Soil Dynamics

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Module - 4
Dynamic Soil Properties
Lecture - 23
Cyclic Stress Ratio, Evaluation of CRR, Correction Factors, Correction for SPT

Let us start our today's lecture of soil dynamics. We were continuing with module 4 that is dynamic soil properties.

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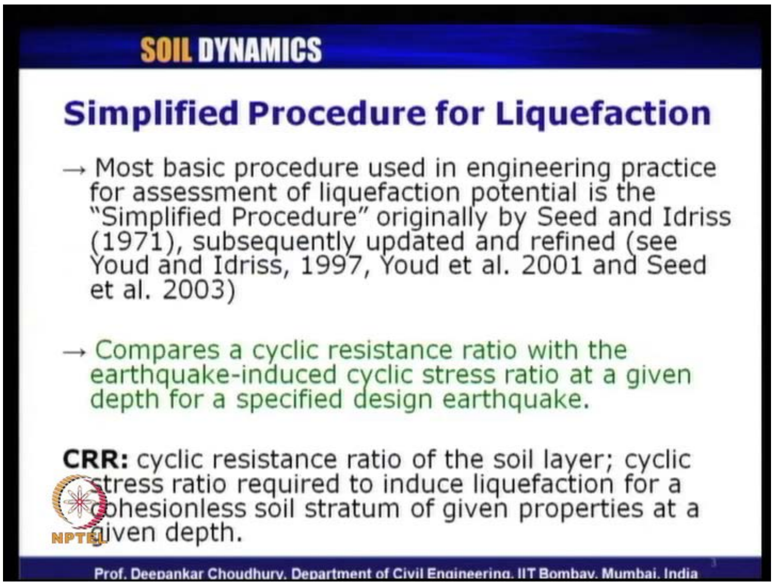

SOIL DYNAMICS

Simplified Procedure for Liquefaction

→ Most basic procedure used in engineering practice for assessment of liquefaction potential is the "Simplified Procedure" originally by Seed and Idriss (1971), subsequently updated and refined (see Youd and Idriss, 1997, Youd et al. 2001 and Seed et al. 2003)

→ Compares a cyclic resistance ratio with the earthquake-induced cyclic stress ratio at a given depth for a specified design earthquake.

CRR: cyclic resistance ratio of the soil layer; cyclic stress ratio required to induce liquefaction for a cohesionless soil stratum of given properties at a given depth.

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A quick recap of what we had studied in the previous lecture; we had learnt the simplified procedure for estimation of liquefaction potential as proposed by Youd et al. 2001. Initially the simplified procedure was proposed by Seed and Idriss in 1971 which has been subsequently updated and modified and Youd et al. 2001; this is the one of the latest methodology used worldwide for computation of liquefaction potential.

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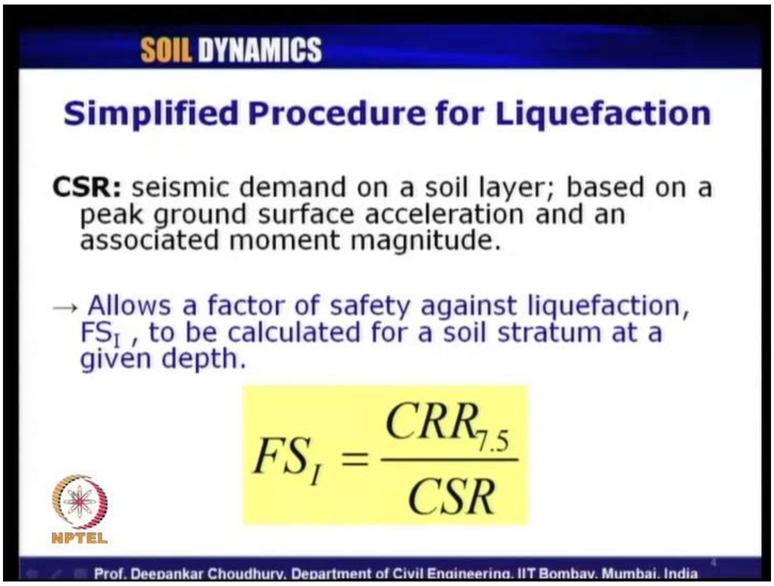

SOIL DYNAMICS

Simplified Procedure for Liquefaction

CSR: seismic demand on a soil layer; based on a peak ground surface acceleration and an associated moment magnitude.

→ Allows a factor of safety against liquefaction, FS_I, to be calculated for a soil stratum at a given depth.

$$FS_I = \frac{CRR_{7.5}}{CSR}$$

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So, two terms have been defined; CRR cyclic resistance ratio and CSR cyclic stress ratio. The factor of safety against liquefaction is defined as CRR 7.5; 7.5 denote the moment magnitude of earthquake of 7.5. CRR is calculated at that magnitude of earthquake by the CSR at a particular depth.

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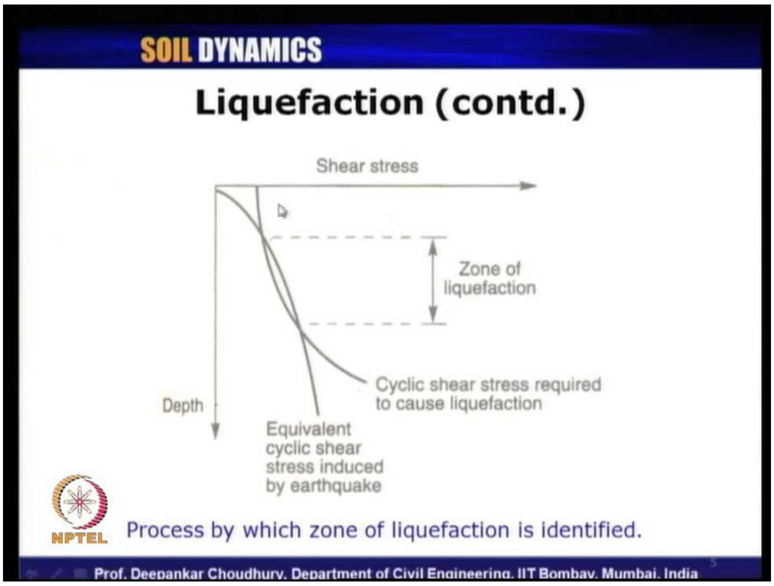

SOIL DYNAMICS

Liquefaction (contd.)

Process by which zone of liquefaction is identified.

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So, this is the basic principle of what we understand by liquefaction. This curve shows the development of equivalent cyclic shear stress induced, because of a particular earthquake and this curve shows cyclic shear stress, which is required to cause liquefaction. So, this is the capacity of the soil. So, if it is less than whatever is produced cyclic shear stress; obviously, the liquefaction is going to happen. So, that is why in this zone we found this is the zone of liquefaction.

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SOIL DYNAMICS

Acceptable Factor of Safety

- 1.3 is recommended, but depends on severity of hazard, importance and vulnerability of structure, tolerable settlements or level of risk acceptable to owner or regulating body, confidence and certainty in underlying data and assumptions
- Lower factor of safety (1.1) may be acceptable for single family dwellings, for example, where potential for lateral spreading is low and differential settlement is hazard of concern, where post-tensioned floor slabs are specified.

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And what are the acceptable factors of safety for design against liquefaction; 1.3 factor of safety is recommended for important structure, whereas lower factor of safety of 1.1 can be used for less important or small buildings like that.

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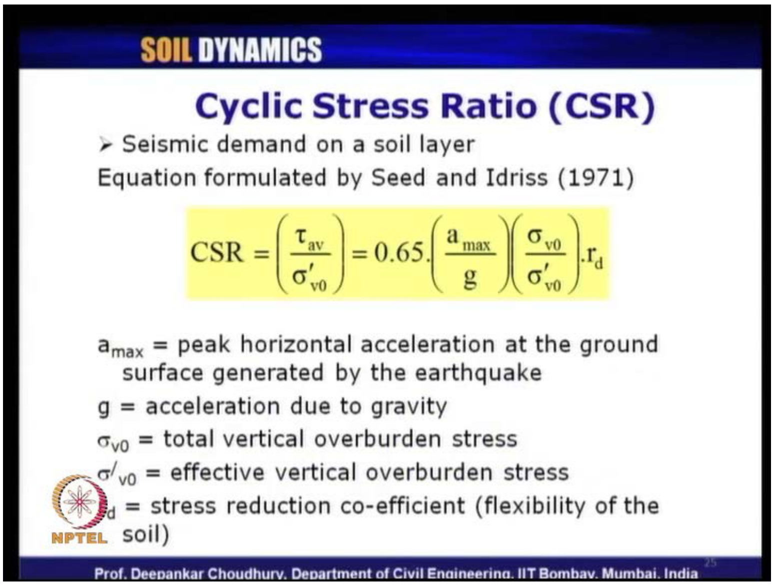

SOIL DYNAMICS

Cyclic Stress Ratio (CSR)

- Seismic demand on a soil layer

Equation formulated by Seed and Idriss (1971)

$$CSR = \left(\frac{\tau_{av}}{\sigma'_{v0}}\right) = 0.65.\left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_{v0}}{\sigma'_{v0}}\right).r_d$$

a_{max} = peak horizontal acceleration at the ground surface generated by the earthquake

g = acceleration due to gravity

σ_{v0} = total vertical overburden stress

σ'_{v0} = effective vertical overburden stress

r_d = stress reduction co-efficient (flexibility of the soil)

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How we compute the cyclic stress ratio CSR; that is the denominated part of the factor of safety expression. So as I have mentioned, it is nothing but the seismic demand on a soil layer and the CSR is estimated using the equation which was formulated by Seed and Idriss in 1971. The expression to compute the CSR is given like this; this is the expression which is equals to the average shear stress getting developed divided by the effective vertical stress at that depth, at a particular depth. So, CSR is nothing but how much average cyclic shear stress is getting developed divided by sigma v naught dash which is expressed or given by Seed and Idriss by this equation. So, this equation is widely used. It is given by 0.65 times a max by g times sigma v naught by sigma v naught dash times r d.

What are these different symbols indicates, let me explain a max; this a max is referred to peak horizontal acceleration at the ground surface generated by the earthquake. So, this is the maximum or peak PGA what we called. So, in case of horizontal acceleration it is PHA actually, peak horizontal acceleration PHA. So, maximum value of acceleration at the ground surface generated by a particular earthquake; you have your seismogram, you have measured your distribution of acceleration pattern with respect to time from which you can find out what is the maximum value or peak value. So, that is nothing but our a max. Suppose it can be 0.3 g or 0.2 g, like that, where g is acceleration due to gravity. So, a max by g is essentially giving you the coefficient of peak horizontal acceleration.

So that 0.2 or 0.3; that numerical number will come without any unit. This term sigma v naught is nothing but total vertical overburden stress at a particular point where you are calculating the CSR and eventually you are calculating the factor of safety against liquefaction at a particular depth. So, sigma v naught is total vertical overburden stress and sigma v naught dash is the effective vertical overburden stress at that particular point or at that particular depth. So, unit of sigma v naught and sigma v naught dash also will be same. So, these also give us non-dimensional parameter and what is r d? r d is called stress reduction coefficient. This stress reduction coefficient was proposed by Seed and Idriss. This is to take care of the flexibility of the soil because the development of this equation was based on rigid beam theory. They considered a rigid beam; soil column they have considered as the rigid beam and then they developed this expression.

Now this correction factor of the rigidity has been applied to consider the flexibility of the soil. So, that is why this correction factor r d has come into picture. This is also a number only, no unit. Finally, CSR should not have any unit because this is the ratio of the stresses, shear stress versus vertical stress effective vertical stress and why this number 0.65 comes into picture; because it has been mentioned by Seed and Idriss from the distribution that only about 65 percent of the cyclic shear stress is getting developed during the process of this liquefaction. So, while calculating the seismic demand that 65 percent of the developed cyclic shear stress is calculated which will give us eventually the average cyclic shear stress. So, that is why this number 0.65 came into picture in the equation. So, is this clear; how this equation was developed by Seed and Idriss and what are the meanings of various parameters and what are the utilities, dimensions, etc.

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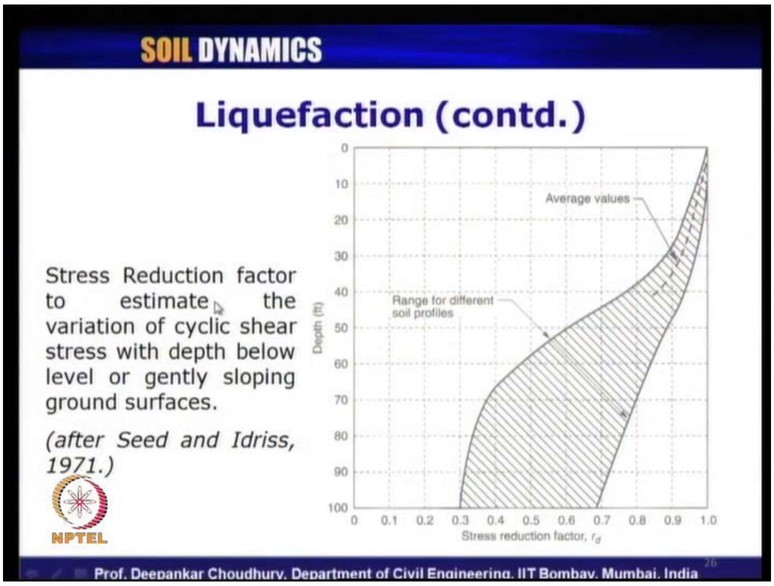

SOIL DYNAMICS

Liquefaction (contd.)

Stress Reduction factor to estimate the variation of cyclic shear stress with depth below level or gently sloping ground surfaces.

(after Seed and Idriss, 1971.)

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Now let us move to how that stress reduction coefficient r d changes with depth. So these values of r d, stress reduction factor rd was recommended by Seed and Idriss in 1971; stress reduction factor to estimate the variation of cyclic shear stress with depth below level of gently sloping ground surfaces. So, you can see this is the range for various soil properties and this dotted line show the average value of the r d. And as the depth increases, the stress reduction factor decreases and at ground surface the stress reduction factor will be one. Later on this variation of r d was proposed also empirically; semi-empirical equation was proposed by other researches, let us see that.

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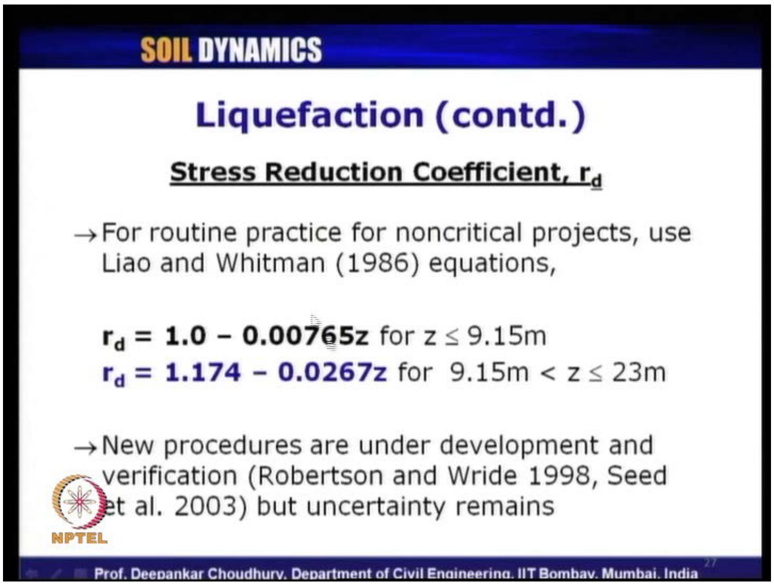

SOIL DYNAMICS

Liquefaction (contd.)

Stress Reduction Coefficient, r_d

→ For routine practice for noncritical projects, use Liao and Whitman (1986) equations,

$\mathbf{r_d = 1.0 - 0.00765z}$ for $z \le 9.15$m

$\mathbf{r_d = 1.174 - 0.0267z}$ for $9.15\text{m} < z \le 23$m

→ New procedures are under development and verification (Robertson and Wride 1998, Seed et al. 2003) but uncertainty remains

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So, stress reduction coefficient r d for routine practice for noncritical projects, Liao and Whitman in 1986; they had proposed equations to compute the values of r d. They have proposed these two expressions that is r d equals to 1 minus this 0.00765 z where z has to be used in meter, z is a depth below ground surface in meter unit because as u know semi-empirical expressions are always unit biased. So, you should remember it is in meter unit.

This expression they mentioned it is valid when the depth concerned is within 9.15 meter. If it is beyond 9.15 meter, up to 23 meter, then they proposed this expression has to be used; r d equals to 1.174 minus 0.0267 times z. So, this was proposed by Liao and Whitman. Now after that new procedures were under development how to give the r d values and also under verification to consider the uncertainty parameters. So, you will find further developments by Robertson and Wride in 1998 and then Seed et al. 2003; they also proposed some expressions for r d.

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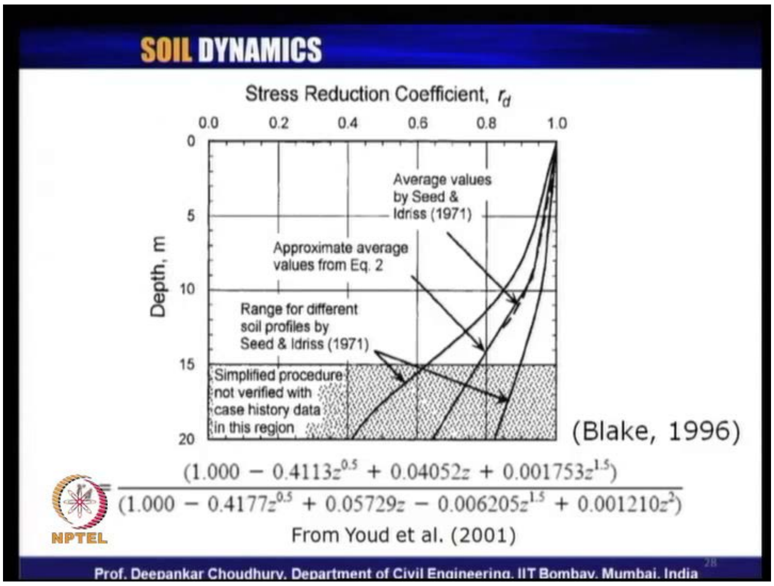

SOIL DYNAMICS

(Blake, 1996)

$$= \frac{(1.000 - 0.4113z^{0.5} + 0.04052z + 0.001753z^{1.5})}{(1.000 - 0.4177z^{0.5} + 0.05729z - 0.006205z^{1.5} + 0.001210z^{2})}$$

From Youd et al. (2001)

Now if you ask that at present for design methodology what value or what expression of r d one should use; I will say that as per Youd et al. 2001 decision; that is again it was a decision taken by all the stalwarts in the field of liquefaction analysis. So, it is worldwide followed. They proposed to take the expression given by the Blake in 1996. What Blake 1996 proposed? r d that stress reduction coefficient can be calculated by using this expression where z is depth below the ground surface in meter unit and their values is given by this.

This is the average value of Seed and Idriss, 1971 we have seen and these are the two extreme ranges obtained by the Seed and Idriss for various soil. So now it is, this is the expression which is commonly used to find out the value of r d. So, you have seen now the development of expressions for r d, how it varies with respect to depth; with increase in depth it decreases. And Seed and Idriss proposed something, later on Liao and Whitman they have changed it and finally, Blake's equation are proposed which is now worldwide used for computation of r d.

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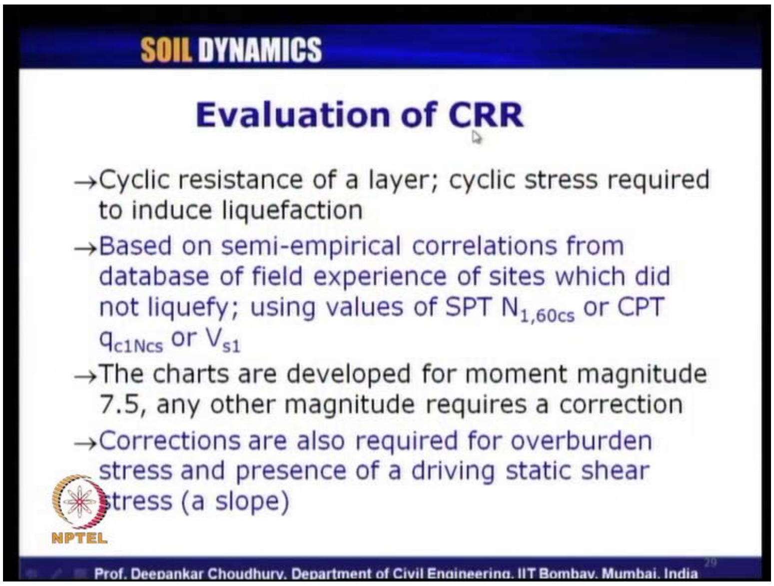
SOIL DYNAMICS

Evaluation of CRR

→Cyclic resistance of a layer; cyclic stress required to induce liquefaction

→Based on semi-empirical correlations from database of field experience of sites which did not liquefy; using values of SPT $N_{1,60cs}$ or CPT q_{c1Ncs} or V_{s1}

→The charts are developed for moment magnitude 7.5, any other magnitude requires a correction

→Corrections are also required for overburden stress and presence of a driving static shear stress (a slope)

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Coming to another component; that is evaluation of CRR cyclic resistance ratio. So, how much the soil is having the capacity to take care of liquefaction until it liquefies or fails. Cyclic resistance of a layer is nothing but cyclic stress which is required to induce liquefaction. So, that is why Seed and Idriss, when in 1971, they proposed the equation for factor of safety; they have given the equation CSR at 7.5 by CSR; means they have used both CSR. One is required to induce liquefaction at magnitude of earthquake moment magnitude 7.5 to how much cyclic stress ratio is actually getting developed for a particular earthquake. But that created several confusions through researchers or practitioners basically; that is factor of safety is ratio of CSR by CSR, CSR 7.5 by CSR.

So that is why Youd et al. 2001; they had proposed the modified expression of factor of safety is CRR 7.5 by CSR. So, CRR is nothing but the resistance. It is the resistance provided by the soil that is cyclic stress required to induce liquefaction. So if go through the Seed and Idriss original paper, do not get confused with the same terminology CSR; the numerator CSR means its capacity, denominator CSR means actually how much is getting developed. Now based on semi-empirical correlations from the database of field experience of sides which did not liquefy, it proposes that use the value of standard penetration test SPT, corrected value N 1, 60cs or the cone penetration test corrected value q c1Ncs or the corrected shear wave value observed through, say, SASW or MASW test V s1. So, all this ‘1’ indicates the corrected values.

There are several other suffix, I will explain them soon in the forthcoming slides what are they denote. The charts are developed for moment magnitude of 7.5. I have already mentioned CRR is computed or referenced; the reference is taken at moment magnitude of 7.5. So that means; any other magnitudes require a correction. Now corrections are also required for overburden stress and presence of driving static shear stress that is because of a sloping ground. So, overburden correction and sloping ground correction factors are also required for this cyclic resistance ratio. So, total how many corrections are required for cyclic resistance ratio? Three. One is moment magnitude correction, second one is overburden correction, and the third one is sloping ground correction.

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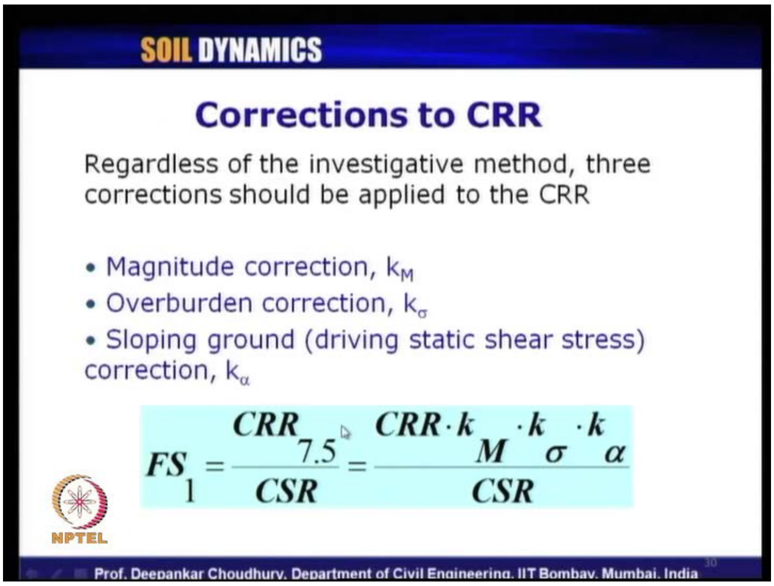

SOIL DYNAMICS

Corrections to CRR

Regardless of the investigative method, three corrections should be applied to the CRR

- Magnitude correction, k_M
- Overburden correction, k_σ
- Sloping ground (driving static shear stress) correction, k_α

$$FS_1 = \frac{CRR_{7.5}}{CSR} = \frac{CRR \cdot k_M \cdot k_\sigma \cdot k_\alpha}{CSR}$$

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So, corrections to CRR what we have discussed just now; regardless of the investigative method, three corrections must be applied to CRR. These are the magnitude correction; it is denoted by K suffix M, M means magnitude. Overburden correction, K suffix sigma; sigma denotes the overburden stress. And sloping ground, this is due to the driving static shear stress correction which is given by K alpha; alpha is the angle of sloping ground with respect to horizontal.

So, factor of safety against liquefaction is expressed by CRR 7.5 by CSR. If we put all the correction factor, if it is not at 7.5; it should be CRR at any magnitude, then you apply the magnitude correction factor K M, then overburden correction factor K sigma and then slopping ground correction factor K alpha divided by CSR. Now let us see the variation of each of these magnitude correction factors or how to compute this different correction factors for CRR.

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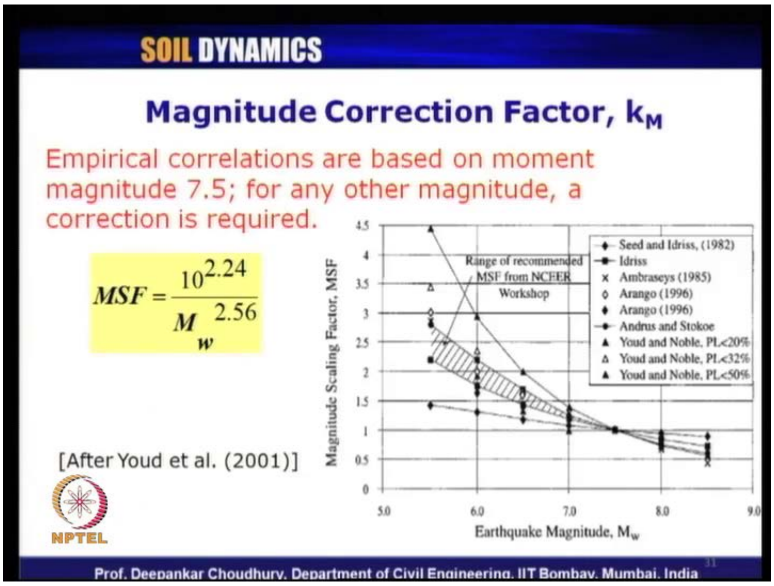

SOIL DYNAMICS

Magnitude Correction Factor, k_M

Empirical correlations are based on moment magnitude 7.5; for any other magnitude, a correction is required.

$$MSF = \frac{10^{2.24}}{M_w^{2.56}}$$

[After Youd et al. (2001)]

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The first one is magnitude correction factor K suffix M. This is the picture given in Youd et al. 2001 after assembling, say, various researchers result. You can see here Seed and Idriss result of 1982, Idriss result, Ambraseys result, Arango result, Andrus and Stokoe result, Youd and Noble result for different PL value. They have given some ranges, how this magnitude scaling factor; this magnitude correction factor is also called magnitude scaling factor; the same thing, the different nomenclature MSF. MSF is magnitude scaling factor is nothing but same as magnitude correction factor K M. How they vary with respect to earthquake magnitude; this is moment magnitude, remember M W. As we have seen, it has been standardized with respect to M W of 7.5. So, if our earthquake magnitude is 7.5 no correction is required.

So, correction factor MSF or K M should be 1. So, look at the graph it is 1 at 7.5; at 7.5 of M W the correction factor is 1. So, no correction is required; that is the reference point. But if the moment magnitude during a particular earthquake at a place is not 7.5 but something else; if it is more than 7.5, the magnitude correction factor or the MSF or K M is less than 1, but if the earthquake magnitude is less than 7.5 it is more than 1. So, what is proposed? It is proposed to use this is the range of recommended MSF from that NCEER Workshop which has been finally proposed in terms of this equation as given in this paper by Youd et al. 2001; that is MSF or K M can be calculated as 10 to the power 2.24 divided by M W. So, whatever be your M W that particular earthquake magnitude to the power 2.56; that will give you the value of magnitude correction factor K M.

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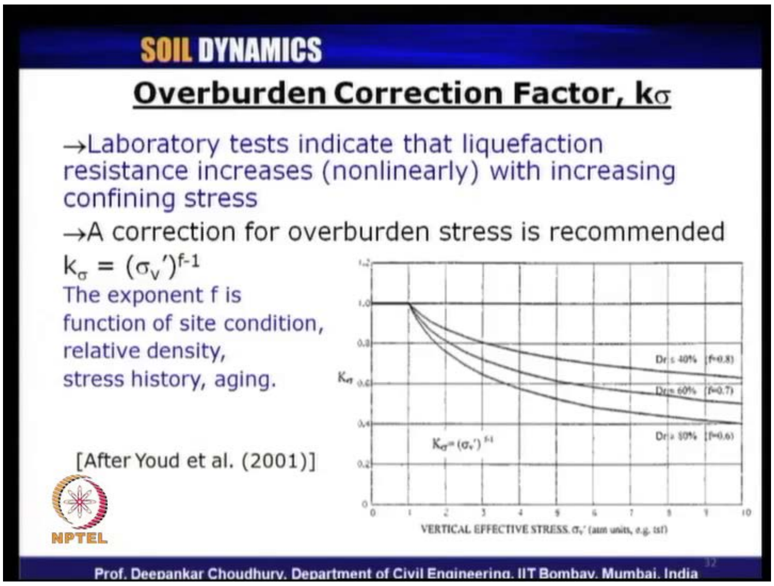

SOIL DYNAMICS

Overburden Correction Factor, kσ

→Laboratory tests indicate that liquefaction resistance increases (nonlinearly) with increasing confining stress

→A correction for overburden stress is recommended

$k_\sigma = (\sigma_v')^{f-1}$

The exponent f is function of site condition, relative density, stress history, aging.

[After Youd et al. (2001)]

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Overburden correction factor K sigma; now laboratory test indicate that liquefaction resistance, it increases nonlinearly with increasing in confining stress. That we have seen earlier also, what are the factors which involves in the liquefaction potential assessment that if the depth is increasing or overburden is increasing; obviously, the chances of getting the soil liquefied will be less, Is it not? Because confining stresses are increasing or overburden is increasing. So, we have to take again a reference frame with respect to which we have to compute the liquefaction potential. Otherwise at different depth for the same soil, we will get different values of liquefaction potential.

So, what is the correction factor for this overburden stress is recommended. K sigma is given by sigma v dash to the power f minus 1. What is sigma v dash? It is the effective vertical stress at the particular depth where you are computing the CRR or where you are computing the factor of safety against liquefaction and what is this exponent f? This exponent f is a function of site condition, relative density, stress history, and aging. So, in Youd et al. 2001, this chart has been given which can be easily used for obtaining the overburden correction factor K sigma.

Look at here; the x axis gives vertical effective stress sigma v dash, but look the unit is atmospheric unit or ton per square feet; one atmospheric is one TSF. So, that is why one, two, three, four. So one atmospheric, two atmospheric; one atmospheric means equivalent to SI unit almost about 100 kPa, actually some 96, 97 kPa, but for all practical purposes we can assume one atmospheric pressure is equivalent to about 100 kPa. Remember it has been standardized again with respect to overburden stress of 100 kPa. So, that is why if you look at the variation of this K sigma the correction factor, the correction factor is one till the overburden stress is one atmospheric pressure or 100 kPa.

So, when you are doing the calculation for factor of safety against liquefaction at a particular depth, at that depth, you calculate the effective vertical stress. If it is less than or equal to 100 kPa, what does it mean? No correction for overburden is required. So, K sigma is one in that case; however, if the overburden stress is increasing, that is effective vertical stress is increasing, beyond 100 kPa or one atmospheric, then K sigma needs to be applied which is less than one and it depends on various values of f. f is calculated depending on different values of Dr; Dr is relative density of the cohesion less soil.

So, here the ranges are given for Dr less equal to 40 percent, the coefficient f should be used as 0.8 in this equation. If the relative density of the soil is less than equals to 40 percent, then f value is 0.8. If the relative density of the soil is about 60 percent, then f value is 0.7. If the relative density of the soil is greater than or equals to 80 percent, f value is 0.6 that has been recommended. So, if any in between values for relative density you can interpolate between these values of f, but remember always whatever be the value of relative density of the soil; if your effective vertical stress is less than 100 kPa, no correction is required.

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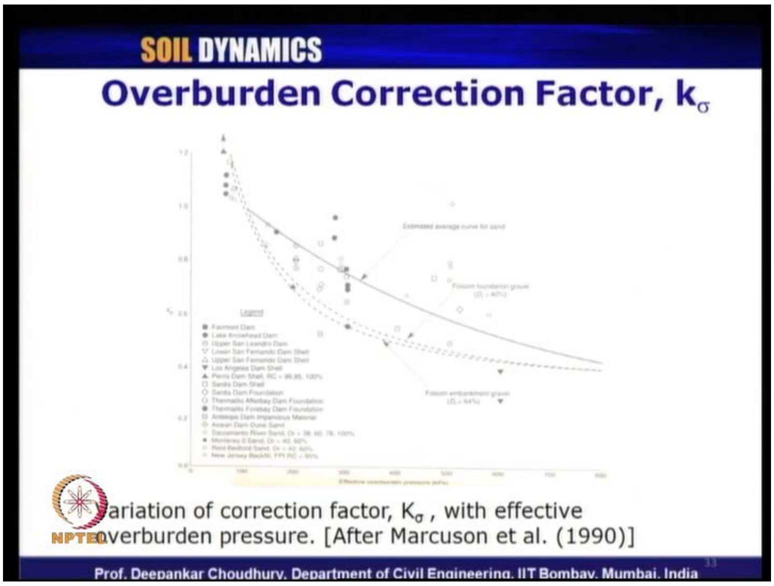
SOIL DYNAMICS

Overburden Correction Factor, k_σ

ariation of correction factor, K_σ , with effective verburden pressure. [After Marcuson et al. (1990)]

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So, overburden correction factor once again it was actually originally proposed by Marcuson et al. in 1990. How? The changes with increase in effective overburden pressure from k sigma equals to 1 to a lower value; that has been further modified and incorporated in Youd et al. 2001 as I have shown in the previous slide just now.

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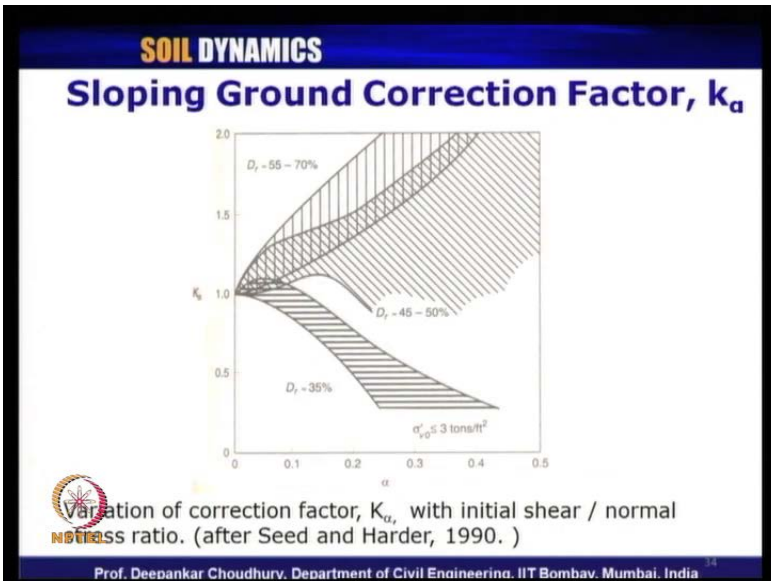
SOIL DYNAMICS

Sloping Ground Correction Factor, k_α

Variation of correction factor, K_α, with initial shear / normal stress ratio. (after Seed and Harder, 1990.)

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Now coming to the third correction factor that is sloping ground correction factor K alpha. For K alpha, it was initially the correction factor was proposed by Seed and Harder in 1990. So, this itself is transferred to the methodology given by Youd et al.

2001 to further follow or adopt for practical computation of liquefaction potential factor of safety. How the k alpha varies with respect to different values of alpha is given here for different values of Dr; that is relative density of the cohesion less soil, the ranges have been given and it depends on if your effective vertical stress is within 3 ton per square feet, then it is applied; that is 3 atmospheric pressure. Otherwise you need not to apply this sloping ground correction factor.

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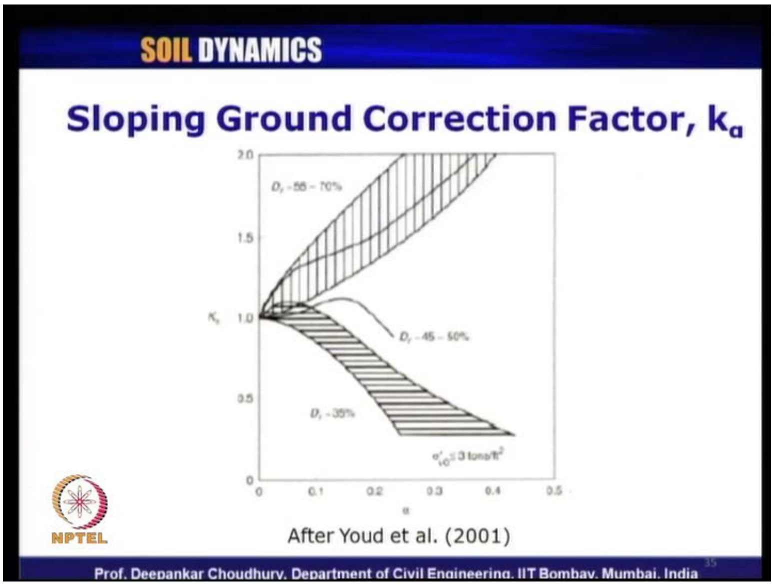

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Sloping Ground Correction Factor, k_α

After Youd et al. (2001)

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So, the same curve has been reproduced by Youd et al. in 2001 and obviously if you do not have any sloping ground; if it is horizontal ground, alpha will be 0, you do not have to incorporate any value of k alpha; it will be one always as expected.

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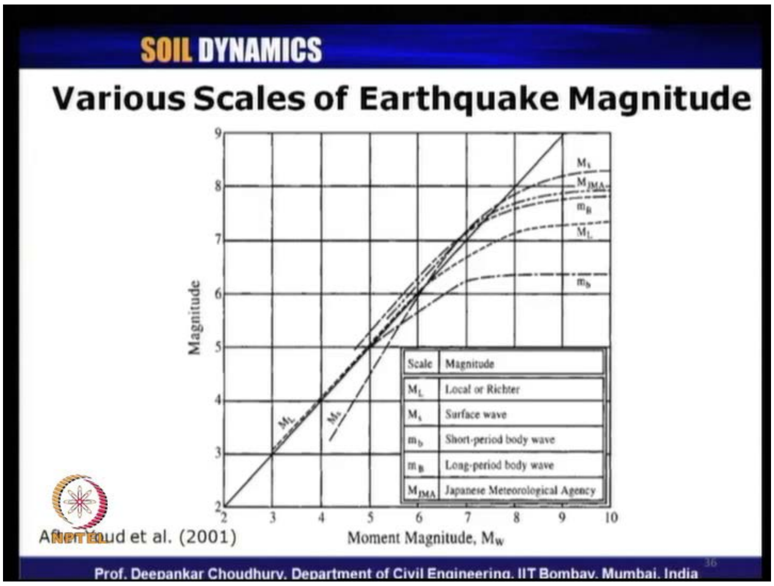

SOIL DYNAMICS

Various Scales of Earthquake Magnitude

Scale	Magnitude
M_L	Local or Richter
M_s	Surface wave
m_b	Short-period body wave
m_B	Long-period body wave
M_{JMA}	Japanese Meteorological Agency

After Youd et al. (2001)

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Now as we have talked about the moment magnitude scale of earthquake, let us see if you have been given with some other scale of earthquake magnitude; how to convert it to moment magnitude scale. So, this is the relationship given between various earthquake magnitudes versus the moment magnitude M W. This is the line of equality; this solid line, 45 degree line you can see 2 2, 3 3, 4 4, like that and difference scale you can see this M L; M L is local earthquake magnitude or which we commonly known as Richter scale of earthquake magnitude. So, many of us are familiar about that scale of earthquake.

The details of various scales I will not discuss in this course, but to give you an idea that if some other scale of earthquake magnitude is given to you, how to proceed further with your liquefaction analysis; that is why I am showing this one that you need to convert that scale to M W, but look at the variation of M L line; it goes like this and then take this route, this one. So, what does it mean? Up to earthquake magnitude of about, say, 6.25 or so, the Richter magnitude and moment magnitude, they are essentially same because it is following this line; Is it not? But at very high value or I should say when the Richter scale magnitude suppose 7, what does it mean? The moment magnitude is about 7.7 or so, Is it not?

Look at this graph, drop it here; read it here about 7.7. So, that way if it is given as M S scale; M S scale is surface wave magnitude scale, m small b is called short period body wave scale, m capital B is called long period body wave scale M JMA is called Japanese Meteorological Agencies scale. So, various earthquake scales have been mentioned here and their relation with respect to moment magnitude, it is given in Youd et al. 2001 paper. So, you can use this one if you have been given with any other scale of earthquake magnitude to convert them to moment magnitude so that you can do your liquefaction analysis properly.

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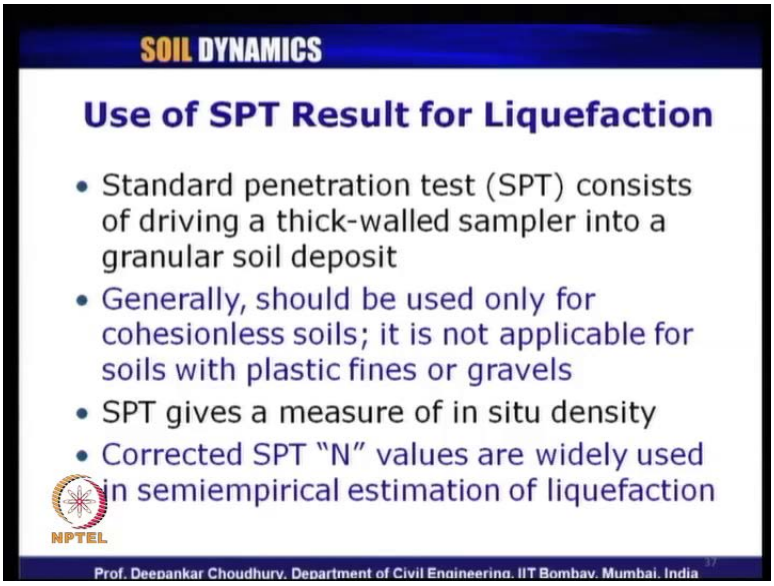

SOIL DYNAMICS

Use of SPT Result for Liquefaction

- Standard penetration test (SPT) consists of driving a thick-walled sampler into a granular soil deposit
- Generally, should be used only for cohesionless soils; it is not applicable for soils with plastic fines or gravels
- SPT gives a measure of in situ density
- Corrected SPT "N" values are widely used in semiempirical estimation of liquefaction

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Now how to use the standard penetration test results for the estimation of liquefaction? Standard penetration test you all know from your any basic codes of soil mechanics. So, I am just quickly going through it. Standard penetration test consists of driving of a thick-walled sampler into a granular soil deposit, mostly, generally should be used only for cohesion less soil, but it is used for soil with plastic fines also; that is for sieve type soil also it is used. SPT gives a measure of in situ density and corrected SPT “N” value; N value is the number of blows required to penetrate a certain distance. As per our Indian condition 15 centimeter, 15 centimeter, 15 centimeter; three15 centimeter we measure number of blows required and the last two 15 centimeters we take how much number of blows are coming; that is nothing but SPT N value. They are widely used in semi-empirical estimation of liquefaction.

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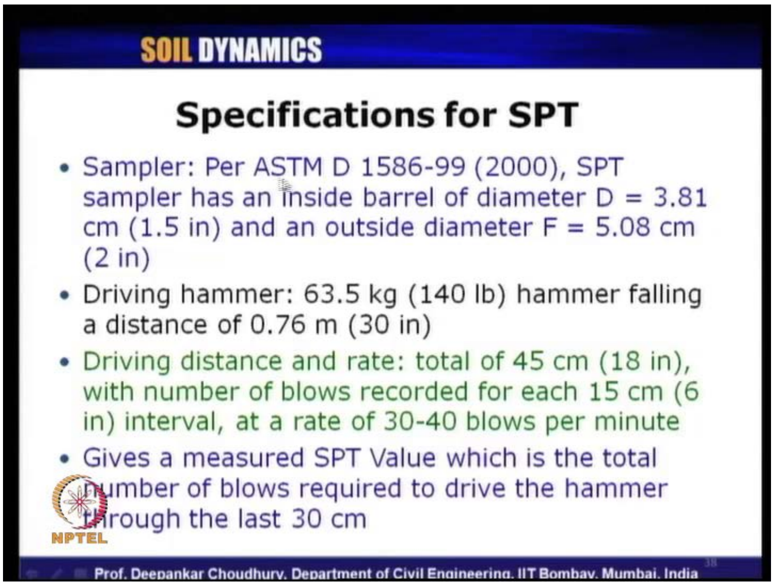

SOIL DYNAMICS

Specifications for SPT

- Sampler: Per ASTM D 1586-99 (2000), SPT sampler has an inside barrel of diameter D = 3.81 cm (1.5 in) and an outside diameter F = 5.08 cm (2 in)
- Driving hammer: 63.5 kg (140 lb) hammer falling a distance of 0.76 m (30 in)
- Driving distance and rate: total of 45 cm (18 in), with number of blows recorded for each 15 cm (6 in) interval, at a rate of 30-40 blows per minute
- Gives a measured SPT Value which is the total number of blows required to drive the hammer through the last 30 cm

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So, specifications for SPT as per ASTM D standard, standard number of this, SPT sampler has an inside barrel diameter of about 3.81 centimeter which is about one and a half inch and outside diameter of about 5.08 centimeter which is about two inch. We know why the sampler dimension also is standardized in terms of inside and outside diameter, why? Because to keep the area ratio of the sampler as minimum, so that the disturbances coming to the soil sample collected in the sampler are minimum.

You remember these things from your basic soil mechanics courses. Then we have inside diameter ratio, outside diameter ratio; all these factors has to be maintained for minimum disturbance to a collected soil samples and driving hammer what is used in SPT as per ASTM standard, 63.5 kg which is about 140 pound hammer which is falling form a height of about 0.76 meter which is about 30 inch. And driving distance and rate, total of 45 centimeter it should penetrate which is about 18 inches with number of blows recorded for each of the 15 centimeter. So, this 45 centimeter is subdivided in 3 segments, 15, 15, 15 centimeters; that is 6 inches each at interval and at the rate of 30 to 40 blows per minute.

This how many numbers of blows the hammer should give, that is also specified because more or less number of blows will obviously give you a different result of N. So, that is why the standardization is required. It gives a measured SPT value which is the total number of blows required to drive the hammer through the last 30 centimeter. The initial

15 centimeter depth is not considered because it is considered as the initial disturbing zone or the sitting value. So, last 30 centimeter; to penetrate that last 30 centimeter how many number of blows are required; that gives us the SPT value, a raw data of SPT N value.

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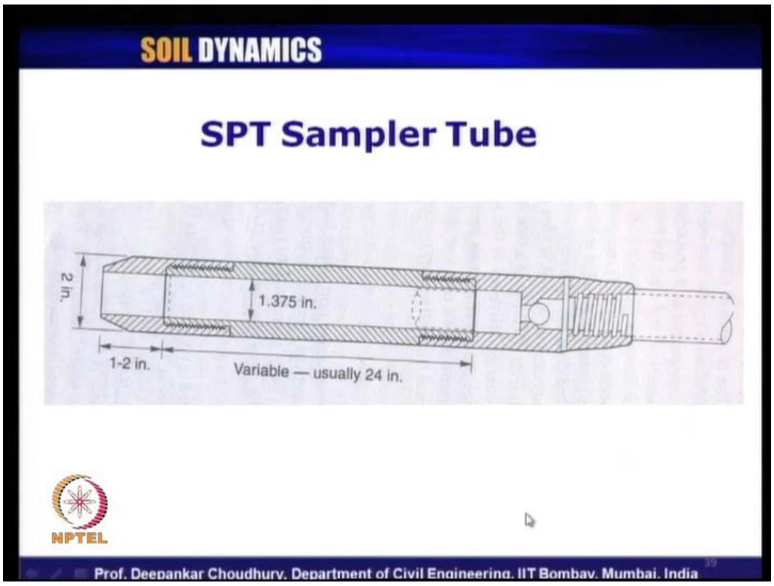

SOIL DYNAMICS

SPT Sampler Tube

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So, this is a picture of SPT sampler tube. You know this is the outside diameter, inside diameter, and this length is variable, this is the cutting shoe or edge. So, it is actually shown here horizontally; it will be vertical with this end, this cutting shoe end will be at the bottom to penetrate the soil and on the top of it you are hammering here and slowly this goes inside and collects the soil sample.

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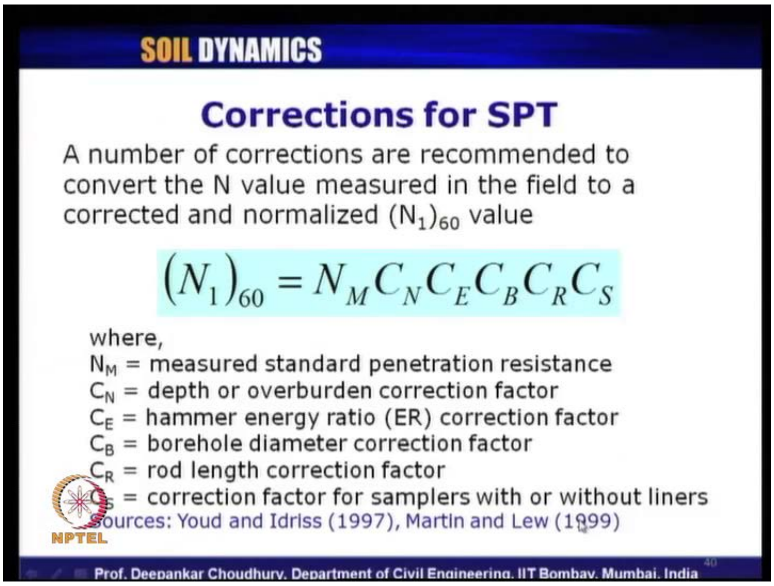

SOIL DYNAMICS

Corrections for SPT

A number of corrections are recommended to convert the N value measured in the field to a corrected and normalized $(N_1)_{60}$ value

$$(N_1)_{60} = N_M C_N C_E C_B C_R C_S$$

where,

N_M = measured standard penetration resistance

C_N = depth or overburden correction factor

C_E = hammer energy ratio (ER) correction factor

C_B = borehole diameter correction factor

C_R = rod length correction factor

C_S = correction factor for samplers with or without liners

Sources: Youd and Idriss (1997), Martin and Lew (1999)

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Now what are the corrections for SPT, standard penetration test; I am talking about now only the corrections related to the static test itself that is static value, I am not coming into the dynamic or liquefaction thing. So, remember these are the corrections which already you know. The number of corrections what I am referring here, these are worldwide standards I am giving; then I will mention what are the Indian corrections recommended as per our Indian Standard Design Code. A number of corrections are recommended to convert the raw N value measured in the field to a corrected normalized (N 1) 60 value.

So, N value to the corrected value is denoted as (N 1) 60. So, (N 1) 60 is corrected value and N M is the measured standard penetration resistance value that is the raw data of N at the site. Then correction factors are C N C E C B C R and C S. What are these corrections? C N is depth or overburden correction factor; C E is hammer energy ratio correction factor; C B is borehole diameter correction factor; C R is rod length correction factor, and C S is correction factor for samplers with or without liners. Why these corrections are required? Let us first understand that.

C N overburden correction is required because we know, as we go deeper and deeper in the soil strata, because of increase in the overburden stress; obviously, the more number of penetration or number of blows will be required for the same soil, but that is not indicative of the strength of the soil; it is because of the overburden. So, that is why it has to be standardized with respect to a standard value of an overburden pressure and that is why this correction C N is required. Now why C E is required energy correction factor? As I said, number of hammer blows is very important. If you use more number of blows, then obviously you will get different values of N and if you use less number of blows, then also you will get different values of N.

So with respect to some standardized value, this how much energy you are transferring from your hammer to the rod has to be defined. So, what is that defined? 60 percent of the hammer energy has to be transmitted. So if 60 percent is transmitted, that is called no correction is required; CE is 1, but if your transmitted energy is more than 60 percent; if you were so active and vibrated it so frequently and several, means huge amount of energy you are able to be transfer; so, you have transferred 77 percent of the energy of the hammer to the sampler correction is required. And if you are extremely slow and supplied a very less amount of energy then the standard value of 60 percent of energy, you also again need correction. So, that is why C E is required.

It depends on what type of hammer you are using; that also is involved in this energy correction factor. Because depending on Donut type hammer and etc, your energy how much is transferred finally to your sampler tube depends on. Why this C B is involved, the borehole diameter correction factor? The borehole in which you are driving your sampler tube to collect the soil sample; if it is very very wide, huge, large diameter borehole, you will get some result. If it is very narrow, your sampler will not be very fortunate or it will also experience the frictions coming through the borehole sides, etc.

So, that is why the borehole diameter plays an important factor in measurement of the N value. So if it is very wide diameter, you have a better penetration of the sampler without any hindrance coming from the surrounding soil, but if it is very less diameter of the bore hole, you have problem in driving your sampler. So, that is why the borehole diameter also important and this correction factor have to be applied. It has also to be referenced with respect to a particular size or diameter of the borehole. Why C R is required, rod length correction factor? See there is a standardized length of the rod given to you for which you do not need any correction. Suppose that rod is not utilized; you have used some larger rod or some smaller rod. Depending on larger or smaller rod, a number of blows required to penetrate that 30 centimeter, last 30 centimeter, we will obviously change.

If you have a long rod which you are through the sampler you are hammering and penetrating to the soil; obviously, it will penetrate much faster that last 30 centimeter, so number of blows counted will be less than what it should be. If you have a small rod, then if you penetrate it, then it will require more number of blows to penetrate that 30 centimeter, last 30 centimeter. So, that is why the rod length correction factor also important to take care with respect to a standard length of rod where no correction will be required; otherwise correction factor has to be used.

That is why C R is also used. C S, what is C S? Correction factor for samplers with or without liners; that is inside the sampler if you put some liner material, so that no hindrance or friction of your sample which you are collecting in the sampler tube is coming into picture. Depending on whether you use liner or you do not use liner, the correction has to be applied because it has to be standardized only with respect to one type; whether it is with liner or without liner. So, that is why the C S is also important correction factor. Now is it clear, why all these correction factors are coming into picture while to find out the correct value of (N 1) 60.

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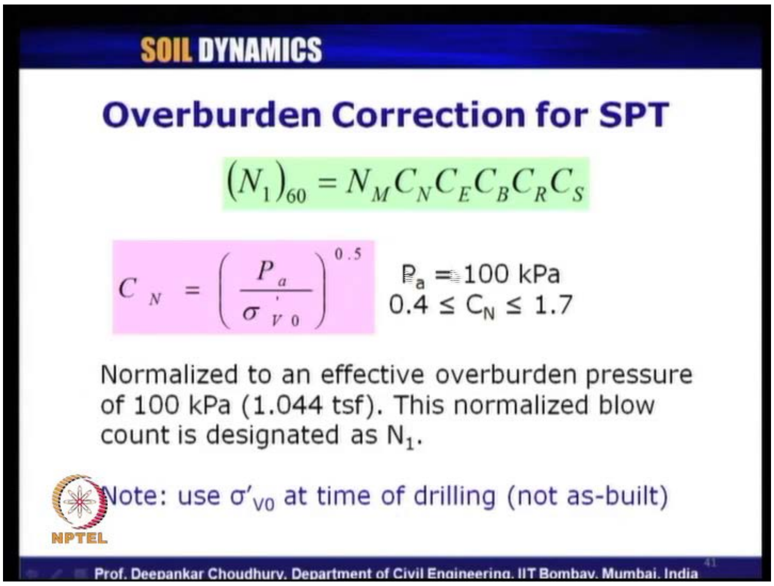

SOIL DYNAMICS

Overburden Correction for SPT

$$(N_1)_{60} = N_M C_N C_E C_B C_R C_S$$

$$C_N = \left(\frac{P_a}{\sigma'_{V0}}\right)^{0.5}$$

$P_a = 100$ kPa

$0.4 \le C_N \le 1.7$

Normalized to an effective overburden pressure of 100 kPa (1.044 tsf). This normalized blow count is designated as N_1.

Note: use σ'_{V0} at time of drilling (not as-built)

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So, let us go through each of the correction factors slowly. C N the first one is overburden correction. It is expressed by this expression P a by sigma v naught dash to the power 0.5. What is P a? P a is nothing but that standard overburden pressure, that is 100 kPa or one atmospheric. If we always do the reference with respect to one atmospheric pressure or 100 kPa value of the overburden pressure, for all overburden corrections irrespective of type of taste or calculations as we have seen till date; that we do the standardization or referencing with respect to 100 kPa or one atmospheric pressure. Here also the same thing has been done.

Sigma v naught dash is nothing but effective vertical stress at the point where you are calculating or computing the value of SPT N value at that particular depth and this value of C N, the corrected value of C N should be within 0.4 to 1.7. So, after putting your values from the field sigma v naught dash, if you calculate suppose your C N value is 2.1, what value of C N you should use in this expression; 1.7 because that is the maximum limit of the value of C N proposed to be used in the expression for SPT correction. So, note it down; this range of C N is also important, what value of C N one should use.

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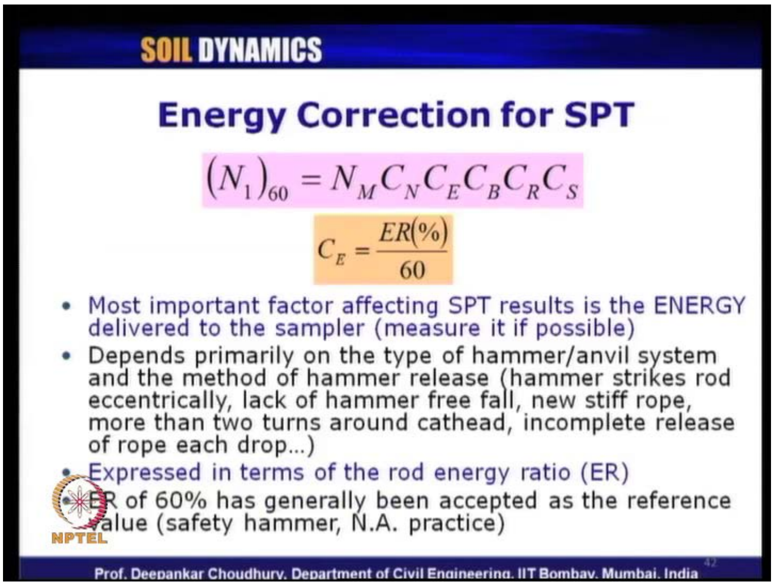

SOIL DYNAMICS

Energy Correction for SPT

$$(N_1)_{60} = N_M C_N C_E C_B C_R C_S$$

$$C_E = \frac{ER(\%)}{60}$$

- Most important factor affecting SPT results is the ENERGY delivered to the sampler (measure it if possible)
- Depends primarily on the type of hammer/anvil system and the method of hammer release (hammer strikes rod eccentrically, lack of hammer free fall, new stiff rope, more than two turns around cathead, incomplete release of rope each drop...)
- Expressed in terms of the rod energy ratio (ER)
- ER of 60% has generally been accepted as the reference value (safety hammer, N.A. practice)

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Next correction factor is energy correction factor C E. C E is as I said how much percentage of energy is actually transmitted to 60 percent. So, 60 is the standard; if it is 60 percent is transferred, it is one; if it is more, then it will be more; if it is less, then less. So, most important factor affecting SPT results is the energy delivered to the sampler and if possible one should measure it; that is how many numbers of blows we are putting in per minute.

So, those things we can calculate how much energy is getting transferred. It depends primarily on the type of hammer whether the anvil system, etc and the method of hammer release; that is whether hammer strikes the rod eccentrically or lack of hammer free fall, new stiff rope, more than two turns around cathead, incomplete release of rope in each drop. These are the factors which changes how much energy is getting transferred to the hammer. It is expressed in terms of rod energy ratio E R and E R 60 percent has generally been accepted as the reference value for the safety hammer.

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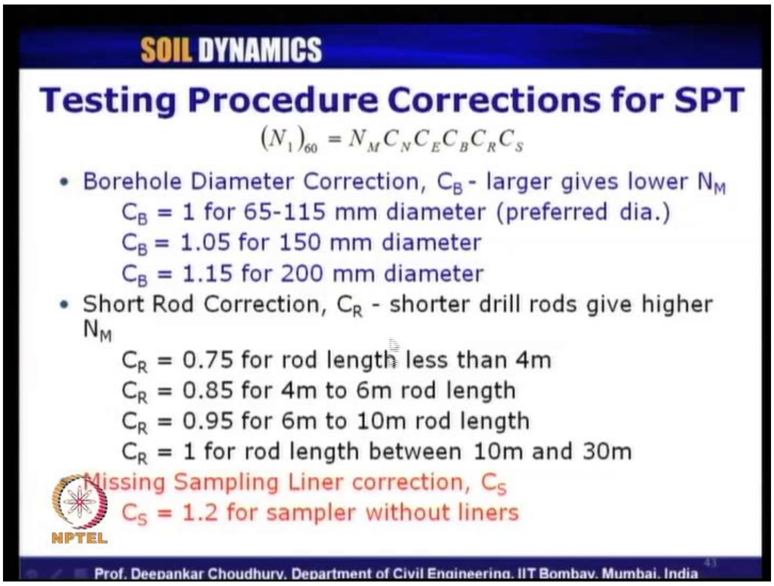

SOIL DYNAMICS

Testing Procedure Corrections for SPT

$$(N_1)_{60} = N_M C_N C_E C_B C_R C_S$$

- Borehole Diameter Correction, C_B - larger gives lower N_M
  - C_B = 1 for 65-115 mm diameter (preferred dia.)
  - C_B = 1.05 for 150 mm diameter
  - C_B = 1.15 for 200 mm diameter
- Short Rod Correction, C_R - shorter drill rods give higher N_M
  - C_R = 0.75 for rod length less than 4m
  - C_R = 0.85 for 4m to 6m rod length
  - C_R = 0.95 for 6m to 10m rod length
  - C_R = 1 for rod length between 10m and 30m
- Missing Sampling Liner correction, C_S
  - C_S = 1.2 for sampler without liners

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And testing procedure corrections that is all remaining other three corrections C B C R C S; these are called testing procedure corrections. C B is borehole diameter correction factor and C B the larger borehole will give us the lower value of N M. Obviously as I said less the borehole diameter, you need more number of blows to be provided to penetrate the same 30 centimeter at the end. So, it has been standardized for a preferred diameter range of borehole of 65 to 115 millimeter diameter. If your borehole is lying in this range, then no correction is required; then correction factor is one. But if you use further wider borehole diameter which is standard practice, actually many a times we go for larger borehole diameter for operational easiness. So 115 millimeter diameter, then factor of a correction factor is 1.05. If it is 200 millimeter diameter, it is 1.15 and like that.

Next one is short rod correction factor C R; shorter drill rod gives higher N M value as I have already mentioned this. C R has been standardized as 1 for rod length if it is between 10 meter to 30 meter then no correction is required. But if you have a smaller rod length, say, less than 4 meter, then correction factor is 0.75; if it is 4 meter to 6 meter then 0.85; if it is between 6 meter to 10 meter of rod length then correction factor is 0.95. And the liner correction factor or sampler correction factor C S is equals to 1.2 for sampler without liners. So if you use liner, no correction is required; then it is one. So, with liners no correction; without liners we have to use 1.2.

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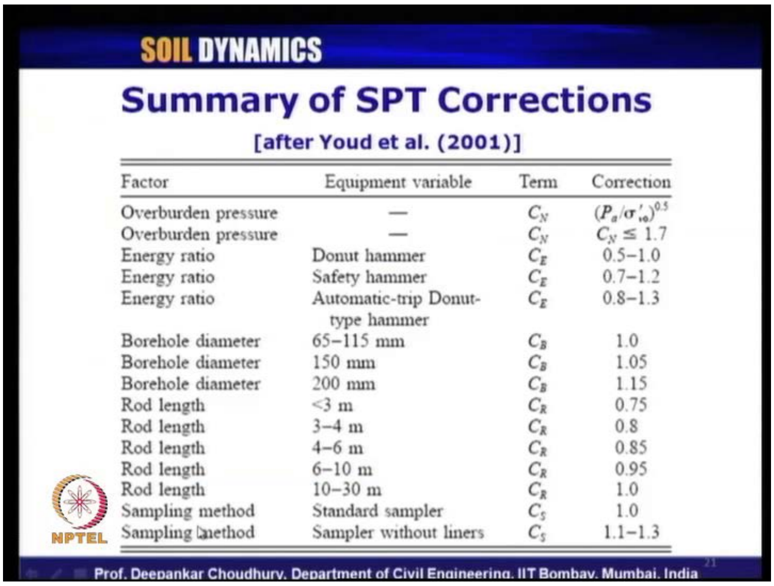

SOIL DYNAMICS

Summary of SPT Corrections

[after Youd et al. (2001)]

Factor	Equipment variable	Term	Correction
Overburden pressure	—	C_N	$(P_a/\sigma'_{vo})^{0.5}$
Overburden pressure	—	C_N	$C_N \leq 1.7$
Energy ratio	Donut hammer	C_E	0.5–1.0
Energy ratio	Safety hammer	C_E	0.7–1.2
Energy ratio	Automatic-trip Donut-type hammer	C_E	0.8–1.3
Borehole diameter	65–115 mm	C_B	1.0
Borehole diameter	150 mm	C_B	1.05
Borehole diameter	200 mm	C_B	1.15
Rod length	<3 m	C_R	0.75
Rod length	3–4 m	C_R	0.8
Rod length	4–6 m	C_R	0.85
Rod length	6–10 m	C_R	0.95
Rod length	10–30 m	C_R	1.0
Sampling method	Standard sampler	C_S	1.0
Sampling method	Sampler without liners	C_S	1.1–1.3

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So, this is the summary chart which is given in Youd et al. 2001. You can see different factors that are overburden pressure, correction factor, energy ratio correction factor, borehole diameter correction factor, rod length correction factor, and sampling method correction factors; different terms already we have discussed. So, this is the summary table what we have discussed just now. C N value upper limit will be up to 1.7 as I have mentioned. Depending on type of hammer, whether Donut hammer or safety hammer; these are the ranges of the correction factor. So as a designer, you can use any range in between this; you can use the average value also for the design.

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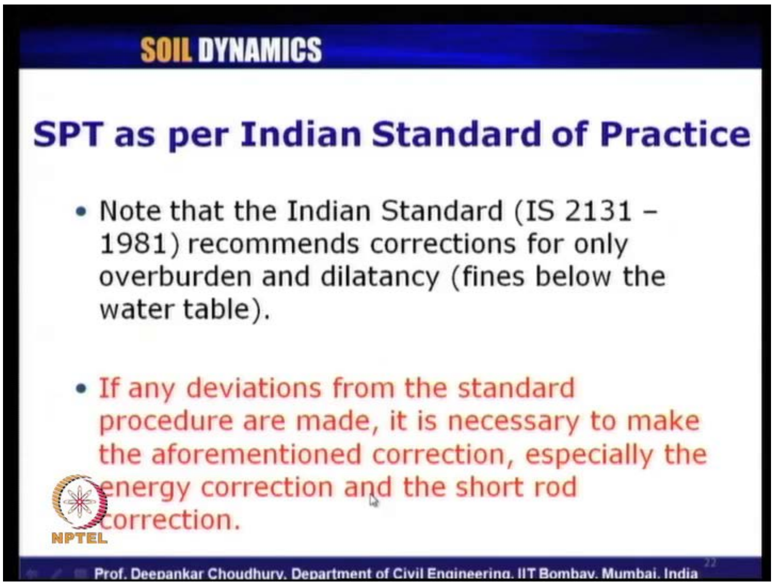

SOIL DYNAMICS

SPT as per Indian Standard of Practice

- Note that the Indian Standard (IS 2131 – 1981) recommends corrections for only overburden and dilatancy (fines below the water table).
- If any deviations from the standard procedure are made, it is necessary to make the aforementioned correction, especially the energy correction and the short rod correction.

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Now what is the correction factors mentioned in Indian Standard of practice? For SPT test IS 2131 - 1981 it recommends corrections; two correction factors are involved for SPT test. Those are overburden correction and dilatancy correction. Dilatancy correction is for fines below the water table. If any deviations from the standard procedure are made, it is necessary to make the aforementioned correction, specially, the energy correction and the short rod correction because the correction factors what is involved, we have seen just now, is pretty huge whereas for other correction factors it is not that significant.

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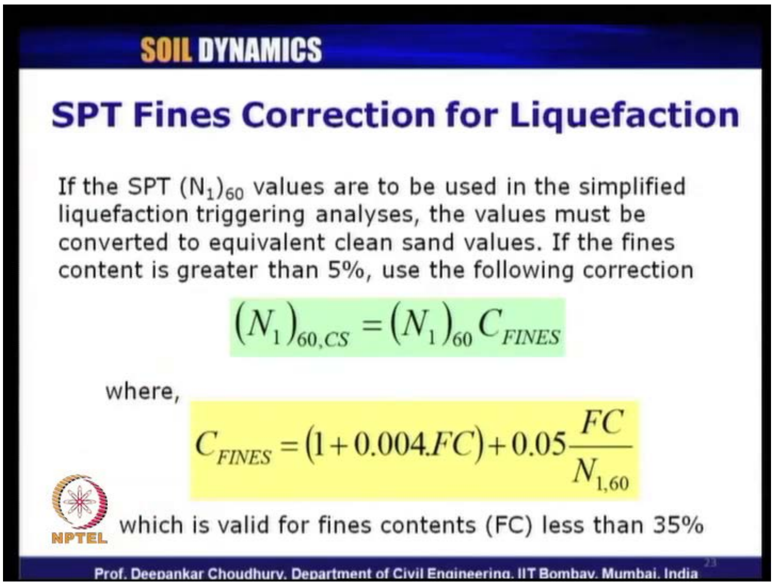

SOIL DYNAMICS

SPT Fines Correction for Liquefaction

If the SPT $(N_1)_{60}$ values are to be used in the simplified liquefaction triggering analyses, the values must be converted to equivalent clean sand values. If the fines content is greater than 5%, use the following correction

$$(N_1)_{60,CS} = (N_1)_{60} C_{FINES}$$

where,

$$C_{FINES} = (1 + 0.004 FC) + 0.05 \frac{FC}{N_{1,60}}$$

which is valid for fines contents (FC) less than 35%

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Now, additional correction factors required for the estimation of liquefaction potential for SPT N value are listed here. So, these are required only when you are going to do the liquefaction analysis. Remember these corrections are not required for other analysis other than liquefaction. So, these are additional correction. SPT fines correction for liquefaction. Why this fine correction is required? Let us read the statement; it says if SPT (N 1) 60, N 1 60 is the corrected SPT value after doing all the corrections which we have discussed just now; that is for any static case also we have to do those corrections; that is overburden correction, energy correction, borehole diameter correction, rod length correction, sampler correction. So, after doing all those correction we already obtain (N 1) 60 value.

Now these values are to be used in the simplified procedure of liquefaction triggering analyses. Now the values must be converted to equivalent clean sand condition. So, if the percent fine content in your soil sample is greater than 5 percent, then the following equation or correction factor has to be used. So, what does it mean? As from the very beginning, the basic definition of liquefaction we have mentioned for cohesion less soil; suppose within your cohesion less soil some amount of percentage fines materials are present; some portion of clay or silty type of materials is present, it is pretty common. If that amount of percent fine in the total amount of your soil while doing the sieve analysis or gradation study, if you find it is greater than 5 percent, then we need to apply this correction which is called equivalent clean sand fine correction. This is fine correction factor and the corrected value is (N 1) 60, CS; CS means clean sand because all the soil has to be standardized with respect to a particular type of soil.

So, this is why we need to do the fines correction. To take care of that, we are standardizing all the calculations of liquefaction analysis in terms of clean sand; that is purely cohesion less soil, but within that cohesion less soil if amount of percent fines is less than 5 percent, what does it mean? No correction is required; no correction for fines required. But if the amount of percent fines exceeds five percent; in that case this is the correction we should apply on the corrected value of (N 1) 60 which we got after making all the previous static corrections. So C FINES, how to compute the C FINES? This is the expression to compute C FINES; C FINES is equals to 1 plus 0.004 times FC plus 0.05 times FC by N 1, 60 where FC is nothing but fines content in percentage and this expression is valid for fines content less than 35 percent. So, this equation we should use to find out the correction factor with respect to fines for amount of fine between 5 to 35 percent.

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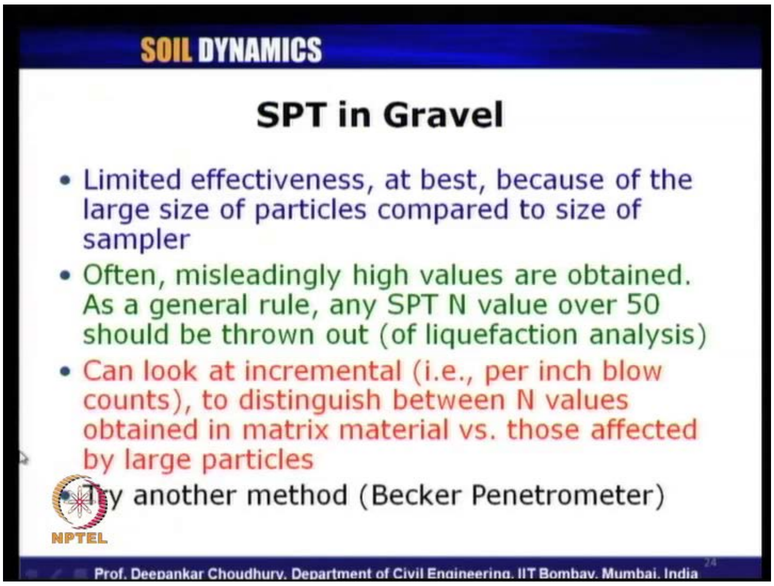

SOIL DYNAMICS

SPT in Gravel

- Limited effectiveness, at best, because of the large size of particles compared to size of sampler
- Often, misleadingly high values are obtained. As a general rule, any SPT N value over 50 should be thrown out (of liquefaction analysis)
- Can look at incremental (i.e., per inch blow counts), to distinguish between N values obtained in matrix material vs. those affected by large particles
- Try another method (Becker Penetrometer)

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Now sometimes standard penetration test is used also for gravels though it is very good for sandy type of soil mostly, but in gravels also SPT are used; though limited effectiveness at best because of the larger size of the particles compared to the size of the sampler. So, many a times whatever value of SPT N value we will get, they may be misleading because whatever size of your sampler tube you're using, many a times the gravel size can be bigger than that. So, it will not give you the proper value of SPT N value.

So, often misleading high values are obtained and what is the general rule? That if the recorded SPT N value is more than 50, then most of the time we need not to carry out the liquefaction analysis because we assume that the soil is not going to liquefy if the SPT N value recorded is more than 50 for plenty numbers of sample repetitive tests. And we should also look at the incremental; that is per inch blow how many counts are coming to distinguish between N values obtained in matrix material versus those affected by large particles.

So, what does it mean? Whether the SPT N value is greater than 50 is truly the representative for the entire soil or it is only because of some pockets where some large particles suddenly appear. So to identify that, we should count per inch or maybe per centimeter blow, how much counts are coming. So, that will give us the confidence whether it is truly a very stiff soil where liquefaction analysis is not required or it is just at a particular location because of presence of large particles suddenly, there is a high value of N value. In that case, if you discard the liquefaction analysis that will not be proper. So, what it is mentioned mostly for the gravels we should try another method which is called Becker Penetrometer test or BPT. Standard penetration test is good for sandy type of soil whereas BPT is good for gravelly type of soil. So with this, we will complete today’s lecture; we will continue our lecture in the next class.