CHAPTER 106

DUNE EROSION AND SEDIMENT PROFILE DUE TO WAVE UPRUSH

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Introduction

Shorelines are continuoualy adjuating in reaponse to the changing hydraulic and meteorological conditions. Storms that generate large waves and surge conditions can alter the nearshore topography and relocate the beach shorelinea, often with aubstantial amounts of beach and dune eroaion. Such storms poae a major threat to coastal developments for which the economic impact can be significant. The ability to predict the rate of erosion and, consequently the shoreline change, is important in making decisions regarding the planning and managing of the coastal regions.

In general, the available methods for the prediction of beach and dune erosion are baaed on the assumption of post-storm equilibrium profile. In this approach it is assumed that, for a given aet of wave and aurge conditions, the entire beach reachea a steady-state, and that the volume of aand released from the dune is equal to the volume of sand required to establiah this profile. Exiating methods that are baaed on this concept include thoae developed by Edelman (1968, 1972), Vellinga (1982, 1983, 1986), Kriebel and Dean (1984), Sargent and Birkemeier (1985), and Kobayaahi (1987). The reliance of these methods on the aasumption of steady-state condition limits their application to extreme eventa generated by aevere storma. Generally, storma do not have aufficient duration or intenaity, such that the beach profile attains equilibrium during the storm.

A numerical model haa been developed to predict beach adjuatment due to dune erosion during a aingle storm event. In thia model, the estimation of the shoreline change is based on the mechanics of aediment-

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swaah interaction at the dune face, Overton, et al. (1988). This approach eatimates the magnitude of dune erosion and beach adjustment associated with each swash, with no dependency on an equilibrium beach profile. Therefore, for a given storm condition, the total change in the beach profile is determined by a series of swash attacks. This technique has the advantage of considering small eventa in which post-atorm equilibrium conditions can not be reached, as well as extreme events. In the numerical scheme presented herein, attention is restricted to the prediction of dune erosion and subsequent beach adjustment due to a single swash.

Methodology

The dune erosion and sediment profile model consists of three distinct components - the hydrodynamics of a bore impacting a vertical barrier, the volume of sand eroded from the dune due to that impact, and the redistribution of that volume of sand on the beach face during the subsidence of the bore. The firat two components have been diacussed elsewhere in the literature and will be discussed herein only briefly. Attention is focuaed on the development of the third component of the model - the adjustment of the beach face due to the erosion event.

The wave uprush is idealized as a bore propagating over a sloping beach. Input data include the depth of the bore at the seaward edge, the slope of the beach, the location of the dune relative to the mean water level, and the sediment characteristics. The bore motion on the beach ia described uaing a two-dimensional hydrodynamic model. This model solves the momentum and continuity equations using a finite-difference technique. The finite-difference mesh is placed at right anglea to the beach face in order to aimplify computations. The model determines the bore height and velocity as it travels up the aloping beach, impacts with, and retreata from the onahore barrier (dune). The solution algorithm of the velocity and preasure fields are based on a modified SOLA-SURF code, Hirt et al. (1975). Modifications include those which incorporate the sloping beach and the moving boundary of the borefront. The hydrodynamics of the bore model are verified using a aimplified analytical solution for the horizontal bed case, as well as a series of laboratory experimenta for the sloping bed case.

The volume of aand released from the dune by the impacting bore is computed in terms of a force parameter which in turn is a function of a the flow characteristica at the dune face. This functional relationship is derived from laboratory tests designed to isolate a single bore and determine its erosive power, Overton, et al. (1988). This relationship has been modified for use in the hydrodynamic model, Overton, et al. (1987).

The amount of sand extracted from the dune is rediatributed in front of the dune by the retreating bore. The reaulting sediment profile ia computed as a function of the backwaah flow parameters and the sediment characteristics. The third component of the model which predicts the deposition pattern in the dune vicinity is based upon both theoretical considerations as well as laboratory results. Because of the nature of the flow pattern at the wall and the importance of turbulence in the mechanica of aediment transport, laboratory experiments were conducted for the development, calibration and independent verification of the model.

Experimental Study

Wave Flume:

The experiments were performed in the Civil Engineering wave flume at North Carolina State University. The glasa walled flume, ia 15.0 m long, 0.6 m wide, and 0.9 m deep. Young (1986), in his investigation of dune erosion due to wave uprush, modified the flume to isolate a aingle bore. The flume waa divided by a sheet of plywood into two portiona. The lower portion was used as a reaervoir, and the upper portion as the main channel with plywood surface bottom aa shown in Figure 1. A head tank, equipped with back and front rotating gates, was installed inside the flume. The head tank was 1.8 m long, 0.6 m wide, and 0.6 m deep. The front gate was equipped with a cantilever weight and springs allowing a sudden release of the gate and, consequently, the water in the head tank. The water released from the head tank formed a

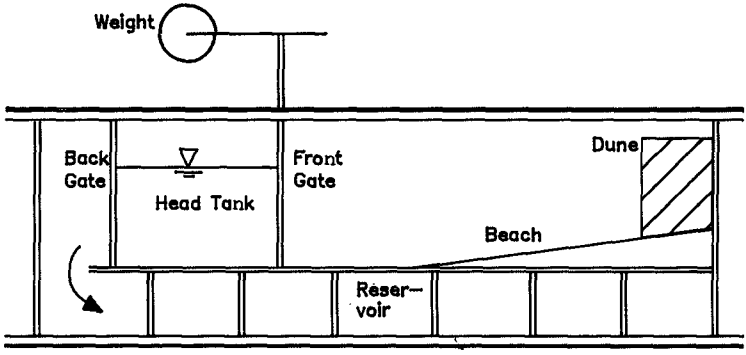

Figure 1. Schematic Diagram of Experimental Setup.

bore propagating on the aloping beach. Aa the bore impacted with the upstream boundary and retreated, the

back gate was opened, using a release spring, allowing the backwash to flow back to the reservoir and thus preventing reflection. A plywood beach, 2.4 m long, was installed at an sngle of three degrees to the horizontal bottom of the channel and 1.2 m in front of the hesd tsnk. A vertical barrier of plywood was erected at the end of the sloping beach to serve as the dune boundary.

Dune Model:

The sand dune model was constructed in a box inside the flume. The box extended the full width of the flume and had a fixed back board and removable front. The sand used to build the dune had a mesn grain size, d_{50}, of 0.68 mm and a grain size distribution as shown in Figure 2. The oven dried sand was then rained into the

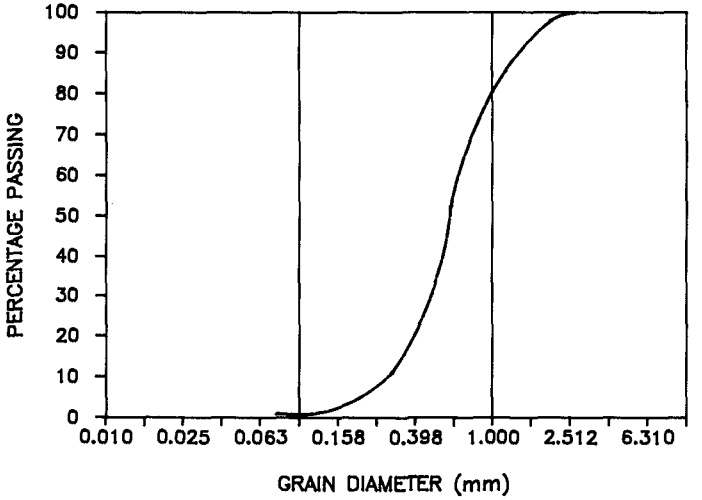

Figure 2. Grain Size Distribution Curve.

box from a constant head of 0.3 m so that a uniform degree of compaction was attained. The sand was rained in using a shallow plastic tray containing two rows of 8 mm diameter holes, three holes in each row. After the sand set in place, 7.5 l of water were poured at the top of the dune at a slow, constant rate. The dune was then allowed to drain for 30 min through holes provided in the front board. The amount of wster and the drainage time were determined such that a sufficient strength was developed in the dune to maintain s vertical face when the front was removed. After removing the front of the box the first 6 cm of the dune front were scraped away to eliminste any cracks or instabilities caused by the ssnd leaning on the front board.

A video caasette recording syatem equipped with time display and single frame sdvancement waa used to record the impact of the bore with the upstream boundary in sll tests. A transpsrent plastic sheet containing s scale, used to depict the initial dune and beach profiles before each run, was mounted on the glsss side of the flume, covering the dune area and extending in front of the dune about 100 cm. In addition, a 35 mm camera was utilized to record the dune and beach profiles immedistely before and sfter each test.

Experimentsl Procedure:

The dune was constructed st the upstream boundary of the flume and the entire aloping besch was covered with a uniform layer of sand. The sand layer was 4.0 cm thick and had the same characteriatica as that of the dune. Two sets of tests, st initial head tank elevations of 23 cm, and 26 cm, were conducted. Each set of tests had three repeats at the same head tank water level. In addition to the video tape, still photos of the initial dune and beach profile before each test, and the eroded dune profile and deposition pattern after the completion of each test were also taken. One photo was taken normsl to the front of the dune to record the uniformity of the eroded profile across the width of the dune.

The volume of sand eroded from the dune, and the deposition pattern in the dune vicinity were computed from still photos. The negstives of the still photos wsre mounted on slides and then projected on a screen so thst the eroded dune profile and deposition pattern could be traced on a sheet of paper. The eroded area of the dune and the sedimentation curve were then determined utilizing a Summagraphics Model 1201 digitizer board and Sigmascan computer software.

Sediment Profile in the Dune Vicinity

Generally, the eroded volume of dune sediment deposited on the beach is a function of the retreating bore flow vsriables snd sediment characteriatics. In order to determine the backwash flow variables thst best represent the sediment profile, it is important to anslyze: (1) the laboratory results of the deposition pattern and (2) the flow behavior ss described by the verified numerical scheme. Based on visual observstions of seversl flume tests, the volume of sand eroded is agitated and kept in suspension by the highly turbulent flow. As the bore begins to retreat, the flow becomes more stable and most of the sediment load is observed to quickly settle with the exception of the smsller size particles. In other words, the deposition psttern is mostly controlled by the flow parameters of the less turbulent backwash snd not the flow field at the time of impact. Laboratory results slso show that the sediment profile extended spproximately 25 cm in front of the dune. A significsnt volume of the aediment load,

conaisting mainly of large to medium size particlea, is depoaited in the first 10 to 15 cm.

The numerical hydrodynamic results reflect qualitatively what was seen in the laboratory. During the period of impact of the bore with the dune, the flow field (velocity and depth) is highly unstable, Figurea 3 and 4. The depth increasea rapidly while the velocity

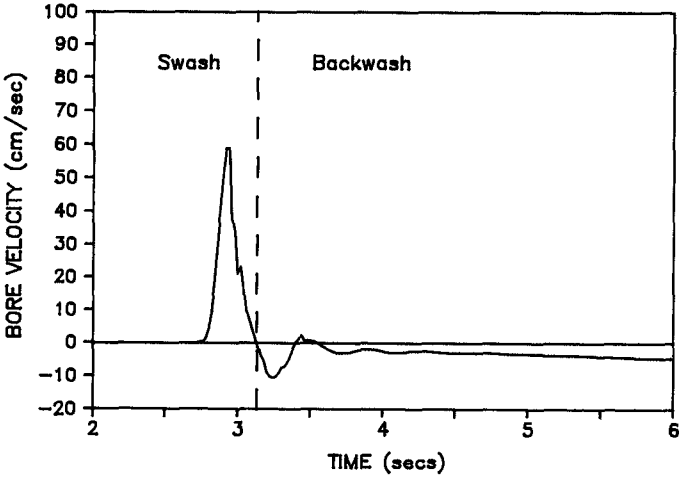

Figure 3. Bore Velocity Averaged over Depth at 6 cm from the Dune Face, Initial Depth of 26 cm.

goea to zero. As the backwash process begins, the depth begins to decreaae and the velocity reversea direction. Both velocity and depth then stabilize changing almost linearly with time. The flow field in the 25 cm in front of the dune varies predictably with distance from the dune. The maximum depths and velocities are reduced and there is a ahift in time for the maximum but the general shape of the curves ia the aame aa that in Figures 3 and 4.

Baaed on the above analyais, the sediment profile in front of the dune ia computed in terms of the backwaah flow height and velocity in the 25 cm adjacent to the dune face and the aediment properties. The flow height is defined aa the average height in this regime. The water height is obtained by computing the water height in each time increment and then averaging over the time period that the bore is in contact with the dune and propagating down slope. The flow velocity ia defined as the depth averaged velocity in the aame 25 cm in front of the dune and over the aame period of time.

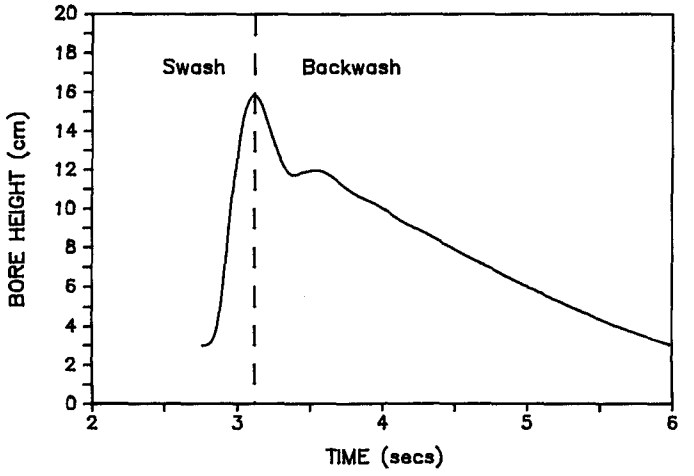

Figure 4. Bore Height at 3 cm from the Dune Face, Initial Depth of 26 cm.

The sediment characteristics utilized in this algorithm are the specific weight, the grain size distribution, and the fall velocity. The sand used in this model has a specific weight of 2.65, and grain size distribution as shown in Figure 2. The fall velocity of the sand particles is computed using the following equation, Henderson (1966)

$$W_s = C\,[(SS - 1)gd_s]^{1/2} \qquad (1)$$

and,

$$C = \left[\frac{2}{3} + \frac{36\,n^2}{gd_s^3(SS-1)}\right]^{1/2} - \left[\frac{36\,n^2}{gd_s^3(SS-1)}\right]^{1/2} \qquad (2)$$

where n is the kinematic viscosity of the fluid, d_s is the grain size diameter, and SS is the specific gravity of the sediment.

Having determined the retreating flow height and velocity, and sediment properties, the sedimentation profile in the dune vicinity is computed as outlined below.

(1) The grain siza distribution curve is subdividad into representative intervals. The sadiment volume ratio (V_r) and the average grain size diameter (d_s) for each interval are determined.

(2) The fall velocity (W_s) of each grain aize is computed using Eq. 1. The settling time (t_s) of each particle is then calculated as the ratio of the average backwash height, and its fall velocity (W_s). The maximum distance (X_s) travelled by each grain size ia computed in terms of its settling time (t_s) and the average backwash velocity.

(3) In order to determine the depth of deposition (Y_s) for a given grain size (d_s), it is assumed that its corresponding volume of aand (V_r) is uniformly distributed over the area of deposition. The depth of deposition is then computed as the ratio of the volume of sand eroded over the deposition area. The area over which a given grain size may be distributed is estimated based on the study of the mechanism of sediment transport and laboratory viaual observations. In general, the smaller the particle aize, the longer a particle will stay in suspension. Therefore for a given sand aample which has a wide range of particle sizes, the small sand particles at the lower end of the curve have a relatively longer settling time than those at its upper end. Thus, based on the settling time of each grain size, most of the small grains do not settle in the immediate vicinity of the dune as do those of large grain sizes. In order to determine the deposition area of the small particles, the point where they begin to aettle should be estimated firat. This is done by arbitrarily dividing the grain size distribution curve into three zones: lower, middle, and upper. The lower and upper zones consiat of the relatively small and large grain sizes, $d_s<0.5$ and $d_s>1.0$, respectively, while the middle zone consists of the rest of the sand particles, $0.5\leq d_s\leq 1.0$. In order to prevent the smaller size particlea, ($d_a<0.5$) from settling too soon, it is required that the deposition area for the lower zone material begins at a distance in front of the dune equal to the travel distance of the smallest particle in the upper zone. The depoaition depth (Y_s) is computed as the ratio (V_r/X_d).

(4) Finally the individual deposition patterna of each distribution interval are superimposed to yield the total sedimentation profile due to a single wave awash in front of the dune.

Results

Applying the above methodology as the third component of the erosion and sediment profile model, the redistribution of sediment in front of the dune after the retreat of a single swash event can be computed numerically. Two tests at different head tank levels were conducted in the laboratory. The first of these, with a head tank level of 26 cm, was used to qualitatively study the process and to aid in the development of the model. The numerical versus the experimental results are shown in Figure 5. Note that

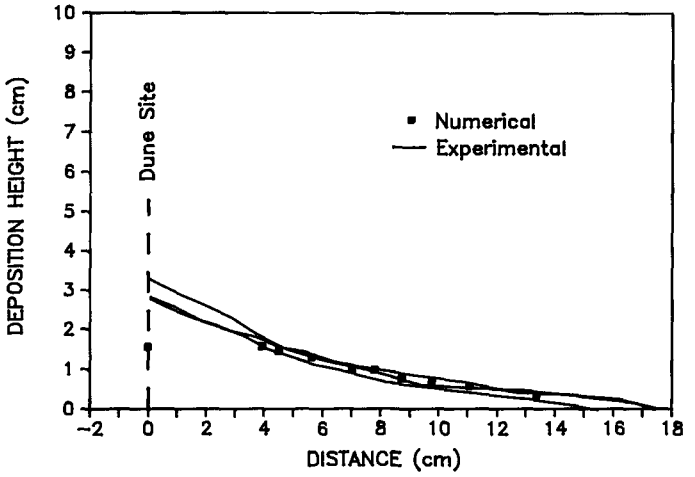

Figure 5. Comparison of Numerical and Three Replicate Experimental Sediment Profiles, Head Tank Level, 26 cm.

the high degree of correlation between the numerical and the experimental results is because the data were used to calibrate the model. In order to further test the ability of the model to reproduce deposition patterns, an independent set of data at 23 cm initial head tank elevation was used. The numerical model was run with head tank elevation set at 23 cm with no additional adjustments to the model. Figure 6 shows comparison of numerical and experimental beach profiles obtained. The model closely predicts the experimental results though with a slight over estimation of the depth of deposition along the beach face. Based on the limited number of cases investigated to date, it is shown that this approach is a viable alternative to use in the prediction of beach and dune erosion due to a storm event.

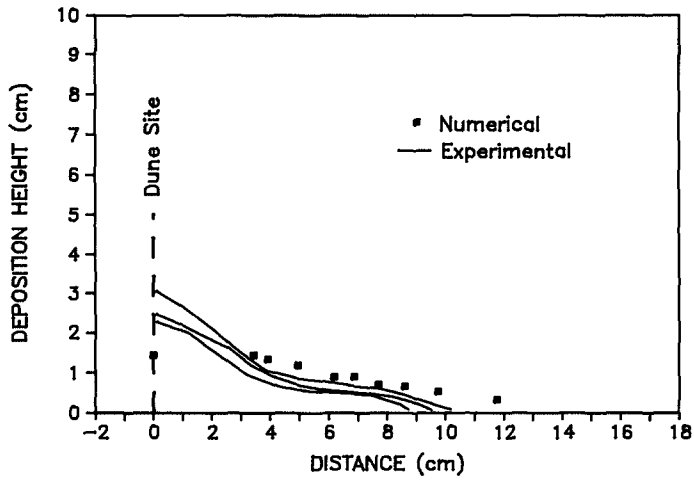

Figure 6. Comparison of Numerical and Three Replicate Experimental Sediment Profiles, Head Tank Level, 23 cm.

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