

Free Surface Flow
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Lecture 56

Welcome back, students, to the final module of this particular course on free surface flows. This module is termed 'Hydraulics of Mobile Bed Channels.' So, in the previous modules, the characteristics of flow in rigid bed channels were discussed. The boundary was considered rigid in all the previous 11 modules. The channel slope and the geometry were fixed, and the roughness magnitudes were invariant.

While these conditions hold good for a wide range of man-made channels and, to some extent, non-erodible natural channels also, there exists a class of open channels in which the boundary is not fixed it is mobile. So, unlined channels, like, for example, those in alluvium both man-made and natural where boundaries are actually deformable, right, and the channel flow carries sediment along with water that comes under this category. So, very briefly as in, only one module is dedicated to it actually, a whole course can be developed on it, which probably will be developed later on hydraulics of sediment transport.

So, this particular module will entail hydraulics of mobile bed channels. So, with that being said, we will start with the introduction part, okay? So, the hydraulics of mobile bed channels, which is basic to successful engineering solutions to a host of sediment problems, such as erosion is the removal of soil deposition is the settling down of sediment and changes in the planform.

From the subject matter of the important area of study, known as sediment transport. So, what is sediment transport? This is also called sedimentation engineering. So, what is sediment transport?

The hydraulics of mobile bed channels, such as erosion, deposition, and changes in planform, is called sediment transport in simple terms. So, it is important to understand that a vast topic like sediment transport cannot be adequately covered within the confines of a single module like this. As such, only a brief introduction to the hydraulics of mobile bed channels, with emphasis on the design of stable unlined canals, is attempted in this module. The alluvium what is alluvium?

So, the alluvium or sediment refers to the loose, non-cohesive material, such as sand and silt, transported by suspended or deposited water. So, we are going to deal with alluvium or sediment. What phenomenon? Transportation or suspension.

So, a channel which is cut through an alluvium and transports water and also, in general, sediment having the same characteristics as in the boundary of the channel is called an alluvial channel. What is an alluvial channel? An alluvial channel is a channel. cut through an alluvium and transports water and sediment having the same characteristics as in the boundary of the channel is termed an alluvial channel. So, this is alluvium or sediment—alluvial channel—and why the hydraulics? What is actually the sediment transport? So, the first topic that we are going to cover today is the initiation of motion of sediments. This is why the sediment is going to move, right? So, when the flow of water in a channel, this channel has non-cohesive material and is observed, it can be seen. seen that the bed may become dynamic. Dynamic means moving. And how dynamic? Dynamic with the particles of the bed moving or sliding. So, how do they move? Sliding, rolling, or jumping mode. So, this is the observation that you can see, and this is specifically for mobile bed channels. Suppose we have a channel in a laboratory, right in a laboratory.

So, in the laboratory means where the flow parameters can be controlled, ok. So, in a controlled laboratory environment. What can we see? If we observe the motion of the bed particles for wide bed shear stress, we can observe for small values of bed shear stress. I am going to write down what bed shear, general bed shear stress is. There may not be any motion of the sediment. This bed shear normally is given by $\gamma R S_0$, where you know all the terms: γ , R is hydraulic radius, γ is ρg , and S_0 is the bed slope.

So, for a small bed shear stress, you might see that there might not be any motion of the sediment at all. However, for large bed shear stress, we will see the motion of the bed particles. Now, based on this observation, an important definition is introduced about critical motion or incipient motion. So, this is important: the condition of flow at which the bed particles will just begin to move is known as the condition of critical motion or incipient motion. Okay, so this definition is important: the condition of the flow at which the bed particles will just begin to move. If the flow is weaker than that or has less strength, there will be no motion. But when the strength is just enough, we see the particles moving. That condition is called critical motion or incipient motion. So, the bed shear stress corresponding to incipient motion is known as critical shear stress denoted by τ_c , where c stands for critical. Another important thing to note is that it should be noted that the motion of the bed particles at $\tau_0 = \tau_c$ is not a step function. but it only implies that, in a statistical

sense, a considerable number of bed particles will be set in motion when the critical shear stress is reached. This is important. So, now, maybe we will start on the next slide. So, considering the sediment, fluid, and flow properties at incipient motion.

There was a scientist called Shields proposed two non-dimensional numbers. One of them is the shear Reynolds number. called R_{*c} that is $(\mu_{*c}) * d/\nu$, and the second was non-dimensional shear stress. that is τ_{*c} is $\tau_c/(\gamma_s - \gamma) * d$. Now, we are so what are the different terms? d is the diameter of the bed particles. γ_s is $\rho_s \times g$, that is the unit weight of sediment particles. γ is $\rho \times g$, that is the unit of water. τ_c is the critical shear stress, and μ_{*c} is $(\sqrt{\tau_c/\rho})$, also called shear velocity.

At incipient motion, ν is the kinematic viscosity of water. So, at the stage of initiation of motion, Shields obtained He just let me Shields obtained the functional relationship between The two non-dimensional numbers, that is τ_{*c} and R_{*c} , which are the non-dimensional shear stress and shear Reynolds number. How did he obtain this? This was obtained through experimental studies.

And obtained a curve, very famously called the Shields curve. So, how does this Shields curve look like? So, this is this Shields curve. You see, there is the non-dimensional shear stress, and this is the shear Reynolds number. And this is non-dimensional sorry, this is shear and all zone this is non-dimensional shear stress.

Okay. So, what does it represent? It represents the mean line through the data points, and many experiments have been done. Okay. It is more or less like, you know, representing the Moody's curve for the pipe flow.

Okay. So for individual, you know, I mean I am going to describe this shield curve some salient features in the next slide. versus the non-dimensional shear stress. And here we have laminar flow at bed threshold of movement where the threshold is there we have turbulent flow.

So, for different regimes for different r star there is a line that that denotes that what should be the shields number in each of these cases. So, let me so, we I mean in the curve it is clear that here up to $R_{*c} = 2$, the flow is similar to the smooth boundary flow. in range of $2 < R_{*c} < 400$ You see 2 and 400, the flow is in transition stage. Here both the particle size d and fluid viscosity ν affect τ_c . So, here τ is τ_c is not affected by particle size. τ_c in this regime is affected by diameter, particle size and fluid viscosity. When Re_{*c} is greater than 400, τ_{*c} is not affected by R_{*c} or the grain size diameter, as the curve reaches a limiting

value of 0.056. And here, at this point, τ_c is a function of only the particle size. This is an indication of the boundary becoming completely rough, and hence the critical stress being independent of the fluid's viscosity. Now, it is to be noted that the minimum value of τ_c is 0.03 and is obtained when Re_{*c} is equal to 10. Thus, for τ_c , which is less than this value—I mean, the shear stress less than this critical value no motion should ever occur.

In a channel of flow where $\tau > \tau_c$, the bed will be in motion. If $\tau_0 < \tau_c$ (the critical value), the bed could be taken as not in motion and hence stable. All right. So, just one more point before we finish. So, if we designate the particle size in mm, for d_{mm} greater than 6 mm, the critical stress should be estimated as $\tau_c = 0.056 (\gamma_s - \gamma_d)$ or $0.056 \times 1.65 \times 9790 \times (d_{mm}/1000)$. Because this is in millimeters, it becomes $0.905 d_{mm}$. So, this means for sediments in water, if d_{mm} is greater than 6, it would correspond to a rough boundary with critical shear stress given by this. Alright, there is I mean, many people have developed empirical relationships for it.

I will write down one of those. I think we can go through it in our next lecture. We will continue with the Shields curve, and that will be enough for today. See you in the next class.