Sediment Suspension and Transport by Waves

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COASTAL SEDIMENT TRANSPORT is one of the most important factors in determining the physical features of the coastal zone. Beach erosion, filling in of navigation channels, sand bar formation and other processes are governed by the rate and direction of sediment transport in the sea. The transport of sand is caused by both breaking and non-breaking waves. Transport in the zone where the waves break—known as the surf zone—is mostly parallel to the shore—known as longshore transport. Transport outside the surf zone is mostly in the shore-normal direction, known as cross-shore transport.

This paper discusses the mechanisms of cross-shore transport in a wave-dominated environment with particular reference to the deductions from recent field measurements and mathematical modeling. Cross-shore transport is particularly important for the determination of beach profiles, grain sorting and the movement of sediment from the beach to deep water.

For sediment to be transported it must first be mixed into the water—a process known as entrainment—and then moved by the water. In the surf zone, entrainment is caused by the violent turbulent motions caused by breaking waves and transport is by the mean longshore current. Outside the surf zone however, transport is mostly confined to the wave boundary layer. The wave boundary layer is a thin—of the order 1 to 10 centimeters (cm)—layer of fluid at the bottom of the sea.

In deep water, the motion caused by surface waves does not penetrate to the bottom. However when waves move close to the shore and the depth decreases, they "feel' the effect of the bottom. The bottom imposes a "no-slip" condition on the potential motion in the rest of the fluid, thereby causing high shear stresses and turbulence. This effect is confined to a thin layer by the periodic reversal of the near-bottom wave velocity. Important processes in the boundary layer are mobilization of sediment from the bed and dissipation of the wave energy.

In the past, the accepted concept of transport was that the sediment was mobilized by the strong wave and created bottom shear stress, and was transported by the weak currents that are normally present in the near-shore regions. Thus, transport was calculated by taking the product of the mean velocity and the mean concentration. This method completely ignores any correlation between the wave motion and the sediment concentration. However, recent field measurements have conclusively shown that the concentration has a strong periodic component that is highly correlated with the wave velocity. Therefore it is necessary to calculate the periodic components of the velocity and the concentration in order to estimate the total transport.

In order to model the transport we have to calculate both the velocity and the sediment concentration. This is done using a simple eddy viscosity formulation of the turbulent mixing in the boundary layer. The velocity is forced by the near-bottom wave motion and can be found at all points when this quantity is known. However, the sediment concentration is forced by the effect of the water

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moving over the bed. In this model the entrainment of sediment is taken to be proportional to the bottom shear stress.

By this method, both the velocity and the sediment concentration—and thus the transport—can be calculated. The only unknown parameter in the model is the constant of proportionality in the entrainment boundary condition. This must be determined by comparing model results with field data. The measured field data must be extrapolated down to the bed in order to make this comparison—a procedure which will involve errors if the point of measurement is far from the bed. In the past, it was not possible to make measurements close to the bed without disturbing the flow so that the calibration of the models was not very accurate.

These problems have been overcome with the development of the Acoustic Backscatter Sensor (ABS). This instrument is mounted on a tripod set on the bottom at a height of about 1 meter (m) from the bottom. A very short pulse of high frequency sound is emitted and the echoes from the sediment in the water are sampled. The magnitude of the echo is then related to the concentration. In this way the concentration can be sampled along a vertical line with a depth resolution of 0.5 cm and a time resolution of 0.5 seconds (s). The ABS can measure the concentration up to 0.5 cm from the bottom without disturbing the flow and therefore the data is very useful for the calibration of the model.

The profiles of mean concentration predicted by the model are in good agreement with the data. Furthermore, the model is able to reproduce many of the features in the observed time series of the concentration at various depths. The correspondence is particularly good at the lower frequencies which is the important range when considering the transport. The calculation of transport shows that the transport caused by the periodic (wave) motion is much greater than that due to the mean (current) motion. This result justifies the inclusion of the periodic components in the model, and means that the model is now able to make improved estimates of the transport.