XVI. ESTUARIAL SEDIMENT BED MODEL

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ABSTRACT

A layered cohesive sediment bed model used to simulate the formation, erosion and consolidation of the type of beds typically found in estuaries is described. The model is divided into three bed sections: unconsolidated stationary suspensions, partially consolidated beds, and settled (fully consolidated) beds. The model is further divided into a finite number of strata in order to account for repeated periods of deposition, as typically occur in estuaries due to the oscillatory tidal flow. The erosion algorithm included in the model simulates the reentrainment of stationary suspensions and the resuspension of partially consolidated and settled bed layers. The empirical consolidation algorithm accounts for the self-weight consolidation of stationary suspensions and partially consolidated beds by increasing the bed density and bed shear strength and decreasing the bed thickness with time. The degree of consolidation of a particular stratum is accounted for by using a separate consolidation time for each stratum. Results from simulations using the bed model are presented in the form of bed structure-time plots.

INTRODUCTION

Surficial layers of estuarial beds, typically composed of flow-deposited cohesive sediments, occur in three different states: stationary suspensions, partially consolidated (or consolidating) beds and settled (or fully consolidated) beds. Stationary suspensions are assemblages of high concentrations of sediment particles that 1) are supported jointly by the water and the developing skeletal soil framework, and 2) have no horizontal movement (35). These suspensions, which may be regarded as extremely under consolidated soil, develop whenever the settling rate of concentrated mobile suspensions exceeds the rate of self-weight consolidation (34). They tend to have a high water content (therefore low bulk density, \( \rho_B \), and a very low, but measurable, shear strength, \( \tau_C \), that must be at least as large as the bed shear stress, \( \tau_B \), which existed during the deposition period (25). Thus, they exhibit a definite non-Newtonian rheology. Kirby and Parker (16) found that stationary suspensions have a surface bulk density of approximately 1050 kg/m\(^3\) and a layered structure. Krone (18) found that, in addition to the bed shear, the structure (or framework) of these suspensions

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depends on the aggregate order in the following manner: if the aggregates deposit without being broken up by the bed shear, the surficial layers will be composed of an aggregate network whose order is one higher than that of the individual settling aggregates; therefore, these layers will have lower bulk densities and shear strengths than those of the aggregates which form them.

Whether or not reentrainment, also referred to as mass erosion (31), of these suspensions occurs during periods of erosion depends upon the mechanical shear strength (i.e. stability) of this aggregate network. That portion which remains on the bed undergoes: 1) mechanical consolidation, due to overburden resulting from the weight of the overlying sediment which crushes the aggregate network below, and 2) thixotropic effects, defined as the slow rearrangement of deposited aggregates attributed to internal energy and unbalanced internal stresses (26). Both processes result in a reduction in the order of aggregation of the sub-surface bed layers. This implies that the bed becomes stratified with respect to bulk density and shear strength, with both properties typically increasing with depth, at least under laboratory conditions (25). Stationary suspensions generally have lifespans that vary from a few hours to a few days. Differential settling caused by sorting processes is another cause of stratified bed formation.

Partially consolidated deposits, formed from the consolidation of stationary suspensions, have a somewhat lower water content and higher shear strength, and are eroded particle by particle or aggregate by aggregate, referred to as resuspension (33) or surface erosion (31), when subjected to an excess bed shear stress (i.e. \( \tau_b > \tau_c \)). Continued consolidation eventually results in the formation of settled mud, defined by Parker and Lee (35) as "assemblages of particles predominantly supported by the effective contact stresses between particles as well as any excess pore water pressure." Settled mud has a much lower water content, a lower order of aggregation, and a higher shear strength, and therefore is better able to resist high bed shear stresses. Settled beds likewise undergo resuspension when subjected to an excess shear. The settled mud in the Severn Estuary and Inner Bristol Channel, United Kingdom, has a bulk density range from 1,300 to 1,700 kg/m\(^3\) (17).

An estuarial sediment bed model that is capable of simulating the formation, erosion and consolidation of flow-deposited cohesive sediment beds is described. This model is coupled to the cohesive sediment transport model CSTM-H, which is a two-dimensional, depth-averaged finite element model that is capable of predicting the temporal and spatial variations in the depth-averaged suspended sediment concentration and bed surface elevation in the water body being modeled (13). In addition to the bed model, CSTM-H contains a deposition and shear flow dispersion algorithm. The bed model can also be used to predict the settlement of dredge spoil deposits.