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THE ROLE OF FLOW REGIMES FOR SEDIMENT TRANSPORT

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ABSTRACT

There is strong interrelationship between resistance to flow, bed configuration, and rate of sediment transport. In order to understand the variation of resistance to flow under different flow and sediment conditions, it is necessary to know the definitions and the conditions under which different bed forms exists. In this paper, brief description about flow regimes and modes of sediment transport is made.

Keywords: River bed; Discharge; Ripples and dunes; Transition; Antidunes; River flow regimes; Suspended sediment transport; Shear stress.

I. INTRODUCTION

The ability of the channel to entrain and transport sediment depends on the balance between (1) gravitational forces acting to settle particles on the bed and (2) drag forces that act to either suspend them in the flow or shove them along downstream.

When the average shear stress due to moving water on the river bed exceeds the critical shear stress, individual particles or grains making up the bed start moving. Since the particles are generally not exactly alike in size, shape or weight and also since a flow in a river with random turbulent fluctuations, all the bed particles do not start moving at the same time. Some particles move more than the rest, some slide and some hop depending on the uncertainties associated with the turbulent flow field and also the variation of drag due to particle shape. Gradually, a plane channel bed develops irregular or regular shapes of unevenness which are called bed forms which vary according to the flow conditions and are termed as "Regimes of flow" (Garde and Ranga Raju 2000), which is explained further below in this section. Regimes of flow will considerably affect the velocity distribution, resistance relation and the transport of sediment in an alluvial river or channel. The regimes of flow can be divided into the following categories (Figure 1):

1. Plane bed with no motion of sediment particles 2. Ripples and dunes 3. Transition, and
4. Antidunes

Plane bed with no motion of sediment particles: When the sediment and flow characteristics are such that the average shear stress on the bed is less than the critical shear stress, the sediment particle on the bed does not move. The water surface remains fairly smooth if the Froude number is low. Resistance offered to the flow is on account of the grain roughness only, and the Manning's equation can be used for prediction of the mean velocity of flow.

Ripples and Dunes: The sediment particles on the bed start moving when the average shear stress of the flow exceeds the critical shear stress. This results in small triangular undulations as the channel bed and is known as ripples. Ripples do not occur for sediment particles coarser than 0.6 mm. The distance between the successive crests of the ripples is usually less than 0.4m and the height from the crest to the trough is usually less than 0.04m. The sediment movement is confined in the region near the channel bed. With increase in discharge, and consequently the average bed shear stress, the ripples grow in sizes which are then termed as dunes.

Dunes are also triangular in shape but are larger than ripples. The triangular sections are not symmetric and the upstream face is inclined at about 10 to 20 degrees and downstream face at an angle of about 30 to 40 degrees with the horizontal. In rivers, dunes may be quite long and also the height (vertical distance between the crest and troughs) may be great. For example, the dunes found in Lower Mississippi river have been found to be about 12m height on an average and length of the order of few hundred meters (Garde and Ranga Raju, 2000). These bed forms are not static, which means that they gradually move forward with time, of course at a very slow and creeping velocity much less than the velocity of flow.

Transition: With further increase in discharge over the dune bed, the ripples and dunes are washed away, and only some very small undulations are left. In some cases, the bed may become nearly flat but the sediment particles remain in motion. With slight increase in discharge, the bed and water surfaces attain a shape of sinusoidal wave form, which are called standing waves . These waves form and disappear and their size doesn't increase much. Thus, in transition regime, rapid changes in bed and water configuration occur with relatively small changes in flow conditions. The Froude number is relatively high but the flow conditions are sub-critical.

Antidunes: When the discharge is increased further and the Froude number increases to more than one, indicating super critical flow, the standing waves, which are symmetrical sand and water waves in the phase, move slowly upstream and break intermittently. These are called antidunes because the movement of the direction of dunes is backwards compared to the direction of flow. Since supercritical flow is rare in case of natural streams and channels, this type of bed forms do not occur generally in nature.

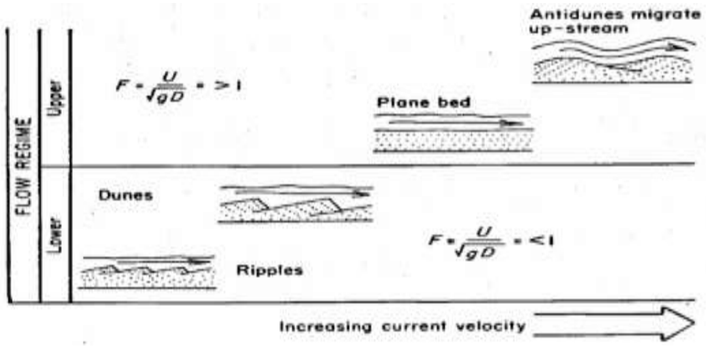

Fig.1: Bed forms and sedimentary structures for different flow regimes

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Modes of Sediment ransport

The sediment load of a river is transported in various ways although these distinctions are to some extent arbitrary and not always very practical in the sense that not all of the components can be separated in practice:

1. Dissolved load

2. Suspended load

3. Intermittent suspension (saltation) load

4. Wash load

5. Bed load

Dissolved Load: Dissolved load is material that has gone into solution and is part of the fluid moving through the channel. Since it is dissolved, it does not depend on forces in the flow to keep it in the water column. The amount of material in solution depends on supply of a solute and the saturation point for the fluid. For example, in limestone areas, calcium carbonate may be at saturation level in river water and the dissolved load may be close to the total sediment load of the river. In contrast, rivers draining insoluble rocks, such as in granitic terrains, may be well below saturation levels for most elements and dissolved load may be relatively small. Obviously, the dissolved load is also very sensitive to water temperature and other things being equal, tropical rivers carry larger dissolved loads than those in temperate environments.

Suspended-sediment load: Suspended-sediment load is the clastic (particulate) material that moves through the channel in the water column. These materials, mainly silt and sand, are kept in suspension by the upward flux of turbulence generated at the bed of the channel. The upward currents must equal or exceed the particle fall-velocity (Figure 4.2) for suspended-sediment load to be sustained.

Wash load: Although wash load is part of the suspended-sediment load it is useful here to make a distinction. Unlike most suspended-sediment load, wash load does not rely on the force of mechanical turbulence generated by flowing water to keep it in suspension. It is so fine (in the clay range) that it is kept in suspension by thermal molecular agitation (sometimes known as Brownian motion, named for the early 19th-century botanist who described the random motion of microscopic pollen spores and dust). Because these clays are always in suspension, wash load is that component of the particulate or clastic load that is “washed” through the river system. Unlike coarser suspended-sediment, wash load tends to be uniformly distributed throughout the water column. That is, unlike the coarser load, it does not vary with height above the bed.

“Glacial flour” is a common source of wash load present in glacial rivers and lakes. In lakes deposition of the wash load may eventually occur but only after months of settling in an undisturbed pond or lake. The repeated annual deposit of wash load from glacial meltwater streams to lakes produces the “varved clays” that form the bottoms of glacial lakes.

Because all clastic sediment in the water column is measured simultaneously with a suspendedsediment sampler, in practice it is not possible to distinguish between wash load and the rest of the suspended load.

Intermittently-suspended or saltation load Some river scientists make the not especially useful distinction between fully-suspended load and bed load by classifying the intermediate and transient transport state as saltation load transport. These are particles that bounce along the channel, partly supported by the turbulence in the flow and partly by the bed. Saltation load may be measured as suspended load (when in the water column) or as bedload (when on the bed). Although the distinction between saltating load and other types of sediment load may be important to those studying the physics of grain movement, most geomorphologists are content to ignore it as a special case.

Bed level changes during floods in alluvial rivers

Water resources engineers need to know the behaviour of alluvial rivers during floods for planning of some of their structures in natural rivers. It is true that their effect on riverbed may not be obvious immediately. In fact, it is not only the water discharge in the river that causes the bed level to change, but also the amount of sediment conveyed by the river which is generally increased many times during floods compared to the normal. In many alluvial streams, the stream bed has been observed to rise during floods, while the bed is lowered after the flood recedes. On the other hand, there are other streams where the bed level has been found to be lowered during rising floods and aggraded (that is, raised) during the receding flood. It has been observed that where a river width is narrower than usual, a rise in flood usually causes a lowering of the river bed and conversely, for wider sections of rivers, there is mostly riverbed rising during floods. It is obvious that the variation of the river bed during floods is dependent on the difference between sediment supply into the reach and the sediment transporting capacity of the reach.

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