

Free Surface Flow
Dr. Mohammad Saud Afzal
Department of Civil Engineering
Indian Institute of Technology Kharagpur

Lecture 58

Welcome back, students, to this lecture on bed forms and resistance. In the last lecture, we studied the basics of mobile bed channels, the Shields curve, and bed forms. Now, we will examine the resistance offered by these bed forms. To estimate the resistance due to the grain, τ_0' . So, we will call τ_0' the resistance due to the grain and τ_0'' the resistance due to the bed forms. It is usual to consider the total shear stress τ_0 to be made up of two components. such that τ_0 is $\tau_0' + \tau_0''$. Assuming the energy slope S_0 to be the same for both components and the total hydraulic radius of the channel R to be made up of two parts, R' and R'' . We can write $\gamma R S_0 = \gamma R' S_0 + \gamma R'' S_0$. Hence, $R = R' + R''$. This one and this one, where R' is equal to the hydraulic radius associated with grain roughness, and R'' is equal to the hydraulic radius associated with bed forms.

Further, Manning's formula is used to represent the channel. resistance. If n is equal to Manning's, if n is equal to Manning's. roughness coefficient of the channel flow, and n_s is equal to Manning's roughness coefficient. corresponding to the grain roughness only when the mean velocity in the channel is $V = (1/n) \times (R^{2/3}) \times (S_0^{1/2})$. Also, $V = (1/n_s) \times R'^{2/3} \times S_0^{1/2}$. So, from these two equations, we can write $R' = (n_s/n)^{3/2}$. How to determine this n_s . There are several formulas available, but for n_s , we use Ticker's equation. use Strickler's n_s as. So, n_s formula we used $(d^{1/6})/21.1$. The shear stress due to the grains, which forms an important. in the study of sediment transport mechanics, is given by. τ_0' is equal to $\gamma R' S_0$. We have written this before also that becomes $(n_s/n)^{3/2} \gamma R' S_0$ ok.

So, this is R'/R . Now, this is the formula. Next is the prediction of bed forms. There have been many attempts to predict the bed forms in terms of flow and sediment by many scientists.

Whether these attempts were analytical or empirical, all these attempts are at best partially successful. So, among many attempts, the notable work is by Garde and Ranga Raju. So, a typical classification due to Garde and Ranga Raju, which I will show you in the figure. It considers S^* as a parameter where $S_0/[(\gamma_s - \gamma)/\gamma]$ and plotted against R/d as significant parameters. So, let me just show you the figure. So, this is by Garde and Ranga Raju. So,

they have plotted S^* , which is $S_0/[(\gamma_s - \gamma)/\gamma]$, and R/d , where R is the hydraulic radius and d is the grain size diameter.

So, they predicted that in this region there is no motion. We will write down the equations very soon. In this region, there is a formation of ripples and dunes. This is a region for transition, and this is the region for the anti-dunes. So, the lines demarcating the various bedform phases can be expressed as per Garde and Ranga Raju as. So, for a plane bed with no motion in the figure, this one $S^* < 0.05 (R/d)^{-1}$ for ripples and dunes.

This S^* lies between $0.05 \times (R/d)^{-1}$ to $0.014 \times (R/d)^{-0.46}$ for ripples and dunes. For transitions, S^* lies between $0.014 \times (R/d)^{-0.46}$ and $0.059 \times 0.014 \times (R/d)^{-0.54}$. And this is the regime three ticks.

So, 1 tick, 2 tick, 3 ticks. And for the last one, for anti-dunes, this S^* is greater than or equal to $0.059 \times 0.014 \times (R/d)^{-0.54}$, 4 ticks and in the curve this one. So, this graph means the previous page or the above equations are useful in the determination of bed forms in a given flow situation. So, this graph or these equations four of these for plane bed with no motion for ripples and dunes based on S^* and R/d are useful in determination of bed forms in given flow situation. So, that is about the bed forms and the resistance offered by them. Now, we will talk about sediment load more on sediment load.

There are different types of sediment loads. One is contact load at small of excess bed shear stress that is $(\tau_0 - \tau_c)$ very small values. The particles may roll or slide on the termed as contact load.

Second is saltation load. Sometimes the sediment particles may leave the bed to hop. Hop means a small jump. to come in contact with the bed again. So this mode of large number of small jumps is called the saltation load. bed load. The sediments that will be transported in a thin layer of order of two grain diameters next to the bed is called bed load. So in that sense, contact load and saltation load can also be considered as bed load, given that it lies under this two, so this is bed, this is one grain, this is two grain.

So any, this entire regime is bed load. We have another called suspended load So, suspended load happens at a higher shear rate. So, at higher shear rates, the fluid turbulence may pick up the displaced particles and keep them in so suspension happens due to the high turbulence, fluid turbulence. So the sediment transported in suspension mode is known as suspended load. An important thing to note is whether a particle will travel as bed load or suspended load depends upon the parameter ω/u^* , where ω is the suspended

fall velocity of the particle, $u^* = \sqrt{(\tau_0/\rho)}$, or shear velocity. So, the suspension occurs when ω/u^* is less than or equal to 2.0 total bed. Another thing is total This is total = bed load + suspended load.

This is known as total load. There is another term referred to as wash load. What is wash load? Sometimes, if the suspended material contains very fine material like clay not found in the boundary of the channel, this material would have to come into a stream and then to a channel as a product of erosion during the runoff process. Such suspended material, which does not form part of the bed material, is known as the wash load.

What is wash load? The suspended material, which is very fine in nature, does not form part of the bed material. So, it comes from other places; it can be from anywhere and is known as wash load. Therefore, the properties of wash load—the physical properties, the material properties—are different from those of the bed material.

So, this is not very significant for our analysis. We mainly have two: bed load and suspended load. So, in the next class, we will see the formulations of bed load transport and suspended load transport. Thank you so much, and this is all for today.