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ADVANCED GEOTECHNICAL ENGINEERING

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Lecture No. 06
Module – 1
Index properties

Welcome to lecture number 6 of module 1 of advanced geotechnical engineering, so in this lecture we are going to discuss about index properties. In the previous lectures we have understood about clay particle water interaction.

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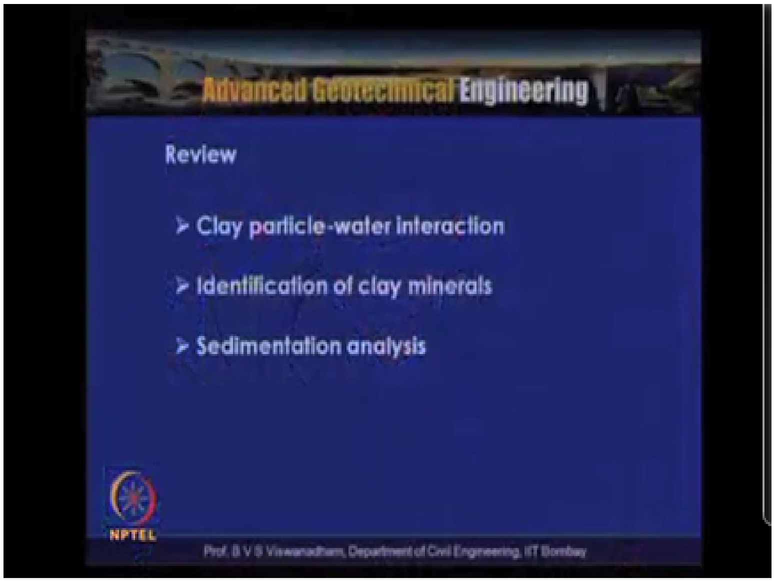

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Review

- Clay particle-water interaction
- Identification of clay minerals
- Sedimentation analysis

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And different methods to determine clay minerals and sedimentation analysis, before introducing sedimentation analysis we also discussed the method for determining gradation of coarse grain particles, when you have got a soil which is more than which is having fines more than 12% then we need to dose sedimentation analysis or it is also refer to as hydrometer analysis.

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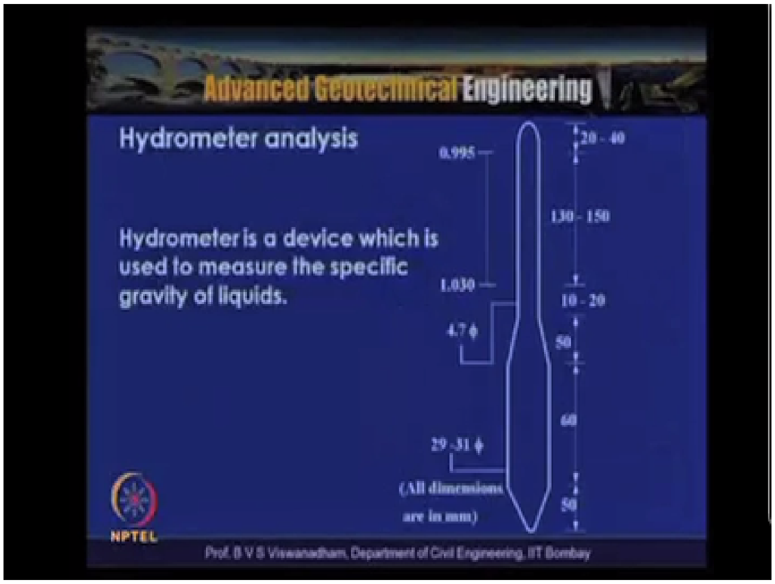

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Hydrometer analysis

Hydrometer is a device which is used to measure the specific gravity of liquids.

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So hydrometer analysis is basically used to determine, the gradation of fine particles hydrometer is a device which is used to measure the specific gravity of liquids. As you see in this slide you have a hydrometer with the dimensions in millimeters and it has got a stem and a bulb at the bottom, this is used basically to measure the specific gravity of the soil suspension. So with this it is possible to measure the specific gravity from time to time as the soil settles the specific gravity can be SS.

For a soil suspension the particle start settling right from the start and the unit weight of the soil suspension changes from 1 from time to time.

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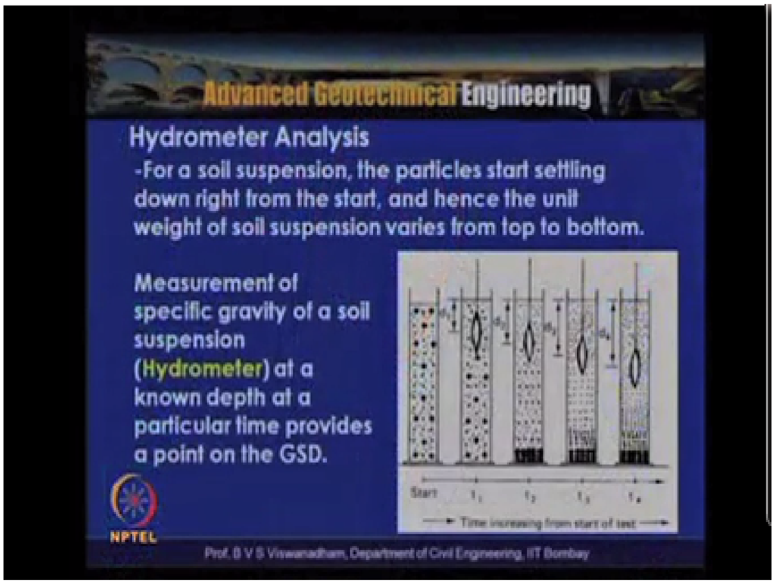

Hydrometer Analysis

-For a soil suspension, the particles start settling down right from the start, and hence the unit weight of soil suspension varies from top to bottom.

Measurement of specific gravity of a soil suspension (Hydrometer) at a known depth at a particular time provides a point on the GSD.

So here in this slide as it is guess it can be seen that this is at the commence of the test and once the hydrometer is place, then the specific gravity of the suspension is measured after elapsing at time t2 and again the reading is taken and here you can see that the particles which are actually settled at the base and after certain time t2, t3 and t4 and this situation of the settlement of the particles is shown.

So measurement of the specificity of the soil suspension at a known depth at a particular time provides a point on the grain size distribution curve. So here the process of the sedimentation of the dispersal specimen is shown here when you have got at time T =0 you have got a suspension.

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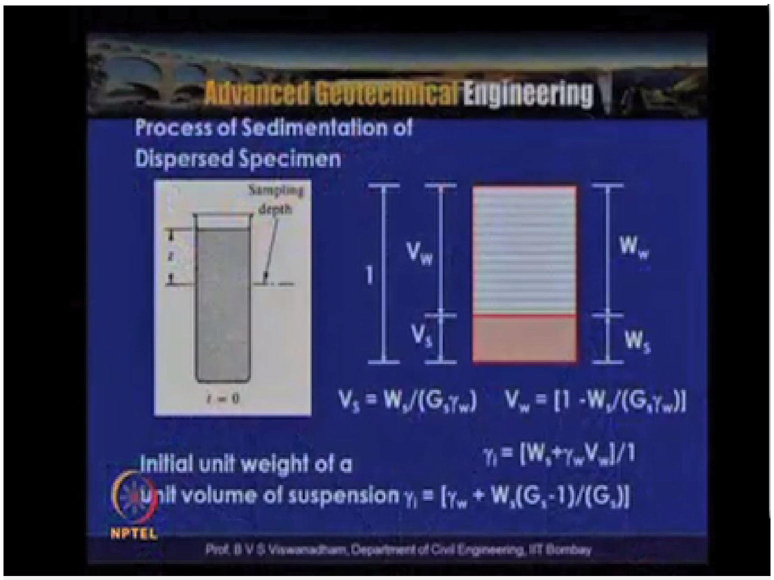

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Process of Sedimentation of Dispersed Specimen

$V_s = W_s/(G_s\gamma_w)$ $V_w = [1 - W_s/(G_s\gamma_w)]$

$\gamma_i = [W_s + \gamma_w V_w]/1$

Initial unit weight of a unit volume of suspension $\gamma_i = [\gamma_w + W_s(G_s-1)/(G_s)]$

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And if you have a sampling depth at a depth jet from the top surface of the suspension, it can be written in the form of a phase diagram, as shown here with the total volume 1 and volume of the solids and volume of water and with the weight of water on the right hand side and weight of solids on the right hand side. So with this volume of solids is nothing but W_s /G s γ_W okay and the volume of water which is nothing but 1 - you know this total volume, that is 1 this volume of water is nothing but 1 - V s and substituting here you will get volume of water =1 - W_s / $G_{'s}$ γ_W.

So the γ_I is nothing but the suspension at any time nothing but weight of w water + weight of the solids /total volume 1, so that is written here as weight of solids + γ_{WV} w whole /1, so / substituting for V_W you will get the initial unit weight of the net weight of a unit volume of the suspension γ_I as γ_W + W_S x G_S - 1/G_S, so this here the GS is nothing but the specific gravity of the soil solids.

In the process of the sedimentation of disperses fun here at level x, if you assume here the size of the particles which have settled from the surface to the depth jet in time TD this is from the Stokes law when you use we can actually obtain D =√ of 18 μ /G s - 1x γ_W root over Z / TD so jet is the difference depth where the measurement is being taken. So above this level x no particle of size greater than will be present and in element depth of D_J you can see here this is a small element depth the more this level exits at a depth jet from the surface of the suspension.

May is assumed that uniform and the particles of the same diameter exist, so the particles are smaller than D and they actually have a uniform specific gravity it is assumed in that particular elemental distance, if the percentage of the weight of the particles finer than D already sediment to the original weight of the soil solids in the special suspension.

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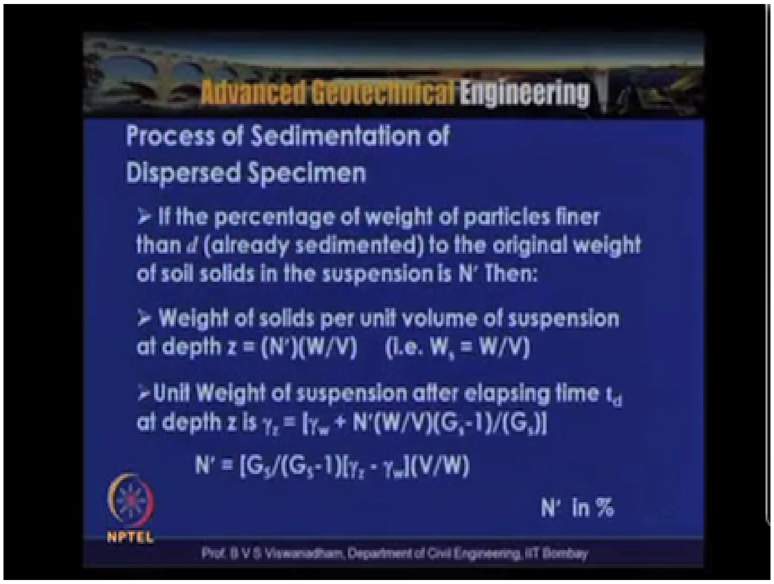

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Process of Sedimentation of Dispersed Specimen

- If the percentage of weight of particles finer than *d* (already sedimented) to the original weight of soil solids in the suspension is N′ Then:
- Weight of solids per unit volume of suspension at depth z = (N′)(W/V) (i.e. W_s = W/V)
- Unit Weight of suspension after elapsing time t_d at depth z is $\gamma_z = [\gamma_w + N'(W/V)(G_s-1)/(G_s)]$

$$N' = [G_s/(G_s-1)][\gamma_z - \gamma_w](V/W)$$

N′ in %

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Is say and that is if the percentage of the weight of the particles finer than D which are already sediment to the original weight of the soil solids in the suspension is say n then we can actually get the weight of the solids per unit volume ohms unit volume of suspension at depth Z as N – x W / V where W_S is nothing but W / V. Unit weight of the suspension after elapsing time TD at a depth Z is given / from the previous discussion γ z = γW x n – x W / V x GS - 1 / G_S.
So with this we can actually obtain and - as G_S / Gs - 1 x γz - γ_W x v / W where n - is in percentage.

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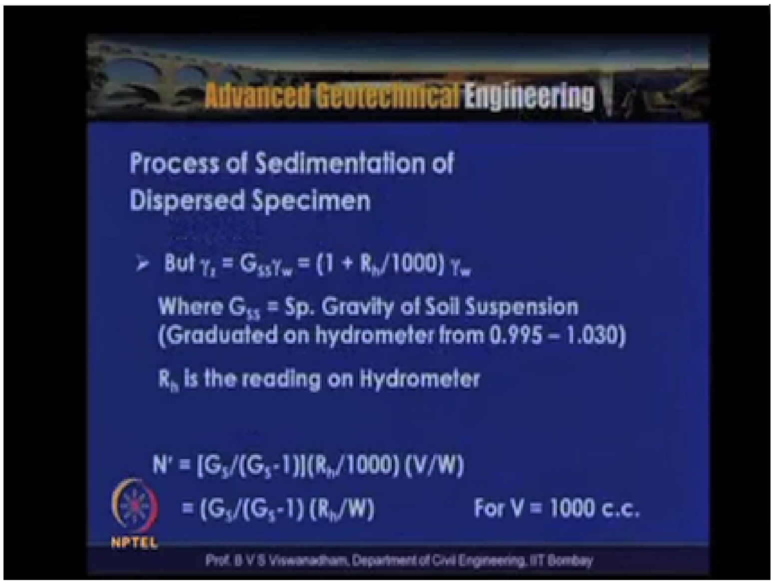

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Process of Sedimentation of Dispersed Specimen

- But $\gamma_z = G_{SS}\gamma_w = (1 + R_h/1000)\ \gamma_w$

Where G_{SS} = Sp. Gravity of Soil Suspension (Graduated on hydrometer from 0.995 – 1.030)

R_h is the reading on Hydrometer

$N' = [G_s/(G_s-1)](R_h/1000)\ (V/W)$

$= (G_s/(G_s-1)\ (R_h/W)$ For V = 1000 c.c.

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So the process of sedimentation with the dispersal specimen but here γZ is nothing but G_{ESS} γ_W we are G_{SS} is nothing but 1 + Rh /1000 x γ_W where J_{sss} is the specific gravity of the soil specific suspension, which is nothing but the graduations on the hydrometer. The graduations on the hydrometer generally vary from 0.95 to 1.03 or a length of the stem so R_H is the reading on the hydrometer, what it is noted during the process of experiment.

So n - is obtained here as G_S / G's - 1 x R_H 1,000 x V / W, so which is simplified further we are for a volume of say thousand C_C of the soil suspension placed initially, we can actually get n -as G_S / G's - 1 x Rh / W is nothing but the weight of the solids taken for the dry solids taken for the dispersion analysis our sedimentation analysis.

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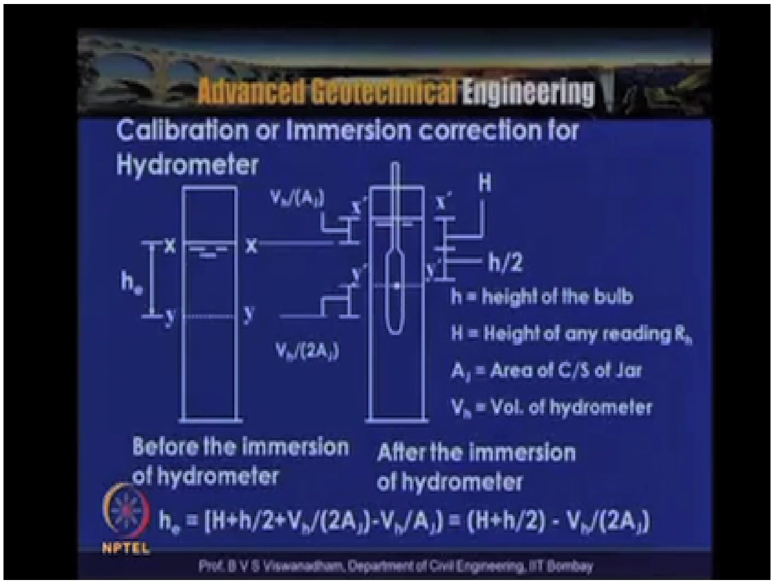

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Calibration or Immersion correction for Hydrometer

h = height of the bulb

H = Height of any reading R_h

A_j = Area of C/S of Jar

V_h = Vol. of hydrometer

Before the immersion of hydrometer

After the immersion of hydrometer

$$h_e = [H+h/2+V_h/(2A_j)-V_h/A_j] = (H+h/2) - V_h/(2A_j)$$

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And as we actually keep the hydrometer in the from time to time it is subjected to it is required to perform immersion Corrections, so in order to calibrate or calibration of the hydrometer for the immersion here in this slide, that two figures which are actually shown, one is before the immersion of the hydrometer another, one is the after version of the hydrometer. Before immersion of the hydrometer at level y y is the point at which the measurement is being made that is where the center of the bulb is assumed to be occurring or assume to be there.

So H_E height from the surface from that the distance from the center of the bulb to the top surface of the soil specimen and when this said the surface top surface be xx and the surface at which the you know center of the bulb meets is say yy, so when the bulb is placed there is a raise in the water that raised in the water suspension region the water suspension is given / V_H / A_J because V_H is but the volume of the hydrometer A_J is nothing but the area of the jar in which the experiment is being performed.

So here it is assumed that Y, Y - which is actually you rises above the it is approximated that 50% of the vh / a G - B it will be subjected to a that with the raise the raise is about v_h / 2 which is about the 50% of the raise of that excitation x –, so with that the immersion correction can be obtained like this H_E = here h + h / 2 + v_h / 2 Ag the distance – V_h / A_G so after simplification it is obtained as h +h / 2 - vh / 2Aj so if it is this immersion correction need to be applied approximately after say two to four minutes of the you know readings whatever we take.

So the here then we discussed about the calibration of the hydrometer for you know basically for immersion correction.

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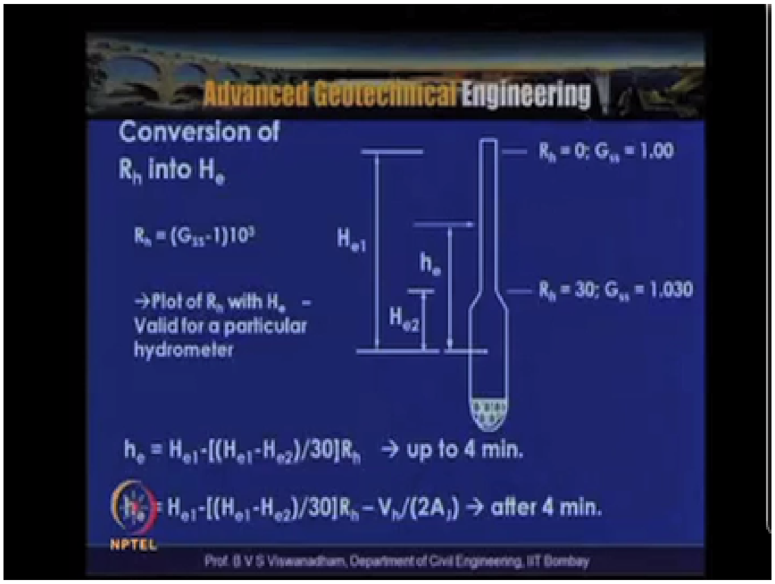

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Conversion of R_h into H_e

$R_h = (G_{ss}-1)10^3$

→Plot of R_h with H_e - Valid for a particular hydrometer

$h_e = H_{e1}-[(H_{e1}-H_{e2})/30]R_h$ → up to 4 min.

$h_e = H_{e1}-[(H_{e1}-H_{e2})/30]R_h - V_h/(2A_j)$ → after 4 min.

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Then the graduations which are actually there as I said here from it starts from 0.952 to 1.030 or in the numbers it is our H = 0 or – 5 to 30 this is these are actually this graduated indicated on the stem of the hydrometer and H_E is the difference where the measurement which are which has been taken and these readings which are achieve one and eighty two are unique for the hydrometer.

So need to be calibrated and then they vary over linear distance with these readings, so the R_H where conversion of our H x H_E is done like this where our H = G_S s - one in 2000 so the plot of our H with H_{II} is valid for a particular hydrometer, that means that each hydrometer will have a you know plot for our H and H_E. So with the linear interpolation if you see up to two minutes or four minutes where we do not have any immersion correction with that H =He1 this distance and - H e1 - H e2 H e1- H t2 /30 x R_H this is up to 44 minutes are here H e that is beyond four minutes H e1 – H t1 - HT 2 / 13 to R H - V H / 2 A G, so this is after 4 minutes.

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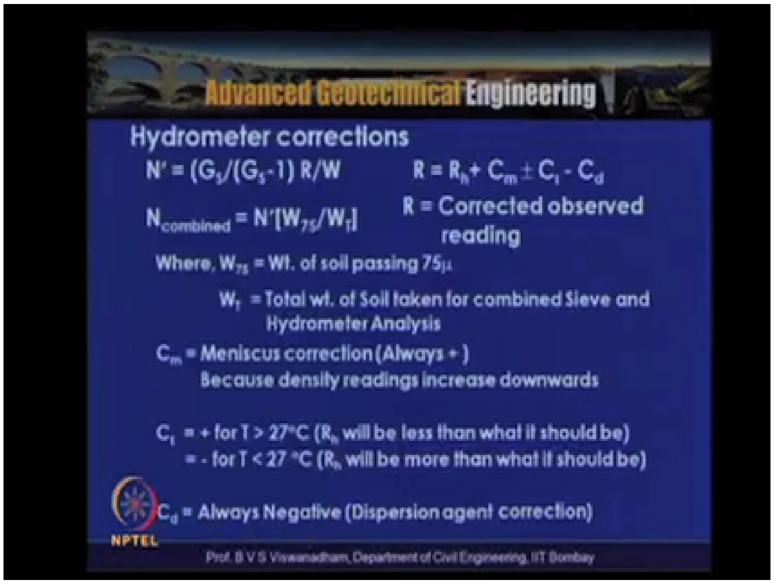

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Hydrometer corrections

$N' = (G_s/(G_s-1)\ R/W$ $R = R_h + C_m \pm C_t - C_d$

$N_{combined} = N'[W_{75}/W_T]$ R = Corrected observed reading

Where, W_{75} = Wt. of soil passing 75μ

W_T = Total wt. of Soil taken for combined Sieve and Hydrometer Analysis

C_m = Meniscus correction (Always +)
Because density readings increase downwards

C_t = + for T > 27°C (R_h will be less than what it should be)
= - for T < 27 °C (R_h will be more than what it should be)

C_d = Always Negative (Dispersion agent correction)

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So here it is summarized along with other Corrections which are actually required for the you know hydrometer reading where n dash $=G_S$ / G's - 1 x R / w, w is nothing but the weight of the solids and R is the corrected hydrometer reading which is used in this expression for calculating the percentage and W is the weight of the solids taken for preparing the soil suspension, where R is nothing but R h + C_M that is meniscus correction + R - C T the temperature correction – CD.

So N combined that is if you have got a performed a sieve analysis and if the percentage of the fines is say more than 12%, then the total soil taken for you know relation that is W_T and total soil passing 75 micron in a given soil mass which is taken for sieve analysis and M combined can be obtained / getting n - / using / G's - 1 x R / W and then putting substituting in n combined =n - / x W 75 / W_T you will be able to get the N combined.

So with that percentage the final and the particle size variation can be plotted and where W 75 is nothing but the weight of the soil fraction passing seventh of a micron W_T is nothing but the total weight of the soil scaled skeleton for buying the sieve and hydrometer analysis. So in the hydrometer Corrections apart from meniscus correction cm, which is a meniscus correction which is applied always positive because the density readings increased downwards that is that the suspension are the hydrometer readings increased downwards.

So because of that the meniscus correction is always positive C_T it is positive for temperature greater than 27 ^{0} so RH will be less than what it should be, so the reading will be less than what it should be. So because of that the temperature correction is positive if the temperature is room temperature is more than 27 ^{0} negative 49, 27 degrees RH will be more than what it should be so because of this it is higher, so what it is done is that the temperature correction is done negative.

And CD is always negative because in order to you know prevent of locking of the soil particles while preparing the suspension the dispersion is not is used like sodium carbonate or sodium alginate or use 2 d flock the soil. So dispersion as in concentration you know to account for that the dispersion correction is always negative. So let us see after having discussed the procedure let us see an example of or the hydrometer analysis with a particular soil kaolin.

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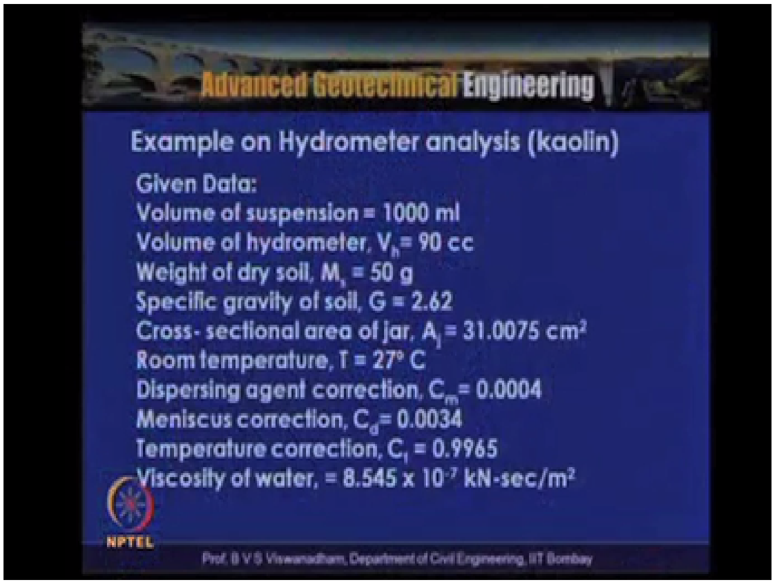

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Example on Hydrometer analysis (kaolin)

Given Data:
Volume of suspension = 1000 ml
Volume of hydrometer, V_h = 90 cc
Weight of dry soil, M_s = 50 g
Specific gravity of soil, G = 2.62
Cross- sectional area of jar, A_j = 31.0075 cm^2
Room temperature, T = 27° C
Dispersing agent correction, C_m = 0.0004
Meniscus correction, C_d = 0.0034
Temperature correction, C_t = 0.9965
Viscosity of water, = 8.545×10^{-7} kN-sec/m^2

Passing you know very fine kaolin soil, so here the volume of the suspension is 1000 ml and the volume of the hydrometer is which is taken for the test is about 90 CC and the weight of the dry soil taken is about 50 grams and the specific gravity the soil is about 2.62, the cross section area of the jar is A_J about 31 centimeter^2 and room temperature is 27 ^{0} dispersing agent correction about CM = 0.0004 meniscus correction CD = 0.034, temperature correction CT = 0.9965 and discuss to the water taken as 8.55 8.54 x 10 two raised to - 7 kilo Newton second per meter ^{2}.

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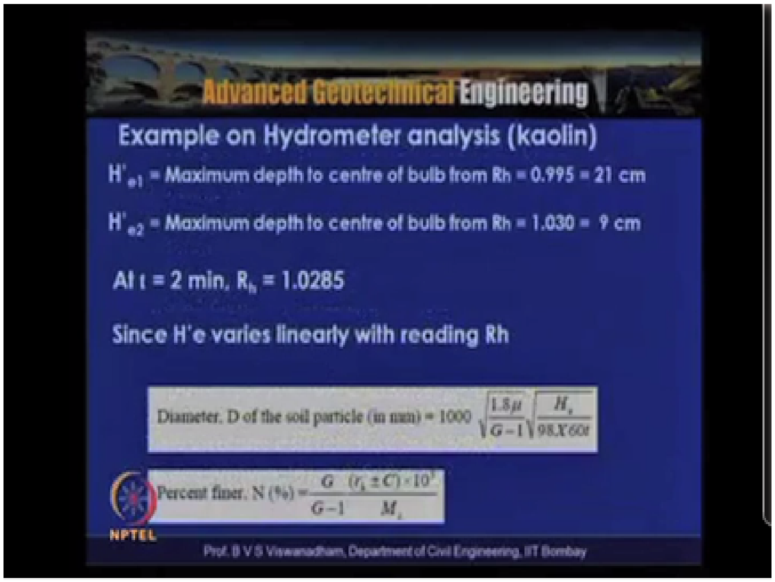

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Example on Hydrometer analysis (kaolin)

H'_{e1} = Maximum depth to centre of bulb from Rh = 0.995 = 21 cm

H'_{e2} = Maximum depth to centre of bulb from Rh = 1.030 = 9 cm

At t = 2 min, R_h = 1.0285

Since H'e varies linearly with reading Rh

Diameter, D of the soil particle (in mm) = $1000\sqrt{\frac{1.8\mu}{G-1}}\sqrt{\frac{H_e}{98 X 60t}}$

Percent finer, N (%) = $\frac{G}{G-1}\frac{(r_h \pm C)\cdot 10^3}{M_s}$

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With this data for the given hydrometer that is achieve one which is nothing here it is indicated ash - e one maximum depth maximum depth to center of the bulk from our H 0.995 that is the topmost reading in the stem of the hydrometer is 21 centimeter, HC2 that is closer to the center of the bulb maximum depth to the center of the ball from for R_H reading 1.030 is 9 centimeter. Let us say at T at time T = minutes after placing the suspension and the reading which is actually taken in the hydrometer is say 28.5 which is indicates that R_H = 1.0285.

Since H- E varies linearly with the R_H the / using this presumption and the diameter of the soil particle is actually calculated / using thousand x 1.8 μ /g RG s - one x √ over h g 98 x 60 x T that is the time at which the you know the reading is being taken and percentage finer n = G / G - 1 γ that is Rh + or - C that is a summation of all the corrections in 2000/ this mass of the solids, which is actually taken for suspension.

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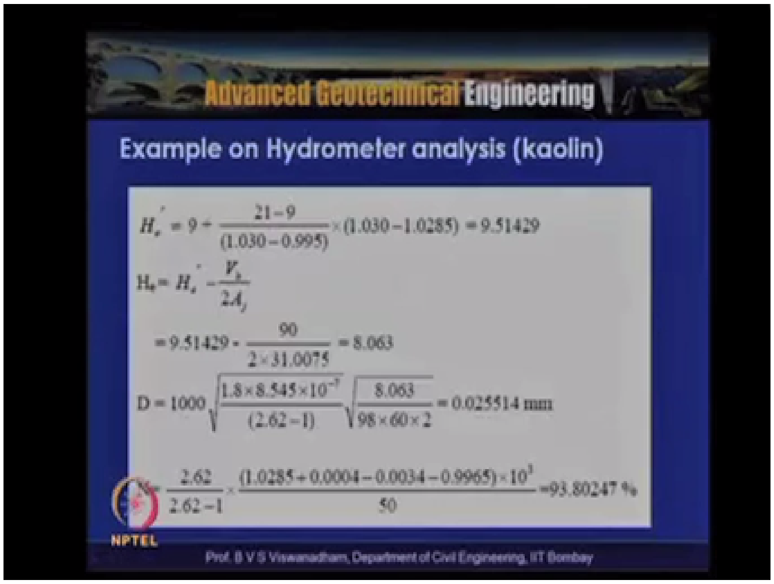

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Example on Hydrometer analysis (kaolin)

$$H_e' = 9 + \frac{21-9}{(1.030-0.995)} \times (1.030-1.0285) = 9.51429$$

$$H_e = H_e' - \frac{V_h}{2A_j}$$

$$= 9.51429 - \frac{90}{2 \times 31.0075} = 8.063$$

$$D = 1000\sqrt{\frac{1.8 \times 8.545 \times 10^{-7}}{(2.62-1)}}\sqrt{\frac{8.063}{98 \times 60 \times 2}} = 0.025514 \text{ mm}$$

$$\frac{2.62}{2.62-1} \times \frac{(1.0285+0.0004-0.0034-0.9965) \times 10^3}{50} = 93.80247\,\%$$

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So here in this slide calculations are given where H E H - E was obtained based on the hydrometer details where it is obtained as 9.14 and with immersion correction that is Vh / 2Ag it is obtained as 8.063. Now substituting in the expression which was shown in the previous slide D =1000 x 1.8 545 x 10 to power of - 7/ the specific gravity - 1that is 2.62 -1 x √ of this 8.0 0 6 3/ 19 18 to 16 x 2 which gives a particle size of 0.025 5mm.

So with this you can actually calculate that n -that is nothing but obtained as about 93%, so based on this for the different timings.

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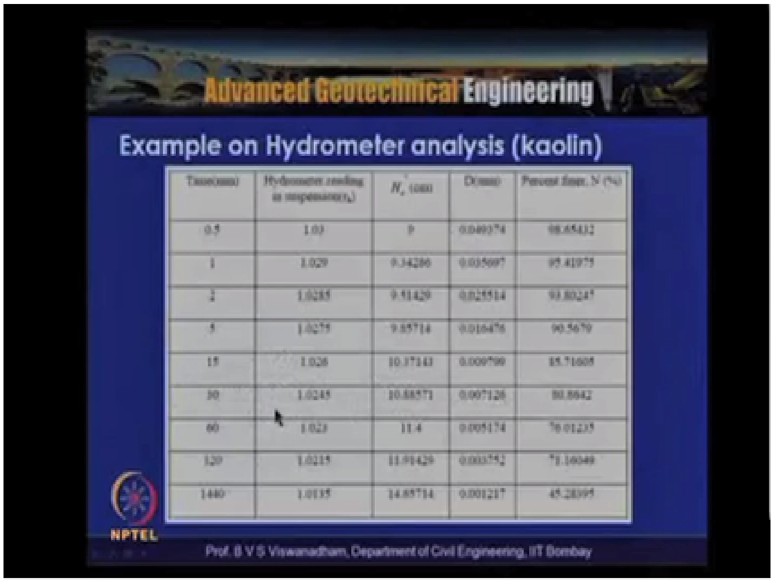

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Example on Hydrometer analysis (kaolin)

Time(min)	Hydrometer reading in suspension(R_h)	H_e (cm)	D(mm)	Percent finer, N (%)
0.5	1.03	9	0.040374	98.65432
1	1.029	9.34286	0.035097	95.41975
2	1.0285	9.51429	0.025514	93.80247
5	1.0275	9.85714	0.016476	90.5679
15	1.026	10.37143	0.009799	85.71605
30	1.0245	10.88571	0.007126	80.8642
60	1.023	11.4	0.005174	76.01235
120	1.0215	11.91429	0.003752	71.16049
1440	1.0135	14.65714	0.001217	45.28395

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When the calculations are done for time 0.5 minute, 1 minute immersion correction was not taken and 2, 5, 15, 30, 60 and then 121 14, 40 these are the reading these are the readings which are actually taken and these are the corrected H - E and then D in particle size in millimeter, so once you plot this the particle size on the log semi-log logarithmic scale and the percentage finer on the y-axis we will get this gradation plot.

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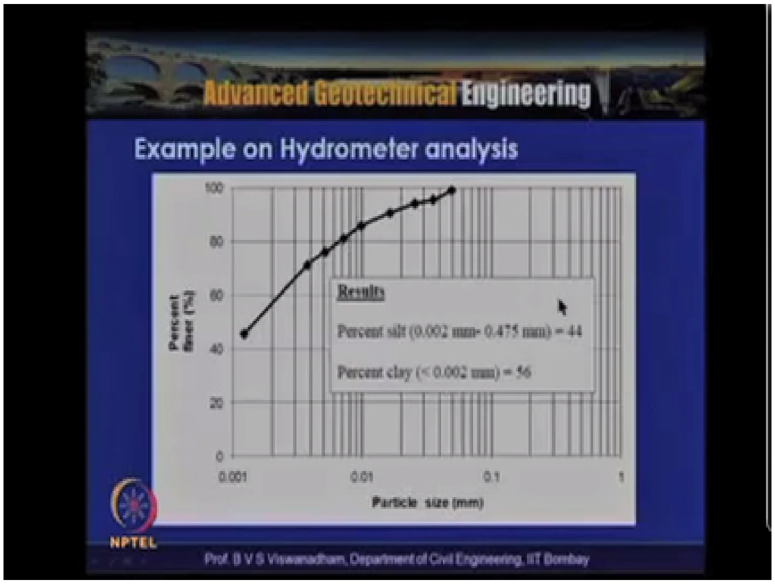

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Example on Hydrometer analysis

Results

Percent silt (0.002 mm- 0.475 mm) = 44

Percent clay (< 0.002 mm) = 56

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So here this is the percentage finer on the y-axis and particle size on the x axis with this is possible, that you will be able to seethe percentage points. Here in this particular curing soil what has been taken the silt particles are about 44% and clay particles are about 56%, that means that is basically silty clay having the clay fraction about 56% and silt fraction about 44% and the 100%fine fractions.

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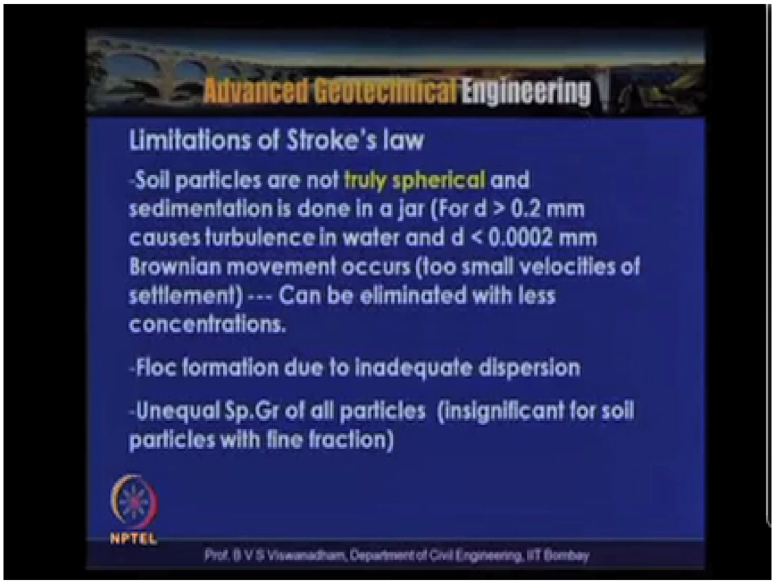

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Limitations of Stroke's law

-Soil particles are not truly spherical and sedimentation is done in a jar (For d > 0.2 mm causes turbulence in water and d < 0.0002 mm Brownian movement occurs (too small velocities of settlement) --- Can be eliminated with less concentrations.

-Floc formation due to inadequate dispersion

-Unequal Sp.Gr of all particles (insignificant for soil particles with fine fraction)

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So limitations we have used the Stokes law for calculating you know the come here arriving at the particle size distribution offline-grained soils however we knew that the clay particles are hardly spherical but they are platelet particles. So the soil particles are not truly spherical and the sedimentation is done in a jar which is actually also induces some sort of limiting boundaries type. So for D greater than 0.2 mm causes turbulence in water and for D < 0.0002 among the Brownian movement occurs.

So this is actually too small for the velocities of settlement so can be eliminated with less concentration. So if you are having a finest fine fractions then it is suggested that very little amount of the soil solids need to be taken particularly for example when we are determining the gradation of a betonies, you should not take about not more than about five grams of soil solids also. So one limitation is that the soil particles are not truly spherical another other formulation is that the flock formation due to inadequate dispersion sometimes what will happen is that what we measure is not the true particle size.

This is because of the flock formation are inadequate dispersion, an unequal specific gravity of all particles insignificant for soil particles with fine traction, so this is unequal specific gravity of the whole particles that is also one it is not it is assumed that all particles are actually having the same specific gravity but there is a possibility, that unequal specific gravity can exist. So basically though it is insignificant this is actually listed as one of the limitations of Stokes law.

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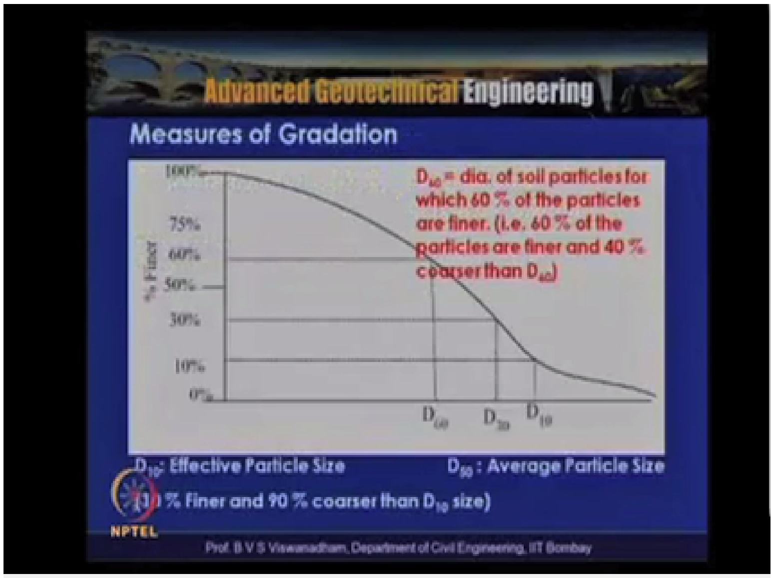

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Measures of Gradation

D_{60} = dia. of soil particles for which 60 % of the particles are finer. (i.e. 60 % of the particles are finer and 40 % coarser than D_{60})

D_{10}: Effective Particle Size

D_{50} : Average Particle Size

(10 % Finer and 90 % coarser than D_{10} size)

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So here in this plot a total particle size distribution curve is actually shown, where you have got percentage finer on the y axis, on the x axis we have got particle sizes, so here it is important to know that some particle sizes are actually characterized they are called -10 as the effective particle size and b 50 as the average particle size. So here in the d 50 means here the 50% of the particles are coarser and 50% of the core particles are finer and d-10 is the effective particle size which is called in this 10 % of the particle sizes are finer and 90 % of the particle and 90 % are actually particles are coarser than that détente size.

So we use D 10, D 15, D 10, D 60, D 30 and for some filter design requirements D 15, D85 are also use. So here in this graph where a well graded portion of the well graded you know distribution is actually shown and diameter of the soil particles for which 60 persist e percent of particles are finer that is 60% of the particles are finer and 40% are coarser than B 60 that is what actually the physical meaning of the suffix 60.

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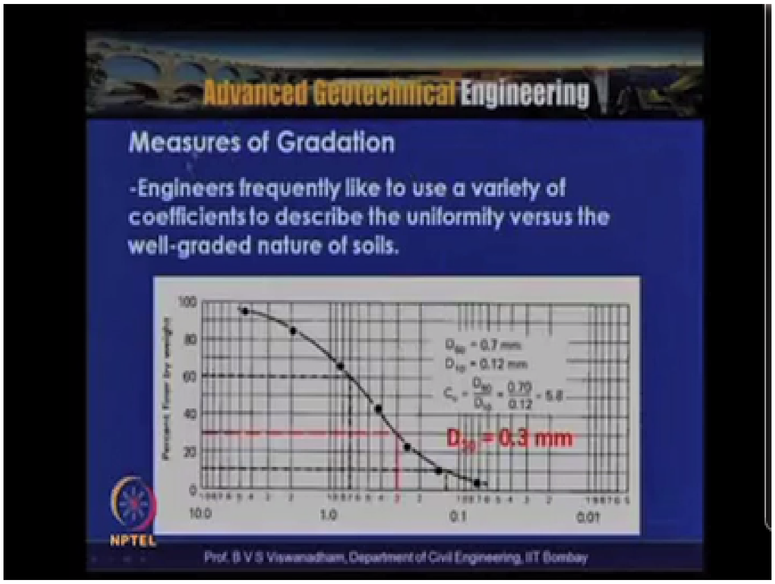

Advanced Geotechnical Engineering

Measures of Gradation

-Engineers frequently like to use a variety of coefficients to describe the uniformity versus the well-graded nature of soils.

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So here we use as I said that D 30 can be determined from the graph like this and there is Cu which is called d60 / d-10so in this case for the type of the so is obtained as 5.8 + d 6 TD 10 which is used to determine the coefficient of curvature, that is the D 30 2/d60 xd-10. So if the value of the Cu =1 that indicates that all particles are actually having almost identical sizes so if the slope of the gradation curve is say very steep then there is a tendency that all uniform graded particles exist in that particular type of distribution.

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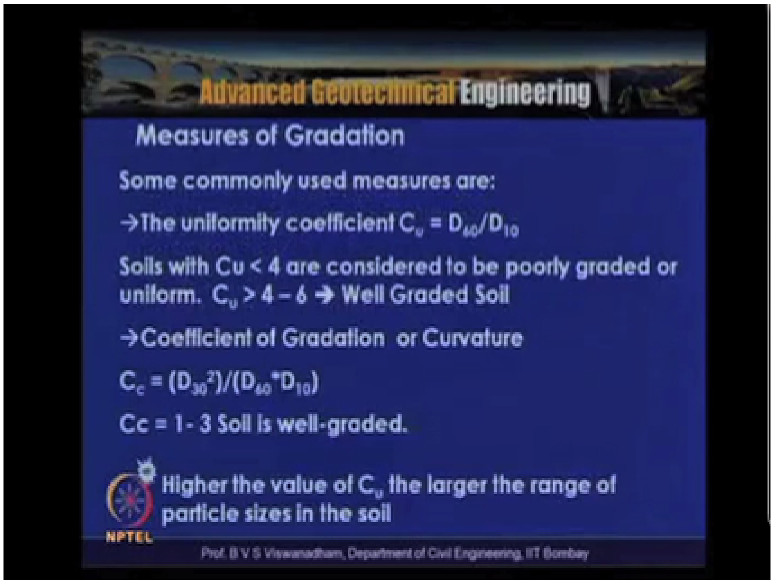

Measures of Gradation

Some commonly used measures are:

→The uniformity coefficient $C_u = D_{60}/D_{10}$

Soils with Cu < 4 are considered to be poorly graded or uniform. $C_u > 4 - 6$ → Well Graded Soil

→Coefficient of Gradation or Curvature

$C_c = (D_{30}^2)/(D_{60}*D_{10})$

Cc = 1 - 3 Soil is well-graded.

Higher the value of C_u the larger the range of particle sizes in the soil

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So some common uses some commonly used measures are the uniformity coefficient which is nothing but this U =D 60 / D10 and soils with Cu less than full are considered to be poorly graded or uniform that's what a steeper curve indicates that you know uniform grade distribution that means that all particles are actually having same size or it is also called as poorly graded and to see you greater than 4 to 6 is called relegate well graded soil and coefficient of the gradation or curvature is called as C C = D30 squared divided by d60 into d-10 if the CC is equal to two three.

So if Cu value is say greater than four to six and CC value is one two three then the soil is said to be well graded so higher the value of Cu the larger the range of the particle sizes in the soil so higher the value of the Cu the larger the range of the particle sizes in B so I so typical characteristics of the grain size distribution curves if you look in T as we discuss

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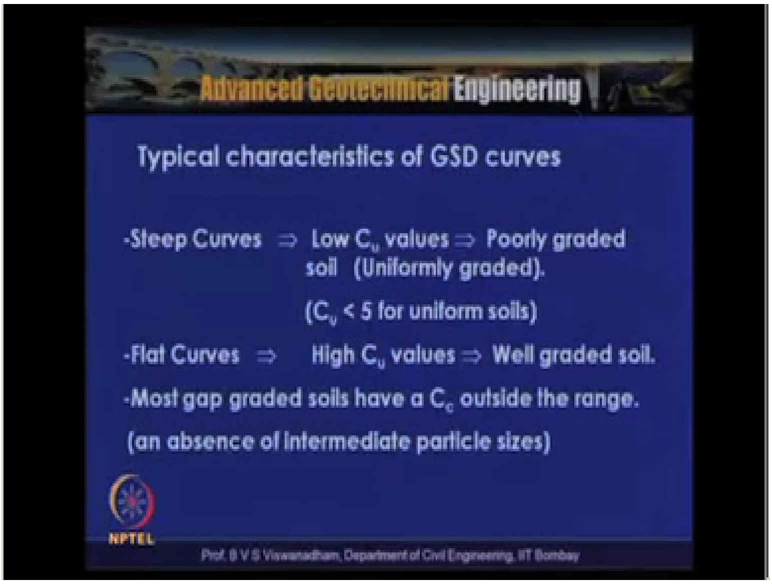

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Typical characteristics of GSD curves

-Steep Curves ⇒ Low C_u values ⇒ Poorly graded soil (Uniformly graded).

($C_u < 5$ for uniform soils)

-Flat Curves ⇒ High C_u values ⇒ Well graded soil.

-Most gap graded soils have a C_c outside the range.

(an absence of intermediate particle sizes)

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Steep curves are possible with low Cu values and they are poorly graded in nature and uniformly graded it is also referred and Cu less than five indicates that for uniformly graded soils and a flat curves with mind slopes the I CU values indicates that well graded soil so most gap graded soils have a CC outside the range that is a gap related soil means that some range of the particle size of the particles will remain absent from the soil matrix so the intermediate particle sizes will be absent in gap graded soils so most grab graded soils have the CC outside the range.

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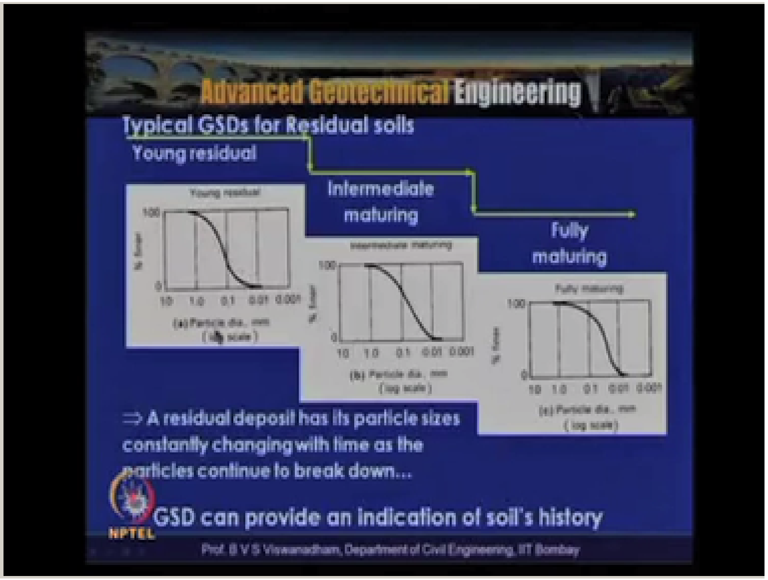

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Typical GSDs for Residual soils

Young residual

Intermediate maturing

Fully maturing

⇒ A residual deposit has its particle sizes constantly changing with time as the particles continue to break down...

GSD can provide an indication of soil's history

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We can also see that the grain size distribution curves can also give the soils history in this slide three different particle size distribution curves are shown one is for a the one which is on this side is for a residual soil deposit and here for the intermediate maturing soil deposit and here is fully maturing soil deposit as can be seen here a residual soil deposit as its particle sizes constantly changing with time as the particles continue to break down.

So in the process of weathering the particles subjected to migration is subjected to change so we can say that the grain size distribution can provide an indication of soils history and typically we also discussed it that the soils get transported from one is one place to other place and then they are called as transported soils with different agencies and here we have got a typical grain size distribution fork like glass and glacial and alluvial soil deposits here this particular figure which is actually shown for the percentage finer on the y axis.

And particle size on the x axis is for a glacial soil deposit and this one is the Glacial and alluvial soil deposit so Reverend deposits basically how well graded and uniform or gap graded depending upon the battle velocity and the volume of the suspended solids and the river area where the deep ocean is occurring.

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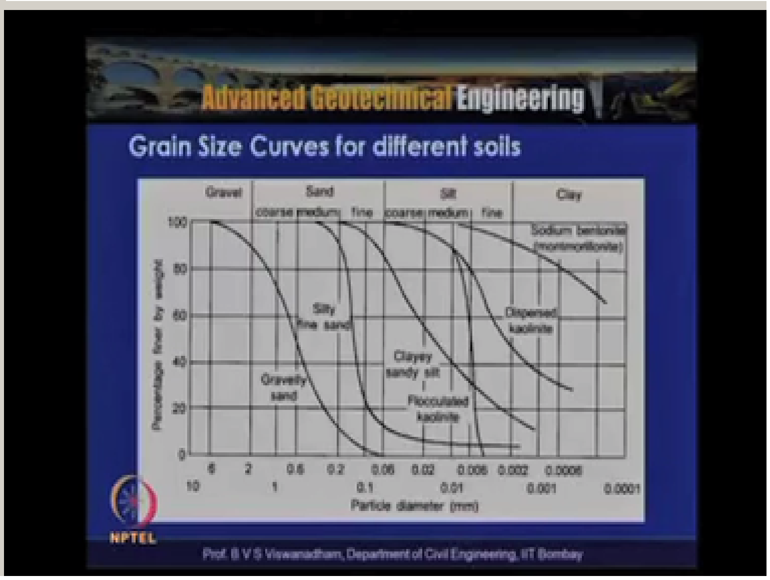

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Grain Size Curves for different soils

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So here in this slide you know number of different types of you know grain size distribution curves are shown and as can be seen here on the this particular portion where a gravelly and you know particle size distribution is shown and here is salty and with a fine sand mixture is shown here and here there is a clay and fine sand clay, clay and sandy silt soil is shown here then here two types of you know one is a flocculated light other one is the dispersal kill night.

And these sodium betonies which is finest of the finest of all where you can see they find a final fraction the particles are very, very small so as we go from this side to this side the particle size diminishes and you have got different you know for example you have got flocculated.

And dispersal have got the here where the dispersions are the between depositions are very predominant and here there is a possibility of flocculation so the flocculate decline it actually has got this type of distribution and dispersal kill net has actually got this type of distribution and here the sodium bantam and mantle night basal soil actually has got a distribution which is actually shown here

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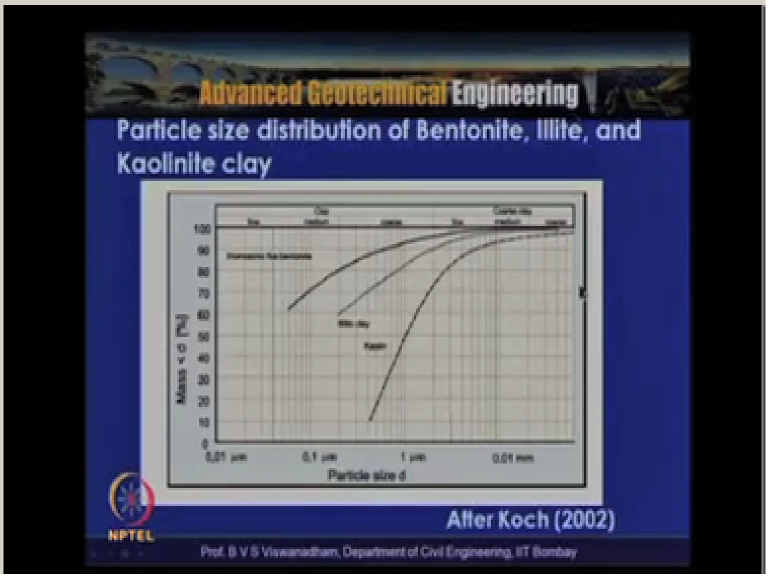

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Particle size distribution of Bentonite, Illite, and Kaolinite clay

After Koch (2002)

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And particle size distribution of betonies and in light and coal night if you consider as we discussed in the previous slide the sodium betonies or sodium basin multiple light has got the final wave has got very, very small fraction of size and when you compare these three minerals the Keller Silas soil is relatively coarser and comes in between is a light and then followed just final is the betonies.

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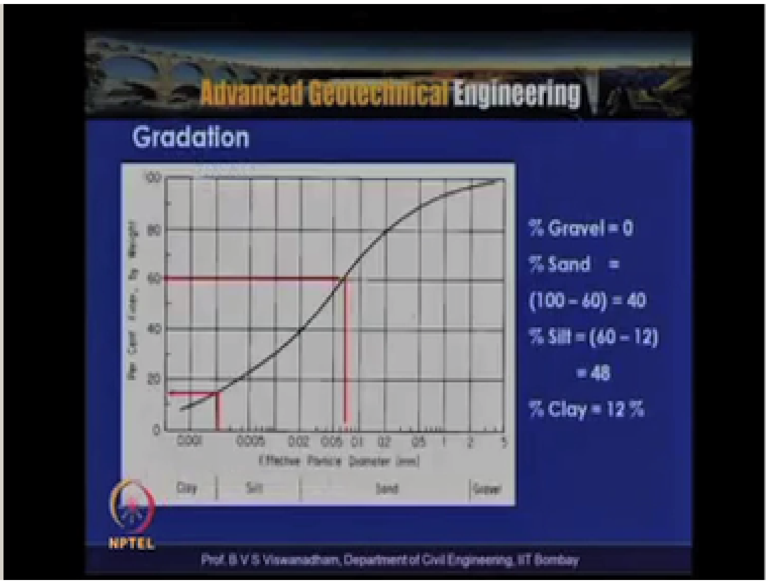

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Gradation

% Gravel = 0

% Sand =

(100 – 60) = 40

% Silt = (60 – 12)

= 48

% Clay = 12 %

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So if you have the typical gradation then it is possible for us to estimate what is the percentage gravel and what is the percentage sand and what is the percentage silt and percentage clay so sometimes if you have got say percentage clay it is possible for us to once we know the index properties of the soil it is possible whether the soil is active or not can be estimated so in this curve for the given example here you have the, the typical grain size distribution.

And the coarser particles is on this side that is gravel sand silt and clay and here the percentage gravel which is more than four point seven five is found to be zero and the sand size is from, from this side to the size of the silt that is 0.075 mm where 100 - 60that is 40% is actually sand and acidities from this 60% and the clay fraction is about 12 percent so that means that this particular soil actually has got about 60% as percentage fines that is passing two hundred among scene.

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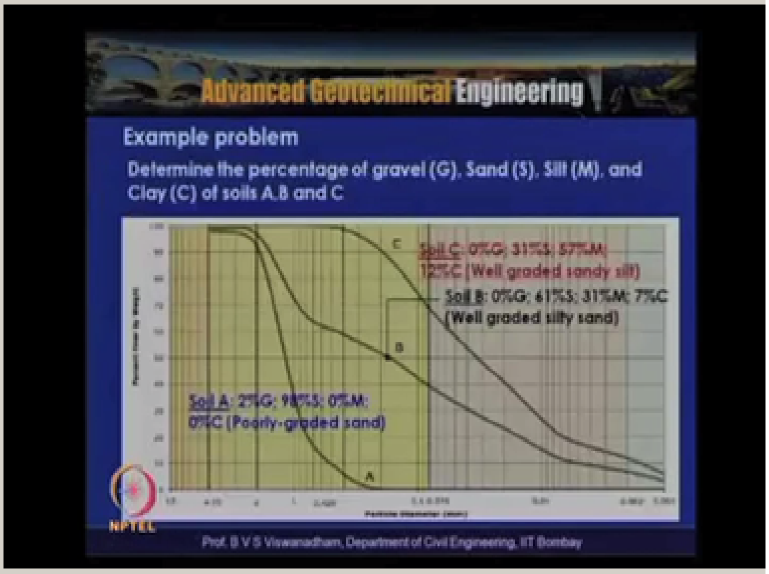

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Example problem

Determine the percentage of gravel (G), Sand (S), Silt (M), and Clay (C) of soils A,B and C

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So in this example problem which is actually shown in this slide we need to determine percentage of the gravel and the sand silt so gravel is indicated as gee sand is indicated as yes and silt has indicated as M and clay as C for soils a B and C so the three typical grain size distribution which are actually shown here one is that the poorly graded and here this is a well graded salty sand and here well gave well graded sand EC so if you look into this here the soil actually has got 2% gravel the gravel is very less the 2% fraction is here.

And then followed by 98% sand and the curve is actually asymptotic here and the 0%silt and 0% clay hence here this is nothing but a poorly graded sand in this case it is a well graded salty sand where it has actually got 61 percent of silt particles sand particles and 31percent silt and 7 percent clay so this is actually referred as well graded silts sand and if you look into this actually has got contracts to inter actually has got silt particles higher so we call it well graded sandy silt where 57 percent silt particles and 31percent sand exists there.

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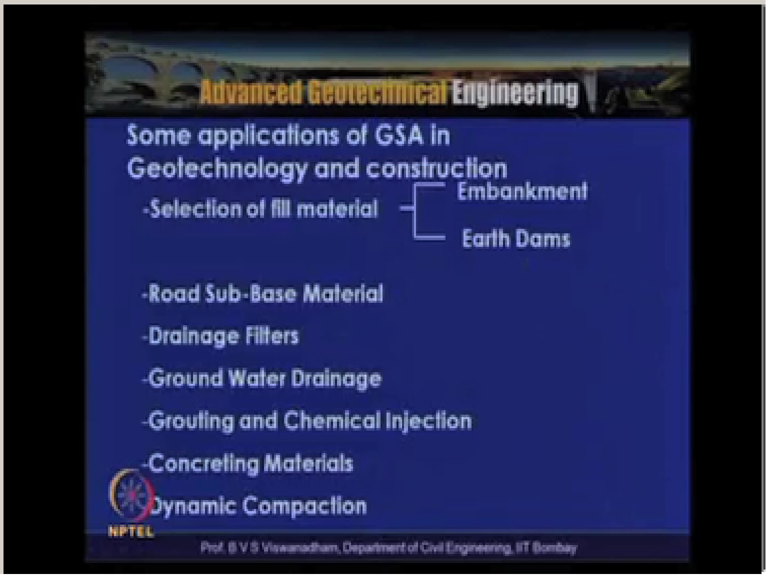

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Some applications of GSA in Geotechnology and construction

- Selection of fill material
  - Embankment
  - Earth Dams
- Road Sub-Base Material
- Drainage Filters
- Ground Water Drainage
- Grouting and Chemical Injection
- Concreting Materials
- Dynamic Compaction

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So some applications of the having determined the particle size distribution we can actually is discuss where the grain size distribution or analysis can be used particularly in geotechnical geo technology and in construction basically very much useful in the selection of the fill material particularly has aortic material or casing material it is required for embankment and at the dam construction and as a road sub base material basically the well graded soils are preferred.

And for the drainage filters in order to allow and retain the final fraction the filters are required and the groundwater drainage and grouting and chemical injection where the fraction of the soil which is actually required to be mentioned and concreting materials and in the dynamic compaction is the process where the soil can be identified by dropping weights from the known heights the practical significance of the grain size distribution can be you know discussing like this.

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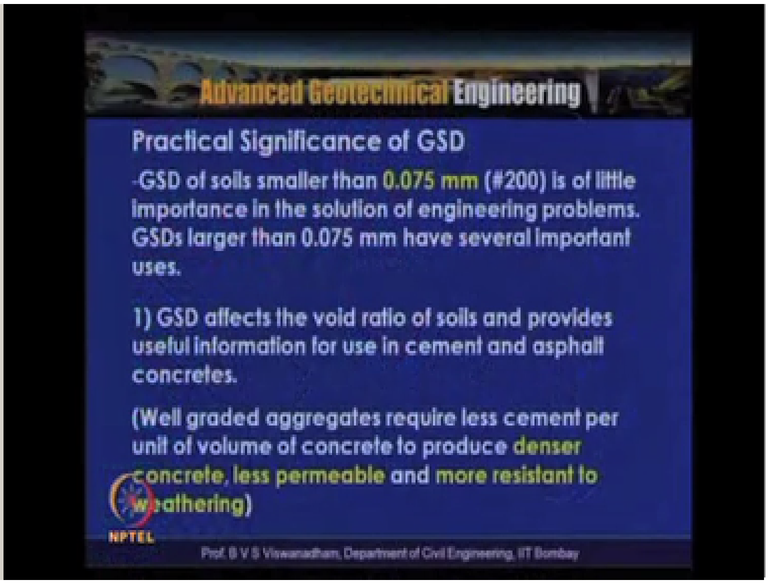
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Practical Significance of GSD

-GSD of soils smaller than 0.075 mm (#200) is of little importance in the solution of engineering problems. GSDs larger than 0.075 mm have several important uses.

1) GSD affects the void ratio of soils and provides useful information for use in cement and asphalt concretes.

(Well graded aggregates require less cement per unit of volume of concrete to produce denser concrete, less permeable and more resistant to weathering)

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Grain size distribution of soils smaller than 75 micron or 0.075 mm is of little importance in the solution of engineering problems but GST is larger than 75 micron have several important uses particularly if you look into this GST it is the void ratio of the soils and provides useful information for use in cement and asphalt concrete particularly during the pavement constructions well graded aggregates require less cement.

Because they have got less wide spaces and if you have what uniformly graded aggregates then it requires more cement in brick tends to become an economical and then less load-bearing so well graded aggregates require less cement per unit volume of concrete to produce denser concrete and it is less permeable and more resistance to resistant to weathering.

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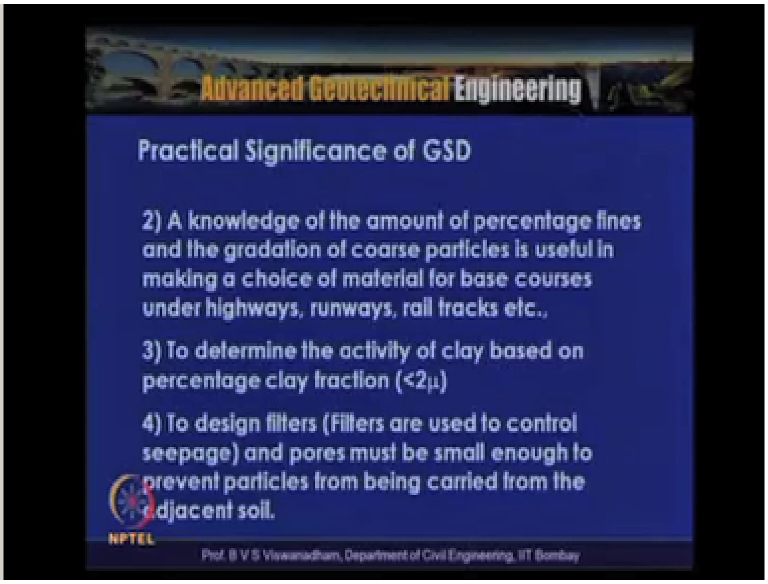

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Practical Significance of GSD

2) A knowledge of the amount of percentage fines and the gradation of coarse particles is useful in making a choice of material for base courses under highways, runways, rail tracks etc.,

3) To determine the activity of clay based on percentage clay fraction (<2μ)

4) To design filters (Filters are used to control seepage) and pores must be small enough to prevent particles from being carried from the adjacent soil.

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Secondly in knowledge of the amount of the percentage of the fines and gradation of the coarse particles is useful in making a choice of material in base courses under highways runways and rail tracks etc and as I said before if you know the percentage clay fraction whether that play is active from the expansiveness point of view whether the soil is expensive or not can be established by with a term called activity so activity of the clay is based on the percentage of the clay fraction.

And another significance of grain size distribution is that to design filters basically filters are used to control the seepage and the pores must be small enough to prevent particles from being carried from the edge sense soil or the base soil which is called so after having disgusted you know grain size distribution and any not to complete are in order to arrive at the knowledge for classifying these soils are grouping the soil we need to understand particularly as far as the fine grained soils is concerned the different possible physical states of the fine-grained soils.

As the soil water content changes soil changes from different states from liquid state to plastic state to semi solid state to solid state that is as the soil is subjected to dry soil changes from liquid in a liquid state to plastic state to semi solid to solid States.

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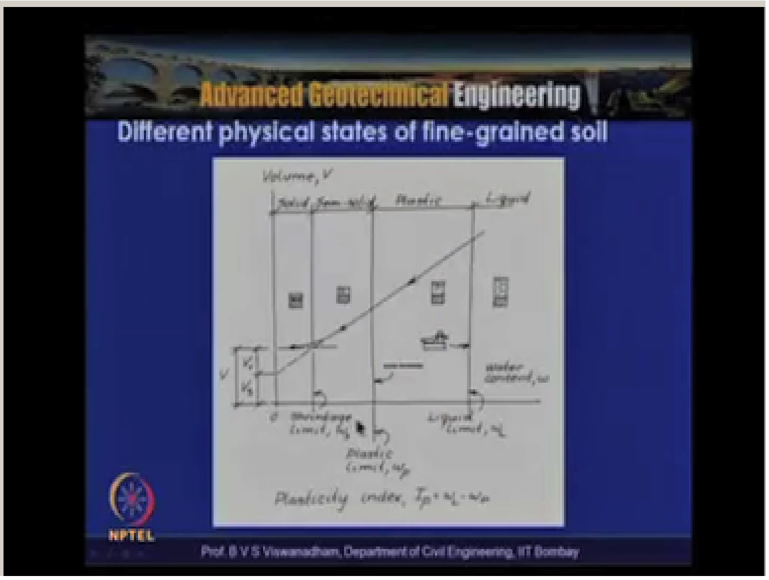

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Different physical states of fine-grained soil

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For the most of the soil deposits which are reasonably compress can occur at this particular water content that is at this point where the they are actually close to plastic state or the this particular limiting water content so we actually need to have understand about the you know these transitions between liquid limit and plastic limit state and plastic state and plastic state and semi-solid state and semi-solid state and solid state.

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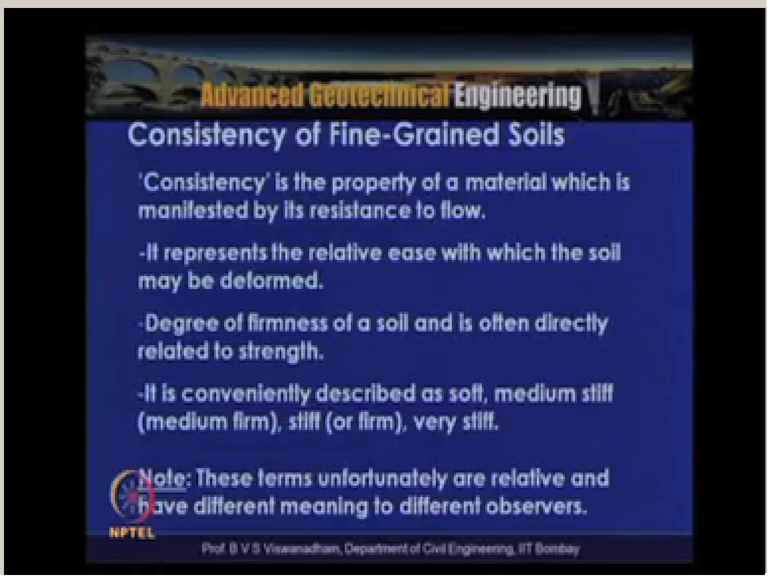

Advanced Geotechnical Engineering

Consistency of Fine-Grained Soils

'Consistency' is the property of a material which is manifested by its resistance to flow.

-It represents the relative ease with which the soil may be deformed.

-Degree of firmness of a soil and is often directly related to strength.

-It is conveniently described as soft, medium stiff (medium firm), stiff (or firm), very stiff.

Note: These terms unfortunately are relative and have different meaning to different observers.

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So before discussing about that we need to understand about the what is the term called consistency of the fine-grained soils so basically it is a property of a material which is manifested by its resistance to flow it represents the relative ease with which the soil may be deformed so the soil is very stiff then it is difficult to get it deformed so degree of the Filner's of a soil and is often directly related to its death it is conveniently described as soft medium stiff medium film stiff or film or very stiff and these terms are unfortunately a relative.

And how different meaning to different observers so the consistency is defined as the property of a material which is manifested by its resistance to flow and it represents the relative ease with which the soil may be deformed in soil mechanics basically it is required to determine the range of the potential behavior of a given soil type based on only few simple test soils might shrink or expand excessively in an uncontrolled manner after they have been placed in geotechnical structures that means that once.

The soils actually has been used for constructing researchers like roadway embankments or roadways upgrades dams levees foundation materials they can be subjected to depending upon the type of the mineral they can be subjected to shrinking or you know you know expanding so soils make lose their strength in able to do carry loads safely.

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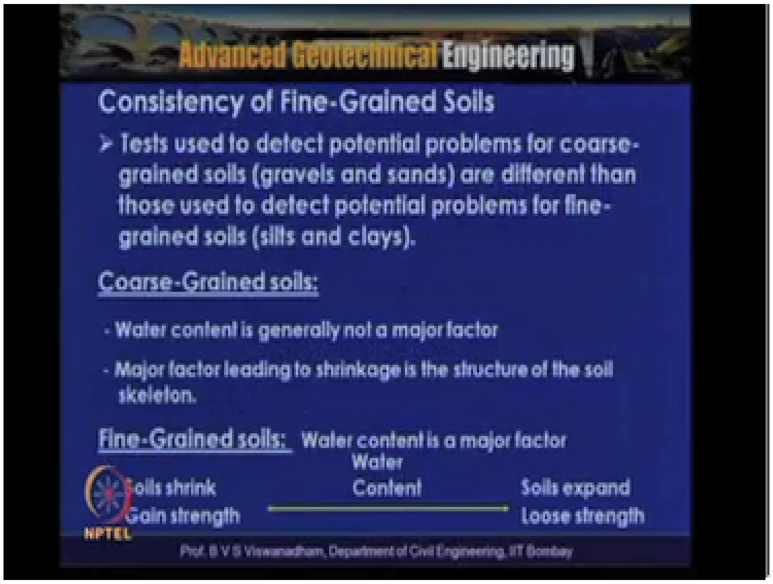

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Consistency of Fine-Grained Soils

➤ Tests used to detect potential problems for coarse-grained soils (gravels and sands) are different than those used to detect potential problems for fine-grained soils (silts and clays).

Coarse-Grained soils:

- Water content is generally not a major factor
- Major factor leading to shrinkage is the structure of the soil skeleton.

Fine-Grained soils: Water content is a major factor

Soils shrink
Gain strength
$\xrightarrow{\text{Water Content}}$
Soils expand
Loose strength

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So the consist see basically here of them when you are discussing about the fine grained soils the test used to detect potential problems for coarse-grained soils are different from the use to detect from the potential problems for the fine grained soils that is silt and clay it has to be noted the tests which are actually used to detect potential problems for coarse-grained soils are different from fine grained soils in coarse grained soils water countries generally is not a major factor.

And a major factor leading to shrinkage is structure of the soil skeleton and incase of fine-grained soils water content is a major factor and soil expand and lose strength and soils shrink and gain strength.

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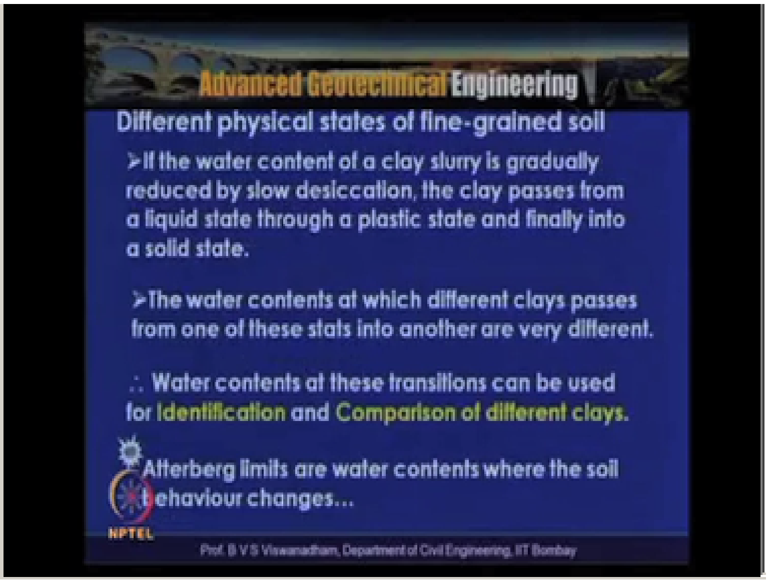

Advanced Geotechnical Engineering

Different physical states of fine-grained soil

- If the water content of a clay slurry is gradually reduced by slow desiccation, the clay passes from a liquid state through a plastic state and finally into a solid state.

- The water contents at which different clays passes from one of these stats into another are very different.

∴ Water contents at these transitions can be used for Identification and Comparison of different clays.

Atterberg limits are water contents where the soil behaviour changes...

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So if the water content of a clay slurry is gradually reduced by a desiccation natural process the pre passes from a liquid state to plastic state as I discussed earlier and finally into a solid state so the water content that we at which the different places place passes from one state to other state is very important and this is unique to a particular type of a soil so water content that these transitions can be used for identification and composition of different place.

So it has been thought that in order to you know class way are we determine the next properties it is required to determine water content at these transitions you can be determined for identification and comparison of the different place at different finding soils so here these rivets are called at they are called attar berg limits or the water contents where the soil behavior changes from one when they change from one state to other state.

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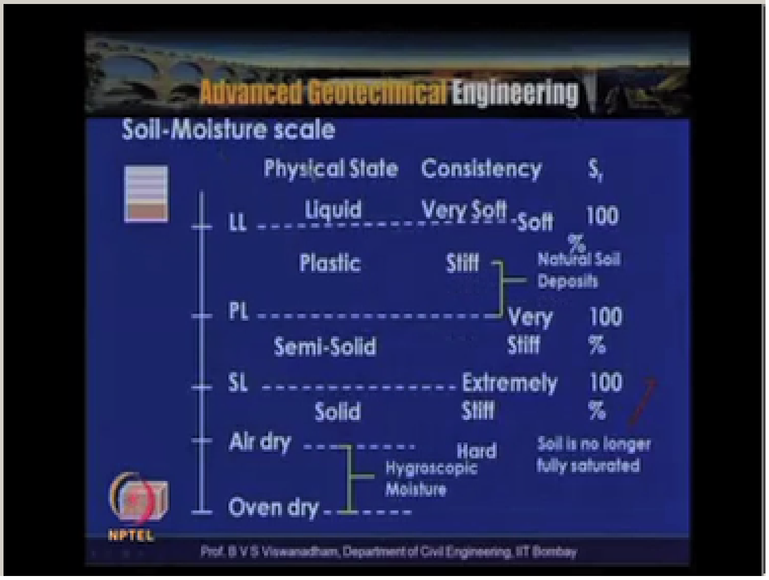

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Soil-Moisture scale

Physical State Consistency S_r

LL Liquid Very Soft -Soft 100 %

Plastic Stiff Natural Soil Deposits

PL Very Stiff 100 %

Semi-Solid

SL Extremely Stiff 100 %

Solid

Air dry Hard Soil is no longer fully saturated

Hygroscopic Moisture

Oven dry

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So here in this slide the soil moisture scary shown where is this is the physical state liquid and here is the consistency and is liquid state and liquid so at this point the transition between this liquid state to plastic state is determined or in called as liquid limit and about this the soil is like a liquid is called very soft and plastic that is between the limit and plastic limit so the plastic limit is the another type of attribute limit which is a transition between plastic state and semi-solid state.

And in this nature in this the natural soil deposits they do occur at this particular water content and shrinkage limit which is a transition between semisolid state to solid state the extremely state so up to if you see that the degree of saturation which is nothing but the volume of water in the volume of voids so here up till here the 100percent saturation is ensured and beyond this state the soil is no longer fully saturated and being it tends to become air starts entering here.

So liquid limit plastic limit and shrinkage limit are the three attributes what we are going to discuss so here when the soil changes from one event transits from these physical States the finally the it can actually changes into this type of solid state.

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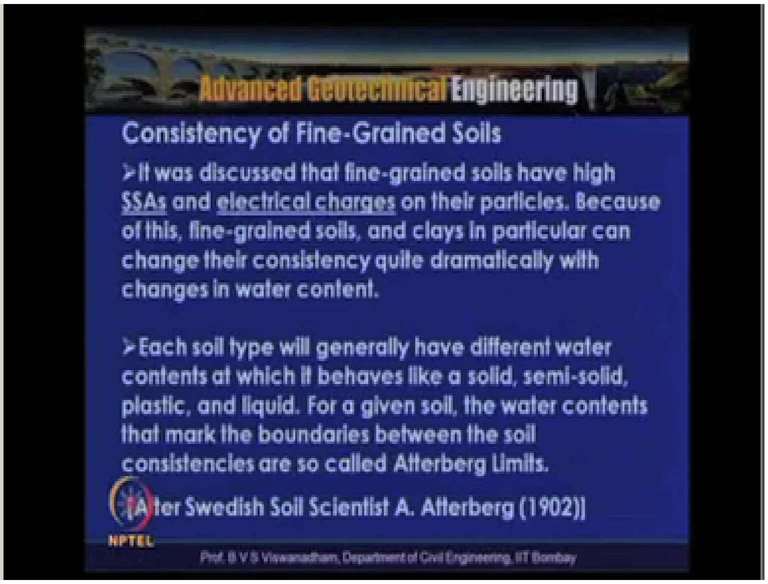

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Consistency of Fine-Grained Soils

- It was discussed that fine-grained soils have high SSAs and electrical charges on their particles. Because of this, fine-grained soils, and clays in particular can change their consistency quite dramatically with changes in water content.

- Each soil type will generally have different water contents at which it behaves like a solid, semi-solid, plastic, and liquid. For a given soil, the water contents that mark the boundaries between the soil consistencies are so called Atterberg Limits.

[After Swedish Soil Scientist A. Atterberg (1902)]

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So if you look into if you connect to the you know specific surface areas analytic electrical charges so it was discussed at that for fine-grained soils we have discussed that they have high specific surface areas and the electrical charges are very predomination their particles so because of these the fine-grained soils and clays in particular can change their consistency quite dramatically with changes in water content so why the particularly clays change you know the consistency from one water country one state to other state if the reason is that because of the high specific surface area.

And the prevalent electrical charges and each soil type will generally have different water contents at which it behaves like a solid semi solid plastic liquid for a given soil the water content that mark the boundaries between the soil are called are defined as a troubled limits

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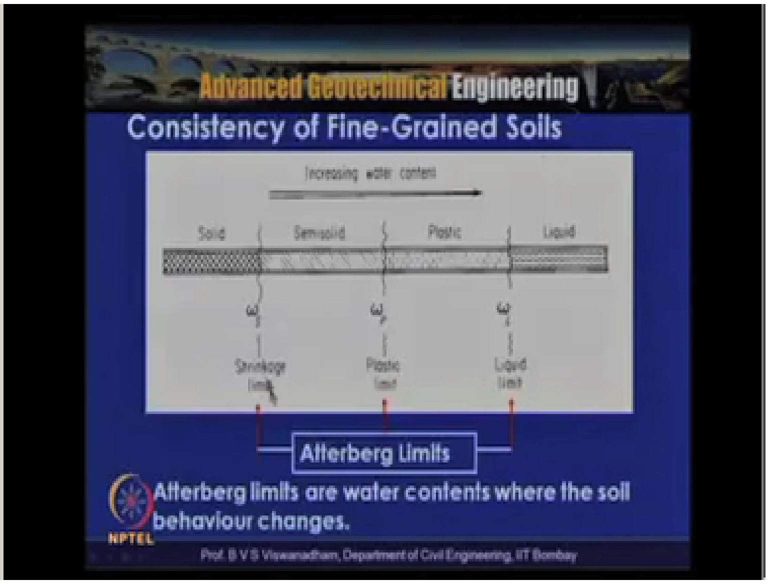

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Consistency of Fine-Grained Soils

Atterberg Limits

Atterberg limits are water contents where the soil behaviour changes.

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So it is pictorially it is indicated here and this particular state is liquid limit and this is plastic limit and this particular state this what this the water content at this transition between semi solids is a turbine limits so alter berg limits are nothing but the water contents way the soil behavior changes.

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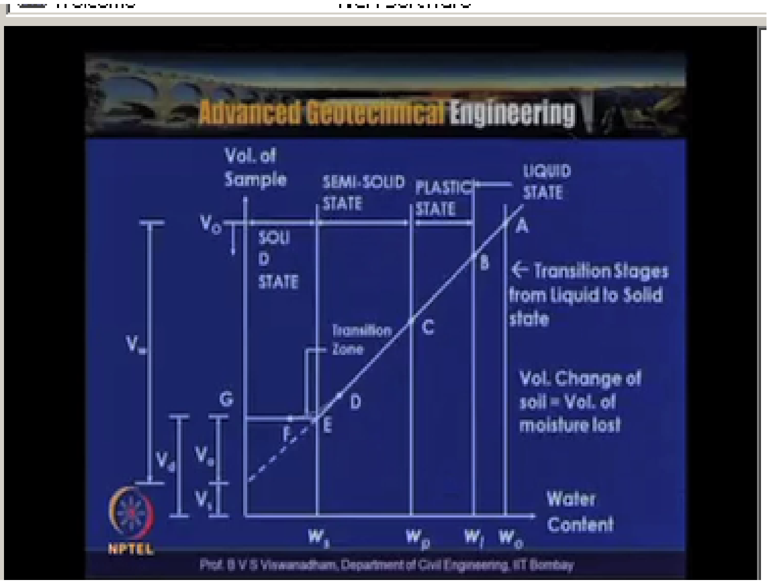

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So here in this particular slide where the volume of the volume is plotted on the y-axis and water content is plotted on the volume of the sample on the y-axis and volume of water content on the x-axis so this particular line which is inclined at 45 degrees it can be seen here that at Point a that is a point where the initial water content but when it transits from liquid state to plastic State that is the point B that is reference in the year as the liquid limit W suffix L and Point C is the plastic limit that is transition between plastic state to semi solid state.

And but where any transits from semi solid state to solid state up till this point the water content is 100 percent of the degree of saturation is under percent and this water content this water content at this particular state of transition between semi solid state to solid state is called as shrinkage limit but beyond this point if you look into this if you magnify here that there is a possibility that the air entry this curvy linear nature of this curve which indicates that here viii which is actually enters into the whites.

And the soils will no longer get compressed and the no volume change will happen so this is nothing but the volume of a plus volume of the solids so this is the volume remains the solid volume remains constant upon further drain so this VD is nothing but the volume of a plus volume of solids and V naught is nothing but the original volume at Point a so one if you define you know these atomic limits the first limit which is called liquid limit is the water content at which a soil is particle.

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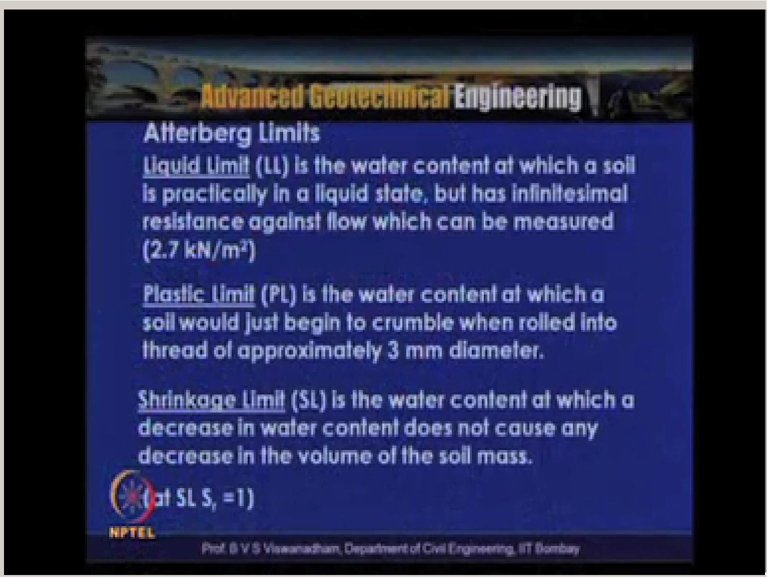

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Atterberg Limits

Liquid Limit (LL) is the water content at which a soil is practically in a liquid state, but has infinitesimal resistance against flow which can be measured (2.7 kN/m^2)

Plastic Limit (PL) is the water content at which a soil would just begin to crumble when rolled into thread of approximately 3 mm diameter.

Shrinkage Limit (SL) is the water content at which a decrease in water content does not cause any decrease in the volume of the soil mass.

(at SL $S_r = 1$)

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It is practically in a liquid state but has input a thermal resistance against the flow and which is actually processes a strength and it is said that the soils possess strength from 1.7 to 2.7 kilo Newton perimeter square or kilo Pascal's the plastic limit is the water content at which the soil would just begin to crumble when drawn into threads of approximately 3mm diameter so this is a limit at which the soil will start crumbling into crumbling when rolled into the threads of approximately 3mmdiameter suppose if the soil is having sandy particles.

And with the little amount of fine fraction you very difficult to make threats so that indicates that the soil is non plastic shrinkage limit is the water content at which a decrease in water can does not cause any decrease in the volume of the soil - so at shrinkage limit the degree of saturation is 1.

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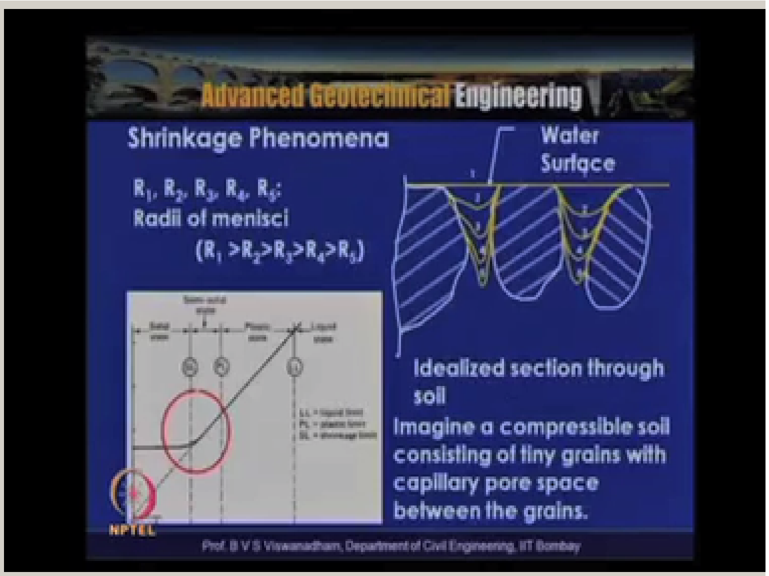

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Shrinkage Phenomena

R_1, R_2, R_3, R_4, R_5: Radii of menisci ($R_1 > R_2 > R_3 > R_4 > R_5$)

Idealized section through soil

Imagine a compressible soil consisting of tiny grains with capillary pore space between the grains.

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In this particular slide an attempt is being made to explain about the shrinkage phenomenon so here this is the solid particle which is indicated with the HS here and this is you know water surface when it actually transiting from semi solid state to solid state assume that R 1 R 2R 3 R 4 or 5 are the radii of this – K water - K between the particles and if you look into this the radius of our one reaction very high or two or three or four or five.

So as it proceeds the menisci radii is decreasing and then here also same situation is shown so this is the idealized section at the process at ditch where the curvilinear portion variants starts entering so here imagine a compressible soil containing time grains with capillary pore spaces between the grains so the mechanism is actually explained like this.

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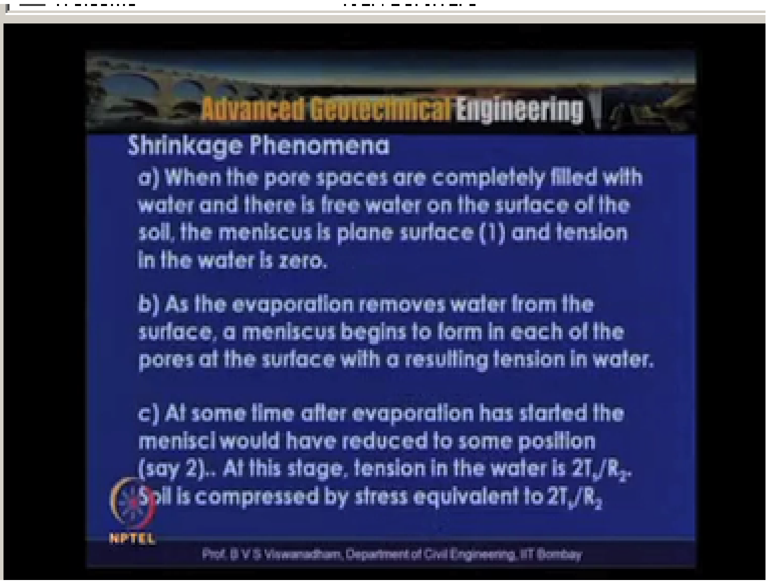

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Shrinkage Phenomena

a) When the pore spaces are completely filled with water and there is free water on the surface of the soil, the meniscus is plane surface (1) and tension in the water is zero.

b) As the evaporation removes water from the surface, a meniscus begins to form in each of the pores at the surface with a resulting tension in water.

c) At some time after evaporation has started the menisci would have reduced to some position (say 2).. At this stage, tension in the water is $2T_s/R_2$. Soil is compressed by stress equivalent to $2T_s/R_2$

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When the pore spaces are completely filled with water there is a free water on the surface of the soil the meniscus ease is a plain surface that is with R 1 radii and the tension the water is 0 that means that water is not exerting any tension on the soil particles but as the operation removes the water from the surface meniscus begins to form.

And each of the ports at the surface with a resulting tension in water so at some time after evaporation has started the menisci would have reduced it to some position say - that is from position 1 to position 2 at this stage the tension in the water is 2 TS by r2 so if you look into this r2 is smaller than r1 so the tension in the water they increases the soil is compressed by the stress equal into 2 TS by r2.

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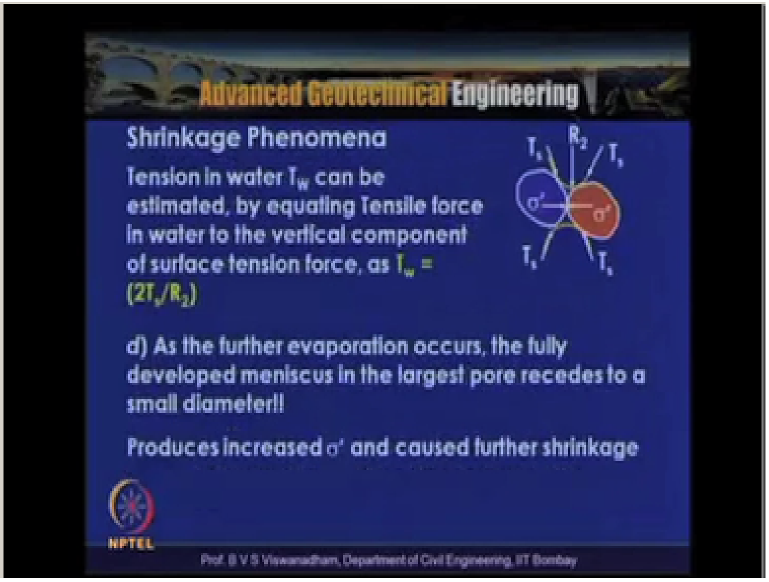

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Shrinkage Phenomena

Tension in water T_w can be estimated, by equating Tensile force in water to the vertical component of surface tension force, as $T_w = (2T_s/R_2)$

d) As the further evaporation occurs, the fully developed meniscus in the largest pore recedes to a small diameter!!

Produces increased σ' and caused further shrinkage

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So as this process continues see what happens is that it is something like the particles are pushed should are pulled towards closer and the tension in water TW can be estimated by equating the tensile forces in the water to the vertical components of the surface tension force with that we can actually calculate T W = 2 TS / r2 so as the further evaporation continues the fully developed will be discussed in the largest pore space he receives to a smallest diameter so this makes the particles to come closer and then to such a state that the particles will no longer be get you know compress it into thee further.

So this producer produces an increase in σ - and causes further increase so as the evaporation process actually goes on the menisci keeps on tending to become short without the tension in the water continues to increase and because of this the fully developed meniscus in the largest pore space research to a the smaller diameter which brings our pulls the particles to the closer distance so this explains and the typical shrinkage phenomenon we actually experience in typical saw fine-grained soils.

As the evaporation continues the menisci continued to recede and the tension in the water continue to increase and the compression between the soil grains and the resultant in case continues to increase so eventually what will happen is that the menisci will reach the smallest radius that is what you are discussed previously by the time menisci reduce to the least possible radius the portion soil will not be there to compress that means that most of the compression which is possible is might have already happened so hence this explains the shrinkage phenomenon.

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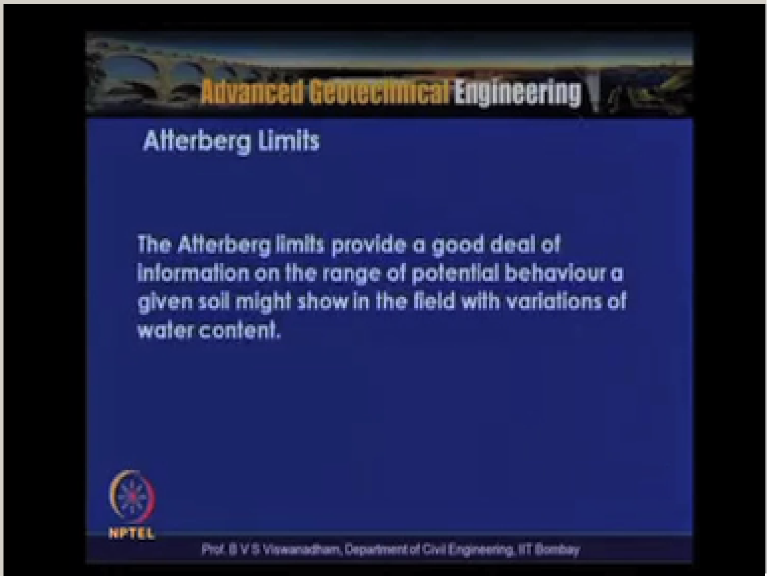

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Atterberg Limits

The Atterberg limits provide a good deal of information on the range of potential behaviour a given soil might show in the field with variations of water content.

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So the active bug limits basically provide a good deal of information on the range of the potential behavior of the given soil which might show in the field and variations in the water and it.

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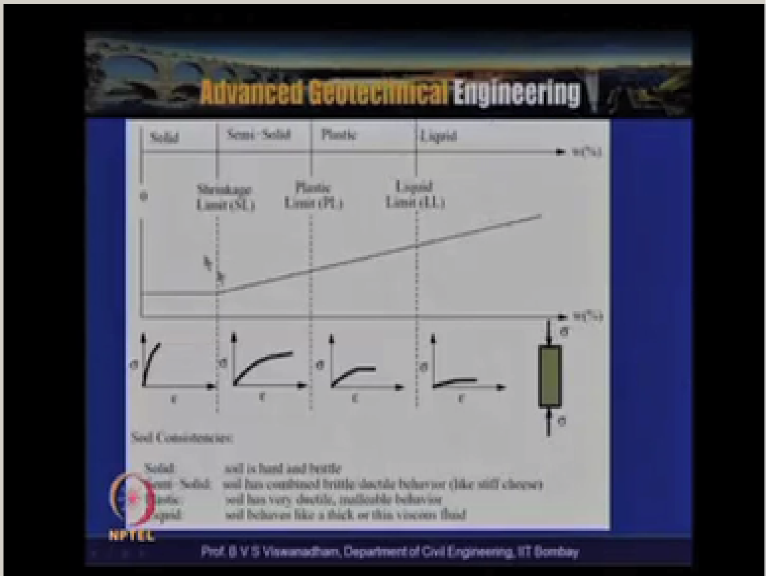

Soil Consistencies:

Solid:	soil is hard and brittle
mi- Solid:	soil has combined brittle-ductile behavior (like stiff cheese)
astic:	soil has very ductile, malleable behavior
quid:	soil behaves like a thick or thin viscous fluid

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So if you look into this the soils actually have got in a solid state and semi-solid state and plastic state in liquid state in the semi solid state or in case of in the solid state the soil is very stiff in nature and has got a so-called a brittle behavior and in case of a semi solid state the soil is combined brittle and ductile behavior like a stiff cheese in case between plus in the plastic state soil is very ductile soil is very ductile is something like a malleable type behavior and here in the liquid state.

But that is actually beyond this or at this particular point soil behaves like a thick or a thin viscous fluid so soil is something like a viscous fluid here so here the stress strain variation that is Sigma is in this direction and epsilon is the strain in the axial direction is actually shown here.

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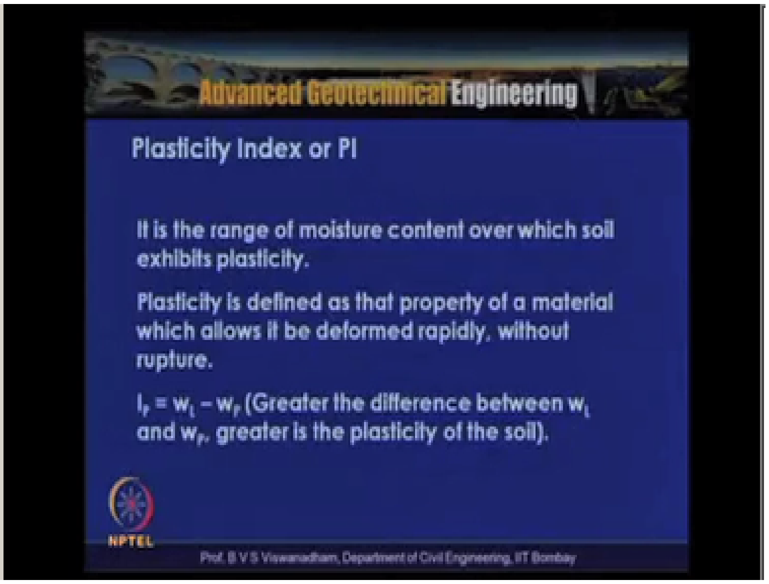

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Plasticity Index or PI

It is the range of moisture content over which soil exhibits plasticity.

Plasticity is defined as that property of a material which allows it be deformed rapidly, without rupture.

$I_P = w_L - w_P$ (Greater the difference between w_L and w_P, greater is the plasticity of the soil).

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So here the plasticity index which is defined as nothing but the difference of the liquid limit minus plastic limit it is the range of the moisture content or which the soil exhibits plasticity it is the range of the moisture content or water content of a soil which exhibits plasticity so plasticity is defined as the property of a material which it allows it to deform rapidly without rupture so greater the difference between the liquid limit and plastic limit the more is the plasticity of the soil the mesh.

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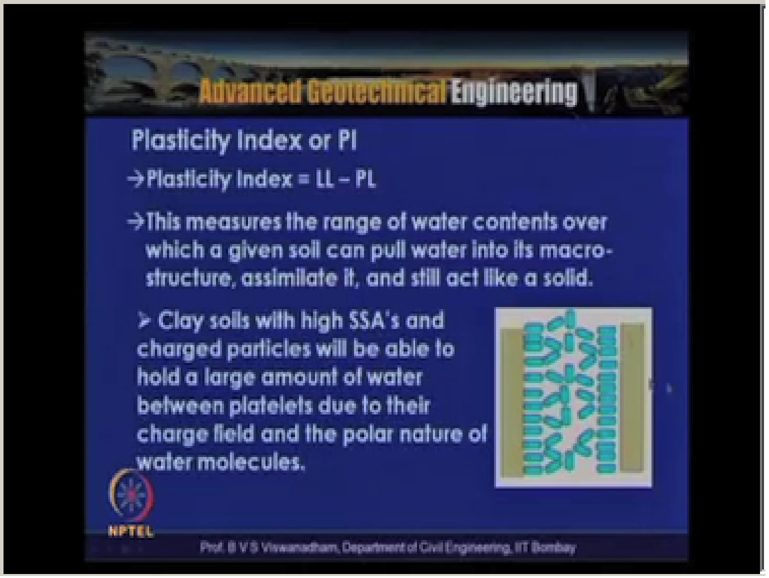

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Plasticity Index or PI

→Plasticity Index = LL – PL

→This measures the range of water contents over which a given soil can pull water into its macro-structure, assimilate it, and still act like a solid.

➢ Clay soils with high SSA's and charged particles will be able to hold a large amount of water between platelets due to their charge field and the polar nature of water molecules.

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This particular you know clay particles which are actually shown there where you have are the water droplets attach it to the Clay's clay negative particle sizes and we have discussed that this form like a adsorbed layer and the captions which are actually present in the particles are also attracted towards the negative charges here so this means that the range of water contents for which a given soil can pull water its microstructure assimilate it.

And still acts like a solid so clay soils generally with high specific surface areas and the charged particles will be able to hold large amount of water between the particles due to their charge field and the poor nature of polar nature of the water molecules and why soils actually have higher PS and you know smaller PS if you look into

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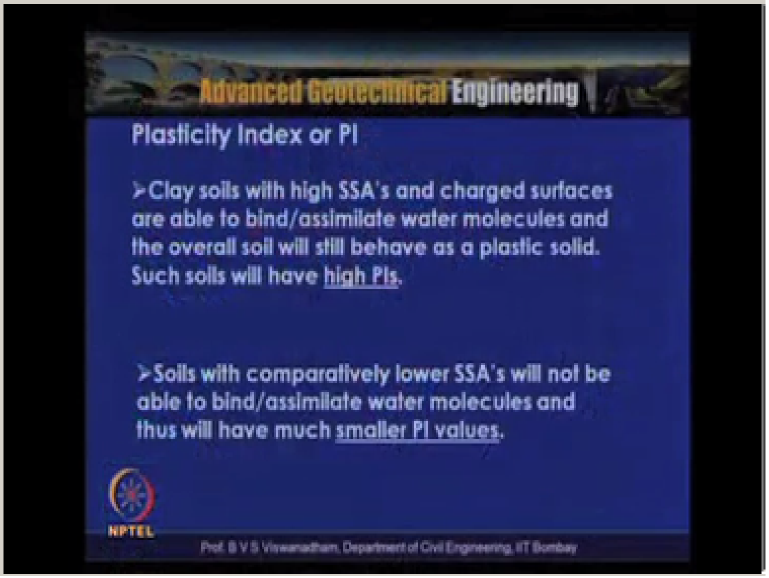

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Plasticity Index or PI

- Clay soils with high SSA's and charged surfaces are able to bind/assimilate water molecules and the overall soil will still behave as a plastic solid. Such soils will have high PIs.

- Soils with comparatively lower SSA's will not be able to bind/assimilate water molecules and thus will have much smaller PI values.

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These clay soils with high specific surface area and charged surfaces are able to bind assimilate water molecules and then Morel soil will still behave as a plastic solid and such soils will have higher pH and soils compared to Lea the lower specific surface areas will not be able to bind or assimilate water molecules and thus will have smaller plasticity index values so forum blanket kind of embankment dam correction construction if we required to have say a Harding zone where we wanted to prevent the water seep age entering into the to retain.

The water in there is a wire or they dam then we need a hot tea which actually has got higher plasticity for certain type of constructions where the low plastic soils are required so soils with Compared to be lower suspicious specific surface area will not be able to bind or assimilate water molecules and this they have actually low plasticity indexes so in this particular lecture number six we actually have understood about the particularly in the form of index properties how to perform a gradation for the fine signed particles.

And then we discussed about the different possible water the soil States when it is actually changing from liquid state to the solid state and introduced the attribute limits like liquid limit plastic limit and shrinkage limit and the difference of liquid limit and plastic limit is said as plasticity index and we by knowing these things and then we can if you can extend further then we will be able to classify the soil so in the next lecture we look into the soil classification and there maiming discussion about the you know about plasticity index and the determination of the liquid limit and other shrinkage limit with some modern method methods etc.

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