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DEPARTMENT OF AGRICULTURAL ENGINEERING

AI3402 SOIL AND WATER CONSERVATION ENGINEERING

Mr. VENKATESHAN P

ASSISTANT PROFESSOR

Mechanics of Sediment Transportation

The four modes of particle transport in water are sliding, rolling, saltation and suspension. Sliding particles remain in continuous contact with the bed, merely tilting to and fro as they move. Rolling grains also remain in continuous contact with the bed, whereas saltation grains 'jump' along the bed in a series of low trajectories. Sediment particles in these three categories collectively form the *bed load*. The suspended load consists of particles in suspension. These particles follow long and irregular paths within the water and seldom come in contact with the bed until they are deposited when the flow slackens. Sliding and rolling are prevalent in low velocity flows, whereas; saltation and suspension take place in high velocity flows. The region of flow influenced by proximity to the surface is called the *boundary layer*. A boundary layer develops wherever a fluid moves over a surface.

The friction between flowing water and the bed generates a boundary layer in which turbulent flow is dominant, except very close to the bed. Movement of sediment (erosion) occurs when the shear stress generated by the frictional force of water flowing over the sediment overcomes the force of gravity acting on the sediment grains and the friction between the grains and the underlying bed. Shear stress is proportional to the square of the mean current speed (and to the density of the water. Movement of grains of a given size begins when the shear stress at the bed reaches a critical value (critical shear stress).

Cohesive sediments contain a high proportion of fine-grained clay minerals and are more difficult to erode than non-cohesive sediments, which often consist mostly of quartz grains. For cohesive sediments, the smaller the particle size, the greater the water velocity required to erode them. Once in suspension, clay particles are transported for long distances by the currents that would be much too weak to erode them. Shear stress is proportional also to the velocity gradient in the boundary layer and to the viscosity of the water.

Types of Sediments Transported Along with Streams

Sediment transport is the movement of solid particles (sediment), typically due to a combination of the force of gravity acting on the sediment, and/or the movement of the fluid in which the sediment is entrained. An understanding of sediment transport is typically used in natural systems, where the particles are clastic rocks (sand, gravel, boulders, etc.), mud, or clay; the fluid is air, water, or ice; and the force of gravity acts to move the particles due to the sloping surface on which they are resting.

Sediment movement in streams and rivers takes two forms. Suspended sediment is the finer particles which are held in suspension by the eddy currents in the flowing stream, and settle out only when the stream velocity decreases, such as when the streambed becomes flatter, or the stream discharges into a pond or a lake. Larger solid particles are rolled along the streambed and are called the bed load. There is an intermediate type of movement where particles move downstream in a series of bounces or jumps, sometimes touching the bed and sometimes carried along in suspension until they fall back to the bed. This is called movement in saltation, and is a very important part of the process of transport by wind, but in liquid flow the height of the bounces is so low that they are not readily distinguished from rolling bed load.

Sediment transport is a direct function of water movement. During transport in a water body, sediment particles become separated into three categories: suspended material which includes silt + clay + sand; the coarser, relatively inactive bed load and the saltation load.

Bed Load

Bed load is the clastic (particulate) material that moves through the channel fully supported by the channel bed itself. These materials, mainly sand and gravel, are kept in motion (rolling and sliding) by the shear stress acting at the boundary. Unlike the suspended load, the bed-load component is almost always capacity limited (i. e. a function of hydraulics rather than supply). A distinction is often made between the bed-material load and the bed load.

Bed-material load is that part of the sediment load found in appreciable quantities in the bed (generally > 0.062 mm in diameter) and is collected in a bed-load sampler. The bed material is the source of this load component and it includes particles that slide and roll along the bed (in bed-load transport) but also those near the bed transported in saltation or suspension phase. Bed load, strictly defined, is just that component of the moving sediment that is supported by the bed (and not by the flow). The term "bed load" refers to a mode of transport and not to a source. Since bed load consists of stony material (gravel and cobbles), it moves by rolling along the bed of a river because it is too heavy to be lifted into suspension by the current of the river. Bed load is especially important during periods of extremely high discharge and in landscapes of large topographical relief, where the river gradient is steep (such as in mountains). It is rarely important in low-lying areas. The portion of the sediment load that is transported along the bed by sliding, rolling or hopping can be termed as the bed load. Bed load moves at velocities slower than the flow and spends most of its time on or near the stream bed. In many streams, grains smaller than 1/8 mm are always suspended while grains great than 8 mm travel as bed load. The strength of flow determines the transport mechanism of grains in between these two sizes. Sediment transport can also be categorized based on the source of the grains: 1) bed material load, which is grains found in the stream bed; and 2) wash load, which is finer grains found as less than a percent or two of the total amount in the bed.

Suspended Load

Suspended load consists of sediment particles that are mechanically transported by suspension within a stream or river. This is in contrast to bed or traction load, which consists of particles that are moved along the bed of a stream and dissolved load which consists of material that has been dissolved in the stream water. In most streams, the suspended load is composed primarily of silt and clay size particles. Sand-size particles can also be part of the suspended load if the stream flow velocity and turbulence are great enough to hold them in suspension.

The suspended load can consists of particles that are intermittently lifted into suspension from the stream bed and of wash load and also those which remains continuously suspended unless there is a significant decrease in stream flow velocity. Wash load particles are finer than those along the stream bed, and therefore must be supplied by bank erosion, mass wasting, and mass transport of sediment from adjacent watersheds into the stream during rainstorms. Water density is proportional to the amount of suspended load being carried. Muddy water high in suspended sediment will therefore increase the particle buoyancy and reduce the critical shear stress required to move the bed load of the stream.

Suspended load comprises sand + silt + clay sized particles that are held in suspension because of the turbulence of the water. The suspended load is further divided into the wash load which is generally considered to be the silt + clay sized material (< 62 μm in particle diameter) and is often referred to as "fine-grained sediment". The wash load is mainly controlled by the supply of this material (usually by means of erosion) to the river. The amount of sand (> 62 μm in particle size) in the suspended load is directly proportional to the turbulence and mainly originates from erosion of the bed and banks of the river. In many rivers, suspended sediment (i.e. the mineral fraction) forms most of the transported load. Particulate sediment that is carried in the body of the flow is of the following types.

1. Suspended load moves at the same velocity as the flow.

2. The *Hjulstrom curve* shows that a much higher velocity is required to entrain clay and fine silt than coarse sand. However, once the fine sediment is in suspension, a much lower velocity is required to maintain it in suspension.

3. The quantity and quality of the load is defined in terms of competence and capacity**.** Competence is the large size clast that a stream can carry, whereas capacity is the volume of sediment carried. Competence (caliber) is a function of velocity and slope whereas capacity is a function of velocity and discharge.

4. A small particle (e.g. clay and fine silt), with a large relative surface area, is held in suspension more easily because of the electrostatic attraction between the unsatisfied charges on the grain's surface and the water molecules. This force, tending to keep the particle in the flow, is large compared to the weight of the particle.

Wash/Dissolved Load

Although wash load is part of the suspended-sediment load it is useful to make a distinction. Unlike most suspended-sediment load, wash load does not rely on the force of mechanical turbulence generated by the 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. 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 and therefore moves with the mean velocity of main stream. That is, unlike the coarser load, it does not vary with height above the bed.

Wash load concentrations are approximately uniform in the water column. This is described by the end member case in which the Rouse number is equal to 0 (i.e. the settling velocity is far less than the turbulent mixing velocity), which leads to a prediction of a perfectly uniform vertical concentration profile of material. The Rouse number is a ratio of sediment fall velocity to upward velocity.

Dissolved load is the term for material; especially ions from chemical weathering that are carried in solution form by a stream. The dissolved load contributes to the total amount of material removed from a catchment. The amount of material carried as dissolved load is typically much smaller than the suspended load, though this is not always the case. Dissolved load comprises a significant portion of the total material flux out of a landscape, and its composition is important in regulating the chemistry and biology of the stream. Factors that govern the percentage of dissolved and suspended loads in the flowing streams include:

1. Climate: Temperature, Precipitation, Vegetation.

2. Vegetation: Type and Amount.
3. Activity by Man: Mining, Construction, Clear Cutting, etc.
4. Rock Solubility: e.g. Hard Water in Carbonate Terranes.
5. Erodibility of Materials in the Drainage Basin.
6. Relief and Slope.