

BEACH EROSION MODEL (EBEACH) USERS MANUAL
VOLUME I: DESCRIPTION OF COMPUTER MODEL

by

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FOREWORD

This users manual describes the numerical computer model EBEACH which is designed to estimate the time-dependent beach-dune erosion associated with severe storm such as hurricanes or northeasters. The users manual is presented in two parts: volume I contains a description of program logic and variables used, volume II provides a more thorough discussion of background theory and model verification. The original research pertaining to the EBEACH model was conducted by the author under the direction of Robert G. Dean as part of the author's Master or Civil Engineering degree at the University of Delaware. The research phase was supported by the National Oceanic and Atmospheric Administration and the Delaware Sea Grant College Program.

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BEACH EROSION MODEL (EBEACH)

I. INTRODUCTION

This report describes the programming requirements of the EBEACH model developed at the University of Delaware by David L. Kriebel and Dr. Robert G. Dean. The background theory, numerical scheme, and model results are presented in Volume II. This volume includes definitions of program variables, a description of input requirements, and a summary of the programming considerations for each subsection of the model.

As a brief review, the objective of this model is to determine time dependent beach-dune erosion resulting from a severe storm surge. The model includes a steady state solution of the equation of continuity for conservation of sand in the onshore-offshore direction:

$$\frac{\partial x}{\partial t} = - \frac{\partial Q_s}{\partial h} \quad (1)$$

This equation is solved simultaneously with a sediment transport relationship based on Dean's (1977) theory that the equilibrium form of the beach profile, defined by the curve:

$$h = Ax^{2/3} \quad (2)$$

is the result of uniform wave energy dissipation per unit volume in the surf zone. This transport equation:

$$Q_s = K (D - D_{eq}) \quad (3)$$

explains the total sediment transport flux, Q_s , in terms of a disequilibrium between the actual energy dissipation, D , and the energy dissipation at equilibrium, D_{eq} . The transport parameter, K , relates the sediment transport volume to the excess energy dissipation in the surf zone.

As input, the model requires a schematic beach profile representation that includes a linearly sloping beach face, a uniform berm height, a variable berm width, a linearly sloping dune face, and uniform dune height. With this initial profile approximation, an actual or predicted storm surge hydrograph is read into the model and the storm surge level at each time step governs the energy dissipation per unit volume, the sediment transport flux, and the rate of profile change. Also, an estimate of the breaking wave height as required to limit the width of the active surf zone.

The output of the model consists of the time-history of:

- (1) The horizontal retreat/advance of any contour elevation.
- (2) The beach profile cross section.
- (3) The total eroded volume per linear foot of shoreline.

These may be compared to the storm surge hydrograph to determine the relative time scales of profile changes and the water level variations. In Volume II, the discussion of the general model results show that, qualitatively, the model captures the essential characteristics of the time dependent beach-dune erosion. Also, in a comparison of model results to field measurements of dune-erosion during hurricane Eloise, it appears that the numerical model gives good quantitative agreement with observed erosion characteristics.

II. PROGRAM DESCRIPTION

The flow chart for the EBEACH simulation model is shown in Figure 1. As mentioned, the user must initially input the schematic beach-dune profile characteristics, from which the discrete form of the initial profile is established. The main program consists of a DO loop in which each iteration represents one time step, simulating one-half hour of real time. At the beginning of each iteration, the water level and wave height for the time step are entered into the program from a data file. From the updated water level and wave height, the surf zone and active onshore profile limits are established according to the wave breaking depth and the location of the new water level relative to the onshore portion of the profile.

With the boundary conditions defined, the active profile is divided into two regions:

- (1) The dynamic region below the water line, in which profile changes are governed by the calculated energy dissipation and continuity.
- (2) The geometric region, above the water line, in which profile changes are governed by continuity only.

In the main program, several DO loops are included to calculate profile changes in the dynamic region. First, the energy dissipation per unit volume and the sediment transport function are determined. Then, to solve the implicit finite-difference form of the governing equation, a recursion relationship is introduced, and a double-sweep solution is employed. Starting from an onshore boundary condition for sediment transport, an offshore sweep is used to determine coefficients in the governing equation; then, starting from an offshore boundary condition, defining the limiting depth of profile change, an onshore sweep is used to determine the horizontal change for each point in the profile up to near the current water level.

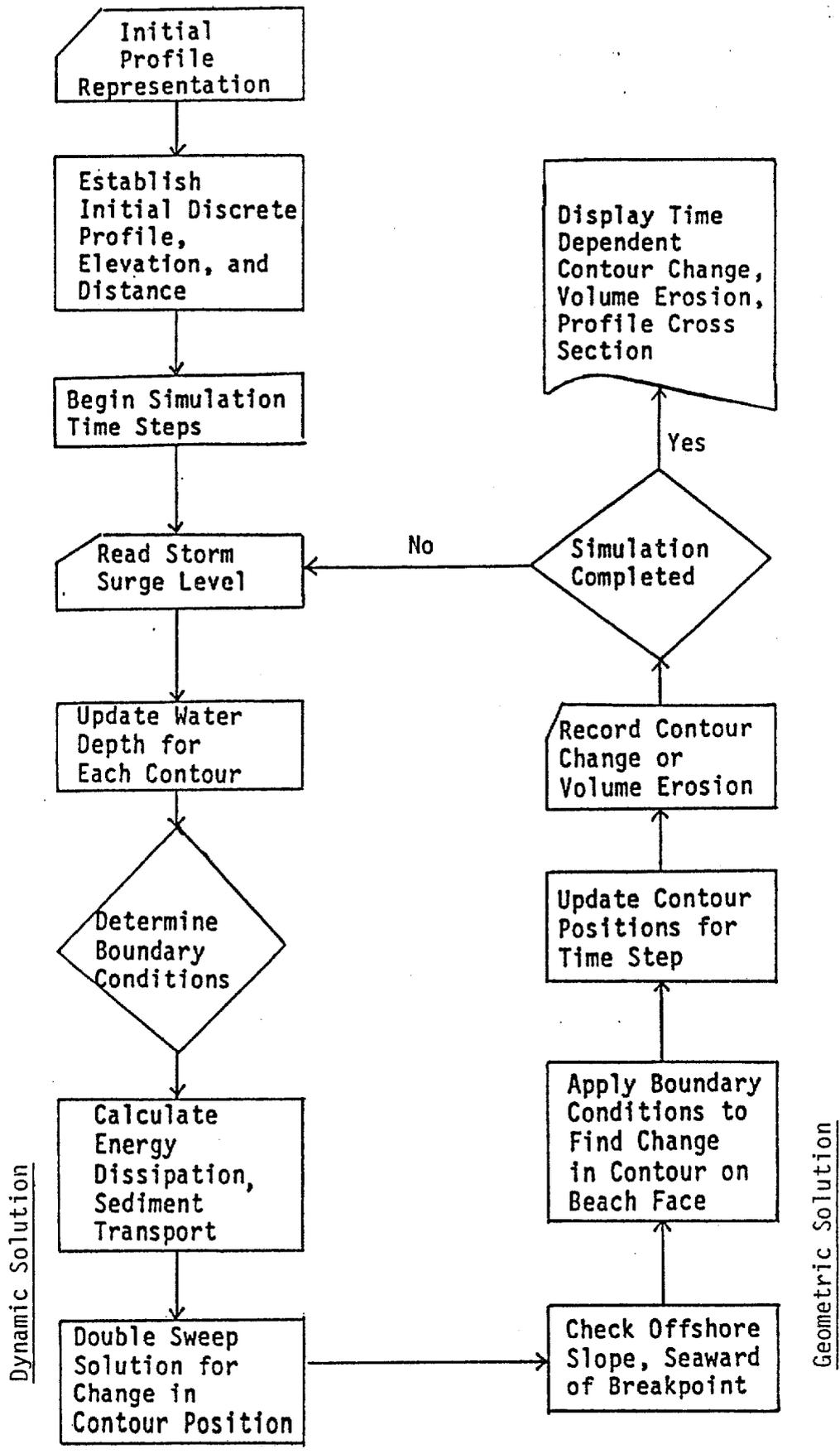


Figure 1 Flow Chart for the EBACH Simulation Model

From this point landward, the profile is governed by continuity according to changes in the offshore profile and the limits of onshore sediment motion. Similar to storm surge-flooding models that "flood" land by opening and closing discrete cells, this model activates erosion in portions of the onshore profile by opening and closing sections of the composite beach-dune face. This procedure is based on the elevation of the water line and the profile shape, principally depending on the berm width. Offshore, at the breaking depth, a loop is included to geometrically maintain a smooth transition between the active surf zone and the adjacent offshore profile.

At the end of the main loop, the final profile changes over the time step resulting from the dynamic and geometric solutions, are recorded as the incremental retreat or advance of each contour line. This updated profile is then used as the initial condition for the next time step and this process is repeated for the duration of the storm surge.

III. VARIABLE LIST

3.1 Spatial Variables

N = Counter to identify the number of each grid point.

H1(N) = Initial contour elevation at each grid point in feet above mean sea level (MSL); - if above MSL, + if below MSL.

X1(N) = Initial horizontal distance from baseline to each grid point in feet; positive when seaward of baseline.

H(N) = Updated contour elevation in feet, relative to current water level.

X(N) = Updated horizontal distance in feet.

DELX(N) = Incremental change in horizontal position of each grid point over time step in feet; positive seaward.

WSEL(LTIME) = Storm surge elevation for current time step in feet above mean sea level; stored in data file initially. Note: WSEL(LTIME) may be stored either as exact elevation or rounded to next larger 0.5' increment. In program, each value is rounded to next larger 0.5' increment for use in erosion simulation.

WSELEV = Original WSEL(LTIME) at each time step.

WAVE(LTIME) = Breaking wave height at current time step in feet; stored in data file initially.

WH = Constant wave height in feet; may be used in place of WAVE(LTIME).

DH = Vertical grid spacing, equal to 0.5'.

BDPT = Breaking depth in feet; equal to 1.3 times wave height.

HBERM = Height of berm or elevation of a break in slope from beach face to dune face in feet; input as positive value, in data file.

HDUNET = Height of dune in feet above MSL; input as positive value in data file.

XDUNET = Initial horizontal distance from baseline to crest of dune in feet.

XBERM = Initial horizontal distance from baseline to crest of berm or change in slope from beach face to dune face in feet.

XMB = Beach face slope; input as positive slope in decimal form.

XMD = Dune face slope; input as positive slope in decimal form.

NBERM = Grid point at crest of berm; remains constant for each simulation.

NSTOP = Grid point boundary condition where $Q_s = 0$ on beach or dune; always equals either NBERM or 1 depending on water level and berm width.

NBREAK = Grid point boundary condition defining breaking depth offshore.

NFLAG = Counter to indicate width of berm; NFLAG = 0 if wide berm has eroded-or-if no berm is present initially.

HSTARI = Initial depth of intersection between beach face slope and concave-upwards equilibrium profile. From Table I in Volume II.

HSTAR = Depth of intersection at each time step; initially equals HSTARI, changes to 0 when water level is on dune face and no berm is present, changes to $H(NBERM)$ when water level is on dune face and berm is still present.

XCRIT
XHCRT = Critical horizontal spacing used to check berm width, offshore slope.

XDUNE = Change in horizontal position for contour elevation of top of dune.

X20
X15
X10
X 5

Change in horizontal position of contour elevations at 20', 15', 10', and 5' above MSL, respectively.

XMSL = Updated horizontal position for contour elevation of original mean sea level.

VOL = Change in volume for each vertical cell from initial position to new position at current time step in ft.³/ft.

SUMVOL(N) = Cumulative net change in volume from NMAX, shoreward to grid point N. SUMVOL(N) must equal zero at top of dune for continuity to be satisfied in profile.

VOLCHK = SUMVOL(1) or SUMVOL at top of dune; used as check on continuity, must equal zero.

VOLERO = Volume eroded in yd.³/ft.

3.2 Temporal Variables

T = Real time counter in hours, increased in increments of ½ hour.

DT = Real time increment in seconds determined by stability criteria.

LTIME = Time counter in main program loop; increased in increments of 1 for each ½ hour.

JTIME = Time counter determined by stability criteria such that MAX real time simulated at JTMAX equals ½ hour.

Example - If DT = 1800 seconds, then JTMAX = 1 and JTIME counter equals real time increment of ½ hour.

If DT = 300 seconds, then JTMAX = 6 and JTIME counter equals real time increment of 1/12 hour.

3.3 Variables for Dynamic Solution

A = "A" parameter or shape factor in $Ax^{2/3}$ profile shape. Determined from mean sand grain size. Note: Due to discrete profile approximation, profile shape is governed by finite difference form of energy dissipation equation using equilibrium energy dissipation value. Therefore, A value is input to determine DISSE but is not actually used in calculations.

DISSE = Equilibrium energy dissipation per unit volume associated with sand grain size and A parameter. From Figure 11 in Volume II, or equal

to $46.3 A^{1.5}$.

KQ = Transport coefficient defining sediment transport volume in terms of excess energy dissipation per unit volume. Determined by Moore (1982) as $0.001144 \text{ ft.}^4/\text{lb}$.

KD = Energy dissipation coefficient equal to $\frac{1}{4} \gamma \kappa^2 \sqrt{g}$ or 55.24.

DISS(N) = Energy dissipation per unit volume occurring in cell between grid points N and N-1.

QS(N) = Sediment transport flux between grid points N and N-1; initially unsmoothed, smoothed for use in dynamic solution.

Q1(N) = Working variable used in smoothing function.

QQ = Smoothed sediment transport flux at HSTAR; sediment transport curve extended uniformly from QQ to zero at NSTOP in increments of QQQ.

NQQ = Grid point at HSTAR.

BDT }
AN }
BN } = Double sweep coefficients defined by DISS, QS, DT, DH, and
CN } = horizontal grid spacing.
ZN }

E(N) }
F(N) } = Double sweep coefficients defined by recursion formula; used to calculate DELX.

κ = Ratio of breaking wave height to breaking depth.

3.4 Variables for Geometric Solution

NSTAR2 = Grid point at HSTAR.

DELSUM = Change in cumulative volume required to satisfy continuity in profile at end of time step NSTAR2 and $N = 1$,

HAVSUM = Change in cumulative volume at beginning of time step between NSTAR2 and $N = 1$.

IV. OCEANOGRAPHIC INPUT DATA

4.1 Storm Surge Data

Two types of storm surge input may be used:

- 1) The actual measured storm surge hydrograph.
- 2) The calculated storm surge hydrograph resulting from a numerical storm surge model.

For standard model application, the numerical storm surge predictions of Dean and Chiu (1981) are input directly into the model. However, by following the specified formats any storm surge hydrograph may be utilized. It should be noted, however, that model does not allow dune overtopping. Therefore, the model should only be used in cases where dune crest is higher than peak storm surge elevation.

The water surface elevation must be listed at one-half hour intervals for the duration of the storm surge. In the main DO loop, the time counter, LTIME, is increased by 1 for each time step, to a maximum, LTMAX, which is determined from the time history of the surge hydrograph. The real time counter, T, increases by 0.5 hours each time step. To supply the storm surge data, the water surface elevation at each time step, WSEL(LTIME), is listed according to the format specifications. Initially, when LTIME = 1, T = 0.5, and WSEL(1) = 0.0. Since the model uses discrete vertical cell widths of 0.5 feet, the storm surge at any time is approximated to the next greatest multiple of 0.5 feet. The current water level is then compared to the previous water level to determine the incremental change in water level, DELWS, at the beginning of the time step.

4.2 Wave Height Data

Two methods may be used to input the wave height:

- 1) The observed, hindcast, or forecast wave height can be read at each time step from a data file.
- 2) A constant representative wave height can be used as a simple approximation.

As noted in Volume II, the exact determination of the wave height is of secondary importance in the numerical solution. From Figures 17 and 18 and Table II changes in wave height have less effect on the storm erosion than changes in the water level. For storms of short duration, a constant wave height of greater than 7 to 10 feet may often be used to obtain a quick estimate of beach-dune changes.

Note: Wave heights of less than about 5 feet probably should not be used in any simulation. For smaller wave heights, end effects associated with the smoothing function applied to the sediment transport curve can significantly change beach recession rates. For simulation of storm conditions where wave heights are greater than 5 feet, these effects seem to be negligible.

V. INITIAL PROFILE REPRESENTATION

The schematic beach profile characteristics are depicted in Figure 2. The offshore profile shape is governed by two parameters, the shape factor, A , and the equilibrium energy dissipation per unit volume, $DISSE$. For a given sand grain size, these values are determined from Figure 11 in Volume II or may be determined by fitting the $x^{2/3}$ curve to the actual profile. Onshore, the composite beach-dune profile is defined by the height and horizontal location of each break in slope. Generally, a representative beach face slope, XMB , and dune face slope, XMD , are determined for the profile of interest. Then, the dune height, $HDUNET$, the berm height, $HBERM$, and the depth of intersection, $HSTARI$, are specified. Note: Depths below sea level are defined as positive and elevations above sea level are defined as negative. Unless otherwise specified all elevations and distances must be given in feet, rounded to the nearest one-half foot. Refer to Figure 2 for physical interpretation of each variable.

To establish initial horizontal locations of various points, the profile must be classified into one of two types. In Figure 3a, if the profile has a wide berm, two horizontal distances from the reference baseline are required: (1) the distance to the top of the dune, $XDUNET$; (2) the distance to the top of the berm, $XBERM$. In Figure 3b, where no broad berm is present, only the distance to the top of the dune, $XDUNET$, is needed. $XBERM$ is set to equal 0.0.

To completely define the profile shape, it is necessary to consider a stair step approximation of the profile, as in Figure 4. To provide a reasonable level of detail in the erosion simulation, a uniform vertical spacing, DH , of 0.5 feet is used. For the finite difference solution, the grid points, N , are considered to be at the center of each vertical cell. Each cell is then identified by its grid number; such that at the top of the dune, $NDUNET$, corresponds to $N = 1$.

Offshore beyond the limit of sediment motion, $N = NMAX$. Note that the dimension size of the dimensioned arrays must be greater than $NMAX$. Several important grid points, the top of the berm, $NBERM$, and the foot of the dune, $NDUNEF$, must be specified; $NDUNEF$ must always equal $NBERM - 1$.

To establish the initial profile shape, the elevation of each grid point is first established. From the initial elevation, $H1(N)$, the initial location of each grid point, $X1(N)$ is also determined according to the profile specifications above. While $H1(N)$ and $X1(N)$ values do not change throughout the program, two working arrays $H(N)$ and $X(N)$ are established to update the elevations and horizontal positions for each time step.

Note: To simulate a wide berm profile, a GO TO control defines the location of the grid point $NBERM$ from the input value of $XBERM$. To simulate a profile with no berm, $XBERM$ is entered as 0.0. This establishes the berm location at the change in slope from the dune to the beach face.

It should also be noted that because of the finite difference solution for energy dissipation, the offshore profile shape

$$h = Ax^{2/3} \quad (4)$$

must also be approximated in a discrete fashion. To do this, the energy dissipation equation must be used to determine the equilibrium horizontal grid spacing, $(X_n - X_{n+1})$ based on the equilibrium energy dissipation, $DISSE$. This approximation results in a slightly shallower profile than the continuous $Ax^{2/3}$ profile.

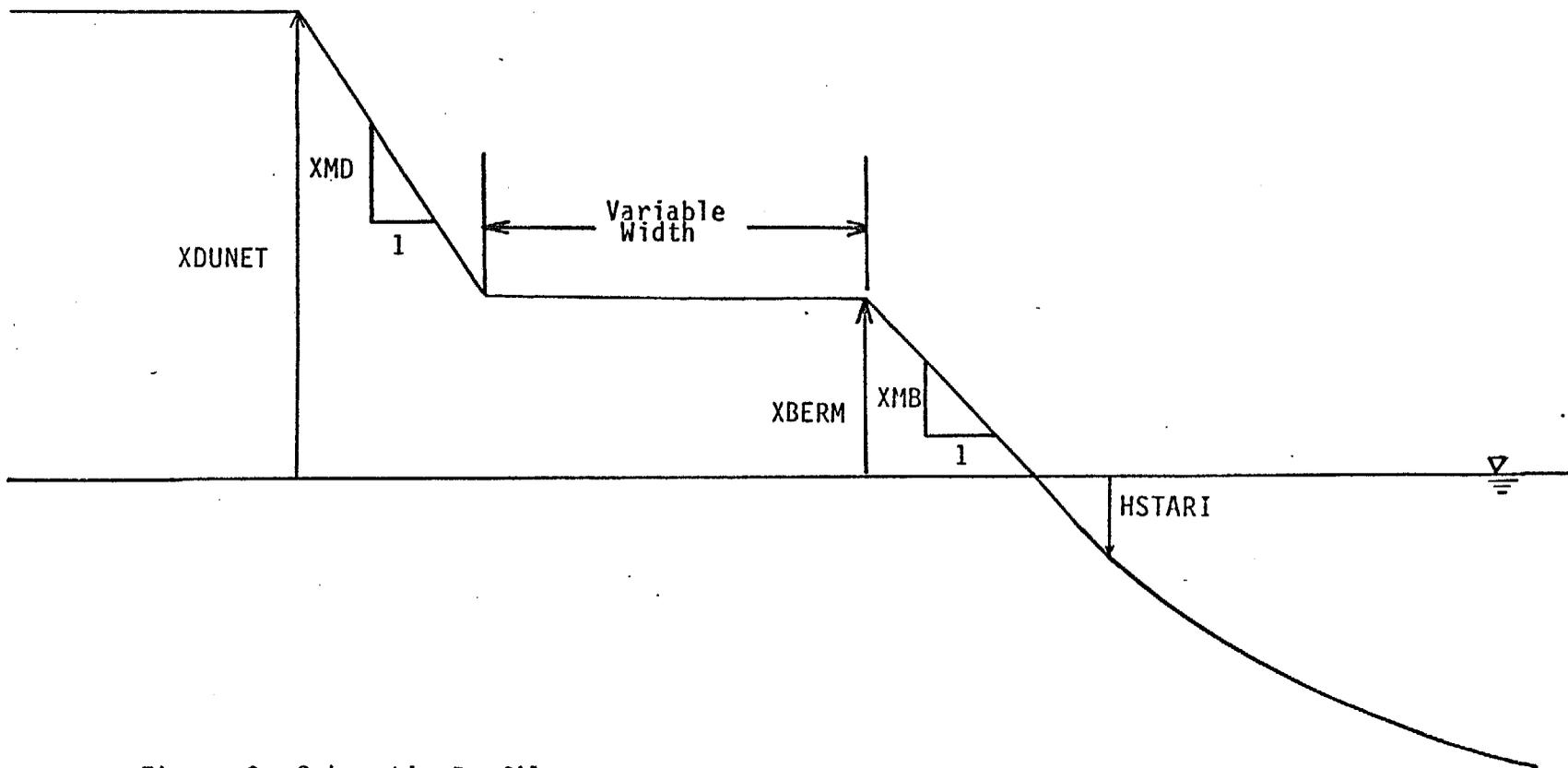


Figure 2 Schematic Profile

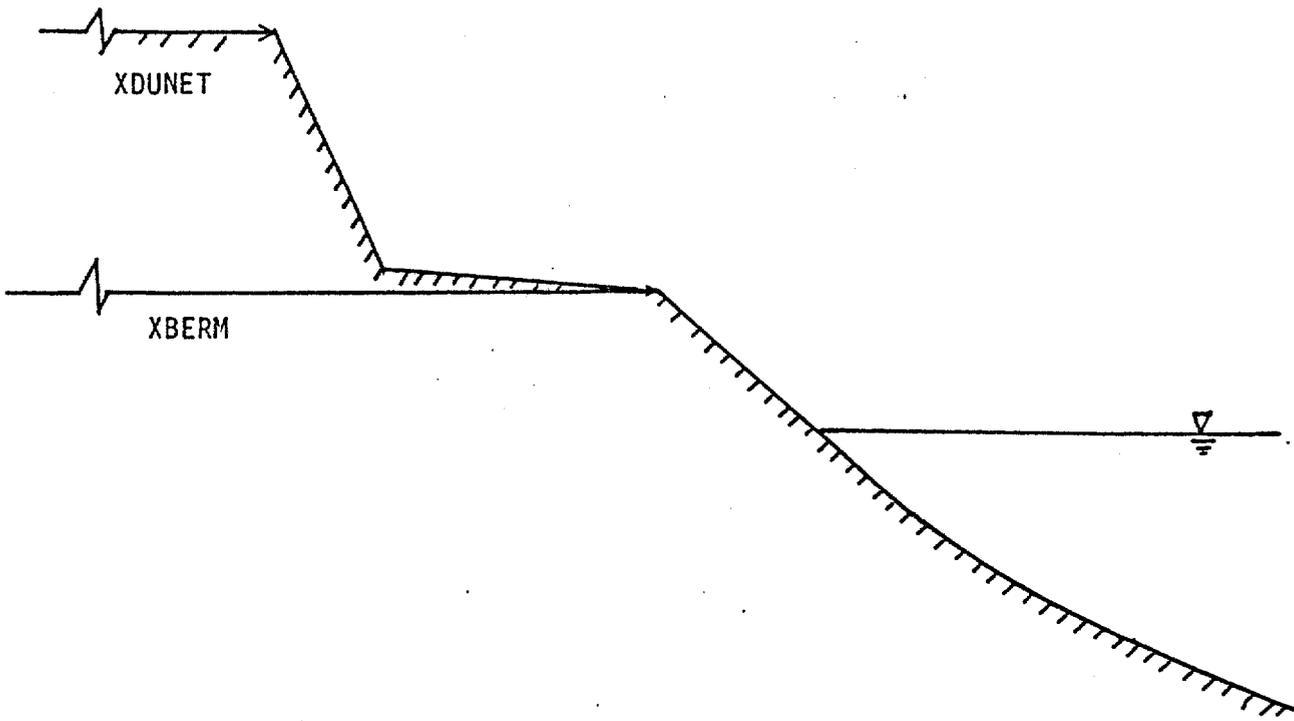


Figure 3a Wide Berm Profile Type

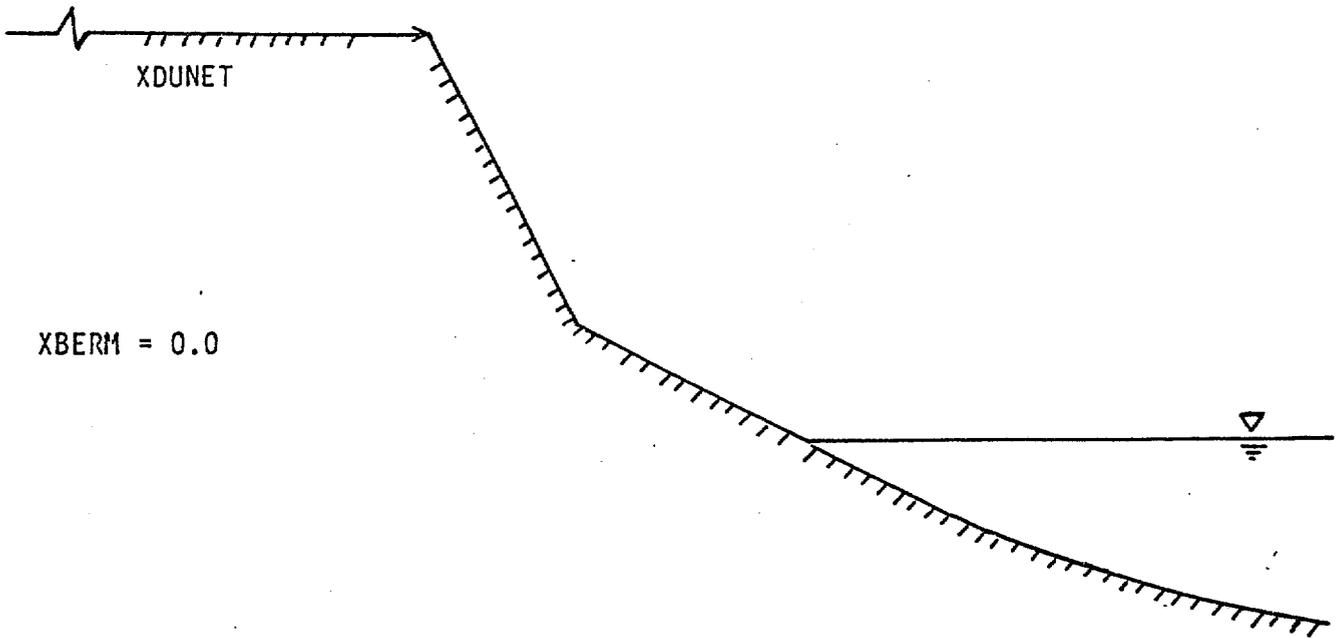


Figure 3b No-Berm Profile Type

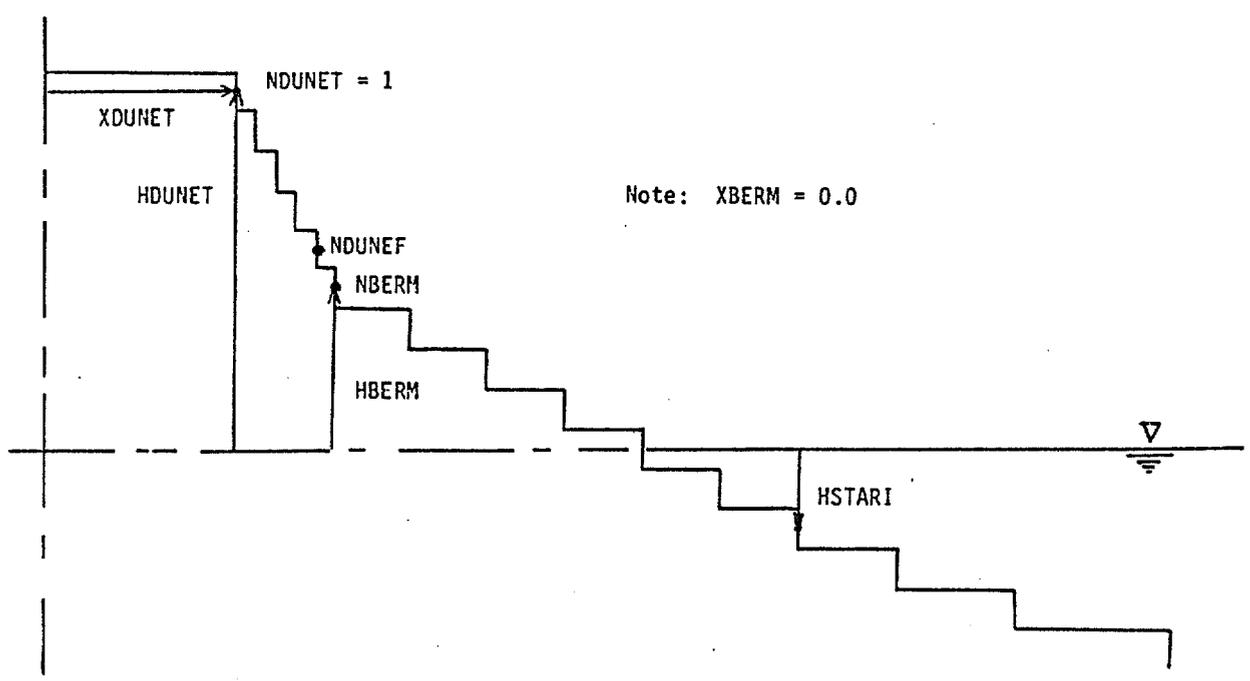
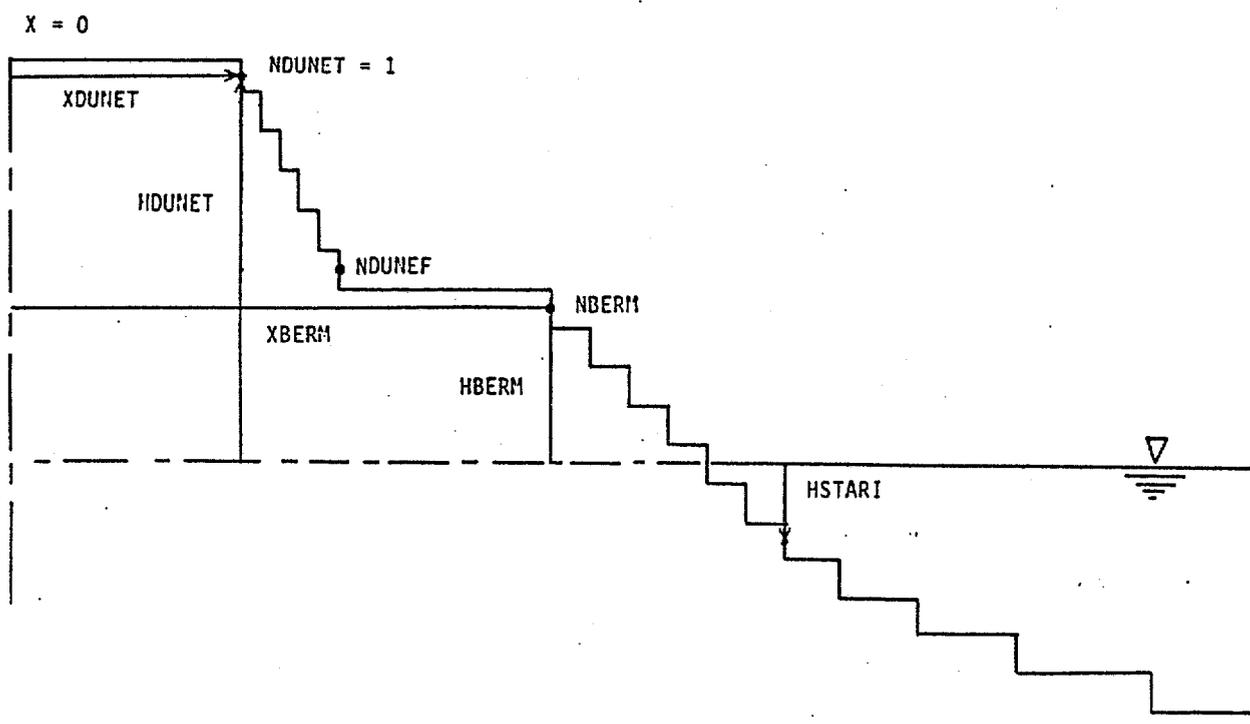


Figure 4 Discrete Stair-Step Approximation with Input Variables

VI. BOUNDARY CONDITIONS

As noted in Volume II, boundary conditions are required to define the limits of sediment transport in the profile. Offshore, the breaking depth defines the width of the surf zone and establishes a limit for offshore sediment transport; thus, the principal function of the wave height in the model is to control the offshore limit of the active profile. Onshore, the water surface elevation relative to the berm height and berm width, from NDUNEF to NBERM, define the shoreward limit of wave induced sediment transport. If a wide berm is present in the initial profile, the model requires that the berm be eroded back to the base of the dune before dune erosion begins. If the berm has eroded back to the dune -or- if no berm is present in the initial profile, the entire beach-dune face erodes uniformly for any water level rise. To regulate the "opening" of the dune to erosion; two parameters are determined at each time step, HSTAR and NSTOP.

HSTAR is defined as a transition depth between the dynamic and geometric solutions. When the water level is below the berm elevation or the break in slope elevation, HSTAR is always equal to HSTARI. Therefore, the beach face slope, XMB, is always steeper than the steepest portion of the concave offshore profile. When the water level is above the berm or break in slope elevation, HSTAR is determined according to the width of the berm. If the berm is wide, HSTAR is temporarily set equal to the water depth at the berm crest. This allows the profile seaward of the berm to erode quickly and assume a concave shape. If the berm has eroded back to the dune -or- if no berm is initially present, HSTAR must be determined at the point of tangency between the dune slope, XMD, and the concave profile. Since dune slopes are typically steep, 1:2 to 1:4, this transition depth is usually at the water line; thus, HSTAR is set to equal

to zero. This results in a final profile shape in which the steep dune face changes to the shallow concave profile at the still water line.

While HSTAR defines the transition between the dynamic and geometric region, or between the linear and the concave profiles, NSTOP governs the onshore limit of sediment transport. In particular, the sediment transport curve is always extended linearly from the calculated value of Q_s at HSTAR, to zero at NSTOP. For cases in which the water level is below the berm height, and when a wide berm exists, NSTOP is set equal to NBERM. This means that Q_s equals zero at the top of the berm. Similarly, if no berm is present and the dune face intersects the beach face, NSTOP is set equal to 1 and the entire beach-dune face erodes uniformly.

For the case in which the water level is above the berm height, the location of NSTOP again depends on the berm width. If a wide berm exists, NSTOP equals NBERM, allowing rapid berm erosion. Once the berm erodes, or for cases in which no berm is present, NSTOP is set equal to 1 and the dune erodes as a unit.

When the water level begins to decrease after the peak surge, the beach continues to erode for a short time, reaching the maximum erosion some time after the peak surge. Since, it is impossible to predetermine this time lag, the program must allow the beach to either erode or accrete at each step. In this case, HSTAR and NSTOP must be allowed to vary depending not only on the water level, and berm width, but also on whether the profile is eroding or accreting. In general, when the water level decreases, the same criteria are used to assign values of HSTAR and NSTOP. However, it should be noted that if: (1) a wide berm had eroded, or (2) if no berm is present initially, a flag, NFLAG, is activated which sets NSTOP equal to 1 at each time step. Therefore,

the solution assumes that the entire profile will continue to erode as the water level decreases.

As the water level continues to fall, erosion slows and eventually the profile begins to rebuild. It is clear that if the numerical solution results in dune rebuilding or accretion, this does not correctly model nature, where the eroded dune is not rebuilt by wave action. Therefore, if DELX(1), at the top of the berm, is ever found to be positive, indicating that the dune is rebuilding, a GO TO statement transfers control back to the beginning of the dynamic solution where HSTAR and NBERM and modified to "close" the dune from profile recovery. Thus, the model simulates recovery of the berm only while the dune remains in an eroded condition.

VII. DYNAMIC SOLUTION

7.1 Energy Dissipation and Sediment Transport

Calculation of the energy dissipation per unit volume and the sediment transport flux is fairly straightforward and follows the governing equations identified in Volume II. For cells seaward of NBREAK or landward of HSTAR, the energy dissipation and sediment transport are set equal to zero. DISS(N) and QS(N) are determined in the active surf zone only. Then, the simple smoothing function is applied to the sediment transport curve, such that most of the discontinuities are eliminated from QS and DISS. Also, the dynamic solution is extended to two cells beyond the breaking depth to provide a smoother transition to zero transport and zero energy dissipation outside the surf zone. Onshore, energy dissipation is not defined from HSTAR landward; however, the sediment transport curve is extended linearly from HSTAR to zero at NSTOP. This establishes a smooth transition in the sediment transport function at the depth, HSTAR, and determines the rate of sediment transport from the beach face into the dynamic portion of the profile.

7.2 Double Sweep Solution

With the smoothed sediment transport function and the associated energy dissipation per unit volume, the double sweep coefficients--AN, BN, CN, ZN, E, and F are easily determined. At $N = 1$, the onshore boundary condition that $E = 0$ and $F = ZN$ is applied. This in turn establishes $E = 0$ and $F = ZN$ for all cells landward of HSTAR. Offshore beyond HSTAR, E, and F are determined according to equations given in Chapter III of Volume II. At the offshore limit, NMAX, the boundary condition $DELX(NMAX) = 0$ is applied and $DELX(N - 1)$ values are determined according to the recursion formula. This onshore sweep proceeds up to the top

of the dune and the governing equation:

$$A_n \Delta X_{n-1} + B_n \Delta X_n + C_n \Delta X_{n+1} = Z_n \quad (5)$$

is satisfied every where in the active profile.

VIII. GEOMETRIC SOLUTION

Although the governing equation is satisfied at this point, the solution must be modified to maintain a smooth profile offshore, to recede the beach-dune face uniformly onshore, and to help guarantee a stable solution. First, because sediment transport decreases immediately beyond the breaking depth, the grid point, NBREAK, grows seaward rapidly, as QS into the breaking cell is much larger than QS leaving that cell. The result of this rapid growth is that the contour at NBREAK tends to grow much more quickly than adjacent offshore contours. Clearly some limit must be placed on the growth of NBREAK to prevent a discontinuous profile slope offshore.

To permit rational growth of NBREAK and adjacent offshore cells, a loop is included that compares the actual horizontal grid spacing against some critical spacing. This critical spacing could be set equal to the angle of repose or some percentage of the beach face slope for convenience. The spacing is set equal to the critical spacing by taking one half of the difference from the cell at N and adding it to the cell at $N + 1$. In this way, the offshore region is allowed to grow as further deposition occurs yet is maintained at a constant slope. NBREAK remains at the break in slope, as in Figure 5.

The geometric solution onshore is rather confusing in the computer program but is conceptually fairly simple, in general, the beach face and dune face must erode uniformly when activated and continuity must be satisfied such that there is no gain or loss of sand from the system. To determine geometric profile changes, HSTAR and NSTOP, are used to limit the geometric solution region. Also, the cumulative change in volume over the profile is monitored to determine the volume changes required to satisfy continuity.

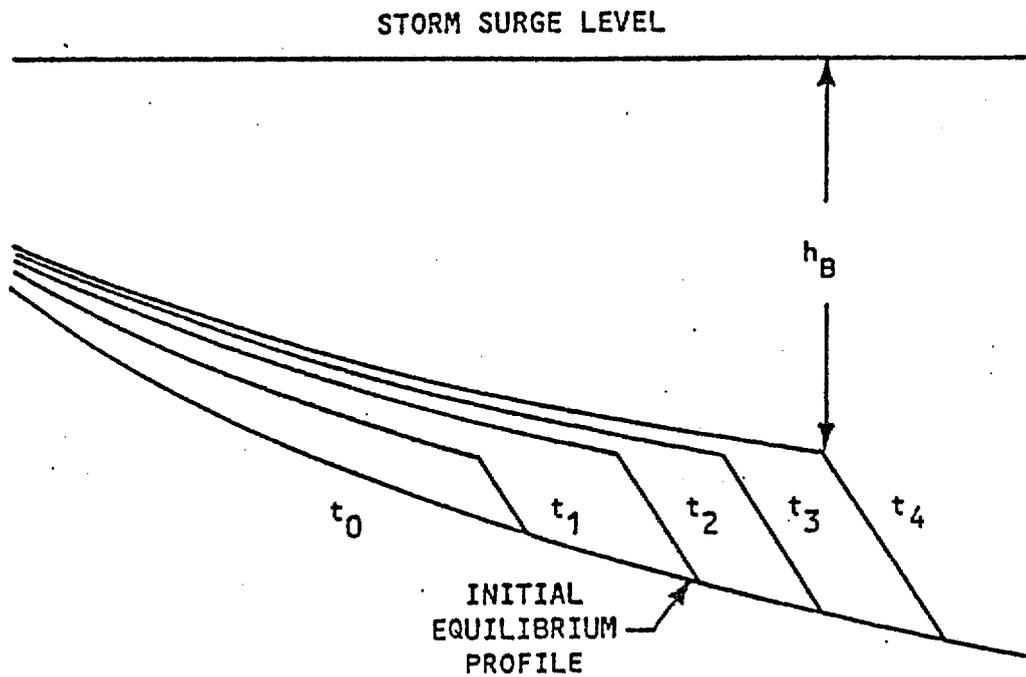


Figure 5 Evolution of Offshore Portion of Profile Showing Change in Slope at Breaking Depth

The volume change offshore at NMAX is clearly zero, as this point never changes location. Since the geometric limits on the offshore slope are imposed previously, the change in volume in each contour from the original profile to the profile at the end of current time step may be determined from NMAX onshore to HSTAR. By cumulatively adding these incremental changes in volume, the total volume change required to satisfy continuity at the top of the berm or dune may be found as $SUMVOL(NSTAR2 + 1)$ or $DELSUM$, where NSTAR2 is the grid point at HSTAR.

On the beach-dune face from HSTAR landward, the change in volume in each contour from the original profile to the profile position at the beginning of the time step is known. These incremental volume changes may be summed to give the net change in volume occurring over the previous time steps in the geometric region. This value is labeled HAVSUM. To determine the uniform beach-dune face

recession necessary to satisfy continuity in the current time step it is a simple matter to distribute the necessary volume, $DSUM = DELSUM - HAVSUM$, as an incremental change in volume or position, for each cell between NSTAR2 and NSTOP. At this point, the geometric solution is complete, unless the water level is decreasing. As mentioned, if the profile is in a state of recovery, the dune face is not permitted to rebuild. Therefore, if the solution results in uniform dune accretion, the solution is repeated with the dune isolated and only berm recovery permitted. This is accomplished by the check in statement labeled 193.

IX. OUTPUT

At the end of each time step, JTIME or LTIME, the horizontal contour change over the time step, DELX(N), is used to update the horizontal positions of the grid points. From these updated values, the contour locations at the end of the time step are recorded. These values are then compared to the original profile position to determine the retreat/advance of each contour. The output consists of contour changes for the dune crest, the still waterline, and the 5, 10, 15, and 20 foot contour lines. If the dune elevation is less than 15 or 20 feet, the output will record zero change for these contours.

The maximum value of SUMVOL, represents the total eroded or deposited volume in $\text{ft}^3/\text{linear ft}$. Therefore, from this maximum volume change, the eroded volume in cubic yards per linear foot may be obtained. Finally, the entire profile characteristics at any time step may be printed or, with the proper software interface, plotted to graphically depict the profile change. It should be noted that in the printed output, the original and current spacial variable, X and H are given for the time step. Also, the energy dissipation, sediment transport flux, incremental change in position, and cumulative volume from offshore are provided.