Soil Mechanics
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Lecture – 23
Flow of water through soils-IV

Welcome to fourth lecture under the topic flow of water through soils. In the previous lecture we have discussed about fluid flow through soils and flow of water through a porous media. Then we also discussed about changes in geostatic stresses with flow of water through soil. And we have introduced an upward flow condition, a flow condition which is defined as a quick sand condition. And we have looked into some typical examples governing the quick sand condition. In this lecture we are going to learn about factors affecting the permeability. Before discussing about the factors affecting permeability, let us look into the methods which are available for measuring permeability in the laboratory. As introduced in the previous lecture, permeability can be measured in the laboratory as well as in the field.

For the field we have got specific methods which are required to be executed to compare the laboratory permeability or sometimes to access the permeability under in-situ conditions. Now in this particular lecture we are going to study about flow of water through soils, particularly the measurement and then their factors affecting this coefficient of permeability which is nothing but the Darcy’s coefficient of permeability. Before looking into this the particular problem is given to practice as a continuation of the previously solved problems. The problem statement is as follows. Determine and plot the total vertical stress, pore water pressure and effective vertical stress distribution at levels A, B and C shown in this cross sectional diagram. So here in this slide the 2 layers of soils are shown. The upper layer is silty clay having specific gravity of solids has 2.7, natural water content as 45.2 % and coarse sand which is lying below this silty clay is under artesian conditions.

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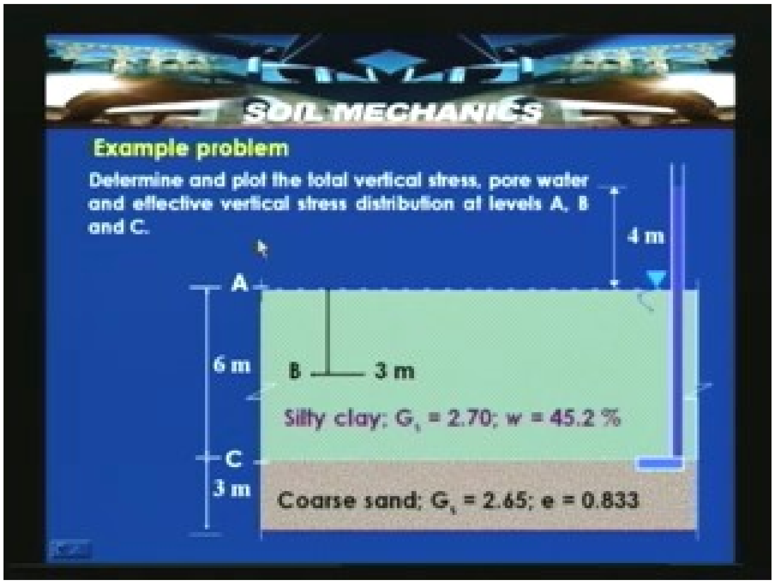

So the head of the water above this natural ground water table is 4 meters. So in view of the concepts already introduced, first determine the total vertical stress at point A, B and C which are at elevations A, B and C. Then considering the flow which is taking place in the vertical direction, determine the pore water pressure at A, at B and at C. Then subtracting pore water pressure from total stress determine the effective stress. And from the given data it is also possible to estimate seepage velocity. So this can be estimated by knowing coefficient of permeability. Let us consider the coefficient of permeability for this type of soil is say 1 × 10 to the power of minus 7 meter per second. By knowing the hydraulic gradient or with which the flow is occurring, we can compute the discharge velocity or superficial velocity which is V = ki. By knowing the natural void ratio or the void ratio from the water content w =45.2 % and specific gravity of solids 2.7, we can compute the void ratio of a soil. The soil being saturated e = w G_s will be valid.

So from these concepts we can determine e. From their the porosity can be calculated S_n = e by 1+ e. By using relationship between seepage velocity and discharge velocity the relationship what we derived in the previous classes is V_s = V by L. By using the computed value of N and computed value of discharge velocity, we can calculate seepage velocity. So this is how the problem works out. What you are required to determine is total vertical stress at elevation A, B and C and pore water pressure at A, B and C by considering the upward flow because the sand layer below is under artesian conditions.

Let us look into the permeability and drainage characteristics of soils. Before introducing the methodologies for determining the permeability's in the laboratory, let us look into the ranges of the values of the permeability's of soils. So coefficient of permeability k meter per second which is given here. The zone with yellow is shown with a permeability ranging from 10 to the power of zero to 10 to the power of minus 6 meter per second.

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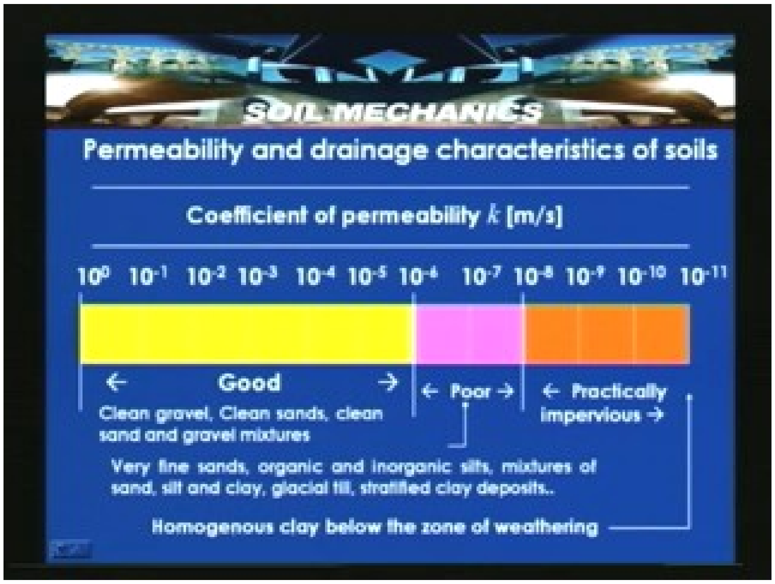

And the zone with pink color shown is ranging from 10 to the power of minus 6 to 10 to the power of minus 8 meter per second. And practically impervious zone which is indicated with orange color is 10 to the power of minus 8 to 10 to the power of minus 11 meter per second. So you can see the range of the values of the permeability for a sandy type of soil or a gravelly type of soil. The permeability is as high as 1 meter per second. For a clayey type of soil, a pure or homogeneous clayey type of soil the permeability can be as low as 10 to the power of minus 11 meter per second. So the contestation behavior could be attributed to the soil type which will be discussing during the later part of the lecture.

So here from the drainage point of view, many times we are required to select a particular material for performing drainage. For example under parking lots or under food paths or under market yard pavement paths or below the road sub grade. So the drainage which is very important in such type of locations. So the good drainage conditions for a soil can prevail if the permeability is in the range of 10 to the power of 0 to 10 to the power of minus 6 meter per second. One can have seen the tendency of decreasing the susceptibility or the qualification for a good drainage material decreases this direction. The poor is the region from 10 to the power of minus 6 to 10 to the power of minus 8 meter per second and practically impervious from 10 to the power of minus 8 to 10 to the power of minus 11 meter per second. The types of soils which will come in this particular type of zone are clean gravels or clean sands or clean sand with gravel mixtures.

So if you have got a clean gravel and clean sands and clean gravel and sand mixtures then they can be qualified to some extend as a good drainage material. In case if you have very fine sands, organic and inorganic silts, mixtures of the sand, silt and clay like glacial till and stratified clay deposits, so stratified clay deposits in the sense like waved clay deposits, in those cases the permeability requirement is 10 to the power of minus 6 to 10 to the power of minus 8 meter per second. And the qualification as a drainage material or a rating is poor. And here homogeneous clay below the zone of weathering can have permeability in the range of 10 to the power of minus 8 to 10 to the power of minus 11 meter per second. And this can be a practically impervious material as far as the drainage point of view, but this particular property can be used or is being used for constructing or preventing the migration of pollutants and contaminants.

Let us look into the measurement of the soil permeabilities. This particular slide we have already seen, once again let us look into this particular slide. The value of the coefficient of permeability k depends upon average size of the pores and is related to particle sizes and their packing. So here the larger particles can have larger pores spaces and smaller particles can have smaller pores spaces. So here average size of the pores and it is related to the particles size and their packing. And particle shape it can be angular or sub angular or rounded. So we have discussed earlier the particles with rounded arrangement can have large pore spaces. So in those cases the permeability can be high.

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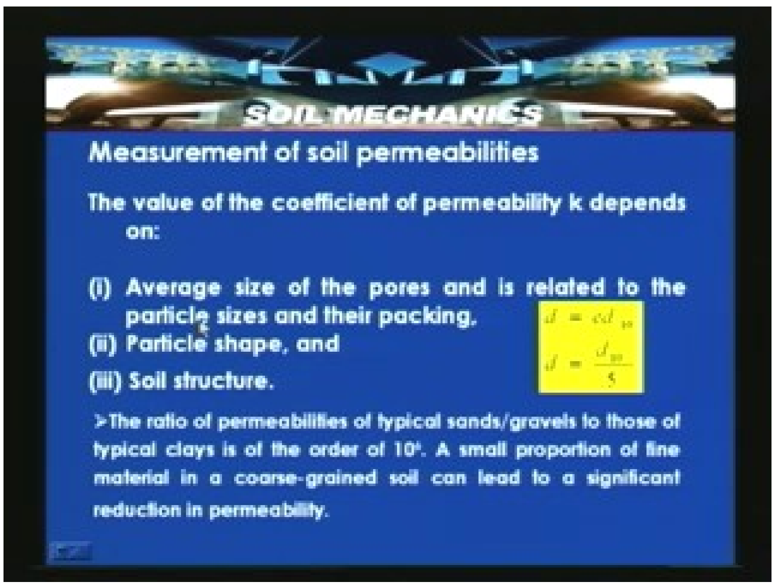

For example if the particles are with sub rounded or angular in shape then the flow can be affected because of the interaction of the water, when it is flowing through those pore channels passing through particles having angular shape. And the soil structure that is arrangement of the particles. Incase of a single grained structure for bulky particles it can have two extremes like loose arrangement and dense arrangement or in the case of natural arrangement it can be medium dense or medium very dense arrangement.

So depending upon the arrangement it can have the effect on the permeability. When it comes to this soil structure for fine grain soils, it all depends upon the physico-chemical environment surrounding the particles. So that can influence the permeability value to a large extend. This is what we discussed in the previous lectures, the ratio of the permeabilities of typical sands and gravels to those of typical clays is of the order of 10 to the power of 6. As you have seen in the previous slide the clay and sand have got a distinct difference in the permeability values. So typical sands and gravels to those of the typical clays is of the order of 10 to the power 6. So one million times difference can be there. A small proportion of the fine material in a coarse grained soil can lead to a significant reduction in the permeability.

So let us look into the methods for measuring the permeability. We have discussed that the number of tests can be used to measure or estimate the permeability. Laboratory methods basically the two methods which are popular, one is constant head test which is basically used for highly permeable soils. And other method which is called falling head test which is basically used for relatively impermeable soils which is meant for clayey soils or silty clay or silten clay mixtures. Indirect methods for computation from the grain size distribution and oedometer test. In the field methods we have discussed about two methods one is pumping methods and borehole methods. Particularly the packer's tests are very famous.

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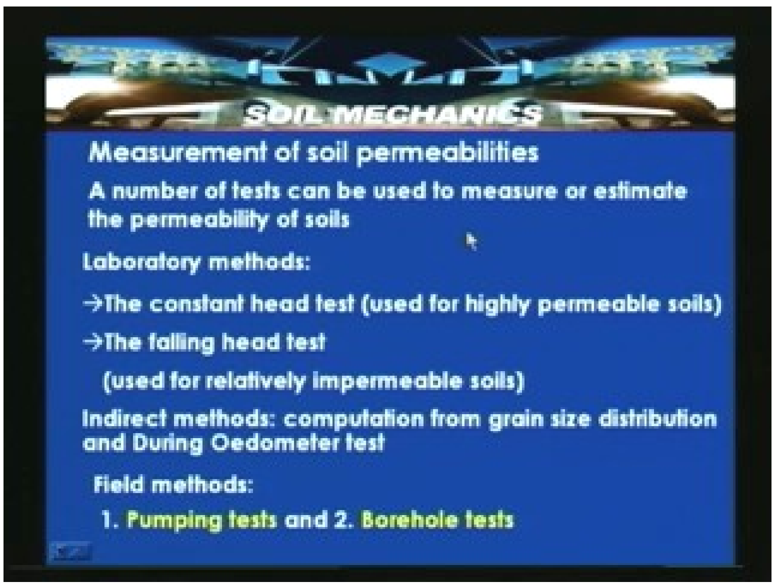

So here we are not discussing about the field methods but there are field methods which are available based on the pumping test for an unconfined layer or a confined layer under an impermeable layer or under a permeable layer. So packer's tests are very famous in determining the permeability value in the field. Let us discuss about the two laboratory methods called constant head test and variable head test or falling head test for determining the permeability in the laboratory. And indirectly for a typically clean sands or mixtures of silt and sand to some extent, the determination of the permeability by using a correlation between an effective particle size and coefficient of permeability is very useful in estimating the permeability value.

Before looking into the laboratory measurement of the permeability, the two important aspects which are required to be understood are has to be ensured or discussed. So in this slide in determining the permeability of coarse grain material, large quantities of flow occur in short periods of time. Because of the large pore spaces the large quantities of flow occur in a short period of time. Contrary to this incase of fine grain soils, small quantities of flow occur over a long periods of time. So the two distinct differences are in case of coarse grain soils, large quantities of flow occur over a short period of time and incase of fine grain soils small quantities of flow occur over a long period of time.

So two aspects that need careful attention for all types of soils, the first aspect is to ensure that the flow occurs only through the soil and not at the interface between soil and the mould in which of the soil is contained during the permeability test. The soil sample is fully saturated before recording observations. So this has to be ensured that the importance of saturation of the sample is very much required. Otherwise the air which is there in the voids of the soil mass can influence the permeability value, can hinder with or can influence the flow channels which are developing through the soil mass.

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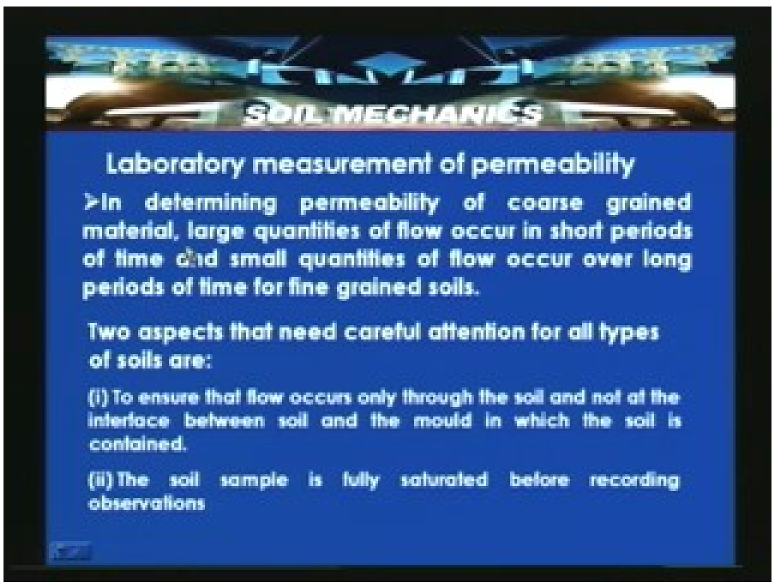

So here the two aspects, one is to ensure that the flow occurs only through the soil not at the interface between the soil and the mould in which the soil is contained. The soil sample is fully saturated before recording observations. So one of the first methods for determining the permeability of relatively permeable soils, basically the soils which are coarse grain in nature they are determined by using constant head permeability test. The setup for this is explained in this slide. It shows like this, a soil sample having a thickness L which is shown here and which is surrounded by two porous stones. One porous stone is placed above and one porous stone is below and a constant head water level is maintained as shown here in this figure.

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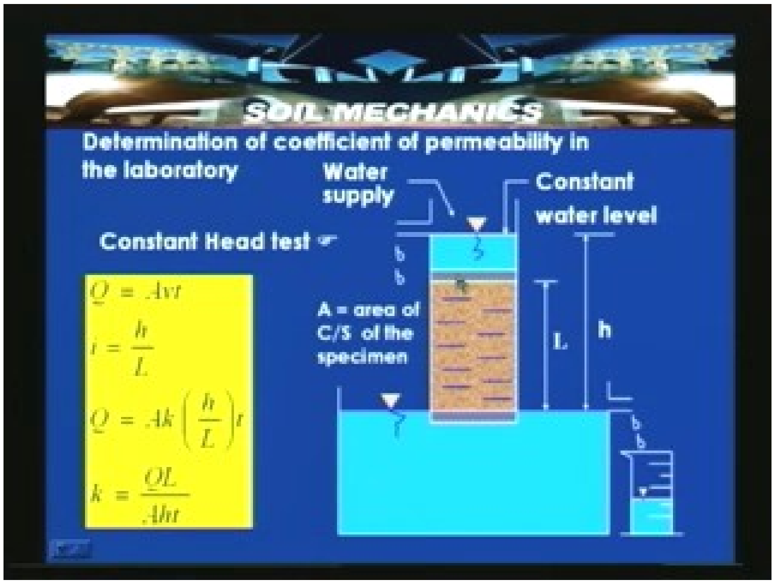

The extra surplus water is collected here. And the water level is maintained here. So here because of this the flow occurs with a hydraulic gradient h over L. So the flow occurs in the downward direction so here a relatively sandy soil is shown and A is the area of the cross section of the specimen perpendicular to the direction of the flow. So this is an arrangement for constant head test. So in order to calculate the flow or coefficient of permeability what one has to do is that after establishing a steady state seepage conditions collect an amount of water say in q at given time t. For a given time t suppose you collect an amount of water in a measuring jar which is q. So based on that by using the relation theory of continuity equation we can say that q is equal to Avt. Where A is the area of the cross section over which the flow is occurred and v is the discharge velocity with which the flow is taking place and t is the time over which this flow q has been collected, i is the hydraulic gradient which is nothing but h over L, L is the length of the specimen where h is the head which is driving the flow.

So the head loss between these two levels is h. So q is equal to AK into h by L that is V has been substituted by adopting the Darcy's law conditions Ki, K which is the coefficient of permeability, i is h by L in time t. So after rearranging we can write k is equal to QL by Aht. So by following this method or by repeating the similar experiment for 3 or 4 times, then average value of the coefficient of permeability k can be determined. So this is basically a method for coarse grain soils, so this has to be conducted either on the disturbed samples or on the remolded samples and it is not possible to perform this particular test on undisturbed samples.

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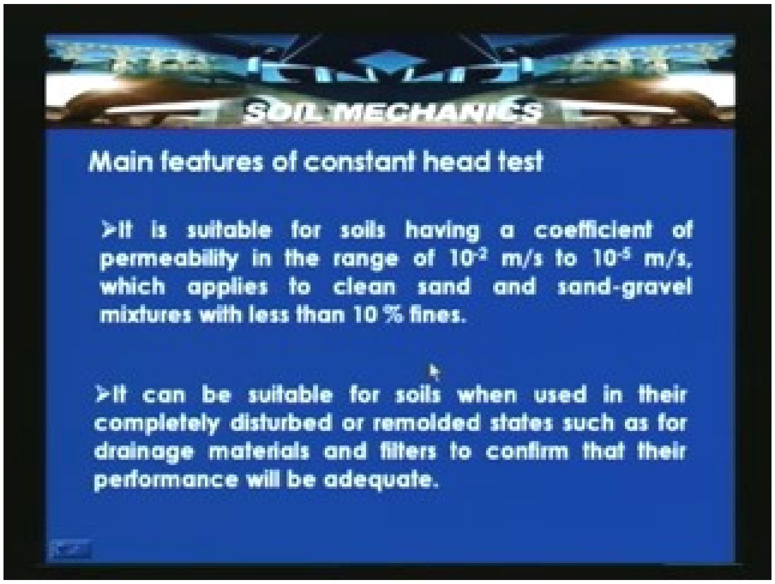

Let us look the main feature of the constant head test. It is suitable for soils having a coefficient of permeability in the range of 10 to the power of minus 2 to 10 to the power of minus 5 meter per seconds.

Like as we introduced previously it should have the permeability in the range of 10 to the power minus 2 to 10 to the power of minus 5 meter per second which applies to clean sand and sand-gravel mixtures with less than 10 % fines. So the fines cannot be more than 10 %, if it is more than 10 then the variable head test or falling head test has to be considered. It can be suitable for soils when used in their completely disturbed or remolded states such as for drainage materials and filters to confirm that their performance will be adequate. So many times it is required or this is performed for checking or qualification of these particular materials as drainage materials or a filter materials.

So the main features of constant head test is basically used for coarse grain soils or soils having permeability in the range of 10 to the power of minus 2 to 10 to the power of minus 5 meter per second. And which applies to clean sand and sand gravel mixtures with less than 10% fines or so. So it can be suitable only for soils when used in their completely disturbed or remolded states such as for drainage materials and filters to confirm that their performance will be adequate.

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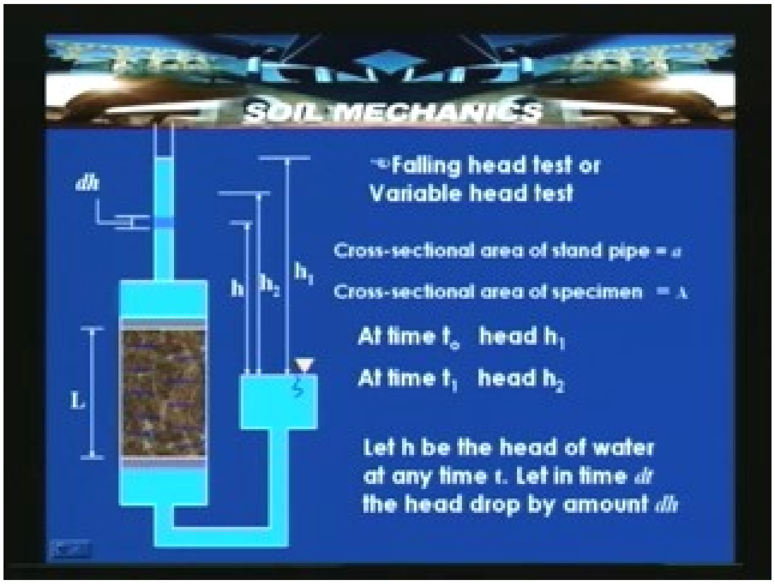

So having seen the constant head test for determining the permeability of coarse grain soils in the laboratory. Let us look into the variable head or falling head test method. This particular arrangement which is shown here is having a soil sample which is relatively impervious, a clayey soil sample which is placed at a certain unit weight and water content. And surrounded by two porous stones, one is placed above and one is below and it is connected with a tube having an area of cross section a. And the bottom portion is connected with a stem which is shown here. So cross-sectional area of the stand pipe which is connected to this particular arrangement is a, that is this cross section area that is having a small diameter d and here A is the cross-sectional area of this soil through which the flow is occurring.

Now let us assume that at time t is equal to zero, the head is h_1, at time t_1 the head is say h_2. That means at time t =0 the head is h_1. Now a time t= t_1 the head is now h_2. So there is a drop of the head from h_1 to h_2. So let h be the head of the water at any time t. So let in time dt the head drop by amount dh. So here assume that let h be the head drop at any time t. So dh is the small head drop in a small time dt. So by using this deliberation let us try to bring out a theoretical deduction. So that we can determine an expression for determining the coefficient of permeability based on falling head test.

So here if you look into it by dropping amount of water from h_1 to h_2, minute amount of water is trickled into the soil. So here the water which is passing into the soil, incase of constant head test we establish that the water is passing through the soil. So the amount of water which is flowing into the soil is very less incase of falling head or variable head test. Considering the previous discussion the quantity of the water flowing through the sample in time dt from the Darcy's law can be estimated like this. Like we did in the constant head test.

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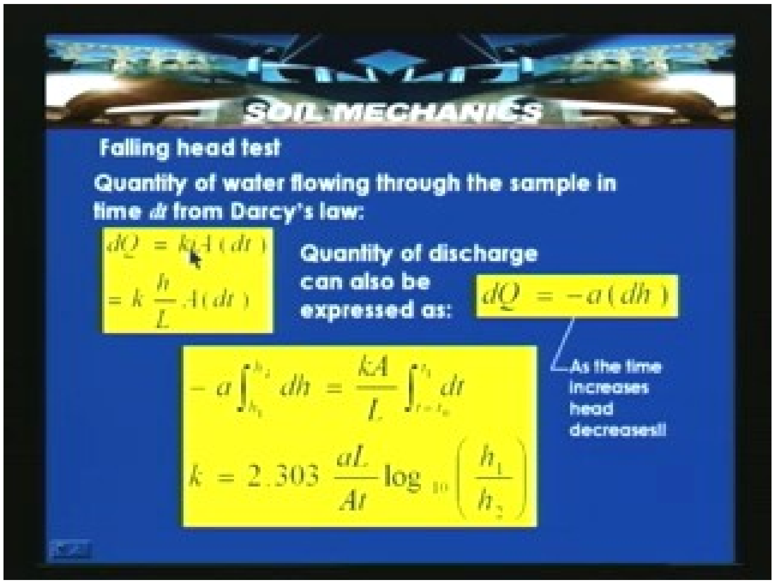

The dQ = kiA (dt), so dt is the time over which the head loss dh has occurred. So dh is the small head and h is the head at time t. So dQ is equal to k into i in which i is equal to h by L, A is the cross section area of the sample and dt is the time. So k into h by L into A into dt, so this quantity of discharge can also be expressed as minus A dh where dh is the small drop which has occurred over a time dt. So this is negative because as the time increases, head decreases so because of this it is expressed as small discharge, dQ is equal to minus A into dh where A is the cross sectional of the sand pipe which is above the system which is shown in the previous slide. Now equating this quantity of the discharge which is dQ= -a (dh) and dQ =k. h by L. A (dt). And integrating between the heads h_1 and h_2, where h_1 is the head at t is equal to t_0 and h_2 is the head at which t is equal to t_1 over the small change head dh. So kA by L where the time is t is equal to t_0-t_1, by simplifying and rearranging we will get k is equal to 2.303 aL by At $\log_{10}$ (h_1 by h_2).

So by using this expression one can determine the permeability of fine grain soils especially clayey soils by using variable head test or falling head test. So here a is the area of the cross section of the stand pipe, L is the length of the sample and A is the area of the cross section of the soil sample through which the flow is taking place and t is the time over which the difference in heads h_1 into h_2 is measured. So by repeating this particular experiment for 2 or 3 times an average value of the coefficient of permeability can be determined and can be registered. So these permeability values what we determine by using the experiment, they can range from 10 to the power of minus 8 meter per second to 10 to the power of minus 11 meter per second. So this is a procedure how we have to determine the falling head test permeability of a given soil particularly a fine grain soil by using falling head test.

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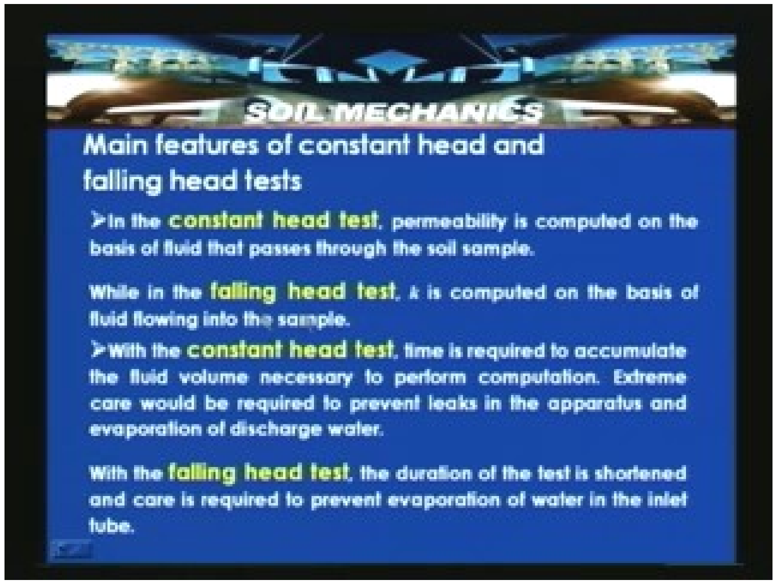

So main features are the major differences between constant head test and falling head test, they can be classified like this. In the constant head test permeability is computed on the basis of the fluid that passes through the soil samples. While in the falling head test, k is the coefficient of permeability is computed on the basis of fluid flowing into the sample. So here the amount of discharge that is the flow which is taking place into the sample.

So with the constant head test, time is required to accumulate the fluid volume necessary to perform computation. Extreme care would be required to prevent leaks in the apparatus and evaporation of discharged water. Incase of the falling head test the duration of the test is shortened and care is required to prevent evaporation of water in the inlet tube. So evaporation of the water in the inlet tube can influence the results, so that has to be taken so that the evaporations are minimal. So having seen the laboratory methods and as we mentioned, there are also methods for determining permeability in the field like pumping test or borehole test and the packer’s tests are famous.

We are not discussing these methods for determining permeability in the field. After having introduced the methods for measuring permeability, let us look into the various factors which we can influence the coefficient of permeability. So this factor affecting the permeability can be understood with the help of the two basic equations. They have been postulated that interconnected voids are visualized as a number of capillary tubes through which the water can flow. So all these interconnected flow channels or tubes are assumed as a thin capillary tube or through which the flow is taking place.

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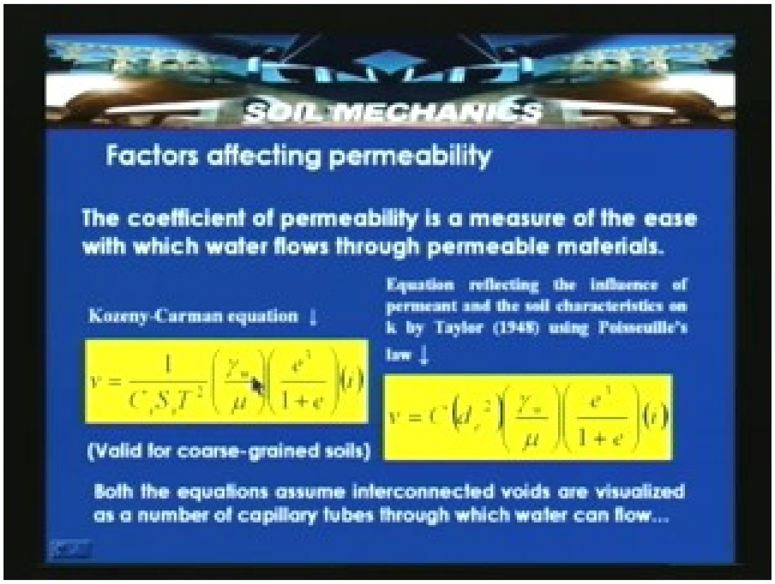

So the first to give one expression that is Kozeny and Carman equation where he has included the mini aspects or mini factors which can influence the permeability. So this is expressed in the form of a Darcy's equation v= ki. So this particular part is nothing but coefficient of permeability k. Another equation reflecting the influence of premeant and soil characteristics on k was proposed by Taylor 1948 using Poiseuille's law which is shown here, which can be read like this V = C into (d_e square) (gamma w by mew) (e cube by 1+e) (i). So if you look for Kozeny and Carman equation which was proposed by Kozeny and Carman basically for coarse-grained or gravelly soils. V= 1 by C_s S_s T square and (gamma w by mew) (e cube by 1+e) (i).

So both the equations assume interconnected voids are visualized as a number of capillary tubes through which the water flow is occurring. So we will discuss this Kozeny and Carman equations in depth and based on that we will evolve at the factors affecting permeability. Let us look into the factors affecting permeability and in the case of Kozeny and Carman equation, the soil is assumed as an assemblage of particles and the flow can take place in a microscopic way through a tortuous path. So this particular path or this particular length of the flow passing through these contact points of the solid grains is called as tortuous path.

So the tortuosity is defined as the ratio of the tortuous length to the imaginary length which is assumed as flow through soil which can pass through the voids as well as through the solid grains in imaginary length. So that length is L, so the tortuosity is nothing but ratio of L_1 by L. So which is indicated here in this Kozeny and Carman equation as t. So it can have a different tortuous lengths passing through this contact points and through the voids in the soil mass. In the Kozeny and Carman equation which is introduced in the previous slide where the v is the discharge velocity, C_s is the shape factor. For granular soil C_s =2.5, S_s is the surface area per unit volume of the solids and T is the tortuosity factor which is root two for granular soils. And this particular Kozeny and Carman equation can be simplified as k which is Darcy's coefficient of permeability which is capital K time's gamma w by mew.

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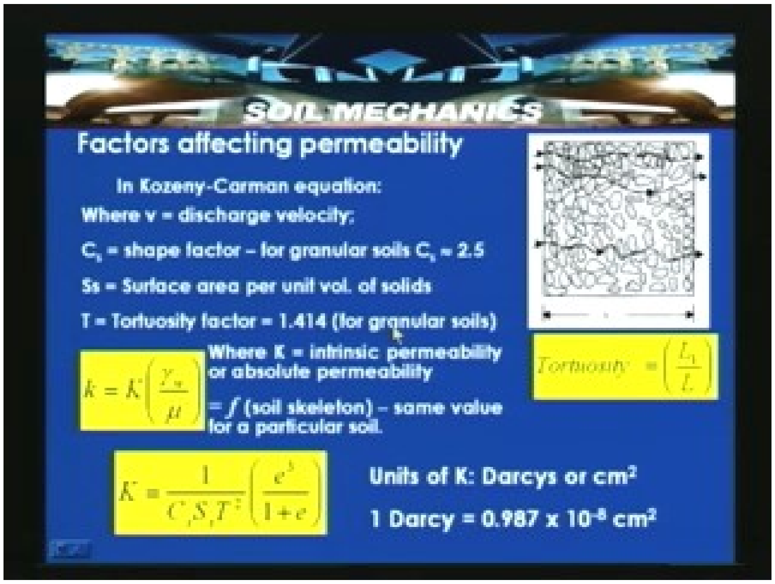

So here the capital K which is defined as intrinsic permeability or absolute permeability which is a function of soil skeleton and which is constant for a particular soil type. So the k which is indicated here in this equation is nothing but 1 by C_s S_s T square and (e cube by 1+e). So here the units for the k are indicated as Darcy's. 1 Darcy's = 0.987 into 10 to the power of minus 8 centimeter square. So the absolute permeability units are nothing but they are centimeter square or Darcy's.

So this is basically a property of soil and which is a function of the soil skeleton. The relationship between k which is coefficient of permeability and absolute permeability is k =capital K time's gamma w by mew. So if you look into this with an increase in viscosity then the coefficient of permeability can be less and this particular absolute permeability value, if there is any change in void ratio then there is a change in the absolute permeability. And the tortuosity, then the specific surface area and then shape factor are included. So that is how this is indicated as which takes care of the soil skeleton properties.

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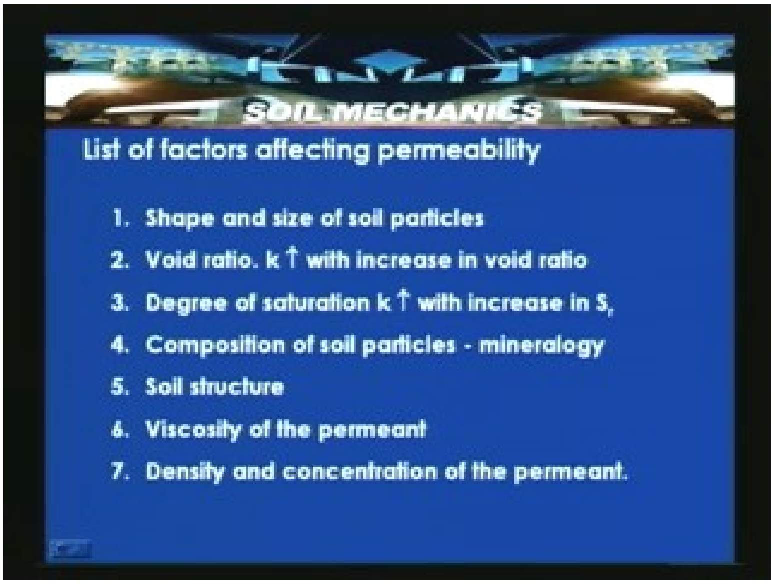

Let us look into the list of factors affecting permeability. They can be listed like this, shape and size of the soil particles. One is the shape and size of the soil particles and void ratio that is k, as void ratio increases k value increases. That means the soil with higher void ratios can have higher permeability. Degree of saturation that is k increases with increase in value of saturation. So at partially saturated soil because of the entrapped air within the voids can have low permeability. Composition of this soil particles, particularly for clayey soils where the minerologies will come into the picture to a large extend. Particularly for silt and sands the mineralogy may not influence in a big way.

Soil structure that is the type of arrangement whether it is single grain or incase of clayey soils whether it is a fine grain soil or whether it is a flocculent structure or dispose structure matters a lot. Or compactive effect that is the one which is not listed here and which also can influence the permeability. And viscosity of the permeant or density and concentration of the permeant, so these are the factors which can influence the coefficient of the permeability. We also discussed that based on the Taylor's equation, relationship between k is proportional to de square which indicates that with increase in grain size then increase in the permeability value can be seen. That is if d e happens to be an effective particles size, a large effective particle size can have the larger permeability.

So that is the one which we discussed is that factors affecting permeability, the effect of the grain size. So Hazen has proposed a relationship between or a correlation based on permeability values determined with sands or which are having the different effective particles sizes. So this particular graph which is shown here d_{10} which is plotted on logarithmic scale and coefficient of permeability k in meter per second is plotted on y axis. The different soils like silt, silty sands, sand with fine, medium and coarse and gravel are selected.

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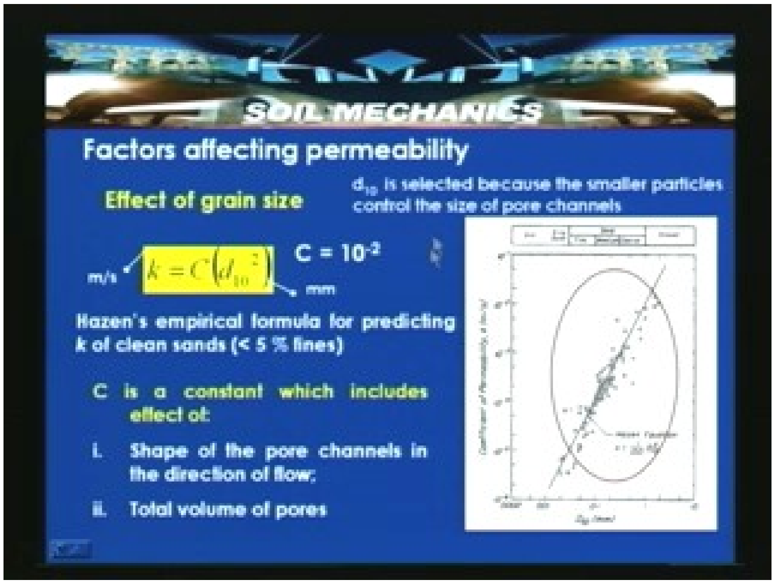

And here once the values are plotted the regression which is obtained is indicated by the regression equation which is named here as a Hazen's equation after William Hazen. It is k= C (d_{10} square) where C is equal to 10 to the power of minus 2. Then we can determine the coefficient of permeability in meter per second if you use C = 10 to the power of minus 2 and d_{10} in mm. So this equation which indicates that the larger the effective particles size the larger is the coefficient of permeability. And this particular relation is basically valid for k value for clean sands or sands with silts less than 5 % fines or so.

So C is a constant which includes the effect of the shape of the pore channels in the direction of the flow and total volume of the pores. So this is very important equation as far as determining the coefficient of permeability based on the particle size distribution. So this is the one of the significance of the particle size distribution we have discussed while discussing about the C_s or S_s or a particle size distribution of soils. So here the Hazen's empirical relationship is shown here which is nothing but k= C (d_{10} square) where C is a constant which is obtained from this regression. So the zone which is circled here that is which is highlighted here shows silt and sandy particles. So this is where the large points are there. So that is the reason why it is said that it is valid for sandy soils.

Another question is that why the d_{10} is only selected. The d_{10} is selected because the smaller particles control the size of the pore channels. Suppose if there are large particles, there is a chance that this large particles which are having large pore spaces can be filled with small particles then pores space can be reduced. So that is the reason why the well graded sand have low permeability compared to the uniformly graded sand. Because of the large void ratio the uniformly graded sand will have large permeability. So in factors affecting permeability we are discussing about the effect of grain size. The permeability of the granular soils depend mainly on the cross-sectional areas of the pore channels.

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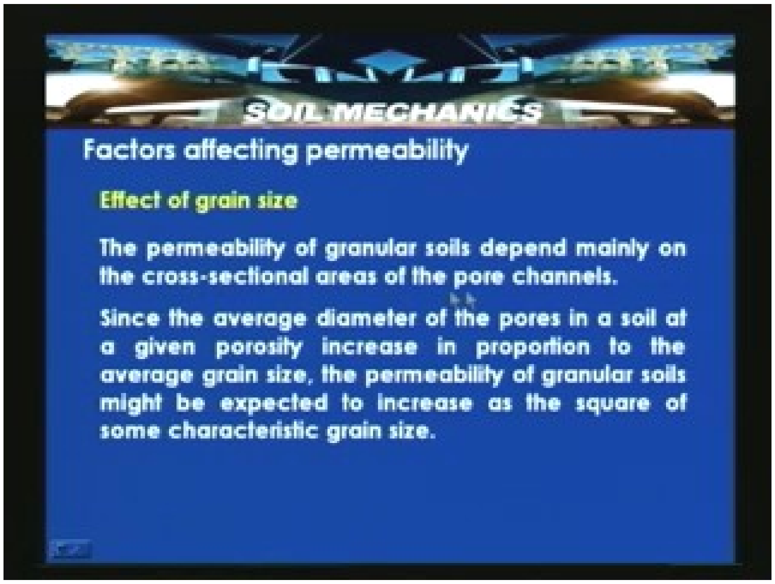

That is what we have discussed and we are highlighting once again that the permeability of the granular soils depends mainly on the cross sectional area of the pore channels. Since the average diameter of the pores in a soil at a given porosity increase in proportion to the average grain size. The permeability of the granular soils might be expected to increase as the square of the some of the characteristic grain size. That is the reason why the Taylor's in 1948 has used k is proportional to around d e square. That is how the Taylor's equation what we discussed earlier has k is proportional to d e square. In the factors effecting the coefficient of permeability, another factor is that the degree of saturation. If you look into it k is proportional to S_r. At low saturation there will be reduction in flow channels available for flow. So here after Das (1987) the chart which is shown here is the degree of saturation is on the x-axis and coefficient of permeability on y axis in mm per second is shown here.

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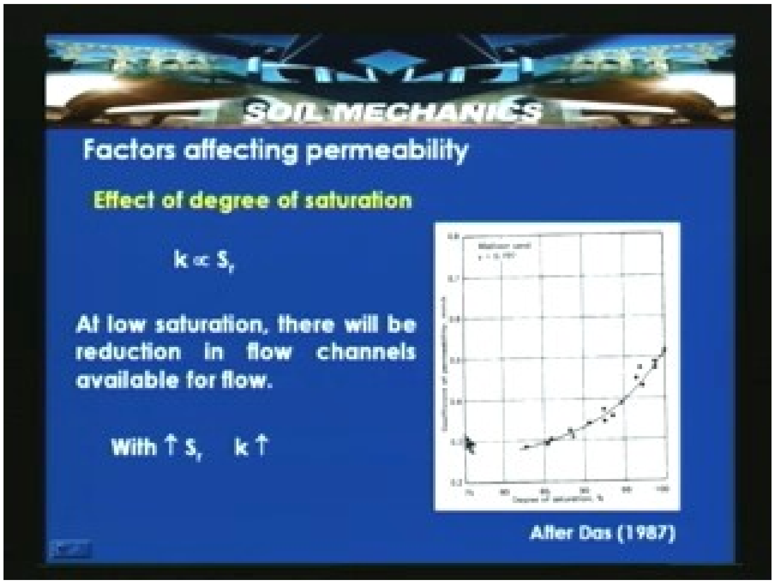

For a medicine sand with u= 0.797. As we can see with an increase in the degree of saturation increase in the coefficient of permeability can be noted. That means the air which is strapped inside the soil voids is sent out because the permeability value increases.

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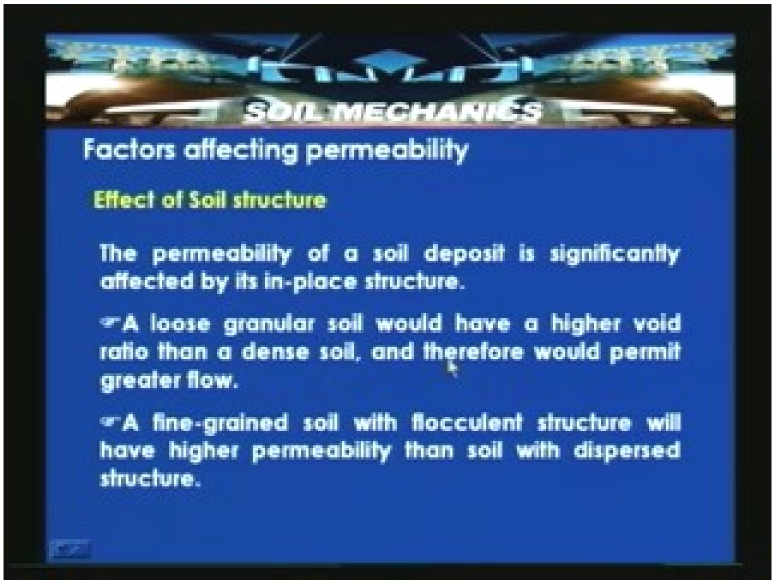

Another important parameter which influences the permeability is the soil structure. The permeability of a soil deposit is significantly affected by its in-place soil structure that is in-situ soil structure. A loose granular soil would have a higher void ratio than a dense soil and therefore would permit greater flow. That is the reason why we have discussed that well graded sand and uniformly graded sand. The well graded sand have low permeability compared to the uniformly graded sand. That means the gradation or particle size composition also very important if you consider the flow through a soil. A fine grained soil with flocculent structure will have higher permeability than soil with dispersed structure.

So this we have discussed while discussing about the comparison characteristics of soils. So here if you connect back that for a given compactive effort if you have got say fine grain soil with a flocculent structure and dispersed structure. The soils with flocculent structure have got more permeability than disperse structure. Incase of flocculent structure the more or less we will get the isotropic condition, the permeability will be same in all directions. The flow will be less tortuous. Incase of a dispersed structure the flow is more of anisotropic condition, the horizontal permeability is different form vertical permeability. That means the flow which is taking place is perpendicular to the direction of this orientation of the plates. Basically they are face to face orientation which are parallel arrangement indicates that the flow will be more tortuous.

That means more time it takes to flow in perpendicular to the plane of the orientation of the plate particles in dispersed structure rather than the flow across this particular plane that is along the plate shape particles. So the permeability along the plate shape particles will be very high compare to it’s perpendicular direction. So the same topic what we discussed is shown here. A fine grain soil with flocculent structure will have higher permeability than soil with dispersed structure. So the soil with dispersed structure is shown here. So here the flow normal to the particle orientation is found to have a more tortuous path and leading to a very low permeability in this direction.

Compared to the flow parallel to the particle orientation if you consider it is less tortuous and can have more permeability. So the disperse structure will have a low permeability overall compared to flocculent structure and also the flow is anisotropic condition, horizontal permeability is different from vertical permeability. The horizontal permeability which is parallel to the orientation particle is very high compared to the vertical permeability that is flow normal to the particle orientation. So even at similar void ratios clay with an undisturbed flocculated structure will possess larger void openings than the same clay having a dispersed structure.

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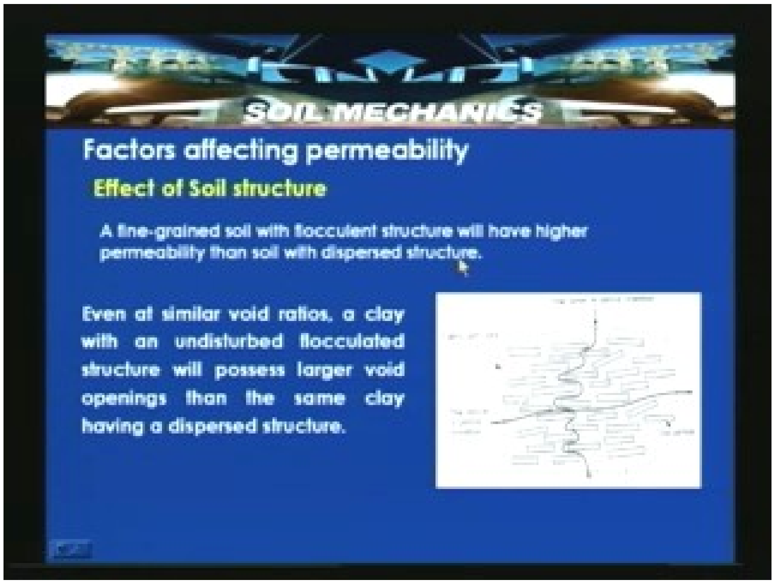

We also discussed like a flocculated structure because of the stress like arrangement have got a three dimensional random arrangement with large opening or spaces or large pore spaces. So larger the pore spaces the more is the flow, that is what we have discussed k is proportional to the d which is the size of the pores spaces. Incase of dispersed structure because of the orientation in which the random arrangement takes place, where the phase two phase orientation takes place and because of that the less flow takes place for the dispersed structure. Then low void ratio prevails for a disperse structure. That means the low void ratio in the sense relatively when you compare with the flocculate structure the flow will be very less in case of dispersed structure.

So here flow through the clusters of the particles of clayey soil is shown. So because of this particular reason we can have a flow path like this and it can be like this. So the clusters or packets of clay particles are shown. So because of this the soil with flocculate structure or flocculent structure exhibits isotropic condition, the permeability will be same in all directions. Incase of dispersed structure it exhibits anisotropic conditions and the permeability of soil is severally affected by the type of the structure.

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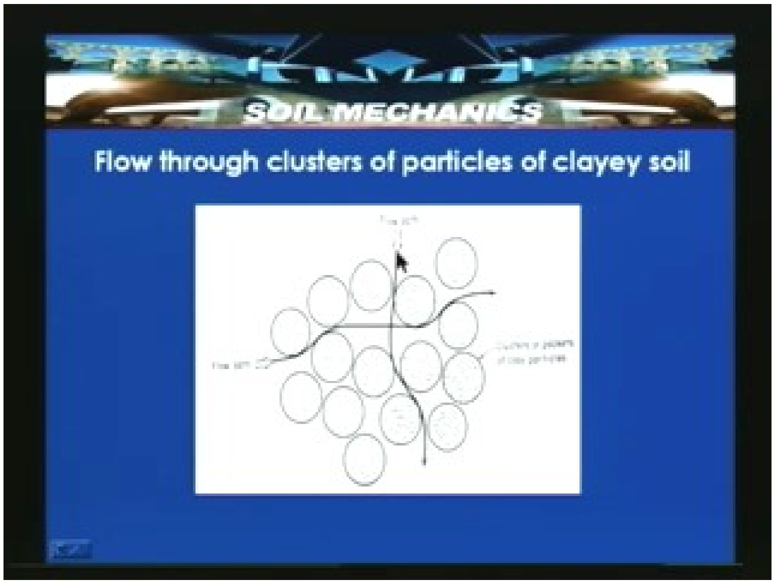

Similarly another factor which is required to be discussed is the compactive effort. Incase of granular soils or sandy soils it can be loose compaction or dense compaction. Incase of clayey soils as we have already studied it can have a low or reduced compaction or proctor compaction or standard proctor compaction or modified proctor compaction.

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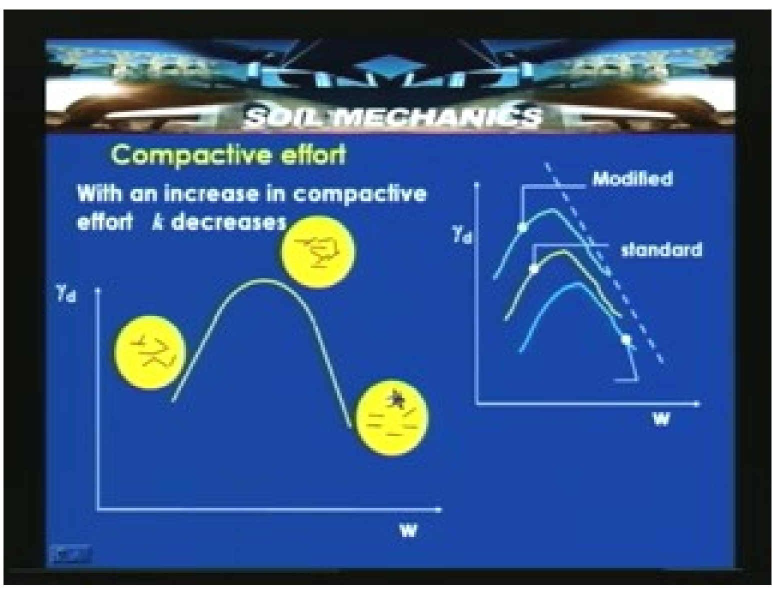

So if you recall the variation of gamma d versus water content can be obtained like this. This is for the reduced compaction and this is for standard proctor compaction and this for modified proctor compaction. With an increase in compaction energy there will be decrease in the opto moisture content, increase in the dry unit weight. And this line is the zero air voids line. So if you select for a particular standard proctor compaction the structure can be some what like this. Here flocculent and here it can be dispersed (Refer Slide Time: 44:48). So by using the same logic what we discussed, the permeability value on the dry side of optimum will be very high compared to the flow of the soil with the same void ratio or same dry unit weight. The soil with a flocculent structure can have higher permeability compared to the soil with a dispersed structure. The discussion we already had because of the type of the soil structure prevailing at that particular void ratio.

So with an increase in compactive effort the k value decreases. That means like modified proctor compaction can induce more packing of the soil particles. Because of that the permeability value decreases. Similarly on the wet side of the optimum the permeability value decreases. So if you look into this particular relationship by using this particular expression what we are discussing is gamma d and water content. Then you got a proctor compaction curve, this is the maximum dry unit weight and optimum water content. So if you plot the permeability value here k which is in meter per second and water content. This side is the dry side of optimum and this is the wet side of optimum. So here on the dry side of optimum the soil can have high permeability and the permeability value decreases.

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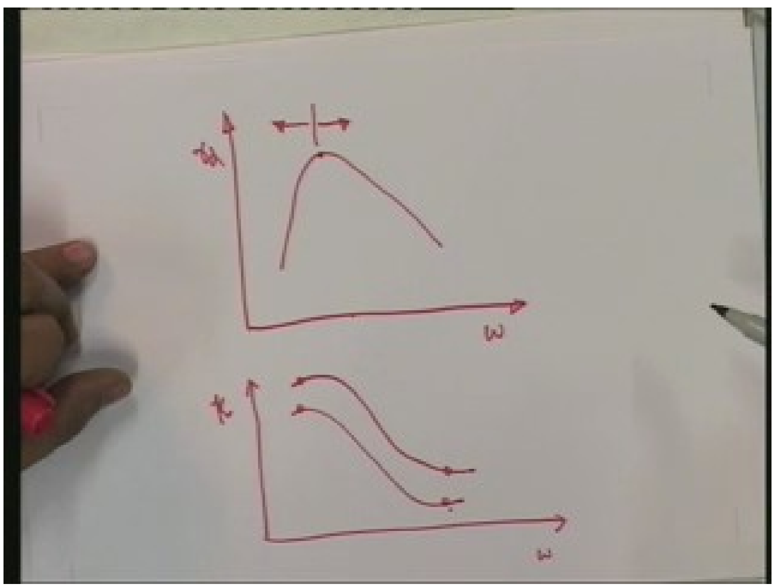

For a given typical soil on the wet side of the optimum the coefficient of permeability will be less. On the dry side of the optimum the coefficient of permeability will be high. So that particular reason is attributed to the type of the soil structure which is prevailing at that particular moist compacted state or this natural state. As we increase the water content say for example for compaction process the orientation of these particles changes. That is that the structure is gradually transforming from flocculent to a disperse structure.
So as we increase the compactive effort then this also shows that the dry side of permeability value will be less. This is for say a standard proctor compaction with

modified compaction it can have a value slightly less compared to this standard proctor compaction. So the increase in compactive effort decreases the coefficient of permeability. So here again we connected back to the type of the soil structure which is prevailing in that moist compacted state for a given soil.

So having seen the compactive effort, now let us look into the effect of soil type. The volume of the water that can flow through a soil mass is related more to the size of the void openings than the number or total number of voids. So the k of the coarse-grained soils is greater than k of the fine grains soils. That is the reason we have to understand particularly by keeping in view of the environment surrounding the particles. So a k coarse-grained soil is greater than k fine grain soils. Even though the void ratios are frequently greater than for fine-grained soils.

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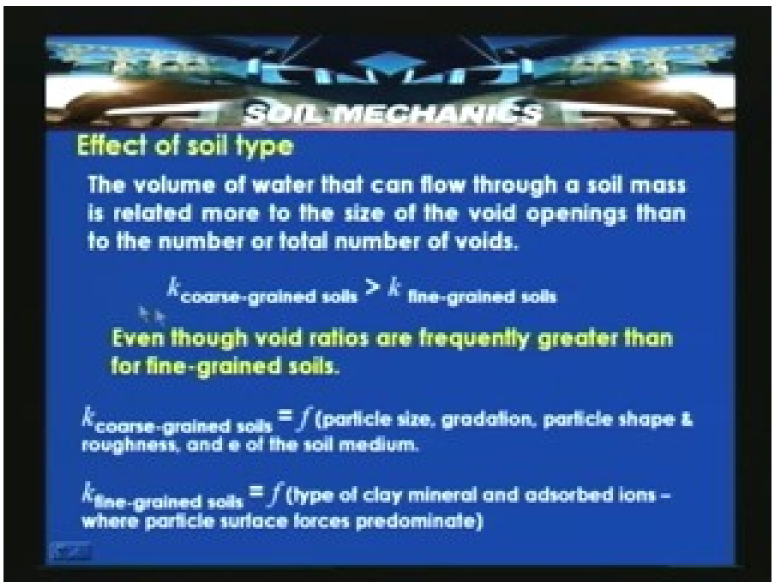

So though the void ratios are very high for fine grain soils, we always see that the k of the coarse grained soils is greater than k of the fine grained soil. The reason is because we have seen that as a void ratio increases the permeability value increases. But it will not happen like this for coarse grained soils and fine grained soils. That means there are other additional factors which influence this particular behavior. So k of the coarse grain soils is a function of particle size, gradation, particle shape and roughness and void ratio of the soil medium. If it comes to the k of the fine grained soil, that is a function of type of the clay mineral and adsorbed ions surrounding the clay particles. Here the particle forces dominate these particular arrangements.

Let us discuss why the k of the coarse-grained soils is more than k of the fine grain soils. So if you look into the effect of the soil type, the concept can be assumed and explained by using the flow through a conduit pipe. So this is for a coarse grain soil or a sandy soil where V maximum is occurring at the center and V minimum is occurring at the wall.

So this is how the flow takes place. So this particular variation is attributed to the frictional drag at the edges as well as some viscous drag which is taking place when the flow is taking place through the sand grains. So this is nothing but the pores space or the pore channel diameter through a sandy soil. When it comes to clayey soil as we all know we have a clay particle, if this is the surface of the clay particle and this is another clay particle having a part of the adsorbed and double layer water is shown here. So this situation is different, where this particular coating of adsorbed water layer is absent incase of sandy soil.

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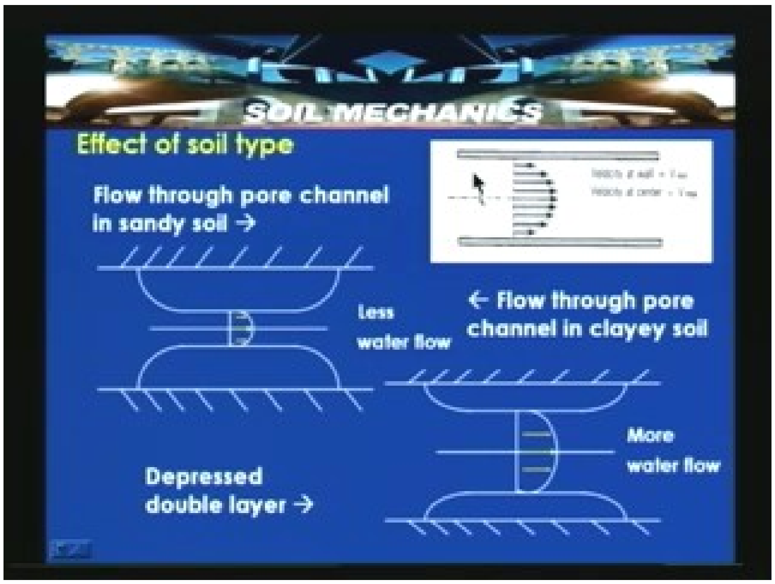

So here in this case as you can see here flow through pore channel in a clayey soil with more developed double layer. Suppose if the layer is depressed because of the some cation exchange which is taking pace there can be more water flow because the double layer is depressed which is shown here. Incase if the double layer is fully developed then we will see that the less water flow takes place. The reasons we will discuss in the next slide where we are trying to explain this particular phenomena of having k for coarse grained soils through the concept of flow of water through a conduit.

So if you look in to here this particular distribution is attributed to friction developed at the conduit wall and the viscous friction developed in the moving fluid. So because of this reason V occurs maximum here and then minimum here. So some energy is lost here. But whereas in case of the flow of water which is taking place through the clay particle, one reason is that the friction drag which is taking place, the flow is attached almost to the wall and because of that very less flow occurs. In addition to that the adsorbed ions will try to keep the water very close to the clayey particles. Because of that the flow which is taking place through this fine grain soil is very less. So the same concept is explained here. For fine grained soils when void spaces are very small, all lines of flow are physically close to the wall of the conduit and therefore only low velocity flow occurs. Mostly the velocity of the flow is occurring along the boundaries of this double layer which are there.

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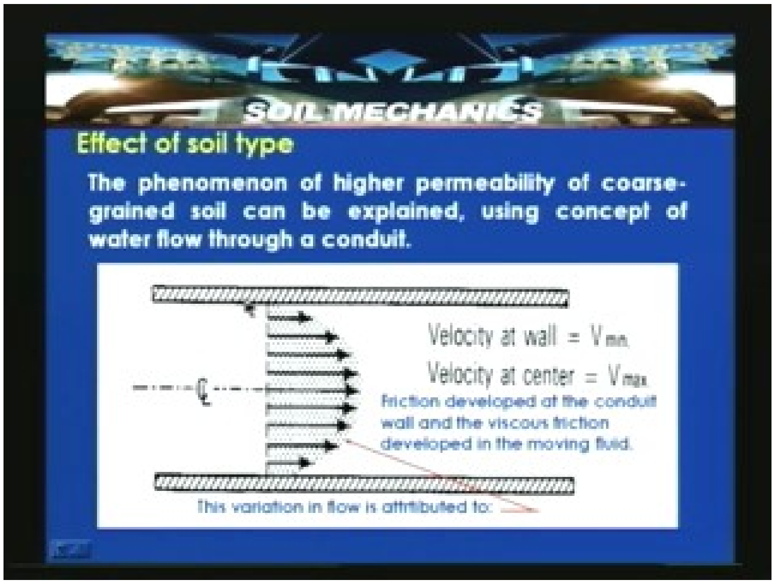

So depending upon the development of the double layer whether it is depressed or completely that also influence the flow condition. Incase of a depressed double layer relatively more flow occurs for a completely developed double layer. In clays, flow in already small channels is further hampered because of the some of the water in the voids is held or adsorbed, to the clay particles, reducing the flow area and further restricting the flow. In case of the clays the reasons are, particularly clays are fine grain soils because of the type of the environment surrounding the particle that is physicochemical environment surrounding the particle influences the flow conditions.

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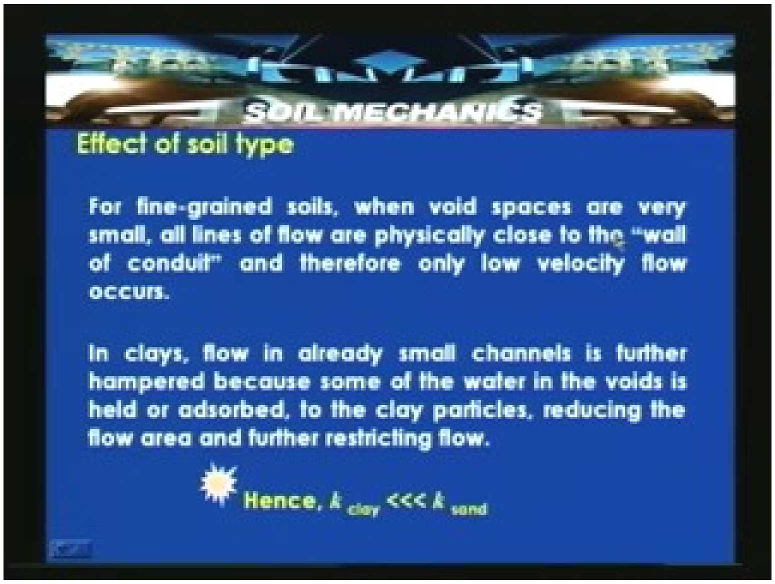

Incase of a sandy soils this is not absent because of the loss of the frictional drag which is occurring at edges except that the velocity is maintained with high flow. So because of that when the flow is high that is seepage velocity is high for a coarse-grained soil than a fine grained soil. Because of this reason the soils particularly with sands or basically forming coarse-grained soils they exhibit very high permeability compared to fine-grained soils. So we can say that the k of the clay is very less compared to k of sand.

So another factor which is discussed is the effect of the permeant. Like as you seen k is proportional to gamma w by mew. So variation of the gamma w with temperature is negligible. So we can see that as mew increases the coefficient of permeability decreases. So higher mew the lower coefficient of permeability, so effect of specific surface area if you look into it we have discussed in the kozeny-carman equation k is proportional to 1 by S_s square, where higher the specific surface area and low is the permeability.

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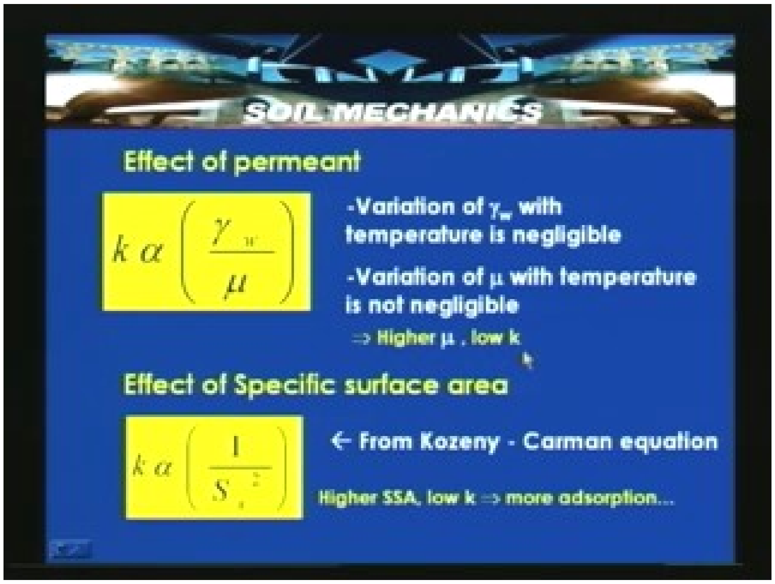

That means depending upon the type of mineral for example kaolinite, Montmorillonite and elite. The kaolinite has got lower specific surface area compared to Montmorillonite. So that means the soils which are having Montmorillonite can have low permeability compared to soils which are having kaolinite. Similarly the quartz which is having very low specific surface area exhibits very high permeability with this particular relationship.

So based on the discussion what we had, we can classify the soils according to their coefficient of permeability. The degree of permeability high, medium, low, very low or practically impervious can be said like this. High we can say that if the permeability is 10 to the power of minus 3 meter per second. Practically impervious if it is less than 10 to the power of minus 9 meter per second, low is 10 to the power of minus 5 to 10 to the power of minus 7 meter per second.

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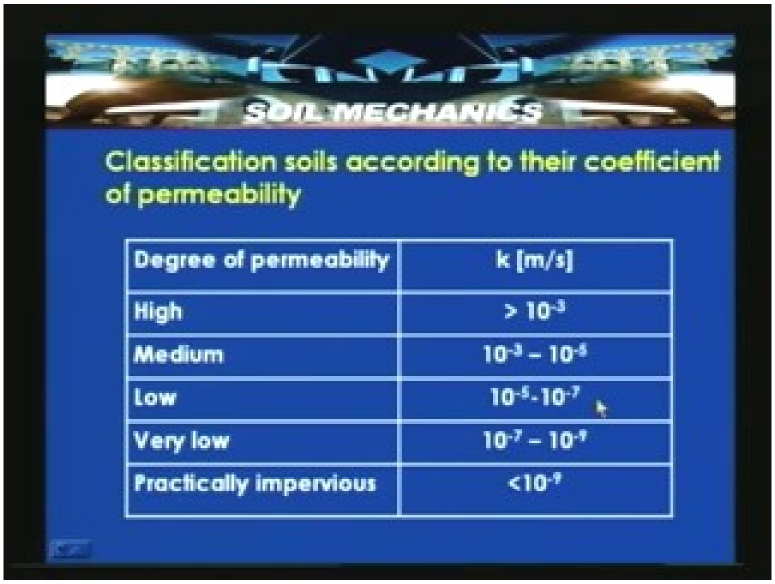

So in this lecture what we tried to understand is that the methods for measuring the permeability in the laboratory and different factors affecting the permeability, especially the compaction effort or type of the soil structure and soil type that is where we have discussed about the flow of water through conduit. And we said that k of the coarse-grained soil is more than k of the fine grained soil, though the void ratio for the fine grained soils is more than coarse grained soils.