CHAPTER ONE HUNDRED FIVE

NUMERICAL MODEL FOR DUNE EROSION DUE TO WAVE UPRUSH

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ABSTRACT

The objective of the work presented herein is to quantitize dune erosion as a function of the swash mechanics. In order to achieve this aim, a numerical model is developed which solves the one dimensional continuity and momentum equations for depth and velocity of the swash at the face of the dune. These parameters are then used as input to the dune erosion model which predicts the extent of toe retreat of the dune as a function of time. Since the model is formulated in real time, both short and long term events may be simulated. This is particularly important in terms of understanding the short term event in which the dune and beach face do not achieve an equilibrium profile.

INTRODUCTION

The prediction of dune retreat due to storm processes is the subject of increasing concern in coastal engineering. Dunes are often used as the primary defense to coastal erosion and flooding. Previous efforts at predicting the rate of dune erosion have generally depended upon the development of a post-storm equilibrium profile, where the volume of sand lost from the dune is determined by the quantitiy of sand required to establish this profile, Hughes and Chiu (4), and Vellinga (7). Therefore, if the beach does not reach an equilibrium condition due to the specifics of the storm parameters, ie. storm duration, wave height, and/or storm surge, this method will over-predict the amount of dune retreat.

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The model described in this paper is being developed to predict the dune erosion for a single storm, and does not require that there be an equilibrium profile established at the end of the event. The model considers the size and position of the dune on the beach, the degree vegetated, and the strength and duration of the storm swash.

This somewhat unique approach to dune erosion modeling (where time is a true variable) depends upon an estimate of the actual volume of sand eroded from the base of the dune for each individual swash uprush. While there is a large body of literature dealing with the mechanism for beach erosion by wave swash, Dean and Maurmeyer (1), there is virtually no literature dealing with the scour of the dune.

METHODOLOGY

In order to quantitize the erosion due to the short term event, it was felt that the interaction between the mechanics of wave swash and sediment scour at the dune toe was of primary importance. A schematic of the idealized model is presented in Figure 1.

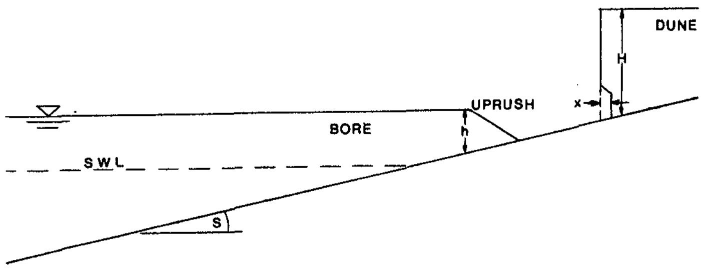

FIGURE 1. Schematic of the model components.

Important geometric considerations are the bore height, water depth, still water level, beach slope, dune height, and dune position on the beach. In addition to these geometric factors, the sand grain size and the density of plant roots are input parameters to the erosion model.

The uprush is modeled as a bore on a frictionless inclined beach following the work of Hibberd and Peregrine (3). The one dimensional equations for continuity and momentum are solved using a Lax-Wendroff solution technique yielding the velocity and depth of the bore as it moves up the beach to the dune. The Hibberd and Peregrine model was modified to include as a boundary condition on the landward side, the position of the dune. The dune acts as an impermeable vertical boundary to the uprush. Therefore, the numerical restraint is that the velocity is held to zero at the dune face. The initial conditions within the fluid are that the bore height is 1.6 times the water depth at the seaward boundary, a relationship shown in the data presented by Svendsen Madsen and Hansen (5), and with a velocity determined by the equations of equilibrium for a moving hydraulic jump. Elsewhere in the fluid domain the water depth is the still water level and the velocities are zero. As the equations are integrated in time, the bore propagates uniformly over the water and then decreases in height as it moves up the beach. As the swash hits the dune a reflected wave is formed and propagates seaward combining with the still advancing uprush. Eventually the bore recedes as the natural backwash.

The specific discharge of the uprush (depth times velocity) is considered to be the key parameter in determining the dune scour. Numerical results of the discharge versus time are presented in Figure 2 for three positions of the dune relative to the intersection of the still water level and the beach. The discharge is characterized by a rapid rise in magnitude, a period of relatively constant value (depending on the location of the dune), and a rapid decrease. The general trends are that the maximum value of the discharge decreases rapidly and the length of time that the bore is attacking the dune increases slightly as the distance of the dune toe up the beach increases.

The erosion at the base of the dune is then estimated by relating the volume eroded to the characteristics of the uprush. This is done on a 'per uprush' basis so that the time of uprush attack as well as the storm duration become important parameters in the estimation of the total amount of dune erosion per storm. This approach has been qualitatively evaluated using laboratory data from our 17 m wave flume. The assumption that the volume of scour at the base of the dune (per unit time) is a function of the specific discharge of the uprush appears to be a good first approximation, and is consistent with relationships derived for sediment transport in rivers, Vanoni (6). We are initiating a series of field experiments with prototype dunes at the U. S. Army Corps of Engineers Field Research Facility, at Duck, North Carolina, in order to more thoroughly evaluate this hypothesis.

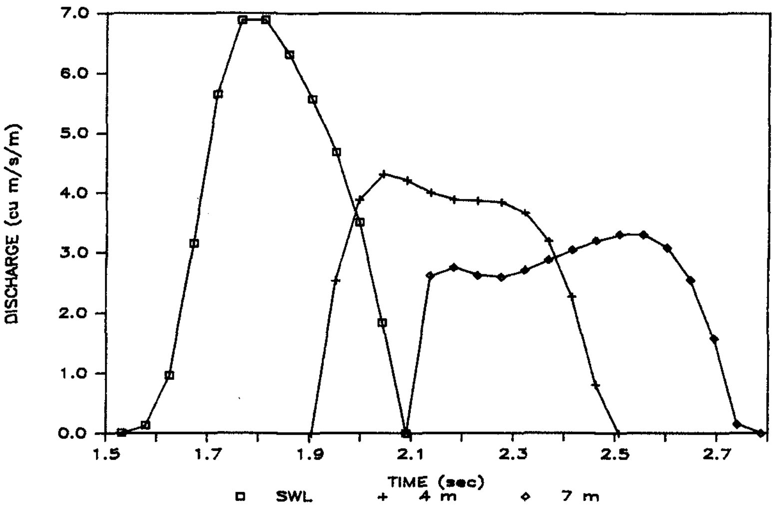

FIGURE 2. Specific discharge at the toe of the dune versus time for three positions of the dune relative to the intersection of the still water level and the beach face.

The scour at the base of the dune will ultimately cause the dune to fail. The depth of scour necessary to undermine the the dune is a function of the properties of the dune sand, the degree of water saturation, and the density of plant roots. The latter can be significant, as shown in the work of Gray and Leiser (2).

This maximum scour is computed as:

D = c/ws + (w/ws)(H/2(tan(phi)))

where D = maximum depth of scour before the dune fails, m,
c = sand cohesion, Pa (function of root density, as shown by Gray and Leiser (2),
ws = specific weight of the sand, N/cu m,
w = specific weigth of the water, N/cu m,
H = dune height, m,
phi = friction angle.

The current model assumes that the volume of sand that fails is distributed at the toe of the dune and that the process of attack of the swash on the face of the dune is repeated. The dune is said to retreat when the volume of sand eroded exceeds that in a column of sand equal to the depth of the scour times the original height of the dune. At this point, the specific discharge of the swash is recalculated given the new position of the dune. This procedure is summarized in Figure 3, a flow chart of the model.

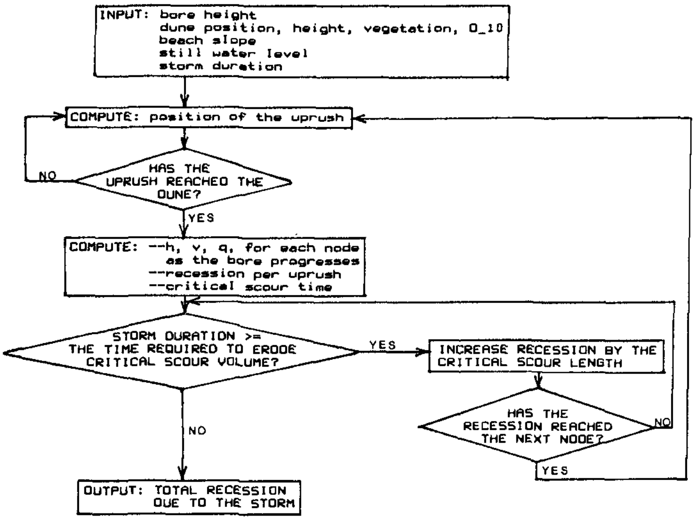

FIGURE 3. Flow chart of the uprush/dune erosion model.

SUMMARY

The model described in this discussion is still in the early stages of development. The additional laboratory and field data which will be collected in the next phase of this research will result in changes and refinements to the present form of the model. The ultimate objective of this work is to develop a dune erosion model which can be coupled to a shoreline erosion model such as the one described by Dean and Maurmeyer (1). Thus, the dune model would serve as an erodable landward boundary for the shoreline model.

ACKNOWLEDGEMENT

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