CHAPTER 137

SIMULATION MODELING OF DUNE EROSION

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Abstract

Using a combination of laboratory, field, and numerical techniques, we have developed a methodology for predicting the extent of dune erosion due to a given set of wave conditions and the beach and dune morphology. A basic assumption in this model is that the volume eroded from the dune is a function of the swash acting on the dune. Because the model is built on this premise, it is necessary to look at the mechanics of two ongoing processes in the storm environment. The first is the relationship between the swash characteristics and the volume of material eroded from the dune face. The second is the relationship between the time history of the swash characteristics at the dune face and the statistics of the storm event, the significant wave height and wave period.

Introduction

The process of dune erosion due to a storm event can be broken into five interacting components. Starting at the ocean side these are -- a statistical description of the storm, the individual wave, wave generated swash on the beach, the force on the dune face due to the swash and the volume eroded from the dune. Wrapped around these parameters is the fact that we are dealing with not a single event (a single wave and swash), but a series of wave and swash events generated during the storm period. However, in order to simplify the first cut description of the model and the process, we begin the discussion with our focus on an individual wave component and work from the dune face seaward.

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Methodology

The assumption that the volume eroded from the dune is a function of the swash acting on the dune is based on flume and field experiments. In a series of laboratory experiments, Overton, et al. (1988) showed that the volume eroded from a vertical planar dune during the action of a single swash is a function of the swash force. The swash force is defined as the product of the fluid density, the uprush velocity squared and the height of the uprush at the moment of impact. Applying this concept to the field, a set of experiments were designed to test this hypothesis for prototype scale dunes under natural swash conditions, Fisher, et al. (1987). At the Army Corps of Engineers Field Research Facility (FRF) at Duck, N. C., man-made dunes approximately one meter high and one meter wide were built on the beach and allowed to erode naturally during the rising tide. The experiments were conducted until either the dune was completely eroded (and/or overtopped) or the swash no longer hit the dune. While it is difficult to isolate the impact of a single swash on the amount of the dune eroded, it is apparent from the data that the total dune erosion during an event is linearly correlated with the summation of the swash force for each individual swash, Figure 1. This relationship seems to hold even when events are

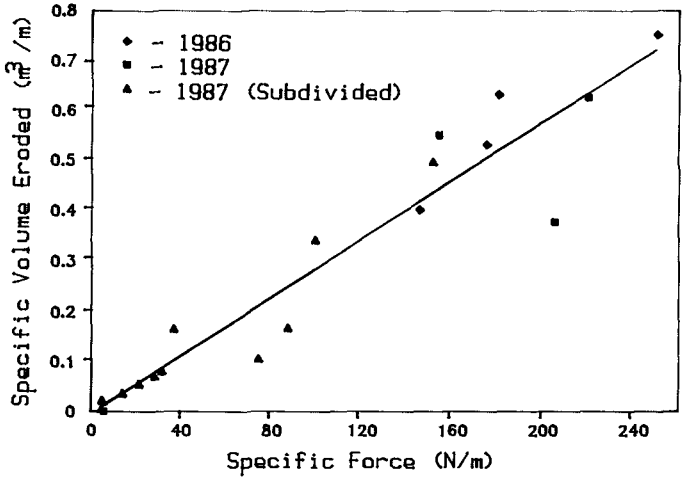

Figure 1. Specific force versus specific volume eroded from field experiments, Duck, N.C.

subdivided into smaller units of time. It is this concept, that a storm event can be represented by a single parameter (the sum of the force in each

individual swash) and thus the amount of dune eroded during that event can be predicted.

Given that we can reasonably predict the volume eroded at the dune face as a function of the swash force, how can we determine the force of any arbitrary swash as it hits the dune? The laboratory experiments investigated a limited range of bore sizes. To increase the flexibility of the model, a numerical model based on the two dimensional hydrodynamics of a bore propagating over a sloping planar beach and impacting with a vertical dune was developed. Variable parameters in the model are depth of the bore at the seaward boundary, distance to the dune from the mean water level and the slope of the beach. This enabled us to determine the velocity and depth of the bore during impact with the dune for a wide range of cases. Using these two parameters, the time history of the swash force on the dune face during impact is given in Figure 2. Note that the force varies rapidly with time, rising quickly

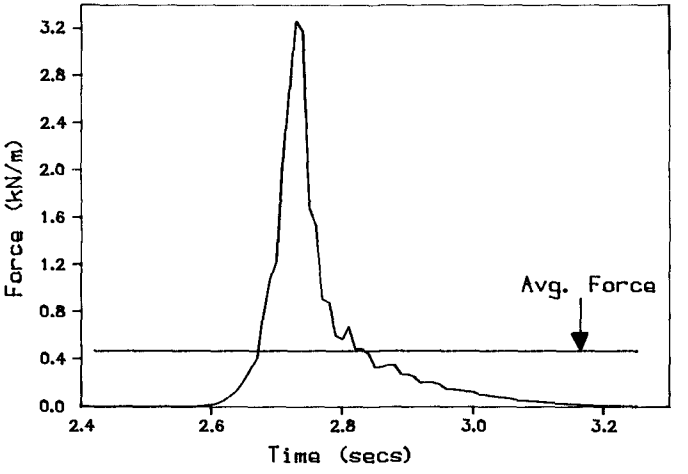

Figure 2. Swash force at the dune versus time - numerical results.

to its maximum and then decaying. In order to be compatible with the laboratory results for the prediction of the volume eroded, the average force during impact is used to represent the effect of a single swash, as discussed in Overton et al. (1987).

In order to reduce computation time in the simulation model, it is desirable to find a direct relationship between the input parameters in the hydrodynamic model and the output parameter, swash

force. Therefore, the relationahip between the height of the bore, the distance to the dune, the alope of the beach, and the swaah force was investigated. A limited range of parametric atudies have been conducted to determine this relationship. First, the height of the bore was varied holding slope of the beach and distance to the dune constant. This relationahip is nonlinear, as shown in Figure 3. Repeating this test for the same slope but for a greater distance (7 m compared to 3 m) to the dune yields similar results but with smaller magnitudes. The cut off at the low end of the curve (small bore heights) indicates that bores of this magnitude do not reach the dune with measurable force. Second, the impact of slope was investigated. Bore height versus awash force is plotted in Figure 4. For a

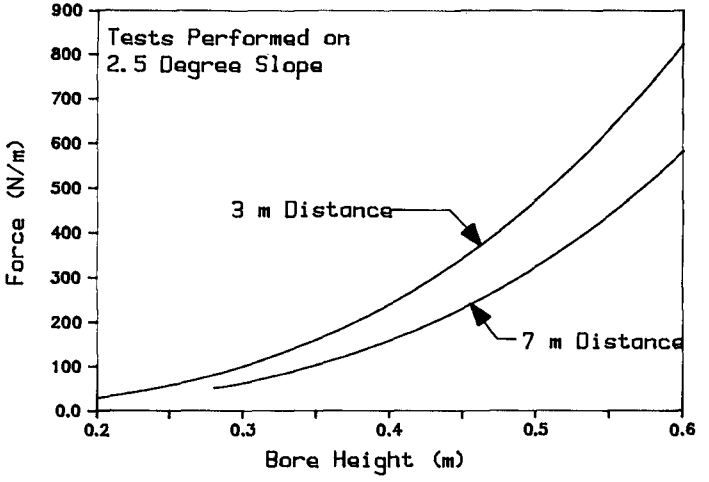

Figure 3. Swash force at the dune veraus bore height, two distances - numerical results.

given distance to the dune, the steeper beach reflecta more of the swash energy and the force at the dune is less for the same bore height when compared to that on a more ahallow slope. Once a full set of these parametric curves haa been generated for the range of applicable values, these relationships can be easily incorporated into the simulation model. This avoida having to run the hydrodynamic model each time a bore is generated on the beach.

How then are the bore characteriatics (height and distance from the dune) generated from the wave information? Wave transformation from deep water to a point of breaking is well described using any number of

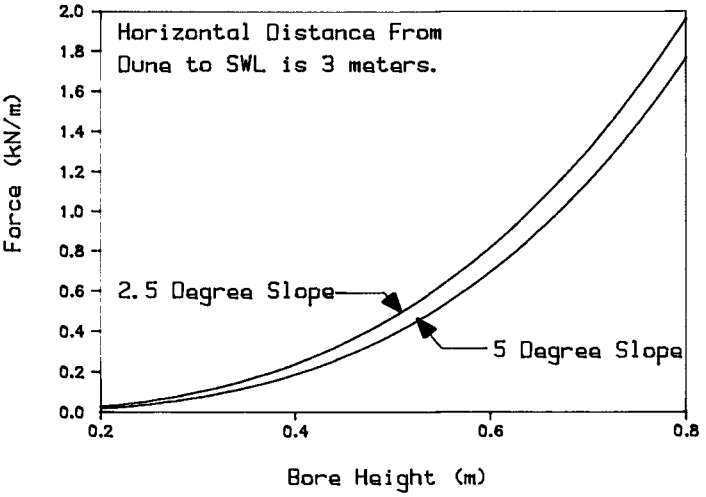

Figure 4. Swash force at the dune versus bore height, two slopes - numerical results.

accepted wave theories. It is the transformation of the breaking wave from a wave of propagation to a wave of translation in the surf zone which is not well understood but which is currently being studied by many investigators. Of particular interest for our application, is a recent set of laboratory experiments conducted by Papanicoloau and Raichlen (1987). Their primary interest was to focus on the breaking and subsequent landward propagation of solitary waves. One piece of information extracted from this set of experiments indicates that after breaking, the wave takes on a borelike form at a certain point on the beach. From this work, it is determined that the wave decays to about one half of its breaking height at the point in which it becomes borelike. The distance traveled from the breaking point is about 20 times the depth at breaking. Similar relationships were also shown to exist in an earlier paper by Svendsen et al., 1978. Therefore, given the height and depth at breaking, the height of the bore and the position along the beach can be determined.

What then are the deep water wave characteristics which represent the given storm event? A storm event can be specified in terms of its significant wave height, period and duration. At this point in the model development, we can no longer ignore the fact that a storm consists of a number of wave events which interact and alter the characteristics of a single swash. Going back through the model, how then do we account for the fact that there is a series of interacting wave components which characterize the storm environment and

not a set of isolated waves propagating without interference to impact with the dune.

Starting with the specification of the storm, we see that it is necessary to take the statistical representation of the storm and break this down into a representative set of individual waves, that is, a record of wave height versus time. Theoretically we can take each individual wave up to breaking, through the swaah zone, up the beach as a bore and calculate the force of impact at the dune. However, because of swash-awaah interactions in the surf zone, we know that each offahore wave does not generate a bore that propagates up the beach to impact with the dune. These interactions may be a function of the distance from mean water level to the dune, the dominant period and the distribution of wave periods in the offshore wave field, and the steepness of the beach as well as, perhaps, other factors. At this point this interaction, or the prediction of the swash period at the dune as a function of the offshore parameters and geometry, is not well understood. In order to better understand this phenomena for application to this model, we analyzed the 1986 and 1987 Duck data with respect to swash period. Data from eight individual field experiments were available for analysis. The offshore period, which was obtained from the offshore data which the FRF routinely collects, for these experimenta ranged from about 6 seconds to 14 seconds. Defining the swash period as the

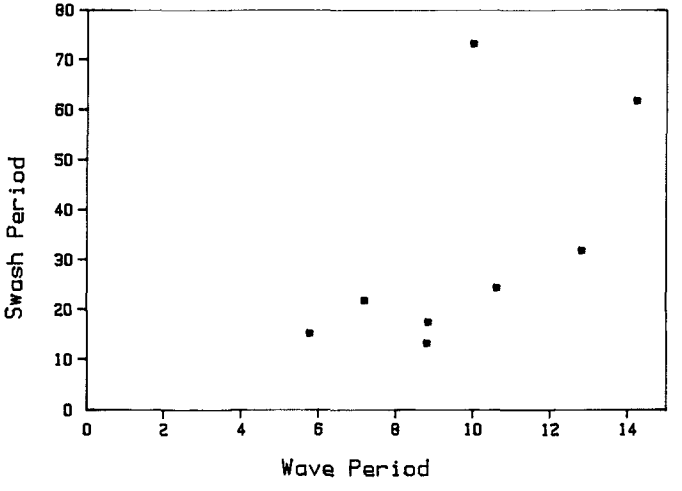

Figure 5. Offshore wave period versus swash period for field experiments at Duck, N.C.

duration of the experiment divided by the number of swash hits on the dune face during thia period, the wave period can be plotted against the swash period for these eight experimenta, Figure 5. There is no definitive correlation between theae two perioda aa evidenced by the wide range of swash periods for a given wave period. A 10 second significant wave period produced awash periods from 10 to 70 seconds during different experimenta. Attempting to determine whether distance from the dune was a dominating factor, the swaah period versua horizontal distance from the dune is plotted in Figure 6. The different symbols correlate to different experimenta. Four experiments were aubdivided into smaller time incrementa and plotted aa swash period versus distance for that aubinterval. Distance from the dune changes during the experiment as the tide risea yielding a correaponding change in swash period. However, the offahore wave period is assumed to be constant for the entire experiment. Again, there ia no definitive correlation between parameters, however, the trend of the data is intuitively correct. The awash period increases for greater distancea to the dune and for the same offshore period.

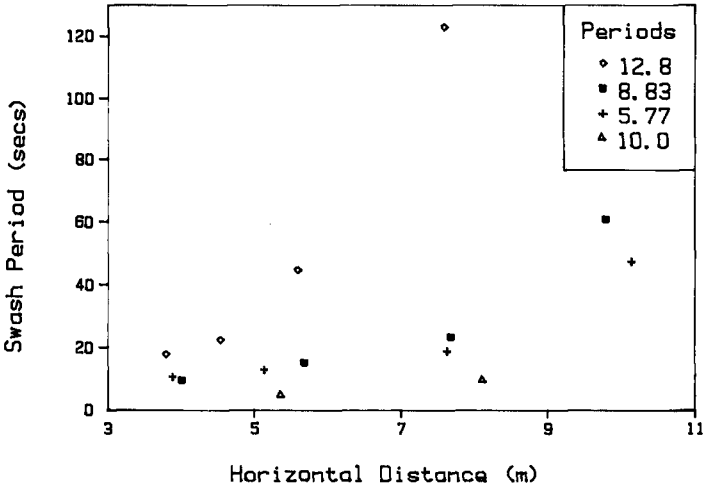

Figure 6. Swaah period versua horizontal distance from the dune for four different offshore periods.

The question remains as to how to put the model together for multiple awashes. Starting at the oceanaide, we will discuss how each component haa been treated in this current version of the model.

Model Development

The assumed input information to the simulation model at the ocean boundary is the significant wave height, the wave period and the duration of the storm event. Using a Rayleigh distribution for the wave heights, we can generate a set of wave heights corresponding to a given significant wave height. The draw back to this approach is that it does not generate a wave time series for which a wave period for each individual wave can be determined. An alternative approach to adjust for this problem is to first use the significant wave height and period and an assumed spectral shape to form a wave spectra. The wave spectra can be represented by the summation of N number of individual wave components specified by a wave height and a wave period. While this technique may not produce a truly random data set, it does identify an individual wave height with a wave period. However, at this point in the model development, we have not tried this alternative approach.

Given a Rayleigh distribution of wave heights, each wave is propagated from deep water to the point of breaking using linear wave theory. The dominant wave period is used as the period of each individual wave. This yields a depth and height at breaking. From that the height of the bore and the position of the bore on the beach is determined from Papanicoloau et al. (1987). The hydrodynamic characteristics at the dune are determined from the results from the 2-D numerical model. At this point a swash force and the subsequent volume eroded for that individual wave is computed.

How are the second and subsequent waves treated? The timing of the generation of the bores and the correlating swash period are critical.

It is assumed that each deep water wave propagates without interference to breaking. From that point a bore is generated which propagates up the beach. In the development of the current methodology for dealing with the swash period, we tried two approaches and selected the one which produced the best results. Each approach is discussed below.

The first approach uses field results to calibrate the model in the following manner. One, a wave height fitting a Rayleigh distribution is generated from a random number generator and the specified significant wave height. Two, using results from the hydrodynamic model, check whether the bore hits the dune. If not, generate a new wave height and test again. If so, calculate swash force and advance in time an increment equal to the given swash period. For this approach, the swash period for the storm event must be known.

The second approach is let the algorithm determine the swash period. For example, for any given bore depth generated the swash may or may not reach the dune given a particular beach slope and the distance from the dune. Therefore, one alternative is to simply generate the set of bore depths and let the numerical model determine whether the bore reaches the dune. If not, advance in time a time step equal to the wave period without adding to the summation of the swash force term. If so, calculate the swaah force, add to the summation series and advance in time. Obviously, using this approach there is no guarantee that the swash period of the model equals that of the field results.

Results

Four simulation tests were conducted using the 1987 Duck field data. Field data used as input in the simulation model were the offshore significant wave height and wave period, the slope of the beach, the distance from the dune to the mean water level, the change in mean water level due to the rising tide, the duration of the eroaion event, and the swash period. Data from three experiments were used. Two experiments were simulated in their entirety while the third was divided into two sub-time periods and simulated as different events. Each aet of test data was processed using both methods for dealing with the swash period. The results, erosion predicted versus eroaion measured, are shown in Figure 7 using method one, in which swash

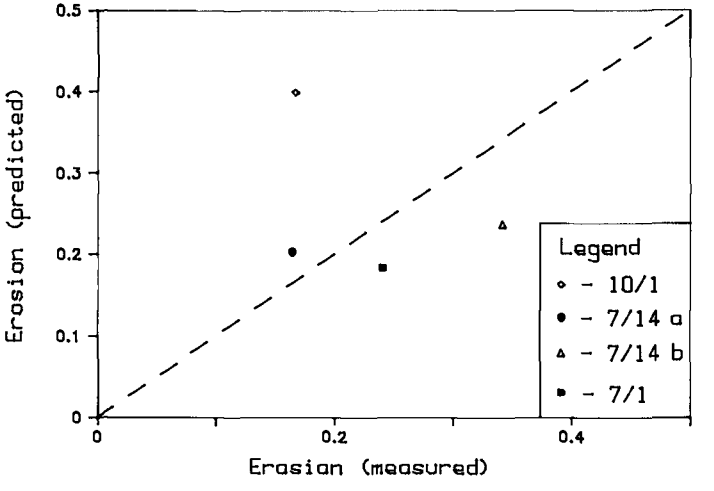

Figure 7. Predicted versus measured erosion.

period is taken as a known. As shown, three of the points are predicted fairly well, though with a tendency

to underestimate the erosion, while one point is over predicted by a factor of two. When comparing these results to those using method two, in which the swash period is determined by the algorithm, there is very good correlation between the predicted and measured for two of the points, 7/14a and 10/1. These are also the experiments which are best predicted in method one. Examining the output of this approach it is seen that the awash period as determined by the simulation algorithm closely approximates the measured swash from the field data. While it is not clear at this point why this correlation is occurring, it does point out that swash period is a significant factor in the simulation model.

Conclusions

The two key components to the simulation model are one, the relationship between the swash characteriatics and the volume of dune eroded and two, the relationship between the statistics of the storm event and the time hiatory of the swash characteristics at the dune face. While the simulation model presented herein has met with limited success and therefore has potential as a predictive tool for dune erosion, several components of the model must be refined. The most obvious of these is the swash period. While we have built a basis for predicting the magnitude of the swash force, we know little about the relationship between the timing of offshore waves and the timing of those waves which impact with the dune. Advances in the understanding of this phenomena will lead to an improved simulation model.

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