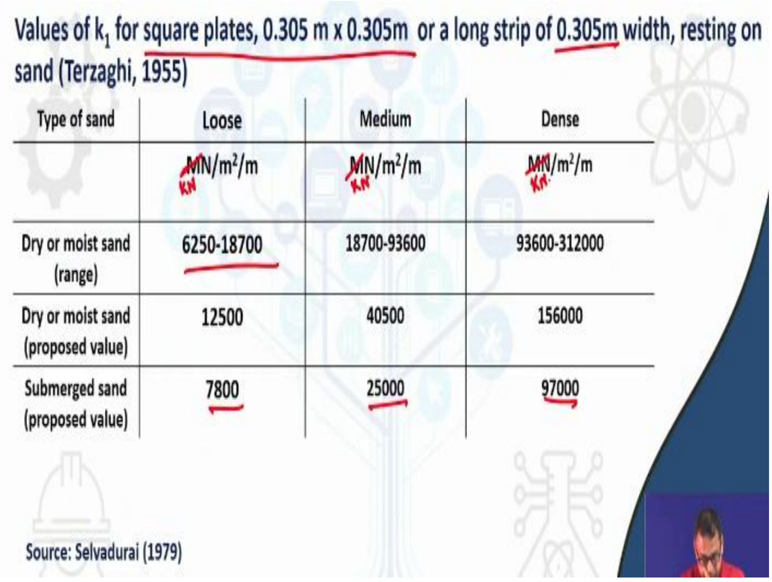
Values of k_1 for square plates, 0.305 m x 0.305m or a long strip of 0.305m width, resting on sand (Terzaghi, 1955)

Type of sand	Loose	Medium	Dense
	MN/m²/m (kN)	MN/m²/m (kN)	MN/m²/m (kN)
Dry or moist sand (range)	6250-18700	18700-93600	93600-312000
Dry or moist sand (proposed value)	12500	40500	156000
Submerged sand (proposed value)	7800	25000	97000

Source: Selvadurai (1979)

The values of k_1 for square plate of size 0.305 meter × 0.305 meter or for a long strip of 0.305 meter width resting on the sand under various conditions are given by Terzaghi. Please note that the k_1 values are in kN/m^2/m. These values are particularly given for a square plate or a long strip of 0.305 m. For any other type or size of foundation, k_1 values from the above table can be used only after applying the appropriate conversions.

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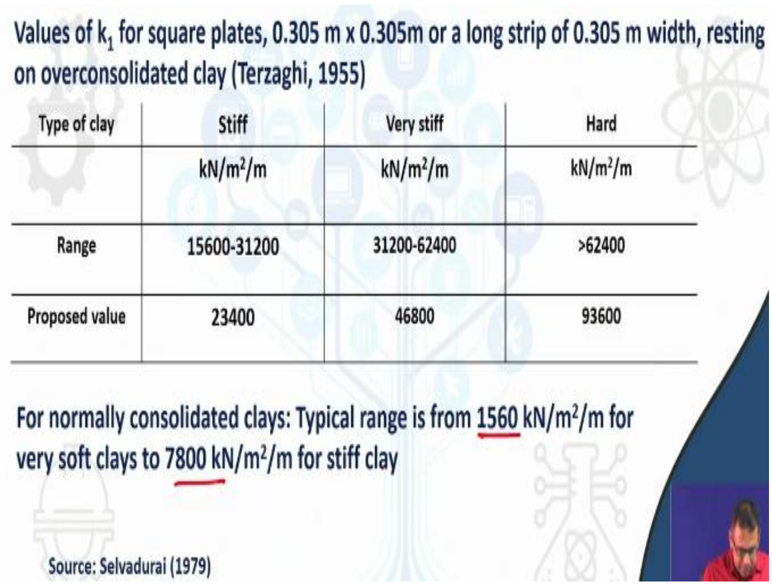
Values of k_1 for square plates, 0.305 m x 0.305m or a long strip of 0.305 m width, resting on overconsolidated clay (Terzaghi, 1955)

Type of clay	Stiff	Very stiff	Hard
	kN/m²/m	kN/m²/m	kN/m²/m
Range	15600-31200	31200-62400	>62400
Proposed value	23400	46800	93600

For normally consolidated clays: Typical range is from 1560 kN/m²/m for very soft clays to 7800 kN/m²/m for stiff clay

Source: Selvadurai (1979)

Similar ranges were given by Selvadurai (1979) for k_1 values for clays under various conditions. All the values in this table are also in kN/m^2/m.

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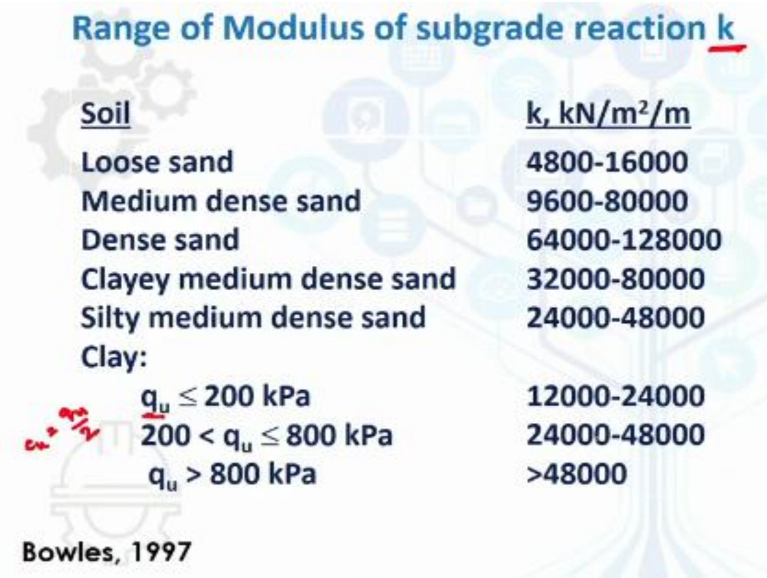

Similar to the ranges given for k_1 values, depending upon the soil type, ranges for k value were also given by Bowles (1997). q_u is the unconfined compression strength of soil which was discussed in the first class ($q_u = c_u/2$).

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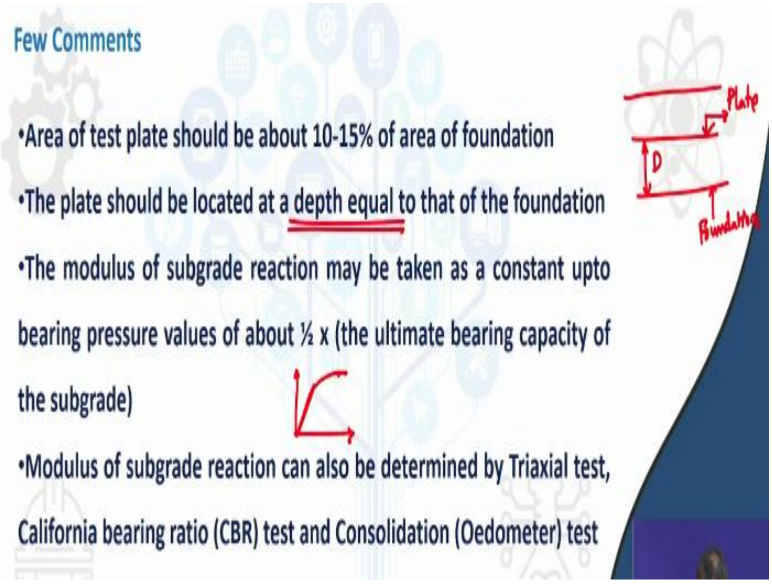

A few aspects should be taken into consideration for the plate load test which are presented in the slide above. The area of the test plate should be about 10 to 15% of area foundation. The plate should be located at a depth equal to the foundation failing to which a depth correction factor should be applied to find out the k value for a particular foundation. The modulus of subgrade reaction may be taken as a constant up to bearing pressure values about half times the ultimate bearing capacity of subgrade. That means the graph between bearing capacity and subgrade modulus reaction should be linear at least up to a value equal to half of the ultimate bearing capacity.

Even if the plate is not at the surface, but at a depth less than the foundation depth, the depth correction factor should be applied. The value of D used in the depth correction would be the difference between depths of plate and footing.

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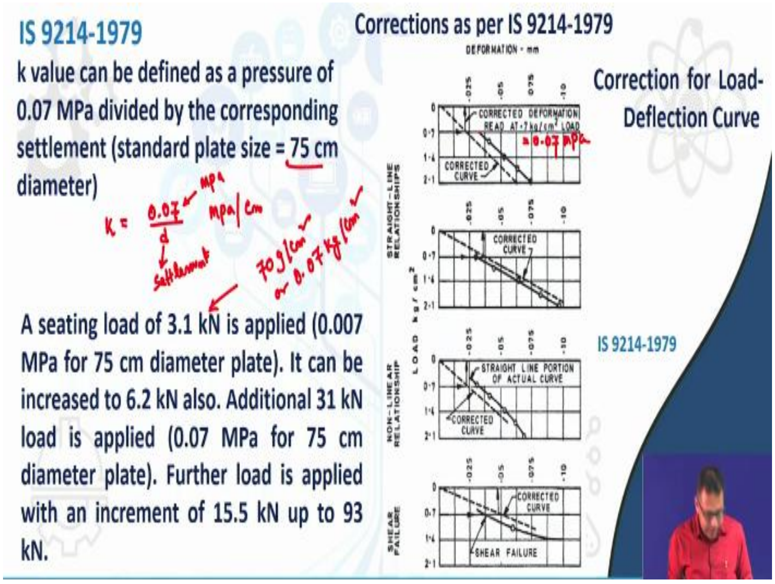

Now, an alternate method to calculate the subgrade modulus as per IS code 9214-1979 will be discussed. According to this code, the k value can be defined as the ratio of 0.07 MPa and the corresponding settlement (in cm) where the standard plate size is 75 cm. The only difference in calculating the k value from the previously discussed method is that the stress corresponding to a settlement was considered before but according to this method, the settlement corresponding to a stress should be considered.

The test procedure is the same as that of the plate load test discussed before. To briefly have an overlook of the procedure, first of all a seating load of 3.1 kN is applied. As the standard plate size is 75 cm, a seating load of 3.1 kN will produce a stress of 0.007 MPa. Sometimes, depending upon the type of soil, the seating load can be applied up to 6.2 kN. Then additional 31 kN load is applied which is 0.07 MPa for 75 cm diameter plate and further load is applied with an increment of 15.5 kN up to 93 kN. So, after applying the seating load, the additional 31 kN load is applied which is equal to 0.07 MPa for 75 cm diameter plate. Ultimately, the k value is obtained by dividing the 0.07 MPa stress with its corresponding settlement value (in cm) obtained from the load-settlement graph.

After obtaining the k value from the load settlement graph, few corrections should be applied to it and the first of them is that if the initial portion of the curve is not linear. First, consider three points on the linear portion of the curve and then draw straight line almost parallel to it that passes through the origin. So, first make the non-linear curve linear (straight line) and then draw a parallel line that passes through the origin. Similarly if a load settlement curve is straight initially, but does not pass through the origin, three points should be considered from the original line to plot a parallel line that passes through the origin.

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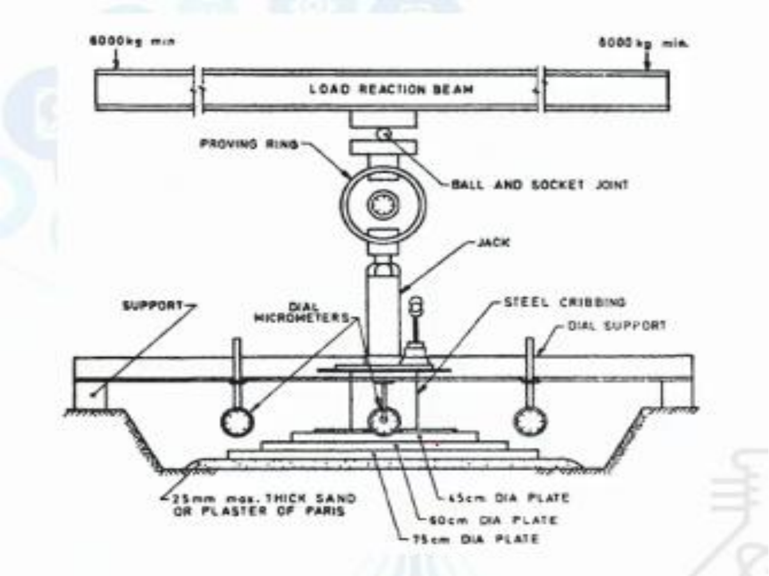

This is test setup which is same as the plate load test already discussed in the previous classes.

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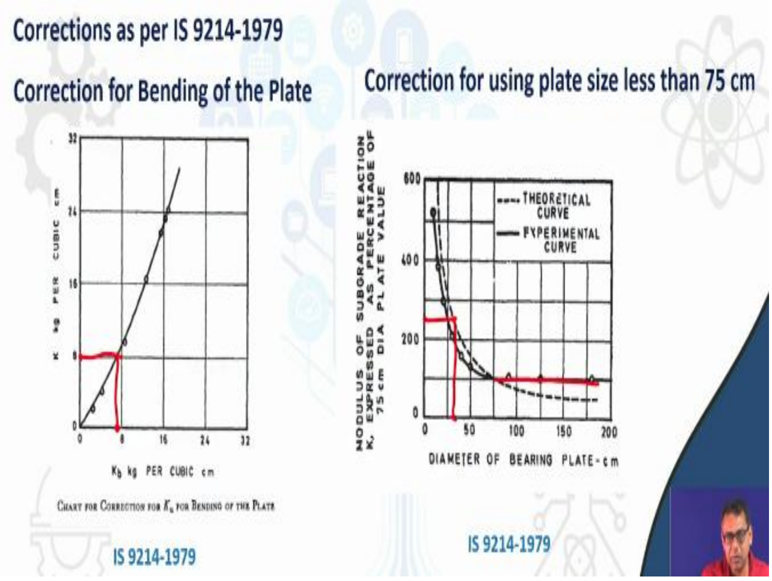

The next correction for the subgrade modulus is the correction for bending of the plate. The chart that helps to apply this correction is given in the IS code which is shown in the slide above. There are two curves given in the IS code for the bending correction. If the plate load test was done using a 75 cm plate, the first curve (left side) in the slide above should be used. In the first curve, the Y-axis represents the uncorrected k value that is obtained from the load deformation curve and the X-axis reads the corrected k values indicated by k_b. If the test was not done by a 75 cm plate, the second curve on the right shown in the slide above should be used. For example the k value obtained from the test done by 30 cm plate would be almost 250 times that of the test by 75 cm plate.

So, it should be remembered that a lower dimension plate size always gives higher k value compared to a higher dimension plate size. But, this pattern becomes invalid beyond 75 cm plate size as the k values will be same for all the plate sizes equal to or above 75 cm.

The next factor to be considered in correcting the k value is the saturation state of the soil. A test done on dry soil would give different result from a test on saturated soil. So, a correction for saturation should also be applied to the k value obtained. To determine this correction factor, a saturated specimen and an unsaturated specimen out of the same soil sample should be tested in the consolidation apparatus under same seating load and same additional 31 kN load. The deformations for both the specimens are determined and used in the correlation:

$$k_{corrected} = \frac{d}{d_s} k_{uncorrected}$$

where, d is the deformation of soil with natural moisture content under a unit load of 31 kN in addition to the seating load of 3.1 kN; d_s is the deformation of soil in saturated condition under a unit load of 31 kN in addition to the seating load of 3.1 kN.

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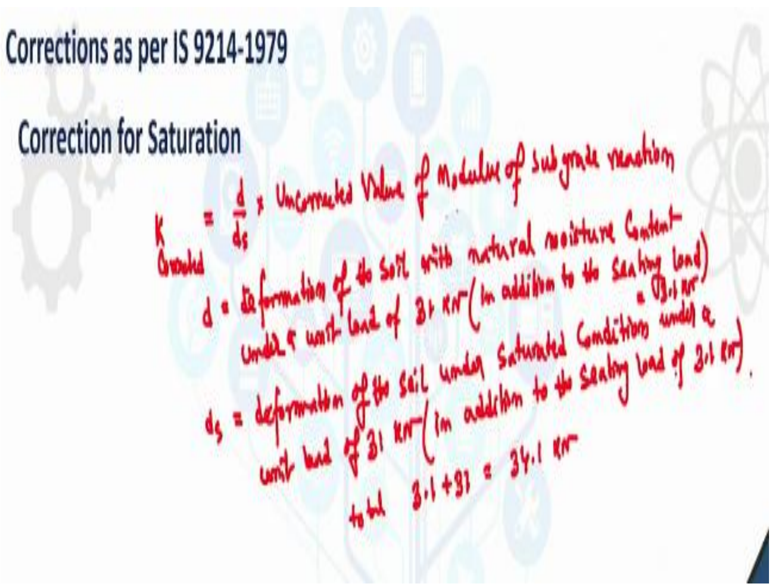

So, uncorrected value of subgrade reaction is under natural moisture content condition. In the next class, I will solve one example problem and then I will show how to determine the k value as per IS method. Thank you.