Environmental Geotechnics
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Lecture – 32
Contaminant transport through porous media - 1

(Refer Slide Time: 00:16)

Let me start talking about the Contaminant transport in porous media. I am sure that most of you will agree with me that flow of water through porous media has already been studied very extensively. And where do you use these concepts? We use these concepts in seepage analysis, consolidation theory and stability of different geotechnical engineering problems, where the migration of the flow water is taking place which creates a media as saturated or unsaturated. So, this is very well understood mechanism of the phenomena.

So, in short, the concept of hydraulic conductivity is very well established you know the laws which can be used for describing the hydraulic conductivity or coefficient of permeability of the porous system. By the same time, I have been talking about that why because of environmental degradation, the chemical flux or the chemical flow in the soils of the porous system has becoming quite important, most of the activities related to present in the sterilization and socialization is causing lot of contaminants or the chemicals to flow in the porous system or the porous media. So, that is where I say that chemical flows in soils or the porous system are also gaining lot of importance.

So, this is where actually we have to do something to incorporate the effect of flow of chemicals in the porous system which we will be talking in the preview of contaminant transport in porous media. Now why it is so, and some of the important examples of this type of situation are most of the industrial activates like waste storage, remediation of contaminated sites and leaching phenomena and so on. So, these are becoming quite important activities, and that is the reason that one should study how contaminant migrate in the porous system.

Now, it is important to understand that what causes this flow to take place, how to occur. So, basically contaminants are dissolved either in inorganic or organic substances in the solvent. And the solvents are either water or the fluids. So, various concentration units are used to define the relative amounts of contaminants which are present in the solvent. The first way of defining the concentration is mass concentration, where you use the term milligrams of contaminant in 1 litre of water; this is known as milligrams per litre.

Now, another way of to defining this is parts per million - ppm, or if you change the word parts per trillion this becomes ppt or parts per billion - ppb and so on. So, essentially parts per million - ppm is nothing but grams of solution divided by million grams of the solution while the contaminants are in this form grams of solution.

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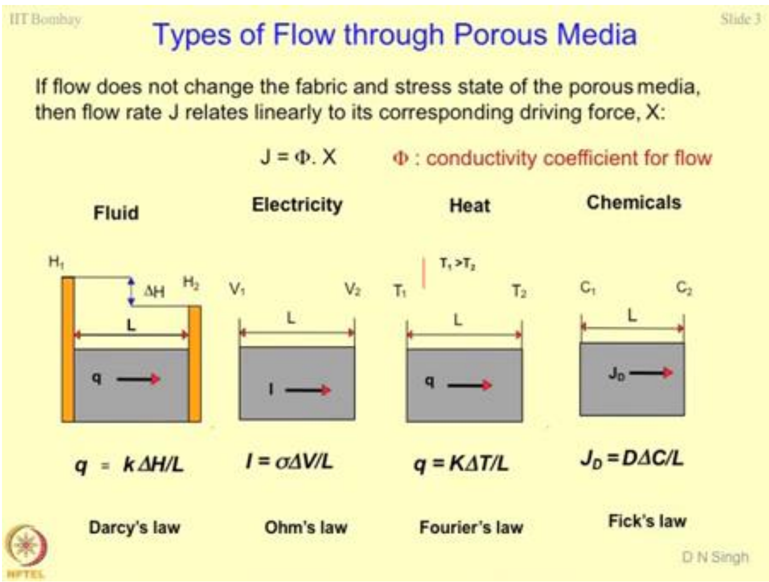

Now, what are the types of flow through porous media which can take place? Now, this is the assumption which most of the time we make that if flow does not change the fabric and stress state of the porous media, then the flow rate J relates linearly to its corresponding driving force, X. Now, this all most generalized form of the flow which takes place through any system where J is nothing but the flow rate, and Φ. I have defined as the flux, and X happens to be the driving force. So, Φ is the conductivity coefficient for flow.

Now, this coefficient will depend upon the type of energy which is flowing through the porous medium. So, for that matter, these are very well conversant and convenient with the flow of fluid, there is a control volume and this is a soil sample or rock sample. One side of this head H_1 is connected, the other side of this head H_2 is connected. The differential head between H_1 and H_2 gives you ΔH. And, if length of the sample is known, you can find out the value of q. Now, q is nothing but the flow of seepage alright.

So, we say that q = constant. ΔH/L

where ΔH/L is nothing but the hydraulic gradient. And, then we say that Darcy's law is valid for this type of situation.

Now, k, k happens to be the coefficient of flow which is permeability when the seepage is taking place. Now, identical to this would be a situation if I replace flow of fluid with flow of electricity. And that case what happens you have the porous system, it could be soil, it could be rock, it could be any other that mixture any porous system. On one side there is a voltage V_1 across at acting electrical voltage; on the other hand, the electrical voltage V_2. And we say that V_1 is not equal to V_2. If V_1 is equal to V_2, there will not be any electrical flow taking place.

So, if I want to define I, I is nothing but the current. So, here the equation becomes J gets replaced by I; phi is nothing but the conductivity coefficient of the flow for electricity or the ions alright. So, this is where we use the term σ. Now, σ is nothing but the conductivity electrical conductivity of the porous media. What about X? X is nothing but the driving force. So, what is causing this force to this current to pass through the media is nothing but voltage gradient. So, Δ/L is nothing but, differential voltage acting across the sample which is causing current to pass through this. So, these are two good similes which are normally used in geotechnical engineering.

I am sure that you must be aware that electrical analogy has been used to define the discharge through porous system, is it not, earthen dam, retaining walls, sheet piles and so on. So, this is where we use the concepts of Ohm’s law. Now, this is very important to understand what I have written over here that if flow does not change the fabric and stress state of the porous media, that means for all practical purpose nothing happens to the porous system that remains as control volume all right So, it is something like this that the flux passes through one point without altering its stress state and the fabric structure. When we say fabric structure, a grain size distribution comes into the picture, and we are saying that, that remains intact, the density is also not changing.

The second part of the statement is when flow rate J relates linearly to its corresponding driving force. Now, this is an assumption that we are assuming a linear relationship between the flow, the flux, a driving force and the material property. So, if you extend this analogy further let us say to the thermal energy field, so what we will notice here is I am sorry this T has gone up this is basically T_1, the temperature acting on the one side of the porous system at the one end; and on the other end the temperature is T_2, where T_1 is greater than T_2. Now, this flow is nothing but the flow of heat or the heat flux.

We assume here that T_1 is greater than T_2. So, the direction of flow of heat is from left to right. If L is the length of the porous system, we can define gradient of heat as $\Delta T/L$, where ΔT happens to be the temperature difference divided by length of the sample multiplied by K. Now, K will be what? How do we define this? What is k? This is coefficient of hydraulic conductivity, k, is it not? Sometimes we say coefficient of permeability or hydraulic conductivity. What is σ? Electrical conductivity. What is K? Thermal conductivity, clear. So, this is nothing but thermal conductivity term.

So, if you know the thermal conductivity of the material which happens to be a very peculiar value, similarly electrical conductivity of a system is going to be a peculiar value. Similarly, a k hydraulic conductivity of the porous system is going to be a peculiar value, clear. So, if you use Fourier’s law, what we come to is that the total flow of heat is nothing but k into thermal gradient. Now, if I extend it further to chemicals all right, so one side of the sample, there is a concentration of C_1. Another side of the sample, there is a concentration of C_2. And then because of the concentration difference if C_1 is not equal to C_2 and what we are assuming the way as shown the arrow over here or the flow of concentration migration C_1 is more than C_2.

So, if I define the flux ΔC as C_1-C_2, the gradient is $\Delta C/L$ which is proportional to J_D. What is J_D? The chemical flux. And D comes over here which will be the coefficient of conductivity of chemicals through the porous system. How do you name this as? This will be diffusion coefficient, clear. So, what we have done is we have diffusion coefficient. Now, can you give me a practical example where would you find this type of situation occurring in nature? Salt water intrusion is the classical example of chemical flow through the porous system. What you are saying is also correct, Sangeetha.

If you dump industrial waste on this side of the porous system, and suppose this happens to be a fresh water supply or a dead end or this could be hard rock, so this is a differential gradient between the concentration. And hence now you can make out that there will be a flux of concentration migrating through the porous system. So, these are the four types of flows which are normally talked about that is simple fluid, simple electricity, simple heat and simple chemical activity. Now, there could be a situation where we may have to talk about the combination of these fields that means there could be hydraulic conductivity associated with contaminant transport, and these contaminants might be having very high temperatures. So, this becomes a multiple attribute problem.

You have done modeling for the fluid flow through the soil mass, is it not? It is very easy either by falling head method or by constant head method, you have obtained value of k, k - hydraulic conductivity or coefficient of permeability. So, what you did is you measure the discharge, you measure $\Delta H/L$. And if these two are known, you could get the value of k. Similarly, I can measure the current passing through the porous system. I can find out what is the voltage difference across the two ends divided by the length of the sample, I can get the conductivity. How about this case?

I know what is the amount of heat migrating through the system, how would you find it out? Vindya, you said yes. So, you should answer this, unfortunately it is not so easy. So, any guess, how would you measure q value, the heat flux which is migrating through the system? So, 10+2 physics. Yes, please.

Student: (Refer Time: 13:19)

Sorry

Student: Calorimeter

Calorimeter? No, idea is to obtain q from the porous media that control volume, you cannot use calorimeter here, but yes, your answer is partially correct. So, if I want to know value of q, I have to use calorimeter definitely. But now can you correct the answer which you have given? Try again. So, from calorimeter, what you will obtain? Specific heat of the soil. So, how do you compute $q = m \times s \times \Delta\theta$, clear.

So, if you know the specific heat of the soil multiplied by the mass of the sample multiplied by delta theta that comes how to be q, so that q you have to compute and put it over here to get the value of K. So, delta theta gets cancelled out. If you use the equation $m \times s \times \Delta\theta$, so this will be equal to $K.\Delta T/L$. So, this will be $m \times s \times l = K$.

So, this is one of the ways of defining the K value or finding of the K value. So, what I wanted to demonstrate here is once you migrate from fluid and let the field to heat and chemical field, what happens? The degree of complexity increases, all right.

In fluid flow, you could measure things directly, even electrical field also you could measure things directly, but when it comes to heat and chemical field, you cannot measure things directly. What you have to do is, you have to conduct some other experiments to supplement your findings. And then from the combination of these two, you again get the parameters all right.

Now, most tricky thing would be the chemical flux, the most notorious and most tricky of the lot. So, we will be spending enough time in talking about how chemical flux migration can be studied in the porous system. And for the time being, what I will do is I will skip discussion on electricity migration and heat migration through the porous medium. And what I am tend to do is after finishing the chemical characterization, I will talk about these two types of characterization, is this ok? Do you find the flow ok now? I am sorry I could not help you, because you have to jump from one to another to another subsection only then I think you can I can give you the complete picture of what is happening here. Everything is linked with each other.

Now, when we talk about chemical flux, the law of law which governs the chemical flux is known as Fick's law all right. Now, if I ask you a question seepage flow would be governed by which equation or by which law out of the four?

Student: Darcy's law.

Darcy's law consolidation mechanism.

Student: Darcy's law.

Darcy's law, compressibility characteristics of saturated soils, Darcy's law. So, we have would be use Ohm's law, Fourier's law and Fick's law that is right. So, the moment you add contaminants to the water or the fluid which is flowing through, then you will notice that other three come into the picture. And I am sure that you will agree and that would be a most realistic situation. As a baseline, we can always say that whatever migrates to porous system cannot be in the purest form of a fluid, so that is where this type of modeling becomes very easy and challenging. Is this part clear, any doubts? Suchith, you like to add something here, yes please.

What is the source of heat? Say solar pond which you are designing. So, top surface happens to be exposed to the water, and water is exposed to the atmosphere or the sun directly. So, water is at elevated temperature and thick layer of the soil is in contact with water on one side, and on the other side it is in contact with the bed rock. So, this becomes the interesting situation where thermal flux is acting across the porous media. Another good example would be landfills. So, all landfill liners they are exposed to many high thermal gradients, why? What are you are dumping in the landfills could be at elevated temperature And the other side of the liner is exposed to the soil mass or the water table and so on. So, again there is a thermal gradient.

The same is true when we talk about chemical gradient also in case of solar ponds or in the case of landfills, where one surface or one side of the porous system is exposed to very high concentration; other side is exposed to low concentration. As Sangeetha and Jain said, there could be some other situation where you are doing too much soils, and then plants may uptake that also becomes a case of chemical migration. And fresh water supply in which the salt water is trying to migrate. So, this becomes soil water intrusion problem and so on. So, this is the general law which talks about how flow can be modeled in the porous system.

Now, let me ask you a question, we had been talking about the porous media several times. What we have defined here is how flow of a flux is taking place. So, that my question to you is what are the attributes of the porous system and how they are going to be included in this type of formulation, is the question clear? See, we have talked about the energy flux which is passing through the porous system. So, one part of the problem is over. The second part of the problem is how would you depict or how would you characterize the porous media itself what parameters attributes are required porosity all right.

So, when you say porous media, the name itself suggest that this system should have porosity clear. Now, if I replace these materials with steel, what happens then? A mechanical no flow, there will be flow. Why, if I put different voltages across the steel wire or a steel plate or whatever, there will be flow, is it not? So that goes into the realm of mechanical engineering. Where you are going to study the response of the metals or metallurgies, they will be talking about the response of the metals and their composition and so on.

Now, what we are interested in is here when we say a porous media, any system which contains pores falls in the realm of porous system, what should be another attribute of the porous media? So, one is porosity. Second one? So, as a black box let us say we are talking about porous system; it is not go into the details of that correct. So, one module is porosity of the system and those parts which you are trying to figure out they fall into the micro characteristics of the porosity.

Another module would be one is porosity, second one how to describe a porous system, a material or a system having porosity and state of saturation, is it not, how much moisture is present clear. So, the second attribute would be a state of moisture which is either distributed or present in the medium. Now, let us see one by one, how energy flux affects the state of moisture distribution in the soil sample, is this part ok? Is the question clear to you? So, we are talking about two attributes, one is porosity, another one is state of saturation. Now, this is how we define the porous media, fluid flow.

Till now you have been studying only migration of water. Suppose, if I give you a saturated sample of soil with Millipore water ok, distilled water and through the sample let us say salt water is migrating. Now, what is going to happen? Density of salt water is more than distilled water or less? More. What do you speculate, what type of flow is going to take place what is the mechanism of the flow now?

Something going to change does not matter. So, what is going to change? Salt water comes into the pores and replaces distilled water. Why, because of the density that is right. So, this becomes a density driven flow, is this part clear? So, we have now raised the complexity of even simple seepage problem, where not only Darcy law is going to valid, we are going to talk about the density driven flow as well. And I am sure that you will appreciate that this situation is going to be more practical, where the density contrast is going to create flow of water molecules or the fluid molecules in the system.

Let us talk about the electricity. Water can be polarized because of application of electrical gradient. Good example is electrophoresis. Think of a situation where the soil sample which was uniformly and fully saturated before application of any electric field. Because of the electrical field application, it becomes polarized clear. So, what you have done, you have altered the state of the porous system just because of electrical gradient. Now, this problem is not same as the one where the porous media happens to be fully saturated non-polarized.

Let us come back to the fluid flow again. Take a completely dry sample of soil apply H 1 and H 2 what type of flow is going to take place did you follow the question? Sorry yes. So, suppose if I say that the state of saturation the sample is 0, there is no moisture in the sample, it is a completely dry sample. And then I am applying H 1 on one side H 2 on one side now what is going to happen to a sample, why it happens?

Student: flow (Refer Time: 25:23)

Exactly, but why it is going to happen? Because of the capillary actually. So, once the capillary come into the picture what type of fluid is going to govern the process; unsaturated soil, clear, so that means, from a saturated state of the material we have now altered our discussion to unsaturated flow occurring in the porous system. So, lot of complexities can be created just like creating the type of the material, its saturation state, its porosity and so on. Is this part clear?

Now, I would like to ask you a question is this situation where I can even talk about the porosity change

Student: In case of consolidation (Refer Time: 26:06)

Sorry, in case of consolidation excellent, that is right, that is correct, is it not. So, we are loading the sample what happen void ratio keep on changing. Any other much complicated situation than this? Ok, let us not complicate the thing let us assume that this system happens to be isotropic and homogeneous. We are trying to understand the mechanisms right now. So, let us not complicate the porous system as such though we are trying to do it as much as we can. Yeah. So, yes please.

Student: flow through active soils (Refer Time: 26:48)

That is right correct very good. So, there could be a situation where the flow is taking place through soils which are highly active clear. So, what happens you started with certain volume of the soil sample, and because of the swelling and shrinkage characteristics, the porosity does not remain same perfectly all right. Now, this is what is known as, Mr. Jha this is what is known as, everybody is talking about THM model these days. It is in fashion THM model, thermo-hydro-mechanical models of soils, is it not? So, this is where lot of research has been conducted to understand how porosity of the system changes when it comes in contact with water or when it comes in contact with some thermal flux.

A good example would be any barrier system or a buffer system which we are creating, so on one side it is exposed to thermal flux, other side may be exposed to the environment when it comes in contact with water also. So, what happens no longer the porosity remains constant. The porosity keeps on changing because of the thermal flux. So, I am sure that you must have realized that it is not so easy to define what type of flow is going to take place through porous system. It is a very, very complicated phenomena; but then we have to understand the basics first.

So, what I intend to do in my lecture today is I will try to give you the basics of the flux migration in the porous system. Though I have talked about a lot how complexities can be involved into this either in terms of the flux which is passing through or in terms of the material properties which may remain constant, which may not remain constant. Any doubts or questions? It is a big theme which I have talked about just now. So, most of the research in geotechnical engineering is right now focused in this direction particularly nuclear industry, hazardous waste industry, where the porous system itself gets altered because of very active state ability there.

Student: (Refer Time: 29:05)

That is very, good correct. How would you define this type of phenomena, what is going to happen to the soil mass of the porous system?

Student: Clogging

Either clogging or the worst situation would be dissolution that is right or even worser than that corrosion of the porous system. So, you may create big, big voids or the cavities in the soil mass all right or the porous system itself may get decay because of the chemical activity, too much of interaction prolong interaction or who knows your porous system might be having of lot of biological entities which may get degraded in the due course of time. So, all those things can be put together to model ultimately how contaminants are going to migrate from one point to another point. And this is where I have used the word fate of contaminants in the porous system.