A Numerical Model to Simulate Sediment Transport in the Vicinity of Coastal Structures

by

Marc Perlin and Robert G. Dean

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PREFACE

The purpose of this report is to provide coastal engineers and researchers with a numerical model which predicts sediment transport and the resulting bathymetry in the vicinity of coastal structures. The work was carried out under the U.S. Army Coastal Engineering Research Center's (CERC) Numerical Modeling of Shoreline Response to Coastal Structures work unit, Shore Protection and Restoration Program, Coastal Engineering Area of Civil Works Research and Development.

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Comments on this publication are invited.

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for TED E. BISHOP
Colonel, Corps of Engineers
Commander and Director

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.852	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.01745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins ¹

¹To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9) (F - 32)$.

To obtain Kelvin (K) readings, use formula: $K = (5/9) (F - 32) + 273.15$.

A NUMERICAL MODEL TO SIMULATE SEDIMENT TRANSPORT IN THE VICINITY OF COASTAL STRUCTURES

by

Marc Perlin and Robert G. Dean

I. INTRODUCTION

1. General.

The need for reliable predictions of shoreline response to man-made or natural modifications is increasing due to environmental concerns and the rising cost of remedial measures. The capability of numerical modeling in addressing problems of shoreline response has advanced with improvements in wave climatology, programs to better understand sediment transport relationships, and improvements in numerical modeling. In-situ and remote sensing technology for the measurement of directional wave characteristics has been developed and applied, primarily within the last two decades. In addition to providing the necessary climatology, the resulting measurements have provided the basis for evaluation and refinement of directional wave prediction procedures. Studies such as the Channel Islands Harbor Longshore Sand Transport Study (Bruno, et al., 1981) and the Nearshore Sediment Transport Study (NSTS) (Gable, 1979) have yielded a better understanding of surf zone dynamics and the resulting sediment transport. The increased capacities of large computers and reduced computing costs combined with improved numerical modeling algorithms have resulted in an extremely promising potential for the numerical modeling of shoreline problems.

Although it is doubtful that numerical modeling will ever replace completely the use of movable-bed physical models, the former type offers many advantages. The modeling of shoreline response is somewhat analogous to the problem of simulating storm surges in the coastal zone in which the scale effects and measurement difficulties essentially preclude physical modeling. For shorelines, the scale effects inherent in modeling sediment are well recognized and the costs of representing a substantial length of shoreline may be prohibitive. The laboratory representation of a realistic wave climate is at the forefront of technology.

The investigation of shoreline response can best proceed by several approaches, with each approach selected for the particular strengths which it offers. Field programs are costly, usually because of the considerable equipment and the extensive time required, but these programs are essential for quantifying the values of constants or parameters, the forms of which may be available from laboratory measurements or theoretical considerations. Laboratory studies occupy a special niche by allowing the wave conditions and independent variables to be controlled readily, experiments to be repeated, and selected measurements to be conducted. Although, as noted before, scale effects are present in laboratory measurements of sediment transport, the physics governing the process should be the same. However, the relative magnitudes of suspended versus bedload transport in the laboratory and field may differ. Laboratory studies can also provide an excellent base for evaluating certain aspects of a numerical model, including wave refraction and diffraction and the resulting shoreline patterns due to, for example, the placement of a littoral barrier. Numerical modeling offers the capability to

incorporate all the hydrodynamic wave-surf zone and sediment transport knowledge that is available from laboratory and field studies. Numerical modeling has the potential of providing accurate predictions of shoreline response to various structural and nourishment alternatives. Additionally, the possibility exists of employing numerical models and available field measurements to learn more about sediment transport mechanisms. In this latter mode, various candidate mechanisms or coefficients would be evaluated by determining the best match between measured and predicted shorelines and the bathymetry. Generally, this mode would require high-quality measurements of the forcing function (waves and nonwave-related currents) and the associated response (sediments) as well as the knowledge of appropriate conditions at the boundaries of the model.

The present report documents the development and application of an n-line numerical model to investigate bathymetric response to time-varying wave conditions and shoreline modification. The model includes both longshore and onshore-offshore sediment transport. Based on laboratory results, a new distribution of longshore sediment transport across the surf zone is used. The wave climate is specified on the model boundaries which do not need to extend to deep water. Efficient algorithms are employed for representing wave refraction and diffraction. The equation of sediment continuity and transport are solved by a completely implicit algorithm which allows a large time-step. Specified sediment transport values or specified contour positions can be accommodated at the model boundaries. The model is suitable for investigating the shoreline response to a variety of modifications such as one or more groins, terminal structures, structures with variable permeability, and beach nourishment with or without terminal structures.

2. Study Objectives.

The objectives of the present study include (a) the documentation of state-of-the-art models, (b) the development and documentation of an improved model which includes the capability to represent n-contour lines and (c) the application of the model to several relevant coastal engineering problems.

II. BACKGROUND

This discussion describes significant contributions which either address numerical modeling of shorelines directly or provide improved capability for modeling.

1. Wave Refraction (Noda, 1972).

Noda developed an algorithm for solving the following steady state equation for wave refraction

$$\vec{\nabla} \times \vec{k} = 0 \quad (1)$$

in which $\vec{\nabla}$, the horizontal vector differential operator, and $\vec{k}$, the wave number, are defined in terms of their components as

$$\vec{\nabla} = \vec{i} \frac{\partial}{\partial x} + \vec{j} \frac{\partial}{\partial y} \quad (2)$$

$$\vec{k} = \vec{i} k_x + \vec{j} k_y \quad (3)$$

where $\vec{i}$ and $\vec{j}$ are the unit vectors in the x and y directions respectively. Equation (1) can be expressed as

$$\frac{\partial(k \sin \theta)}{\partial x} = \frac{\partial(k \cos \theta)}{\partial y} \quad (4)$$

in which θ is the direction of the vector wave number relative to the x-axis and k denotes $|\vec{k}|$. Noda expanded Equation (4) to the following form

$$k \cos \theta \frac{\partial \theta}{\partial x} + \sin \theta \frac{\partial k}{\partial x} = -k \sin \theta \frac{\partial \theta}{\partial y} + \cos \theta \frac{\partial k}{\partial y} \quad (5)$$

Since $\frac{\partial k}{\partial x}$ and $\frac{\partial k}{\partial y}$ are known from the angular frequency σ , the water depth h, and the dispersion equation

$$\sigma^2 = g k \tanh kh \quad (6)$$

Equation (5) can be solved numerically, although there are problems of directional stability. The primary advantage of Equation (5) is that it allows the wave direction θ to be determined on a specified grid, compared to unspecified locations that would be obtained by, for example, wave ray tracing.

2. Crenulate Bays (LeBlond, 1972).

LeBlond attempted to model the evaluation of an initially straight shoreline between two headlands into a crenulate bay. The model constitutes a one-line (shoreline) representation. The transport equation employed related the total sediment transport to total water transport in the surf zone as predicted by the formulation provided by Longuet-Higgins (1970). The initial shoreline patterns resemble crenulate bays in nature; however, the predictions were found to be unstable for reasonably long periods of computational time and did not approach a realistic platform.

3. Crenulate Bays (Rea and Komar, 1975).

Rea and Komar employed a rather ingenious system of orthogonal grid cells to provide a cell which locally is displaced perpendicular to the general shoreline orientation. A one-line representation was employed. A simple and approximate representation of wave diffraction was employed. Although the model yielded reasonable results for the examples presented, the unique coordinate system would not be suitable for a general model as the coordinate system must be "tailored" to some degree to conform to the expected shoreline configurations.

4. General One-line Shoreline Model (Price, Tomlinson, and Willis, 1972).

Price, Tomlinson, and Willis' formulation consists of the sediment continuity equation and the total sediment transport equation

$$Q_s = \frac{0.70 E_b (nC)_b \sin \alpha_b \cos \alpha_b}{\gamma_w (1 - p) (S_s - 1)} \quad (7)$$

in which E represents the wave energy density, (nC) the group velocity, α the angle between the breaking wave front and the shoreline, γ_w the specific weight of water, p the in-place sediment porosity, and S_s the specific gravity of the sediment relative to the water in which it is immersed. The subscript "b" represents values at breaking.

Two formulations were presented by Price, Tomlinson, and Willis (1972). In the first, Equation (7) was substituted into the continuity equation and the results cast into a finite-difference form. In the second, the two equations were employed separately. The latter formulation was selected due to its simplicity and used for the results presented.

Computations were carried out for the case of beach response due to the placement of a long impermeable barrier. The total sediment transport equation by Komar (1969) was used and the planform was calculated at successive times. Refraction was apparently not accounted for in the numerical model. To verify the computations, a physical model study was carried out for the same conditions using crushed coal as the modeling material. The comparison was interpreted as good for up to 3 hours; however, for greater times, substantial differences occurred and these were interpreted as being due to wave refraction not being represented. The crushed coal was supplied to the model at the updrift end at a rate based on the Komar equation, and the results were interpreted as substantiating this relationship. However, the updrift end of the model beach receded substantially both in the numerical and physical models. In the physical model, this can only be interpreted as due to the Komar equation predictions being less than the actual transport rate, possibly due to the low specific gravity (1.35) of the crushed coal. The predicted recession of the updrift beach is puzzling, although it could be due to a problem in properly representing the updrift boundary condition.

Other one-line models for shoreline changes in the vicinity of coastal structures were developed by LeMehaute and Soldate (1977) and Perlin (1978). Perlin also developed a two-line model formulation, with one-line representing the shoreline and the second the offshore. Dragos (1981) developed an n-line model for bathymetric changes due to the presence of a littoral barrier.

III. THE NUMERICAL MODEL

1. Description.

There are several methods of modeling bathymetric changes due to the presence of a littoral barrier. An attempt can be made to either model the complete hydrodynamics and the resulting sediment transport or model using a combination of analytical and empirical sediment transport equations. The second method was chosen due to past relative success.

At least two methods of employing sediment transport equations exist: a fixed longshore and cross-shore grid system where the depth is allowed to vary or a fixed longshore and depth system where the cross-shore distance is allowed to change. Although it may seem somewhat awkward, the latter system was chosen for the model. This method allows the modeler to think of bathymetric changes due to a littoral barrier in terms of the effect on the contours; i.e., the contour realinement due to the structure's presence is observed. One limitation of this approach, at least as it was applied here, is that each depth contour must be single-valued; it is not possible to represent bars.

The next step in formulating the model was choosing the specific representation of the bathymetry. The model is an n-line representation of the surf zone in which the longshore direction x is divided into equal segments each Δx in length. The bathymetry is represented by n-contour lines, each a specified depth, which change in offshore location according to the equation of continuity. There are two components of sediment transport at each of the contour lines, a longshore component, Q_x , and an offshore component, Q_y . Figure 1 is a definition sketch showing the beach profile representation in a series of steps and the planform profile representation and notations used.

Implementation of the sediment transport equations requires knowledge of the wave field and the equilibrium offshore profile. A discussion of the refraction and diffraction schemes follows. The equilibrium profile is introduced when it is convenient. As an introduction to the logic used in the numerical model, a flow chart is presented in Figure 2.

2. Refraction.

A refraction scheme compatible with variable Δy 's was required because of the variable distance to fixed depth contours (as opposed to the more usual fixed grid system where a grid center has a longshore and offshore coordinate with a variable depth). One of the benefits of the n-line model is the ease with which the response of the contours to a particular wave and structure condition can be visualized. A fixed grid system and an interpolation scheme could have been used to obtain the wave field; however, this would have reduced accuracy and increased computation time. The scheme developed also saves computation time because it does not use differential products terms.

Figure 1. Definition sketch.

Figure 2. Flow chart.

The first of the governing equations used is the conservation of waves equation

$$\frac{d\sigma}{dt} + \vec{\nabla}_H \times \vec{k} = 0 \quad (8)$$

where $\vec{\nabla}_H$ is the horizontal differential operator equal to $\vec{i}(\partial/\partial x) + \vec{j}(\partial/\partial y)$ in which $\vec{i}$ and $\vec{j}$ are the unit vectors in the x and y directions, respectively, and x is the longshore direction, with positive to the right when facing the water, y the offshore direction, with positive seaward, and z the vertical coordinate, with positive defined as upwards. For the steady-state case, equation (8) yields

$$\frac{\partial}{\partial x} (k_y) - \frac{\partial}{\partial y} (k_x) = 0 \quad (9)$$

where k_x and k_y are the wave number projections in the respective directions. Defining α as the angle k makes with the y-axis positive in the counter-clockwise direction, the equation can be written in final form as

$$\frac{\partial}{\partial x} (k \cos \theta) = \frac{\partial}{\partial y} (k \sin \theta) \quad (10)$$

where $\theta = \alpha + \pi$ (in radians). Noda (1972) and others have developed numerical solutions to expanded forms of equation (10). In the present study, equation (10) was initially central-differenced in the x-direction and forward-differenced in the y-direction with Snell's law used to specify the boundary conditions on the offshore boundary and one of the sides (i.e., the side of the wave angle approach). However, a numerical problem arose. The argument of the arcsine exceeded +1.0 for large $\Delta y/\Delta x$. To overcome this problem, a dissipative interface was used on the forward-difference term (after Abbott, 1979). The final finite-differenced form of equation (10) is

$$\theta_{i,j}^{n+1} = \sin^{-1} \left\{ \frac{1}{k_{i,j}} \left[\tau(k \sin \theta)_{i-1,j+1} + (1-2\tau)(k \sin \theta)_{i,j+1} \right. \right. \\ \left. \left. + \tau(k \sin \theta)_{i+1,j+1} - \frac{\Delta y}{2\Delta x} \left((k \cos \theta)_{i-1,j}^{\frac{1}{2}} - (k \cos \theta)_{i-1,j} \right) \right] \right\} \quad (11)$$

where τ has been taken as 0.25. The past $\theta_{i,j}^n$ and the present $\theta_{i,j}^n$ wave angles are numerically averaged to give the $\theta_{i,j}$. Newton's method is used to compute the wave number via the linear wave theory dispersion relation. In addition, numerical smoothing is used at the conclusion of the wave field calculation. This approximates in an ad hoc manner diffractive effects (lateral transfer of wave energy along the wave) which exist in nature but have been omitted due to use of the equation for refraction (equation 8). The smoothing routine is

$$\theta_{i,j} = \frac{1}{4} \theta_{i-1,j} + \frac{1}{2} \theta_{i,j} + \frac{1}{4} \theta_{i+1,j} \quad (12)$$

The second governing equation used in the refraction scheme is conservation of energy. Neglecting dissipation of energy due to friction, percolation, and turbulence, this equation can be expressed as

$$\vec{\nabla} \cdot (E \vec{C}_G) = 0 \quad (13)$$

where E is the average energy per unit surface area and $\vec{C}_G$ the group velocity of the wave train. Performing the operation indicated and replacing $\vec{C}_G$ by its components ($C_G \sin \theta$) and ($C_G \cos \theta$) results in the following:

$$\frac{\partial}{\partial x} (E C_G \sin \theta) + \frac{\partial}{\partial y} (E C_G \cos \theta) = 0 \quad (14)$$

Assuming linear theory,

$$E = \frac{\rho g H^2}{8} \quad (15a)$$

where ρ is the mass density of water, g the gravitational constant, and H the wave height. Dividing the equation by $\frac{\rho g}{8}$, finite-differencing and weighting the forward-differenced term as before, and solving for the wave height, results in the following:

$$H_{i,j}^{n+1} = \left\{ \frac{1}{(C_G \cos \theta)_{i,j}} \left[(\tau)(H^2 C_G \cos \theta)_{i-1,j+1} + (1-2\tau)(H^2 C_G \cos \theta)_{i,j+1} + (\tau)(H^2 C_G \cos \theta)_{i+1,j+1} + \frac{\Delta y}{2\Delta x} [(H^2 C_G \sin \theta)_{i+1,j} - (H^2 C_G \sin \theta)_{i-1,j}] \right] \right\}^{1/2} \quad (15b)$$

This equation is also solved by iterative techniques and the $H_{i,j}^{n+1}$ and $H_{i,j}^n$ are averaged at the conclusion of each iteration.

C_G is determined by the linear wave theory relationship

$$C_G = \frac{C}{2} \left(1 + \frac{2kh}{\sinh 2kh} \right) \quad (16)$$

where h is the water depth, k the wave number, and C the wave celerity. Wave height boundary conditions are input along the same boundaries as the wave angles using linear theory shoaling and refraction coefficients. The θ 's have been previously determined. In both equations (11) and (15) for a variable grid system, the points $(i+1, j)$ and $(i-1, j)$ need to be determined (i.e., because the y coordinates are not fixed, adjacent values with the same subscripts can be farther or closer to shore, therefore interpolation must be used). The actual values are found by searching the $(i+1)$ and $(i-1)$ cross-shore lines, finding the adjacent values in the positive and negative y -direction, and interpolating to determine the value.

3. Diffraction.

The diffraction solution (in the lee of the structure) used in the model is based on the method of Penny and Price (1952). Assumptions used in this method include a semi-infinite breakwater, which is infinitesimally thin, linear wave theory and constant depth. A definition sketch for wave diffraction is shown in Figure 3. The quantity THETA0 represents the angle of wave incidence relative to the jetty axis, ANGLE represents the angle from the jetty at the point where the diffraction coefficient is to be computed, and RAD is the radial distance. The radial distance is then cast into a dimensionless parameter, RHOND ($= 2\pi \text{ RAD}/L$), where L is the wavelength. This is equivalent to multiplying the radial distance by the wave number k .

The diffraction coefficient AMP is expressed as the modulus of the diffracted wave

$$\text{AMP} = (\text{Sum } 1)^2 + (\text{Sum } 2)^2 \quad (17)$$

where

$$\begin{aligned} \text{Sum } 1 = & [\cos (\text{RHOND} (\cos (\text{ANGLE}-\text{THETA0}))) \cdot \left(\frac{1}{2} (1.0 + C_F + S)\right)] + \\ & [\sin (\text{RHOND} (\cos (\text{ANGLE}-\text{THETA0}))) \cdot \left(-\frac{1}{2} (S - C_F)\right)] + \\ & [\cos (\text{RHOND} (\cos (\text{ANGLE}+\text{THETA0}))) \cdot \left(\frac{1}{2} (1.0 + C_F + S)\right)] + \\ & [\sin (\text{RHOND} (\cos (\text{ANGLE}+\text{THETA0}))) \cdot \left(\frac{1}{2} (S - C_F)\right)] \quad (18) \end{aligned}$$

$$\begin{aligned} \text{Sum } 2 = & [\cos (\text{RHOND} (\cos (\text{ANGLE}-\text{THETA0}))) \cdot \left(-\frac{1}{2} (S - C_F)\right)] + \\ & [\sin (\text{RHOND} (\cos (\text{ANGLE}-\text{THETA0}))) \cdot \left(\frac{1}{2} (1.0 + C_F + S)\right)] + \\ & [\cos (\text{RHOND} (\cos (\text{ANGLE}+\text{THETA0}))) \cdot \left(-\frac{1}{2} (S - C_F)\right)] + \\ & [\sin (\text{RHOND} (\cos (\text{ANGLE}+\text{THETA0}))) \cdot \left(\frac{1}{2} (1.0 + C_F + S)\right)] \quad (19) \end{aligned}$$

In Equations (18) and (19), C_F and S represent Fresnel integrals and are computed in the model by means of an approximation after Abramowitz and Stegun (1965).

Having obtained AMP, the wave height at the location in question is simply the product of the specified partially refracted incident wave height and AMP. The angle of the wave crest is computed assuming a circular wave front along any radial; this angle is then refracted using Snell's law.

Throughout the refraction and diffraction schemes, the local wave heights are limited by the value, $0.78 \times \text{depth}$.

Figure 3. Definition sketch for wave diffraction.

4. Sand Transport Model.

a. Governing Equations. Three basic equations are used to simulate the sediment transport and bathymetry changes according to the wave field. The equation of continuity

$$\frac{\partial y}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = 0 \quad (20)$$

requires as input, knowledge of the longshore and cross-shore components of sediment transport. The total transport alongshore has been measured by several investigators and many equations exist; however, the distribution of the transport across the surf zone is not well known. Fulford (1982) based on laboratory data from Savage (1959), developed a distribution of longshore sediment transport across the surf zone for the case of straight and parallel contours. Fulford's use of Savages experiment was based on two assumptions: 1) the structure must be a total littoral barrier and 2) onshore-offshore sediment transport could be neglected. Test 5-57 was chosen because the two criteria were nearly met. Savage reported that the groin acted as a total littoral barrier for the first 35 hours of the test (i.e., no bypassing occurred prior to 35 hours). This does not mean that no onshore-offshore transport occurred because as the profile steepens on the updrift side, onshore-offshore transport does occur. However, it was assumed to be negligible. In addition, the initial profile had been molded to an equilibrium profile via 150 hours of waves. Thus, the two criteria required to develop an inferred longshore distribution of sediment transport were nearly satisfied. This distribution is shown as a dashline in Figure 4. The smaller "maximum" is believed to be an extraneous effect of a groin downdrift from the location in the experiment where the data were taken. Therefore, this feature was replaced by a monotonically decreasing, smooth curve as shown by the "altered" curve. To analytically represent this distribution, a function of the following form was chosen

$$q_x(y) = (B)(y)^{n-1} e^{-(y)^n} \quad (21)$$

This type of equation is convenient because it is easily integrable, and by properly choosing the constant, B, the integral of the equation from zero to infinity can be required to equal a particular value. This too is highly desirable because, as was done in the model, the integral is set equal to one and then multiplying by the value of the well-known longshore transport equation, the value of the transport at any location across the surf zone can be determined. Further investigation suggested a value of $n = 3$ to produce a curve similar to Fulford's curve. A more general form of the equation which allows more flexibility and curve fitting is

$$q_x(y) = B(y + a)^2 e^{\left\{ - \left[\frac{y + a}{cy_b} \right] \right\}^3} \quad (22)$$

Figure 4. Distribution of sediment transport across the surf zone.

where y_b = distance to the point of breaking

a = constant to allow sediment transport above mean water line (MWL) (swash transport or transport in region of wave setup) to be represented

c = a constant establishing the width of the curve (to be determined)

$$B = \frac{3}{c^3 y_b^3} \quad \left(\text{causes} \quad \int_0^\infty q_x(y) dy = 1.0 \right)$$

Based on Fulford's (1982) results and considering a to be proportional to the breaking height divided by the beach slope, the constant of proportionality was determined to be unity; i.e., $a = h_b / (\partial h / \partial y)$. Using equation (22) and a digitized version of the curve shown in Figure 4, a nonlinear least squares regression was carried out to determine the value of c . A Taylor's series expansion of the form

$$f^{k+1}(c, y) = f^k(c, y) + \frac{\partial f}{\partial c} \Delta c \quad (23)$$

where k and $k+1$ represent the number of the iteration carried out. Least squares regression minimizes the square of the difference between observed and predicted values with respect to a change in the parameter being computed, or

$$\frac{\partial}{\partial (\Delta c)} \left\{ \sum_{n=1}^N \left[f_{OBS} - (f^k(c, y) + \frac{\partial f}{\partial c} \Delta c) \right]^2 \right\} = 0 \quad (24)$$

where f_{OBS} represents the observed values, which in this case is $q_x(y)_{OBS}$. Carrying out the differentiation indicated and manipulating terms, Δc can be solved in terms of known quantities.

An iterative procedure was then used by updating the values of $f^k(c, y)$, $\partial f / \partial c$, and c until an acceptably small change in c results. For the data herein, the value of c was determined to be 1.25. The final form of sediment transport of a y location in the surf zone results for a shoreline with straight and parallel contours, as

$$q_x(y) = \frac{3}{(1.25)^3 (y_b)^3} (y + a)^2 e^{-[(y + a)/(1.25 y_b)]^3} \quad (25)$$

This equation, which is also presented in Figure 4, predicts the relative transport at point y. To obtain the fraction of transport between two y coordinates, the integral of equation (25), from y_1 to y_2 , must be used.

$$Q_{xND} = Q_x \Big|_{y_1}^{y_2} = \int_{y_1}^{y_2} q_x(y) dy = e^{-[(y_1 + a)/(1.25 y_b)]^3} - e^{-[(y_2 + a)/(1.25 y_b)]^3} \quad (26)$$

Q_{xND} is dimensionless; therefore, to compute a value in, say, cubic feet per second, it must be multiplied by the total transport along a perpendicular to the shoreline obtained from the total longshore transport equation used in the model

$$Q = C' H_b^{5/2} \sin(2\alpha_b) \quad (27)$$

See Appendix A for a discussion of the constant C' . It is noted that the transformation of $q_x(y)$ to $q_x(h)$ can be effected by multiplying by the one-dimensional Jacobian ($\Delta y/\Delta h$). This latter form ($q_x(h)$) is more useful here because the present model simulates the changes in contour position (Δy) rather than changes by depth (Δh).

In the numerical model, $Q_x(I,J)$ (see Fig. 1) is determined using equation (26) except for the shoreline contour, $J=1$, and the farthest offshore contour simulated, $J = JMAX$. The shoreline contour longshore transport, $Q_x(I,1)$, in order to include swash transport, uses equation (16); however, the first term is set equal to 1.0. The seawardmost contour transport, $Q_x(I,JMAX)$, in order to include any longshore transport not yet accounted for, neglects the second term of equation (26) (i.e., it accounts for transport from $y(I,JMAX)$ to infinity). The dimensionless numbers are then multiplied by Q determined from equation (27). This method is based on parallel contours which may not exist. In order to compensate for the nonparallel nature of the contours (note that refraction does account for it as far as the wave field is concerned), the term $\sin(2\alpha_b)$ of equation (27) is replaced by $\sin(2\alpha_l)$ shoreward of the breakpoint, where α_l represents the angle between the "local" wave angle and the "local" contour. It can be argued that for a spilling breaker, the remaining surf zone at any point "sees" a total transport similar to equation (27), where α_b and H_b are the local values. The problem is that the constant of proportionality was determined for the entire surf zone and for nearly straight and parallel contours. This not being the case, the equation was altered on intuitive grounds to reflect the fact that the contours are no longer straight and parallel.

The second input required by the continuity equation to predict the bathymetric changes is the cross-shore sediment transport. The governing equation for onshore-offshore transport (after Bakker, 1968) is

$$Q_{y_{i,j}} = \Delta x C_{OFF_{i,j}} \left[y_{i,j-1} - y_{i,j} + W_{EQ_{i,j}} \right] \quad (28)$$

where C_{OFF} is an activity factor (inside the surf zone = 10^{-5} feet per second for the prototype simulation herein, 10^{-4} feet per second for the physical model simulation) (see App. A. for a discussion) and $W_{EQ(i,j)}$ is the positive equilibrium profile distance between $y(i,j)$ and $y(i,j-1)$, determined from the equilibrium profile used in the numerical model $h = Ay^{2/3}$ (Dean, 1977). See Appendix A for discussion of the value of A. The physical interpretation of equation (28) is that as this profile steepens (flattens), sediment is transported offshore (onshore).

b. Methods of Solution. Three separate finite-difference techniques were used to solve the equations:

- (1) Explicit longshore-continuity and explicit cross-shore continuity;
- (2) Implicit longshore-continuity and explicit cross-shore continuity for half a time-step then vice versa; and
- (3) Implicit longshore-cross-shore continuity.

An explicit formulation was first developed which used the refraction scheme, the distribution of longshore sediment transport across the surf zone, and the onshore-offshore sediment transport equation. Problems in addition to the usual ones which are encountered with explicit methods (e.g., computation time and cost) were immediately realized. In the explicit method, both transport computations are based on the former values of the contour locations and are completely uncoupled. Stability of an explicit scheme requires a small time-step. In addition, the noncoupled nature of the equations, in some cases, resulted in crossing of the contours due to the transport computed.

It is logical to assume that an implicit formulation of the longshore transport equation used as input to the continuity equation along with the explicit onshore-offshore transport component would help the numerical stability (on the other half time-step, the longshore component would be computed explicitly and the onshore-offshore transport equation would be solved implicitly with the continuity equation). Although this scheme would be superior to the explicit procedure, it still would be susceptible to crossing contours. It should be noted that the magnitude of the coefficient used in the onshore-offshore equation is very important to the extent that the simulation models natural phenomena. If the coefficient is very small or vanishes, sediment will not move offshore and contours will cross because of the variation in the distribution of longshore sediment transport across the surf zone. If the coefficient is too large, the onshore-offshore transport, may become large enough that on a particular time step, an offshore contour

would move too far shoreward, thereby crossing an inshore contour or vice versa. Once the contours cross, not only does the bathymetry become unrealistic, but mathematically, the equation which computes the longshore distribution across the surf zone changes signs at some locations and the entire model becomes physically unrealistic.

To circumvent these problems, an implicit scheme that simultaneously solves the three governing equations, was developed. Utilizing equation (26), and the one-dimensional Jacobian ($\Delta y/\Delta h$) to convert to $Q_x(h)$, the total longshore transport equation (27), the following equation is obtained,

$$Q_{x_{i,j}} = \left\{ \exp \left(- \left(\frac{(h_{i,j-1})^{3/2} + H_{b_i} A^{3/2}}{1.25 h_{b_i}} \right)^3 \right) - \exp \left(- \left(\frac{(h_{i,j})^{3/2} + H_{b_i} A^{3/2}}{1.25 h_{b_i}} \right)^3 \right) \right\} \times \left(C' H_{b_{i,j}}^{5/2} \right) \times \sin (2\theta - 2\alpha_c) \quad (29)$$

$Q_x(i,j)$ represents the sediment transport between depths $h(i,j)$ and $h(i,j-1)$ (see Fig. 1). The term in brackets represents the normalized distribution of longshore transport between $h(i,j)$ and $h(i,j-1)$; θ is the averaged wave angle at the location of $Q_x(i,j)$ and α_c is the local contour orientation angle. Defining everything except $\sin (2\theta - 2\alpha_c)$ as $v(i,j)$ and using a superscript to denote a time step, this equation can be written

$$Q_{x_{i,j}}^{n+1} = v_{i,j} \sin (2\theta - 2\alpha_c^{n+1}) \quad (30)$$

The assumption has been made that the wave field (H and θ) do not vary during the bathymetric changes over the time-step. Using the following trigonometric identities,

$$\sin (2a - 2b) = \sin 2a \cos 2b - \cos 2a \sin 2b \quad (31a)$$

$$\cos 2a = 2 \cos^2 a - 1 \quad (31b)$$

$$\sin 2a = 2 \sin a \cos a \quad (31c)$$

and recognizing that the following expression is an approximation

$$\sin (\alpha_c^{n+1})_{i,j} \approx \frac{\frac{1}{2} (y_{i,j}^{n+1} - y_{i-1,j}^{n+1} + y_{i,j}^n - y_{i-1,j}^n)}{((\Delta x)^2 + (y_{i,j} - y_{i-1,j})^2)^{1/2}} \quad (32)$$

along with assuming that the change in the denominator is small for a reasonable time-step (the numerator has been averaged over the n^{th} and $n + 1^{\text{th}}$ time-steps), equation (30) results in

$$Q_{x,i,j}^{n+1} + (S3)_{i,j} y_{i,j}^{n+1} - (S3)_{i,j} y_{i-1,j}^{n+1} = (RHS1)_{i,j}^n \quad (33)$$

where $(S3)_{i,j} = \left(\frac{1}{2}\right) (v_{i,j}) \cos(2\theta) (2 \cos \alpha_c) \frac{1}{(\Delta x^2 + \Delta y^2)^{1/2}}$

$$(RHS1)_{i,j}^n = (v_{i,j}) (2 \sin \theta \cos \theta) (\cos^2 \alpha_c - 1) - (S3)_{i,j} (y_{i,j}^n - y_{i-1,j}^n)$$

Here it has also been assumed that $\cos^2 \alpha_c$ does not change over the time step. Equation (33) is the final form of the longshore sediment transport equation prior to its use in conjunction with the other equations.

Averaging y values on the n^{th} and $(n+1)^{\text{th}}$ time-steps, equation (29) can be rewritten as

$$Q_{y,i,j} = \text{Const6}_{i,j} \left\{ \frac{1}{2} \left(y_{i,j-1}^{n+1} + y_{i,j-1}^n - y_{i,j}^{n+1} - y_{i,j}^n \right) + W_{EQ,i,j} \right\} \quad (34)$$

where $\text{Const6}(i,j) = \text{Coff}(i,j) \cdot \Delta x$. This is the final form on the onshore-offshore sediment transport equation.

The equation of continuity, finite-differenced for the n^{th} and $(n+1)^{\text{th}}$ time-steps, can be written as

$$\frac{y_{i,j}^{n+1} - y_{i,j}^n}{\Delta t} = \frac{1}{2\Delta x \Delta h} \left\{ Q_{x,i,j}^{n+1} + Q_{x,i,j}^n - Q_{x,i+1,j}^{n+1} - Q_{x,i+1,j}^n + Q_{y,i,j}^{n+1} + Q_{y,i,j}^n - Q_{y,i,j+1}^{n+1} - Q_{y,i,j+1}^n \right\} \quad (35)$$

Defining $R_{i,j}$ as $1/(2\Delta x \Delta h)$, inserting equations (33) and (34) into equation (35), and transferring all known quantities for the n^{th} time-step to the right-hand side of the equation result in

$$\begin{aligned} y_{i,j}^{n+1} + (\Delta t R_{i,j}) S3_{i,j} y_{i,j}^{n+1} - (\Delta t R_{i,j}) S3_{i,j} y_{i-1,j}^{n+1} - (\Delta t R_{i,j}) S3_{i+1,j} y_{i+1,j}^{n+1} \\ + (\Delta t R_{i,j}) S3_{i+1,j} y_{i,j}^{n+1} - (\Delta t R_{i,j} \text{Const6}_{i,j}) \left(\frac{1}{2} [y_{i,j-1}^{n+1} - y_{i,j}^{n+1}] \right) \\ + (\Delta t R_{i,j} \text{Const6}_{i,j+1}) \left(\frac{1}{2} [y_{i,j}^{n+1} - y_{i,j+1}^{n+1}] \right) = (\text{AWARE})_{i,j} \quad (36) \end{aligned}$$

Equation (36) can be rewritten as

$$(1 + U + V + Z1 + Z2) y_{i,j}^{n+1} - (U) y_{i-1,j}^{n+1} - (V) y_{i+1,j}^{n+1} - (Z1) y_{i,j-1}^{n+1} - (Z2) y_{i,j+1}^{n+1} = (AWARE)_{i,j} \quad (37)$$

where

$$U = \Delta t R_{i,j} S3_{i,j}$$

$$V = \Delta t R_{i,j} S3_{i+1,j}$$

$$Z1 = \left(\frac{\Delta t}{2}\right) R_{i,j} \text{Const6}_{i,j}$$

$$Z2 = \left(\frac{\Delta t}{2}\right) R_{i,j} \text{Const6}_{i,j+1}$$

Equation (37) is a weighted, centered scheme in which $y_{i,j}^{n+1}$ is computed using a weighting of itself and its four adjacent grid "neighbors". The weighting factors (U, V, Z1, and Z2) are functions of the wave climate, the slope between contours, and the variables included in the original formulation. An investigation of a small gridded system demonstrated that by writing simultaneous equations, one for each $y_{i,j}$, a banded matrix results. This matrix can be solved by LEQT1B, one of the available routines from the International Math and Statistics Library (IMSL). A schematic representation of the matrix A which results from the matrix equation $[A][y] = [B]$ is presented in Figure 5. In this schematic, the large zeros represent triangular corner sections of all zeros and the 0...0 represents bands of zeros, the number of which is dependent on the number of contours simulated (the number of zero bands between either remote nonzero bands and the tridiagonal nonzero bands equals two less than the number of contours modeled (in both the upper and lower codiagonals of the matrix)). An inspection of the subscripts in equation (29) yields the reason the zero bands are required. The more j values (contours) used, the more y grids there are along any perpendicular to shore. This causes zeros to appear in the matrix between bands as the weighting factors await being used to operate on $y^{n+1}(i-1,j)$ and $y^{n+1}(i+1,j)$. For this reason, the expense of simulating an increasing number of contours is exponential. The LEQT1B routine, utilizes banded storage and saves both storage and computation time; however, the routine has no special way of handling the interior zero bands. One refinement which would save computation time would be to develop an algorithm to solve and store the matrix by taking advantage of these inner zero bands; however, it is beyond the scope of this project.

Of course, the matrix requires boundary values on longshore extremities and on both onshore and offshore boundaries. The longshore boundary conditions are treated by modeling a sufficient stretch of shoreline so that effects of a structure's presence are minimal. The y values along these boundaries can therefore be fixed at their initial locations. In the onshore-offshore direction, boundaries are treated quite differently. The

Note: Size of matrix full storage mode
 $[(\text{IMAX}-2)(\text{JMAX}) \times (\text{IMAX}-2)(\text{JMAX})]$
 Size of matrix banded storage mode
 $[(\text{IMAX}-2)(\text{JMAX}) \times (2\text{JMAX} + 1)]$

Figure 5. Schematic representation of banded matrix if not stored in banded storage mode.

berm and beach face are assumed to move in conjunction with the shoreline position. The required sediment transport is then computed by the change in position of the shoreline. The two equations are

$$y_{i,0}^{n+1} = y_{i,0}^n + [y_{i,1}^{n+1} - y_{i,1}^n] \quad (38a)$$

$$Q_{y_{i,1}}^{n+1} = - \left[\frac{\text{Berm } \Delta x}{\Delta t} \right] [y_{i,1}^{n+1} - y_{i,1}^n] \quad (38b)$$

The offshore boundary is treated by keeping $y^{n+1}(i,j_{\text{max}})$ (the contour beyond the last simulated contour) fixed, until the angle of repose is exceeded. Then, the $y^{n+1}(i,j_{\text{max}}+1)$ is reset (at the conclusion of the $n+1$ time-step) to a position such that the slope equals the angle of repose. Note that $y^{n+1}(i,0)$ is represented in the program by YZERO_i.

There are also no-flow boundary conditions required at each of the structures being modeled. These are imposed on the adjacent y -grid points which are located downdrift (i.e., in the shadow zone) of the structure and shoreward of the structures' seaward extremities. They are imposed by setting $S3_{i,j}$ of equation (33) and $\text{DISTR}_{i,j}$ (the term in square brackets in equation (29)) equal to zero, thereby causing $Q_x(i,j)$ to be zero (i.e., the no-sediment flow condition). This boundary condition is imposed automatically for every shore-perpendicular structure.

It was found that even with the implicit formulation, high frequency oscillations occurred in the y values immediately updrift and downdrift of the structure. The solution did not "blow up"; however, on larger time-steps "sloshing" (oscillating) did occur. Part of this problem was due to the boundary condition at the structure which had been such that either no sand was allowed along a contour line or the sand determined by the equations was allowed to be transported. Because of the very large angle which existed around the tip of the structure when a contour first exceeded the length of the structure, very large amounts of sediment transport were predicted. In the nature where analog sand transport rather than digitized transport occurs, this does not happen. Therefore, the boundary condition was altered to constantly allow sand transport around the end of the structure in proportion to that part of the contour representation which exceeded the structure (i.e., the transport was calculated for the location at tip of the structure as if the structure was not there and then a proportion of this value was allowed to bypass). Although the transport around the tip of the structure is based on the values from the past time-step, it more closely simulated the natural phenomenon.

Additionally, a dissipative interface is used on the y values as follows:

$$y_{i,j} = (\tau) y_{i-1,j} + (1 - 2\tau) y_{i,j} + (\tau) y_{i+1,j} \quad (39)$$

where τ was again taken as 0.25. It is noted that only high frequency oscillations in y are affected by the use of equation (39); the total sum of y values is not affected. Also, in all the dissipative interface

schemes used, if a boundary point is being computed, either a forward-difference or a backward-difference of equation (39) is used (after Abbott, 1979):

$$\text{Backward: } y_{i,j} = (\tau)y_{i-1,j} + (1 - \tau)y_{i,j} \quad (40a)$$

$$\text{Forward: } y_{i,j} = (\tau)y_{i+1,j} + (1 - \tau)y_{i,j} \quad (40b)$$

IV. SIMULATIONS AND VERIFICATION

Several simulations were run; two were attempts at verifying the numerical model, the others were run to gain insight. Because a complete data set does not exist, only the available data are compared. The first modeling effort was to simulate the physical model tests of Savage (1959). A second set of cases was run for shore-perpendicular structures. Next, an effort was made to model sediment transport in the vicinity of a hypothetical dredge disposal site in the 11- to 14-foot depths off Oregon Inlet. Finally, the Channel Islands Harbor Longshore Transport Study (Bruno, et al., 1981) was modeled. Bathymetric changes were closely monitored during this study; however, the wave climate (H , θ , T) used was determined from the Littoral Environmental Observation (LEO) data and uncertainties exist as to the accuracy of the data.

1. Simulation of Savage's Physical Model Tests.

The numerical model was used to simulate one of the physical model tests of Savage (1959). Test 5-57 was simulated numerically for a 10-hour period. In this physical model, the mean sediment size was 0.22 millimeters, the wave height averaged 0.25 feet, the wave period was 1.5 second, the wave angle was 30° (at a depth of 2.3 feet), and the groin was approximately 9.5 feet from still water to its seaward limit. C_{OFF} was held constant at 10^{-4} feet per second throughout the profile for this simulation. The offshore profile is presented in Savage (1959). Figure 6 represents three of the eight contours simulated. Note that the initial 0.3- and 0.5-foot-depth contours, in the numerical representation are too far seaward by approximately 2 feet. This is due to the $h = Ay^{2/3}$ equation as compared to the equilibrium physical model profile. Realizing this, it is the shape of the contour which must be used as an indication of the numerical model predictions. The general trend of the contours is similar, although the numerical model contours are displaced farther seaward as expected. The major differences are in the diffraction zone.

2. Several Runs Using Shore Perpendicular Structures to Demonstrate Effects of Altering Some of the Pertinent Parameters.

In the following simulations, the models were run until their near-equilibrium values were achieved. Coefficient C_{OFF} was not a function of depth (beyond the surf zone) but was held constant throughout the simulated area. Important variables are as shown in the figures. Only one wave condition ($H_0 = 3$ feet, $T = 7$ seconds, and a deepwater wave angle α_0

Note: Discrepancy between initial Savage contours and initial model contours is due to use of the $h = Ay^2/3$ profile.

Figure 6. Simulation of the physical model of Savage (1959).

of 60°) was used as input for all four cases. Case 4.2a used an equilibrium shape factor A of 0.0899 and one groin. Case 4.2b was similar to 4.2a with the only modification being, that the A value was changed to 0.1486. In this way, a direct comparison was made based only on the shape of the equilibrium profile. Cases 4.2c and 4.2d used A-values of 0.0899 and 0.1486, respectively, but this time three shore-perpendicular, evenly spaced structures were simulated.

a. Comparison of Cases 4.2a and 4.2b. The most obvious difference between Figures 7 and 8 is the volume of sand impounded updrift and eroded downdrift. This is due to blockage of more of the active transport zone in the second case (i.e., a shorter groin is required for an equivalent performance on a steeper beach). The next obvious difference is the size of the perturbation which exists in the offshore contours. Clearly, case 4.2b is more perturbed and this is expected because larger offshore transports occur due to the steepening on the updrift side. Conversely, this means less sediment is initially bypassed (and along with the downdrift requirement for larger volumes of sand) causes larger erosional features in case 4.2b. Another interesting feature is the downdrift fillet which occurs in the third, fourth, and fifth contours. The fillet is due to the shape of the sixth contour which occurs because of the inability of the wave to transport more sediment (due to the reduction in wave height and angle in the diffraction shadow zone). The remaining difference is also due to the volume of sediment being impounded; i.e., the distance and extent of change the presence of the groin causes upcoast and downcoast.

b. Comparison of Cases 4.2c and 4.2d. The variations between cases 4.2c and 4.2d are very similar to the differences between cases 4.2a and 4.2b as would be expected with a groin field (here, three groins) as compared with a single groin (see Figs. 9 and 10). There is, however, one additional feature which can be attributed to the additional groins. Note that in the direction of littoral drift, the size of the fillet is decreasing. This is due to the updrift beach having an uninterrupted supply of sediment while the downdrift groin compartments are supplied sand at a rate determined by the bypassing. Part of this feature may also be due to the system not having attained complete equilibrium.

The effects of the fixed boundary conditions are evident on all cases run. In these example cases, the boundaries are clearly too close to the structure to provide a proper representation of the fillet contours.

3. Simulations of Sediment Transport of Dredge Disposal in the Vicinity of Oregon Inlet.

Hypothetical dredge disposal movement in the nearshore but beyond what is normally the surf zone at Oregon Inlet's adjacent beach to the south was modeled. In order to do these simulations, the program was altered such that for every n^{th} iteration (time periods), the contours were shifted seaward to simulate the addition of dredged sediment disposal. The program presented in Appendix B does require slight modification to simulate this situation.

In general, the fifth and sixth contours were shifted seaward on a monthly basis to simulate the disposal of 121,000 cubic yards of sediment.

Note: $J=7$ and 8 contours not shown

Figure 7. Equilibrium planform, case 4.2a.

Figure 8. Equilibrium planform, case 4.2b.

Figure 9. Equilibrium planform, case 4.2c.

Figure 10. Equilibrium planform, case 4.2d.

In all these simulations, the following variables were held constant: (a) a time-step of 3 hours, (b) a shoreline length of 10,000 feet, (c) a longshore space-step of 200 feet, (d) an A value of $0.15 \text{ foot}^{1/3}$ for the equilibrium profile (see Fig. 11), (e) a berm height of 5.3 feet with a beach face slope of 0.05, and (f) a duration of 1 year. The wave climate was provided by the U.S. Army Engineer Waterways Experiment Station Wave Information Study (WIS) 1975 data and was initiated at different times of the year as indicated in the specific cases below. All simulations, prior to any addition of sediment, used the bathymetry shown in Figure 12. The shoreline (relative to mean low water, MLW) was scaled from a bathymetry-topography survey provided by the U. S. Army Engineer District, Wilmington. The initial offshore bathymetry was computed according to the equilibrium profile and the 0-foot contour; i.e., the profile was shifted seaward or landward, accordingly, (see App. C.) The boundary profiles were fixed throughout the simulations. The variation of COFF outside the surf zone was used because of the importance of the time rate of change in this simulation. Table 1 presents the percentage of sediment which moves out of the control volume (i.e., imaginary boundaries around the area where sediment was added) directly onshore and the percentage of sediment remaining in the control volume at the conclusion of the simulation for each of the cases. In addition, a seventh (case 3) and eighth (case 4) were modeled. In Case 3, the only difference was that sediment was placed at the 11- and 14-foot contours. Case 4, however, was quite different and will be described in detail later. It has a 20,000-foot shoreline, a longshore space-step of 400 feet, and sediment was added on a weekly basis. Also, the resolution in the profile was better.

a. Specific Cases.

(1) Case 2.a. In order to provide insight for the interpretation of the other modeling efforts, a simulation of the shoreline evolution using the January to December WIS time series, with no addition of sediment, was carried out. As expected, the contours almost attain an equilibrium planform shape (i.e., straight and parallel between the fixed end profiles; they do not, however, become aligned parallel to the base line because of the end conditions). Because of the scales involved, alongshore versus onshore-offshore, plotting the contours without distortion does not yield much information. Appendix C provides a listing of the final contours for all the cases modeled.

(2) Case 2.b. The only difference between cases 2.a and 2.b is the suppression of the WIS wave angle which was set equal to zero (i.e., wave crest approach is shore-parallel at the offshore boundary of the model). This does not cause the longshore sediment transport to vanish completely. There are still local gradients in the contours which cause refraction and relative angles between wave crest and contour, thereby driving the longshore sediment transport (even if refraction was not considered, the local angle between the wave crest and contour would cause sediment transport). Note the larger onshore transport (Table 1) for this case compared with Case 2.a. This is due to the reduction in longshore transport caused by the wave angle of 0° . The model still tries to smooth the contour lines; however, more of the smoothing for the present case must be done by onshore-offshore transport.

Figure 11. Stepped version of equilibrium profile used in the Oregon Inlet modeling, $h = Ay^2/3$ ($A = 0.15 \text{ feet}^1/3$).

Figure 12. Initial contours used in the numerical model for all the Oregon Inlet simulations. (The scale for case 4 was twice the scale shown.)

Table 1. Summary of results at Oregon Inlet.

Case No.	Description	Pct Onshore out of control volume	Pct Remaining in control volume
2.a	No sediment added, WIS waves Jan. - Dec.	Onshore Movement (992 yd ³)	Increase (14,148 yd ³)
2.b	No sediment added, WIS waves ($\alpha = 0^\circ$) Jan. - Dec.	Onshore Movement (1624 yd ³)	Increase (9,356 yd ³)
2.c1	121,000 yd ³ added monthly, WIS waves Jan - Dec.	31.7 (460,264 yd ³)	38.6 (559,984 yd ³)
2.c2	121,000 yd ³ added monthly, WIS waves Apr. - Mar.	32.1 (466,160 yd ³)	36.9 (535,392 yd ³)
2.c3	121,000 yd ³ added monthly, WIS waves July - June.	28.6 (415,784 yd ³)	47.0 (682,088 yd ³)
2.c4	121,000 yd ³ added monthly, WIS waves Oct. - Sept.	27.2 (395,556 yd ³)	46.8 (670,848 yd ³)
3	121,000 yd ³ added monthly at the 11- and 14-foot contours WIS waves, Jan. - Dec.	8.9 * (32,164 yd ³)	78.0 (283,016 yd ³)
4	27,923 yd ³ added weekly on the 7-8-, 9-, and 10-foot contours, WIS waves Jan. - Dec.	19.0 (275,796 yd ³)	47.4 (687,525 yd ³)

* After 17 weeks, the addition of sand caused contours to cross. Prior sediment added was 363,000 yd³. Problem was rectified; however, case was not rerun.

(3) Case 2.c1. In this simulation, sediment is added to the system each month. It was simulated by advancing the 7- and 11-foot contours on a monthly basis to represent 121,000 cubic yards per month. Specifically, the sand volumes were "tapered" starting at the center of the nourished area over a distance of + 2,700 feet from the center. Table 2 presents the monthly Δy values for the blocks between the 7- to 11-foot contours and the 11- to 14 foot contours. Figure 13 shows the planform Δy values added monthly. WIS waves were used with the sequence being the normal calendar year, January through December.

Figure 13. Monthly incremental values of Δy due to dredge disposal illustrated for the block between 7- and 11-foot contours.

The initial and final fifth and sixth contours have been plotted in Figures 14 and 15. The first figure has no distortion; the second is distorted 10 to 1. The simulation predicts that 31.7 percent of the dredge disposal will move shoreward out of the control volume. An additional 29.7 percent efflux occurs in the offshore and longshore directions, leaving only 38.6 percent of the total amount of sediment added remaining in the control volume. It is not clear what quantity of the sediment leaving in the longshore direction would reach shore. It is conceivable that most of this sediment would eventually reach the surf zone. The rate at which this material would move ashore would be expected to be slower than the rate at which the large mounds would move ashore because the deviation of the profile from equilibrium is much less.

(4) Cases 2.c2, 2.c3, and 2.c4. The next three simulations were the same as 2.c1 except the time series of wave events has been seasonally altered. Cases 2.c2, 2.c3 and 2.c4 use the 1975 wave climate from April through March, July through June, and October through September, respectively. The maximum variation is about 5 percent for the sediment volume moving onshore, and about 10 percent for the volume remaining. The variation in the

Table 2. Monthly values of Δy for the steps located between the 7- to 10-foot contours and the 11- to 14-foot contours.

Value of I	Monthly Δy value (ft) for steps between	
	7- and 11-foot contours	11- and 14-foot contours
26	145.8	194.4
25,27	135.4	180.5
24,28	125.0	166.6
23,29	114.6	152.7
22,30	104.1	138.9
21,31	93.7	125.0
20,32	83.3	111.1
19,33	72.9	97.2
18,34	62.5	83.3
17,35	52.1	69.4
16,36	41.7	55.5
15,37	31.2	41.7
14,38	20.8	27.8
13,39	10.4	13.9
All Others	0	0

Figure 14. Initial and final 7- and 11-foot contours (no distortion).

Figure 15. Initial and final contours for case 2.c] [$y(I,5)$ and $y(I,6)$].

quantity moving onshore could be caused by waves that first tend to move more sediment longshore; then, the waves that transport more sediment onshore have a less out-of-equilibrium profile to cause movement upon. The variation in percentage remaining is due to the variation of the time series of the wave climate, with the last month in the simulation being especially important.

(5) Case 3. Instead of extending the 7- and 11-foot contours monthly to simulate the disposal of dredged sediments, the 11- and 14-foot contours were extended (194.4 feet each at the center of the disposal area). This case was modeled because the larger available dredge could not dump in more shallow water. The reduction and increase in the percent of onshore volume and the percent volume remaining (8.9 percent and 78.0 percent, respectively) demonstrate the sensitivity of the depths investigated. Qualitatively, these depths are the depths to which offshore bars occur along the Atlantic U.S. coast.

(6) Case 4. Further investigation of the disposal process demonstrated the need for an 11,000-foot shore-parallel disposal length with the sediment placed at the 11-foot contour building to about 7 feet. It was decided to model this physical situation also. The total shoreline length was changed to 20,000 feet, and the space step to 400 feet; the length of the disposal area in the longshore direction was increased to 10,800 feet. The resolution in the vicinity of the depths of the dump was improved by adding the additional contours and the profile is shown in Figure 16. As in the other seven cases, 1,452,000 cubic yards was added annually to the system; however, the addition was accomplished on a weekly basis (27,923 cubic yards per week). Sediment was still added by extending the contours seaward, but rather than placing one-fourth of the sediment at each of the four contours, the volumes were determined based on the trapezoidal cross section shown in Figure 17. This cross section more closely resembles the disposal mound formed by hopper dredging. The incremental values Figure 18 show, in planform, the extension of the contours to simulate the weekly sediment addition at the 8-foot contour.

A schematic illustration of the sediment transported from the nourished region is presented in Appendix C. Nineteen percent of the sediment added moved directly onshore out of the control volume.

b. Conclusions for the Movement of Disposed Sediment in the Vicinity of Oregon Inlet. The computer simulations, tempered with engineering judgment, demonstrate that between 15 and 35 percent of the material added to the 7- and 11-foot contours, or to the 7- 8- 9-, and 10-foot contours would be transported into the nearshore transport system during the first year. If the disposal process was continued, the system would approach steady state in terms of the volume of deposited material residing offshore.

For the case of sediment addition at the 11- and 14-foot contours, the computer simulations, tempered with engineering judgment, show that between 5 and 25 percent of the material added would be transported into the nearshore transport system during the first year.

Figure 16. Stepped version of equilibrium profile used in the Oregon Inlet modeling, $h=Ay^{2/3}$ ($A=0.15 \text{ feet}^{1/3}$), case 4. Note the resolution at 7, 8, 9, and 10 feet.

Figure 17. Shore-perpendicular cross section of disposal mound. The volumes represent the volume percentage of the trapezoidal section between contours and therefore, the quantity of sediment added to the 7-, 8-, 9-, and 10- foot contours.

Figure 18. Incremental values of Δy due to dredge disposal, illustrated for the block between 8- and 9-foot contours (case 4).

4. Simulation of the Longshore Sand Transport Study at Channel Islands Harbor, California.

The CIH Longshore Sand Transport Study (Bruno, et al., 1981) was the only field study found suitable for verification purposes. Wave data collected included the LEO data and a two pressure-sensor gage array. Although the pressure gages were not in operation throughout the study, it was expected that the data they produced would be superior to that of the LEO data. However, these data were not available in a reduced form, so the LEO data were used. An adjustment of 11° was made to the breaker angle to orient the angle with respect to the base line, rather than to the local shoreline orientation angle. Observations had been taken twice daily at three locations; the middle location was used (observer No. 5714). Waves which approached the shoreline at angles too large to have originated in a depth of 10 meters, according to Snell's law, were set equal to 90° at that depth (crest of wave perpendicular to the baseline). The 10-meter depth was chosen because it is the approximate depth at the tip of the offshore breakwater (for this reason, it was also chosen as the depth of the step beyond the $y(I, JMAX + 2)^{th}$ contour). It was assumed that each of the two daily observations occurred for 12 hours and using a time-step of 6 hours, this meant two time-steps per wave. In cases where parts of the wave data (H_b , α_b , or T) were missed by the observer or were equal to zero, the data were ignored (no computations were made), but the time was included. Because the time rate of change is important for this simulation, the variation of $Coff$ outside the break point was used.

The period chosen to model was 20 April through 1 December 1976. The initial survey was taken after dredging of the sediment trap and for this reason was known to be out of equilibrium. The bathymetric surveys were conducted using several methods, the most advanced being a Lighter Amphibious Resupply Cargo vessel (LARC) proceeding along shore-perpendicular lines (approximately in the vicinity of each survey station) taking fathometer readings every 10 seconds, with positioning systems trilaterating the vessel's position concurrently. These data were recorded on tape. The beach-face data were taken using standard surveying methods. Because the data fluctuated randomly about the stations, depending on the speed of the craft, the (x, y) coordinate positions had to be altered to fixed changes in x and y . This was accomplished using an interpolation routine. The x values were made to coincide with the stations used in the surveys, and the y values were determined at 100-foot intervals beginning from the base line. Stations 100+00 and 118+00 were located at the north jetty and termination of the detached breakwater, respectively (these correspond to I values of 16.5 and 34.5 in the model). See Figure 19.

Monotonic profiles of the form $h = A(y - y_{del})^{2/3}$ were fit to the data along each station line. " y_{del} " represents the zero location of the fitted shoreline, the value of which was unknown. Because dredging had been done in the lee of the breakwater, there was no reason to expect the A value to correspond to the value upcoast where the influence of the structure and the dredging was negligible. For this reason, the profiles of Stations 122+00 through 134+00 were evaluated separately to determine an A value for the equilibrium profile to be used in the numerical model. For the detailed method used (LaGrange Multipliers and Newton-Raphson Method for nonlinear

Figure 19. Idealized numerical model representation of offshore breakwater at Channel Islands Harbor, California.

equations) and the computer programs see Appendix D. The two values obtained for the surveys of 20 April and 1 December 1976 were averaged to obtain the value used in the model, $A = 0.2606$. Stations 101+00 through 121+00 were treated separately for the purpose of obtaining values with which to initialize those parts of the contours in the model and for comparison of the model predictions with the prototype values. Note that although the breakwater extends only to about Station 118+00, the influence of the structure and dredging extends beyond that location and so, although arbitrary, the 121+00 station was chosen as the dividing line. The initial and final values of the scaling parameter A for the profiles were 0.3233 and 0.3528, respectively. Because the initial shoreline is so irregular, a discontinuity between 121+00 and 122+00 is not evident.

One further idealization was made. The jetty-breakwater system was idealized as shown in Figure 19. This was required to simplify the physical situation, and although waves, currents, and sediment do pass through the opening in the prototype, it is hoped that they are of secondary importance.

The results of the numerical modeling of Channel Islands Harbor are presented in Figures 20 and 21. The first figure presents the shoreline contour (depth = 0); the second figure presents the farthest offshore, modeled contour. In both cases, the initial shoreline represents the model and prototype (after fitting of the profiles). The initial shoreline contour is further offshore along the section of beach beyond the end of the breakwater, while in the lee of the breakwater, as would be expected after dredging, the shoreline is closer to the base line. The final prototype contour has undergone erosion along the reach beyond the tip of the structure, and accretion in the lee.

The model's shoreline contour has undergone similar changes, and on the average, represents the final prototype contour quite well. The J_{MAX}^{th} contour has been displaced quite similarly to the shoreline contour with shoreward movement (erosion) along the reach beyond the tip of the breakwater and seaward movement (accretion) within. It appears that the final model's shoreline has predicted too much erosion and not enough accretion. Several parameters could be incorrect, with the onshore-offshore sediment transport rate coefficient, C_{OFF} , perhaps the most likely. Overall, the model seemed to predict reasonable values of the contours.

V. SUMMARY AND RECOMMENDATIONS

Some of the parameters that the model does not include are important and should be mentioned. As stated previously, the model does not include bar formation. This is precluded by an n -line system. There are no provisions for water level fluctuations or currents. Improvement to the model could also be facilitated with better longshore and cross-shore sediment transport relationships. A more reliable equation for distribution of sediment transport across the surf zone would also be helpful (or further testing and calibration of the equation proposed herein). Finally, combining refraction and diffraction using equations to predict their combined effect would improve the wave field. The program was constructed such that improvement

Figure 20. CIH simulation of shoreline contour, 20 April - 1 December 1976 (from LEO data).

Figure 21. CIH simulation of $(JMAX)^{th}$ contour, 20 April - 1 December 1976 (from LEO data).

could be accomplished with minimum effort. Therefore, if a more suitable equation becomes available, the change of a subroutine should be sufficient for implementation of the equation.

Although the model is limited by the omission of the aforementioned parameters, it is reasonably correct. The ability to simulate various physical situations (shore-perpendicular structures, beach fills, breakwater and shore-perpendicular structures) has been demonstrated. In the CIH simulation where the data were first transformed to monotonically decreasing contours and LEO wave data were used, the model still predicts the prototype shoreline changes in a reasonable fashion.

Further research and model development should include exercising the model in a number of different situations. Several theoretical cases should be simulated, which if analyzed properly, would provide a tool for the coastal engineer. Combined refraction and diffraction should be included, if possible, along with any of the aforementioned parameters which have been omitted and for which relationships exist. Perhaps the most difficult problem to researchers working on modeling sediment transport in the vicinity of structures is the availability of field data. High-quality concurrent wave and bathymetric change data in the vicinity of coastal structures do not exist. One suggested field experiment is to monitor changes both updrift and downdrift of a jettied inlet which has a bypassing plant. Monitoring should begin immediately after bypassing, when the profiles are out of equilibrium. The recorded bathymetric and wave data would then provide data with which to calibrate, verify, and evaluate the existing models.

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APPENDIX A

DISCUSSION OF CONSTANTS AND SOME OF THE VARIABLES REQUIRED BY THE MODEL

Establishing the grid-contour system requires several variables. IMAX represents the number of cross-shore grid lines desired and JMAX the number of contours simulated. DX represents the spacing between the IMAX grid lines and DY the spacing between the contours. DX is a value which must be chosen along with IMAX and JMAX such that sufficient detail is obtained where necessary (e.g., in the shadow zone, if diffraction effects are believed to be very important, DX must be assigned a sufficiently small value so that at least some points lie within the shadow zone for the larger wave angles). DY is not a constant, but a dimensional array which is computed by the model according to the contour location. Once the depths of contours to be modeled are chosen, the initialization of DY and the y values are computed with the following equation after Dean, 1977

$$h = A y^{2/3} \quad (A-1)$$

where h is the depth, y is the offshore distance and A is the scaling parameter Dean gives values for A for several diameter sediments; however, if long-term beach profiles are available for the site being modeled, the modeler may want to choose a slightly different A value to more closely match the site-specific beach profile. Figure A-1 presents values of A versus diameter (after Moore, 1982). The model is programmed to input the h(I,J) values (depths as shown in Figure 1, called DEEP (I,J) in the program) read in the value of A (called ADEAN in program) and it then computes the y values. Also shown in Figure 1 is the height of the berm (BERM) and this value, along with the beach-face slope (SFACE), is required as program input and can be obtained from beach profile site data. Because the model does not include water level fluctuations such as tides, all values are to be referenced to a chosen datum. Other geometrical constants depending on the site include SJETTY (the length of the jetty), MMAX (the number of structures to be input), and IJET (M), M = 1,2,...MMAX (the smaller I value adjacent to the Mth structure's location). If no structure is required, as in a beach fill, the value of SJETTY must be entered as 0.0, with MMAX and IJET (M) entered as 1 and (IMAX/2), respectively. As set up presently, the groin locations must be equally spaced.

One constant used throughout the program is the breaking wave criteria (CAPP in the program) equal to 0.78. It is required in several different computations and always governs the maximum wave height allowed according to the depth.

Another group of variables assigned values within the program is the sediment and fluid properties. These include fluid mass density, sediment mass density, porosity, and the angle of repose (e.g., RHO = 1.99, RHOS = 5.14, POROS = 0.40, and REPOSE = 32°, respectively). The values can easily be changed to reflect site conditions.

Figure A-1. A versus sediment diameter (after Moore, 1982).

Another very important set of constants is the constant chosen for the longshore and cross-shore components of sediment transport. Equation (27), the total longshore transport equation, contains the constant C' equal to

$$C' = \frac{K \rho_s (g)^{1/2}}{(\rho_s - \rho) (1 - p) (16) (\kappa)^{1/2}} \quad (A-2)$$

where

$K = 0.77$ (Komar and Inman, 1970)

g is the acceleration of gravity (32.17 ft/sec²)

ρ_s and ρ are the mass densities of the sediment and the seawater (5.14 and 1.99 slugs per cubic feet, respectively)

p is the porosity (0.40), and

κ is taken as 0.78.

Using these values to compute C' (TKSI in the program), a value of 0.325 is obtained. It is stressed that if any of these values are different for the site to be modeled, they should be changed and the program will compute another value for C' .

The parameter C_{OFF} is an "activity factor" which, based on earlier work primarily within the surf zone, was found to be

$$C_{OFF} = 10^{-5} \text{ ft/s}, \quad h < h_b$$

To generalize this concept for transport seaward of the surf zone, the wave energy dissipation per unit volume was utilized as a measure of mobilization of the bottom sediment. Inside the surf zone, the dominant wave energy dissipation is caused by wave breaking; outside the surf zone, the dominant mode of wave energy dissipation is due to bottom friction. These two components will be denoted by D_1 and D_2 , respectively.

(a) Energy Dissipation by Wave Breaking. The wave energy dissipation per unit volume by wave breaking, D_1 , is

$$D_1 = \frac{1}{h} \frac{\partial}{\partial y} (E C_G) \quad (A-3)$$

which, employing the spilling breaker assumption ($H = \kappa h$) within the surf zone, can be shown to be

$$D_1 = \frac{5}{16} \rho g^{3/2} \kappa^2 h^{1/2} \frac{\partial h}{\partial y} \quad (A-4)$$

or

$$D_1 = \frac{5}{24} \rho g^{3/2} \kappa^2 A^{3/2} \quad (A-5)$$

in which A is the scale parameter in the equilibrium beach profile

$$h(y) = A y^{2/3} \quad (A-6)$$

(b) Energy Dissipation by Bottom Friction. The wave energy dissipation per unit volume due to bottom friction, D_2 , is

$$D_2 = \frac{1}{h} \tau u_b = \frac{1}{h} \rho C_f \overline{|u_b| u_b^2} \quad (A-7)$$

in which C_f is a bottom friction coefficient, u_b is the bottom water particle velocity and the overbar indicates a time average. For linear waves, equation (A-7) can be reduced to

$$D_2 = \frac{1}{6\pi} \frac{\rho}{h} C_f \frac{H^3 \omega^3}{\sinh^3 kh} \quad (A-8)$$

The activity coefficient C_{OFF} , outside the surf zone, is expressed as

$$C_{OFF} = \frac{1}{\Gamma} \frac{D_2}{D_1} \times 10^{-5} \text{ ft/s}, \quad h > h_b \quad (A-9)$$

$$C_{OFF} = \frac{4}{5\Gamma} \frac{C_f \omega^3}{g^{3/2} \kappa^2 A^{3/2} h} \left(\frac{H}{\sinh kh} \right)^3 \times 10^{-5} \quad (A-10)$$

in which Γ is a parameter relating the efficiency with which breaking wave energy (which occurs primarily near the water surface) mobilizes the sediment bottom ($0 < \Gamma \leq 1$). Herein, Γ is taken to be one.

Figure A-2 presents an example of the variation of the activity coefficient versus relative depth for a particular wave period and deep water wave height. It is seen that the activity coefficient reduces rapidly with increasing depth.

The value of C_{OFF} for the physical modeling of Savage's (1959) data was taken as 10^{-4} feet per second. Perlin (1978) presents some rationale for choosing a value of C_{OFF} ; however, very little testing has been done and none is based on actual field measurement.

Figure A-2. Example of activity coefficient, C_{off} versus water depth, h , for particular wave conditions.

Finally, wave data are read into the program and the simulation begins. (For information regarding "Read Formats" for the various constants and variables, see Appendix E). Wave data required are wave height, wave period, wave angle relative to the x-axis of the model at a depth, WDEPTH and the duration of the wave climate (HS, T, ALPWIS, and a combination of NTIMES x DELT, respectively, in the model). As is always the case with numerical models, the time step and space steps are very important to both stability and accuracy. Time steps on the order of 3 to 6 hours (10,800 to 21,600 seconds) or less are recommended. However, the complexity of the bathymetry, variation and time series of the wave data, constants used (especially C_{OFF}) along with several other factors, greatly influences the stability and accuracy of the results.

Table A-1 lists several of the important variables in the computer program.

Table A-1. List of important variables in the program

ABAND	The input banded matrix which stores the values from equation (37)
ADEAN	The value of the scaling parameter in the equilibrium beach profile
ALPHAS	The angle a contour makes with the x-direction base line (counter-clockwise is positive)
ALPWIS	The angle (-90° to +90°) the wave crest makes with the x-direction (counter-clockwise is positive)
AMP	The amplitude of the diffracted wave in the shadow zone
ANGGEN	The wave angle at a depth, WDEPTH
ANGLOC	The local contour orientation angle
AWARE	See equations (36) and (37)
BERM	The height of the berm above water level
BMATRX	The matrix which, upon solution of the banded matrix problem yields the new y values
C	The wave celerity
CAPPA	The breaking wave index
CC	Constant which establishes the width of the distribution of sediment transport across the surf zone
CG	The group velocity throughout the wave field
CGEN	The linear wave theory celerity at a depth, WDEPTH

CGGEN	The linear wave theory group velocity at a depth, WDEPTH
CO	The deepwater, linear wave theory wave celerity
COFF	The onshore-offshore transport rate coefficient within the surf zone
CONST	The constant in the longshore sediment transport relationship (0.77)
CONST6	The space step, DX, multiplied by the activity coefficient
DEEP	The water depth at any grid location
DEEPB	The initial breaking depth along each profile (between adjacent profiles)
DEEBI	The initial breaking depth along each profile (at each profile, rather than between them)
DELT	The time-step in seconds (DELT x NTIMES = wave condition duration)
DIAM	The mean diameter of the sediment particles
DISTR	See equations (36) and (37)
DX	The alongshore space-step in the x-direction (distance between I values)
DY	The onshore-offshore space-step in the y-direction as defined by the stepped profile
ELO	The deepwater, linear wave theory wavelength
ELTIP	The wavelength at the tip of the structure
EPS	The change in the wave number which is acceptably small
G	The acceleration of gravity (32.17 feet/second ²)
GAMMA	The specific weight of seawater
H	The wave height throughout the wave field
HB	The maximum wave height which could exist throughout the wave field (where $H = 0.78 * h$)
HBI	The initial breaking wave height along any profile at the y values rather than between them
HBQ	The initial breaking wave height along any profile, between adjacent profiles

HGEN	Average wave height at a depth, WDEPTH
HS	The significant wave height input
I	The longshore grid location
IBREAK	The leeward side of the initial breaker location J value
IJET	Represents the lesser I value adjacent to the structure (these must be evenly spaced alongshore)
IMAX	The total number of grid points in the x-direction (alongshore)
J	The offshore contour location
JMAX	The value of the seawardmost contour simulated
JUSE	(JMAX + 2) the seawardmost contour at which the wave field is calculated
J1	Landward contour of refraction zone
J2	Seaward contour of refraction zone
J1REF	Landward J values of boundary of refraction zone
J2REF	Seaward J values of boundary of refraction zone
MMAX	The number of shore-perpendicular structures to be simulated (present maximum of 16)
NITER	The counterindex in the refraction routine
NTIME	The counterindex in the time simulation "D0" loop
NTIMES	The number of iterations of time-step, DELT, for which a particular wave is simulated
NUNIV	The total number of time-steps simulated at any time
PI	The value of $\pi = 3.141592654$
POROS	The porosity of the sediment
QX	The longshore sediment transport rate at a specific location
QXTOT	The total alongshore sediment transport rate due to the height and angle of the initial breaking wave
QY	The onshore-offshore sediment transport rate at a specific location
R	See equations (36) and (37)

REPOSE	The angle of repose of the sediment
RHO	The mass density of seawater
RHOND	The dimensionless distance from the tip of structure where diffraction is initiated
RHOS	The mass density of sediment
RK	The wave number
S3	See equations (36) and (37)
SFACE	The slope of the shoreface
SJETTY	The length of the shore-perpendicular structure (from the base line)
SIGMA	The wave radian frequency
T	The wave period
TAU	The dissipative interface parameter
THETA	The wave angle throughout the wave field
THEATO	The wave angle at the tip of the structure
TKSI	The longshore sediment transport rate coefficient
TWOPI	Twice the value of π
U	See equations (36) and (37)
UCRIT	The critical velocity required to move the sediment according to the Sheid's diagram
V	See equations (36) and (37)
WDEPTH	The depth of water in meters to which the input wave conditions are to be transformed
WEQ	The equilibrium profile distance between contours as defined by the stepped profile
XCOOR	The x-coordinate where the wave field is to be calculated. Together with YCOOR, they determine whether the position is within or beyond the diffraction shadow zone
XDISTN	The location of the structure along the shoreline in feet
Y	The distance offshore to the contours

YC00R	The y-coordinate where the wave field is to be calculated. Together with XC00R, they determine whether the position is within or beyond the diffraction shadow zone
YDISS	The value of y after the use of the dissipative interface
YOLD	The previous value of y
YZERO	The berm contour location
Z1	See equation (37)
Z2	See equation (37)

APPENDIX B
PROGRAM LISTING

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100 C* ***** PROGRAM IMPLICIT SEDTRAN
200 C*THIS PROGRAM IS SET-UP TO HANDLE MULTIPLE GROINS(M<=10).
300 COMMON/A/ C(60,20),RK(60,20),Y(60,20),DEEP(60,20),ALPHAS(60,20)
400 COMMON/AA/YZERO(60)
500 COMMON/BB/WEQ(60,20)
600 COMMON/B/ THETA(60,20),QXTOT(60), OLDANG(60,20), DY(60,20)
700 COMMON/C/ H(60,20),CG(60,20),HOLD(60,20),HB(60,20),YB(60)
800 COMMON/N USED/JUSE,T,CO,CGEN,CGGEN,ANGGEN,DX,BERM,THETA0(10),MMAX
900 COMMON/D/SIGMA,G,ELO,JMAX,IMAX,P1,TWOPI,PIO2,HGEN,IJET(10),SJETTY
1000 COMMON/F/ADEAN,REPOSE,DIAM
1100 COMMON/AAA/DELT,NTIMES
1200 COMMON/COUNT/NUNIV
1300 COMMON/EXPL/QYEXP(60,20),YIMP(60,20)
1400 DIMENSION CHANGE(20),HC(10),TC(10)
1500 DIMENSION YORIG(60,20),YZERO0(60),SANGLE(20)
1600 NUNIV=0
1700 JMAX=8
1800 JUSE=JMAX+2
1900 IMAX=50
2000 PI=3.141592654
2100 TWOPI=PI*2.
2200 PIO2=PI/2.0
2300 REPOSE=32.*TWOPI/360.
2400 WRITE(6,732)
2500 732 FORMAT('*****')
2600 WRITE(6,733)
2700 733 FORMAT(2X,'TO WHAT DEPTH ARE THE WAVES TO BE TRANSFORMED')
2800 C*WDEPTH MUST BE A DEPTH BEYOND THE END OF THE STRUCT, PREFERABLY AT
2900 C**DEEP(JMAX) OR GREATER(OR ELSE SNELL'S LAW OR SHOAL COULD BLOWUP IN
3000 C***DEEPER WATER. IT'S IN METERS HERE!
3100 READ(5,770) WDEPTH
3200 770 FORMAT(10X,F10.3)
3300 WDEPTH=WDEPTH*3.28084
3400 WRITE(6,762) WDEPTH
3500 762 FORMAT(2X,"THE DEPTH (IN FT) WAVES TRANSFORMED TO, WDEPTH= ",
3600 * F10.3)
3700 WRITE(6,732)
3800 WRITE(6,777)
3900 777 FORMAT(2X,"ITS TIME FOR SJETTY, BERM, SFACE, AND DIAM"./)
4000 C*SJETTY MUST BE MUCH LESS THAN Y(I,JMAX).
4100 READ(5,776) SJETTY,BERM,SFACE,DIAM
4200 776 FORMAT(2F10.3,F10.4,F10.3)
4300 WRITE(6,761) SJETTY
4400 761 FORMAT(2X,'THE LENGTH OF THE STRUCTURE, SJETTY= ',F10.3)
4500 WRITE(6,740) BERM
4600 740 FORMAT(2X,'THE HEIGHT OF THE BERM, BERM= ',F10.3)
4700 WRITE(6,739)SFACE
4800 739 FORMAT(2X,'THE SLOPE OF THE BEACH FACE, SFACE= ',F10.4)
4900 WRITE(6,738) DIAM
5000 738 FORMAT(2X,'THE SEDIMENT DIAMETER, DIAM= ',F10.3)
5100 WRITE(6,732)
5200 780 FORMAT(2X,'SUPPLY MMAX( THE NO. OF GROINS) AND THEIR I-LOC',/)
5300 UCRTI=16.3*SQRT(DIAM*0.00328)
5400 C*THE NO. OF MULTIPLE GROINS,MMAX MUST BE GIVEN THEIR X LOCATIONS.
5500 READ(5,779) MMAX
5600 779 FORMAT(I3)
5700 DO 760 M=1,MMAX
5800 C*IJET REPS LESSER I-VALUE ADJACENT TO STRUCTURE.
5900 760 READ(5,779) IJET(M)
6000 WRITE(6,759) (M,IJET(M),M=1,MMAX)
6100 759 FORMAT(2X,'THE NUMBER',I5,' GROIN IS LOCATED AT GRID',I5)
6200 WRITE(6,732)
6300 C*CONVERT TO RADIANS.
6400 C*FIRST MUST GIVE Y COORS POSITIONS AND DEPTHS.
6500 C*FIRST, MUST SET UP ALL OF THE DEEP-VALUES.
6600 WRITE(6,773)
6700 773 FORMAT(2X,"NOW ENTER THE VALUE OF ADEAN")
6800 READ(5,774)ADEAN
6900 774 FORMAT(F10.4)
7000 WRITE(6,749) ADEAN
7100 749 FORMAT(2X,'THE VALUE OF ADEAN= ',F10.4,' IN THE EQ. H=AY**2/3')
7200 WRITE(6,732)

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7300      WRITE(6,772)
7400      772 FORMAT(2X,"READ IN THE SPACE STEP,TIMESTEP",/)
7500      READ(5,775)   DX,DELT
7600      775 FORMAT(2(F10.3))
7700      WRITE(6,737)   DX
7800      737 FORMAT(2X,'THE VALUE OF THE LONGSHORE SPACE-STEP, DX= ',F10.3)
7900      WRITE(6,736)   DELT
8000      736 FORMAT(2X,'THE TIME-STEP IN SECONDS, DELT= ',F10.3)
8100      DATA CHANGE/1.,2.,3.,5.,7.,11.,14.,17.,25.,32.808,10*0.0/
8200      DO 220 J=1,JMAX+2
8300      DO 220 I=1,IMAX
8400      220 DEEP(I,J)=CHANGE(J)
8500      DATA(HC(I),I=1,8)/1.87,0.5,0.35,.25,.21,.20,.19,.19/
8600      DATA(TC(I),I=1,8)/2.,3.,4.,6.,8.,10.,12.,14./
8700      DO 200 J=1,JMAX+2
8800      DO 200 I=1,IMAX
8900      200 Y(I,J+1)=(0.5*(DEEP(I,J+1)+DEEP(I,J)))/ADEAN)**1.5+Y(I,1)
9000      WRITE(6,732)
9100      C*****
9200      C*WE WILL ALWAYS REQUIRE Y(I,JMAX+2) TO COMPUTE DY AND YBAR.
9300      C*WE WILL ALWAYS REQUIRE DEEP(I,JMAX+2) TO COMP SEDIMENT TRANSPORT.
9400      C*****
9500      WRITE(6,734)
9600      734 FORMAT(2X,'THE BOUNDARY Y-VALUES, I=1,IMAX ARE AS FOLLOWS',/)
9700      WRITE(6,801)    (Y(1,J),J=1,JMAX+2)
9800      WRITE(6,801)    (Y(IMAX,J),J=1,JMAX+2)
9900      WRITE(6,732)
10000     WRITE(6,735)
10100     735 FORMAT(/,2X,'THE DEPTHS BETWEEN CONTOURS ARE AS FOLLOWS',/)
10200     WRITE(6,801)    (DEEP(1,J),J=1,JMAX+2)
10300     WRITE(6,732)
10400     801 FORMAT(2X,10(F8.2))
10500     DO 2 I=1,IMAX
10600     2 YZERO(I)=Y(I,1)-(BERM/SFACE)
10700     C*WILL COMPUTE THE EQUIL WIDTH BETWEEN CONTOURS, HERE.
10800     DO 1 I=1,IMAX
10900     WEQ(I,1)=Y(I,1)-YZERO(I)
11000     DO 1 J=1,JMAX
11100     IF(J.NE.1) GO TO 32
11200     YTEMP1=0.0
11300     GO TO 33
11400     32 YTEMP1=((0.5*(DEEP(I,J-1)+DEEP(I,J)))/ADEAN)**1.5
11500     33 YTEMP2=((0.5*(DEEP(I,J)+DEEP(I,J+1)))/ADEAN)**1.5
11600     WEQ(I,J+1)=YTEMP2-YTEMP1
11700     1 CONTINUE
11800     C*LET'S STORE THE ORIG VALUES TO COMPUTE VOL CHANGES OVER CONTOURS,LATER
11900     DO 796 I=1,IMAX+1
12000     YZEROO(I)=YZERO(I)
12100     DO 796 J=1,JMAX+2
12200     796 YDRIG(I,J)=Y(I,J)
12300     C*****
12400     C*READ THE DISK FILE AND TRANSFORM PARAMETERS INTO MY UNITS.
12500     C*****!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
12600     C*ALL ADJUSTMENTS TO WAVE ANGLE,HEIGHT,CELERITY,GROUP VEL, WILL BE MADE
12700     C**HERE, AND THRUOUT THE REST OF THE PROG, THEY WILL BE AS IF OCCURRED
12800     C**AT WDEPTH!
12900     798 READ(5,799,END=1000) HS,T,ALPWIS
13000     799 FORMAT(10X,3F6.1)
13100     NTIMES=1
13200     NCHECK=NUNIV*NTIMES
13300     HGEN=0.707107*HS
13400     SIGMA=TWOPI/T
13500     G=32.17
13600     CO=G*T/TWOPI
13700     ELO=CO*T
13800     IF(T.LE.2.0) GO TO 797
13900     HCC=0.23
14000     DO 444 I=2.7
14100     T2=TC(I)
14200     IF(T.GT.T2) GO TO 444
14300     T1=TC(I-1)
14400     DELTAT=T2-T1

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14500      DT=(T-T1)/DELTAT
14600      DTT=(T2-T)/DELT
14700      HCC=HC(I)*DT+HC(I-1)*DTT
14800      GO TO 446
14900  444 CONTINUE
15000  446 CONTINUE
15100      IF(HGEN.LT.HCC) GO TO 797
15200      ANGEN=ALPWSI*TWOP/360.
15300  C*****
15400      CALL WVNUM(WDEPTH,T,DUMKK)
15500  C*ANGGEN,HGEN,CGEN,CGEN REPRESENT THE WAVE ANGLE,HEIGHT,CELERITY AND
15600  C**GROUP VEL(RESPCT.) OF THE SPECIFIED WAVE INPUT AT A DEPTH, WDEPTH
15700      CALL WVNUM(11.0,T,DUMKKK)
15800      C11=TWOP/(T*DUMKKK)
15900      CG11=0.5*C11*(1.+(2.*DUMKKK*11.0/SINH(2.*DUMKKK*11.0)))
16000      CGEN=TWOP/(T*DUMKK)
16100      CGGEN=0.5*CGEN*(1.+(2.*DUMKK*WDEPTH/SINH(2.*DUMKK*WDEPTH)))
16200      CALL TRANS
16300  797 IF(NCHECK.NE.NUNIV) NUNIV=NCHECK
16400  709 GO TO 798
16500  1000 CONTINUE
16600      STOP
16700      END
16800  C*****
16900      SUBROUTINE TRANS
17000  C*THIS SUBROUTINE WILL COMPUTE SEDIMENT TRANSPORT
17100      COMMON/A/ C(60,20),RK(60,20),Y(60,20),DEEP(60,20),ALPHAS(60,20)
17200      COMMON/AA/YZERO(60)
17300      COMMON/BB/WEQ(60,20)
17400      COMMON/B/ THETA(60,20),QXTOT(60), OLDANG(60,20), DY(60,20)
17500      COMMON/C/ H(60,20),CG(60,20),HOLD(60,20),HB(60,20),YB(60)
17600      COMMON/N USED/JUSE,T,CO,CGEN,CGGEN,ANGGEN,DX,BERM,THETA(10),MMAX
17700      COMMON/D/SIGMA,G,ELD,JMAX,IMAX,PI,TWOP,PIO2,HGEN,IJET(10),SUETTY
17800      COMMON/E/RHO,RHOS,POROS,CONST,TKSI
17900      COMMON/F/ADEAN,REPDSE,DIAM
18000      COMMON/G/IBREAK(60),HNDNBR(20)
18100      COMMON/P/HBO(60),DEEPB(60)
18200      COMMOND/ZZZ/NTIME
18300      COMMON/AAA/DELT,NTIMES
18400      COMMOND/COUNT/NUNIV
18500      DIMENSION YOLD(60,20),R(60,20),S(60,20),HC(60,20),QY(60,20),YDISS(
18600      * 60,20)
18700      DIMENSION RHS1(60,20),S3(60,20),THETAB(60,20),ANGLOC(60,20)
18800      DIMENSION DISTR(60,20),AWARE(60,20)
18900  C*****
19000  C*****
19100  C***** NOTE : SIZE OF ABAND AND XL HAVE TO BE CHANGED
19200  C***** ACCORDING TO JMAX+1+JMAX AND JMAX+1,RESPECT.
19300  C***** CHANGE REQ'D AT 7040 AND 18650
19400  C*****
19500      * ),BMATRX(432),ABAND(432,19),QX(60,20),XL(432,10),CONST6(60,20)
19600      COMMON/MP/ RKB(60),HBI(60),DEEPI(60)
19700      COMMON/EXPL/QYEXP(60,20),YIMP(60,20)
19800      DIMENSION SANGLE(20)
19900  C*LET'S ZERO-OUT ALL OF THE DIMENSIONED MATRICES.
20000      DO 1000 J=1,JMAX+2
20100      SANGLE(J)=0.0
20200      DO 1000 I=1,IMAX+2
20300      YOLD(I,J)=0.0
20400      R(I,J)=0.0
20500      S(I,J)=0.0
20600      HC(I,J)=0.0
20700      QY(I,J)=0.0
20800      YDISS(I,J)=0.0
20900      RHS1(I,J)=0.0
21000      S3(I,J)=0.0
21100      THETAB(I,J)=0.0
21200      ANGLOC(I,J)=0.0
21300      DISTR(I,J)=0.0
21400      AWARE(I,J)=0.0
21500      QX(I,J)=0.0
21600      CONST6(I,J)=0.0

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21700      1000 CONTINUE
21800      RHO=1.99
21900      RHOS=5.14
22000      POROS=0.40
22100      CONST=0.77
22200      CAPPA=0.78
22300      TAU=0.25
22400      TKS1=(CONST*RHO*SQRT(G))/((RHOS-RHO)*(1.0-POROS)*16.0*SQRT(CAPPA))
22500 C* QX(I,J) IS THE TRANSPORT BETWEEN THE (I,J+1) AND (I,J) CONTOURS.
22600 C*THE 'DO 1 LOOP' SIMULATES TIME---TIME=DELT*NTIMES.
22700      COFF=0.00001
22800      GAMMA=RHO*G
22900      DO 1 NTIME=1,NTIMES
23000      NUNIV=NUNIV+1
23100 C*THE MATRICES ABAND AND BMATRX MUST BE "ZEROED OUT"
23200      K=0
23300      DO 26 I=2,IMAX-1
23400      DO 26 J=1,JMAX
23500      K=K+1
23600      BMATRX(K)=0.0
23700      DO 26 L=1,JMAX+1+JMAX
23800      26 ABAND(K,L)=0.0
23900      XNTIME=1.0*(NTIME)
24000      CALL PREDIF
24100 C*SMOOTHING OF THE WAVE ANGLE,THETA, IS RE'D TO ACCT FOR DIFF EFFECTS.
24200      CALL SMOOTH(THETA,IMAX,JMAX,IJET,SJETTY,MMAX,Y)
24300      CALL QTRAN
24400 C*FIRST THE LONGSHORE SEDIMENT TRANSPORT WILL BE OISTRIBUTED
24500 C***ACROSS THE SURF ZONE...
24600      CC=1.25
24700 C***QX(I,J) WILL BE DETERMINED BY SUBTRACTING FROM THE INTEGRAL
24800 C**OF QX FROM DEEP(I,J-1) TO INFINITY, THE INTEGRAL OF QX FROM DEEP(I,J)
24900 C***TO INFINITY. IN THIS WAY THE SEDIMENT TRANS FROM JMAX OUT GETS
25000 C***INCLUDED IN QX(I,JMAX). TO INCLUDE THE SWASH TRANS, WHEN J=1
25100 C*WE WILL SUBTRACT FROM 2 TO INFINITY FROM 1.0
25200 C*LOOP FOR VALUES WHICH ARE HELD CONST AND STORED.
25300      THETAB(1,1)=0.5*(THETA(1,1)+0.0)
25400      R(1,1)=0.5/(DX*(DEEP(1,1)+BERM/2.))
25500      DO 290 I=2,IMAX
25600      R(I,1)=0.5/(DX*(DEEP(I,1)+BERM/2.))
25700 C* THETAB(I,1)=0.25*(THETA(I,1)+THETA(I-1,1)+0.0)
25800      THETAB(I,1)=0.5*(THETA(I,1)+THETA(I-1,1))
25900 C*NO NEED TO COMPUTE PROP ANGLE AT STRUCTS BECAUSE QX =0.0 AT IJET(M)+1
26000      ANGLOC(I,1)=ATAN((Y(I,1)-Y(I-1,1))/DX)
26100 C*HBQ(IJET(M)+1) IS PROPERLY SET IN THE SUBROUTINE QTRAN.
26200      DISTR(I,1)=1.0-EXP(-((DEEP(I,1)**1.5+HBQ(I)*ADEAN**1.5)/
26300      * (CC*DEEPB(I)**1.5))**3)
26400      DISTR(I,1)=DISTR(I,1)*TKSI*HBQ(I)**2.5
26500      DO 290 J=2,JMAX
26600      R(I,J)=0.5/(DX*(DEEP(I,J)-DEEP(I,J-1)))
26700      THETAB(I,J)=0.5*(THETA(I,J)+THETA(I-1,J))
26800      ANGLOC(I,J)=ATAN((Y(I,J)-Y(I-1,J))/DX)
26900      DISTR(I,J)=EXP(-((DEEP(I,J-1)**1.5+HBQ(I)*ADEAN**1.5)/(CC*DEEPB(I)
27000      * **1.5))**3)-EXP(-((DEEP(I,J)**1.5+HBQ(I)*ADEAN**1.5)/(CC*
27100      * DEEPB(I)**1.5))**3)
27200      DISTR(I,J)=DISTR(I,J)*TKSI*HBQ(I)**2.5
27300      290 CONTINUE
27400      DO 301 J=1,JMAX
27500      DO 301 I=2,IMAX
27600      AWARE(I,J)=DELT*R(I,J)*(QX(I,J)-QX(I+1,J)+QY(I,J)-QY(I,J+1))+Y(I,J)
27700      * )
27800      S1=2.*SIN(THETAB(I,J))*COS(THETAB(I,J))*(-1.+2.*COS(
27900      * ANGLOC(I,J))**2)
28000      S2=COS(2.*THETAB(I,J))*COS(ANGLOC(I,J))/(SQRT(DX**2+
28100      * (Y(I,J)-Y(I-1,J))**2))
28200      S3(I,J)=S2*DISTR(I,J)
28300      IF(SJETTY.EQ.0.0) GO TO 302
28400      DO 325 M=1,MMAX
28500      IF(I.NE.IJET(M)+1) GO TO 325
28600      IF(THETA(M).GE.0.0) ISIDE=IJET(M)
28700      IF(THETA(M).LT.0.0) ISIDE=IJET(M)+1
28800      YSEA=0.5*(Y(ISIDE,J)+Y(ISIDE,J+1))
28900      YSHORE=0.5*(Y(ISIDE,J)+Y(ISIDE,J-1))

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29000      IF(YSEA.GT.SJETTY.AND.YSHORE.GT.SJETTY)   GO TO 302
29100      IF(YSEA.GT.SJETTY.AND.YSHORE.LE.SJETTY)   GO TO 298
29200      C*BECAUSE A NO FLOW B.C. IS USED ALONG THE STRUCT, NO ATTN WAS PAID
29300      C**TO GETTING PROPER VALUES OF ANGLOC, THETAB,DISTR,ETC.
29400      S3(I,J)=O.O
29500      DISTR(I,J)=O.O
29600      GO TO 302
29700      325 CONTINUE
29800      GO TO 302
29900      C***ABOVE, ALL PARAMETERS(I.E.,S1,S2,S3,THETAB,DISTR,ANGLOC)
30000      C***ARE COMPUTED AS IF THE STRUCT IS NOT THERE. THE B.C. AT THE
30100      C***STRUCT TIP ASSUMES QX COMPUTED AS IF NO STRUCT PRESENT AND THEN
30200      C***BYPASSES ACCORDING TO "RATIO".
30300      298 RATIO=(YSEA-SJETTY)/(YSEA-YSHORE)
30400      S3(I,J)=S3(I,J)*RATIO
30500      DISTR(I,J)=DISTR(I,J)*RATIO
30600      302 RHS1(I,J)=DISTR(I,J)*S1-S3(I,J)*(Y(I,J)-Y(I-1,J))
30700      301 CONTINUE
30800      CALL BREAK(IMAX,JMAX)
30900      C*TO DETERMINE DECAY OF CONST6(I,J),NEED WAVE NO. AT BREAKING.
31000      DO 754 I=1,IMAX+1
31100      754 CALL WVNUM(DEEPBI(I),T,RKB(I))
31200      C*USING SHIELD'S DIAG,Y AXIS=0.05 & (TAUO=RHO*C*U**2),GET UCRIT(FT/SEC)
31300      UCRIT=16.3*SQRT(DIAM*.00328)
31400      DO 750 I=1,IMAX+1
31500      CONST6(I,1)=COFF*DX
31600      DO 750 J=2,JMAX+2
31700      C*CONST6(I,J) DOES W/ QY(I,J) WHICH IS ASSOC W/ DEEP(I,J-1)
31800      IF(DEEP(I,J-1).LE.DEEPBI(I))   GO TO 751
31900      C*HERE, MUST CAUSE COFF TO DECAY (WE'RE BEYOND SURF ZONE)
32000      UMAXB=HBI(I)*G*T*RKB(I)/(2.*TWOPI*COSH(RKB(I)*DEEPBI(I)))
32100      UMAX=H(I,J-1)*G*T*RKB(I,J-1)/(2.*TWOPI*COSH(RKB(I,J-1)*DEEP(I,J-1)))
32200      IF(UCRIT.LT.UMAX.AND.UCRIT.LT.UMAXB)   GO TO 749
32300      CONST6(I,J)=O.O
32400      GO TO 750
32500      749 TOP=O.O1*H(I,J-1)**3*SIGMA**3/(SINH(RKB(I,J-1)*DEEP(I,J-1))**3)
32600      BOT=DEEP(I,J-1)*(O.625*TWOPI*G**1.5*O.78**2*ADEAN**1.5+
32700      * (O.O1*HBI(I)**3*SIGMA**3/(DEEPBI(I)*(SINH(RKB(I)*DEEPBI(I))**3)))
32800      CONST6(I,J)=DX*COFF*TOP/BOT
32900      GO TO 750
33000      751 CONST6(I,J)=COFF*DX
33100      750 CONTINUE
33200      K=O
33300      C**PUT INTO BANDED FORM USING THE ALGRITHM A(M,N)->B(M,NN) WHERE
33400      C***NN=KB+1-M+N(KB IS THE NUMBER OF LOWER CODIAGONALS(=JMAX,HERE)).
33500      DO 304 I=2,IMAX-1
33600      DO 304 J=1,JMAX
33700      K=K+1
33800      AWARE(I,J)=AWARE(I,J)+DELT*RHS1(I,J)*R(I,J)-DELT*R(I,J)*RHS1(I+1,J
33900      * )+DELT*R(I,J)*CONST6(I,J)*WEQ(I,J)-DELT*R(I,J)*CONST6(I,J+1)*
34000      * WEQ(I,J+1)
34100      YDUM=YZERO(I)
34200      IF(J.NE.1)   YDUM=Y(I,J-1)
34300      AWARE(I,J)=AWARE(I,J)+DELT*R(I,J)*CONST6(I,J)*O.5*(YDUM-Y(I,J))
34400      * -DELT*R(I,J)*CONST6(I,J+1)*O.5*(Y(I,J)-Y(I,J+1))
34500      U=DELT*R(I,J)*S3(I,J)
34600      V=DELT*R(I,J)*S3(I+1,J)
34700      Z1=DELT*R(I,J)*CONST6(I,J)*O.5
34800      Z2=DELT*R(I,J)*CONST6(I,J+1)*O.5
34900      C*NOW WILL SET UP THE MATRICES ABAND AND BMATRX.
35000      ABAND(K,JMAX+1)=1.O+U+V+Z1+Z2
35100      IF(I.NE.2)   GO TO 305
35200      AWARE(I,J)=AWARE(I,J)+U*Y(I-1,J)
35300      GO TO 310
35400      305 ABAND(K,1)=-U
35500      310 IF(I.NE.IMAX-1)   GO TO 306
35600      AWARE(I,J)=AWARE(I,J)+V*Y(IMAX,J)
35700      GO TO 311
35800      306 ABAND(K,JMAX+1+JMAX)=-V
35900      311 IF(J.NE.1)   GO TO 307
36000      ABAND(K,JMAX+1)=ABAND(K,JMAX+1)-Z1
36100      AWARE(I,1)=AWARE(I,1)+Z1*(YZERO(I)-Y(I,1))
36200      GO TO 312

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36300      307 ABAND(K,JMAX)=-Z1
36400      312 IF(J.NE.JMAX) GO TO 308
36500      AWARE(I,J)=AWARE(I,J)+Z2*Y(I,JMAX+1)
36600      GO TO 309
36700      308 ABAND(K,JMAX+2)=-Z2
36800      309 BMATRIX(K)=AWARE(I,J)
36900      304 CONTINUE
37000      KMAX=K
37100      C**CALL INSL ROUTINE LEQT1B TO SOLVE THE BANDED MATRIX.
37200      CALL LEQT1B(ABAND,KMAX,JMAX,JMAX,432,BMATRIX,1,432,O,XL,IER)
37300      C*NOW, GIVE Y'S THEIR NEW VALUES STORING OLD VALUES IN YOLD.
37400      K=O
37500      DO 315 I=2,IMAX-1
37600      YOLD(I,JMAX+1)=Y(I,JMAX+1)
37700      DO 315 J= 1,JMAX
37800      K=K+1
37900      YOLD(I,J)=Y(I,J)
38000      Y(I,J)=BMATRIX(K)
38100      315 CONTINUE
38200      DO 320 J=1,JMAX+3
38300      YOLD(1,J)=Y(1,J)
38400      320 YOLD(IMAX,J)=Y(IMAX,J)
38500      C*WILL USE ABBOTT'S DISSIPATIVE INTERFACE TO RID HIGH FREQ OSCILLATIONS
38600      DO 650 J=1,JMAX
38700      DO 650 I=2,IMAX-1
38800      YDISS(I,J)=TAU*Y(I-1,J)+(1.-2.*TAU)*Y(I,J)+TAU*Y(I+1,J)
38900      IF(SJSETTY.EQ.O.O) GO TO 650
39000      DO 649 M=1,MMAX
39100      IF(I.NE.IJET(M).AND.I.NE.IJET(M)+1) GO TO 649
39200      IF(Y(IJET(M),J).GT.SJSETTY.OR.Y(IJET(M)+1,J).GT.SJSETTY)GO TO 649
39300      IF(I.EQ.IJET(M))YDISS(I,J)=TAU*Y(I-1,J)+(1.-TAU)*Y(I,J)
39400      IF(I.EQ.(IJET(M)+1))YDISS(I,J)=TAU*Y(I+1,J)+(1.-TAU)*Y(I,J)
39500      649 CONTINUE
39600      650 CONTINUE
39700      DO 651 J=1,JMAX
39800      DO 651 I=2,IMAX-1
39900      651 Y(I,J)=YDISS(I,J)
40000      C*THIS LOOP WILL STORE THE IMPLICIT Y VALUES REQ'D TO COMP QY&QX
40100      DO 40 I=1,IMAX+1
40200      DO 40 J=1,JMAX+3
40300      40 YIMP(I,J)=Y(I,J)
40400      C*THIS LOOP WILL EXPLICITLY MOVE CONTOURS SEAWARD IF REPOSE EXCEEDED.
40500      KOUNT=O
40600      SLOPEM=TAN(O.9*REPOSE)
40700      DO 48 I=1,IMAX
40800      43 KOUNT=KOUNT+1
40900      IF(KOUNT.GT.50000) GO TO 41
41000      C*LET US COMPUTE ALL THE SLOPES(PSLOP) FOR EACH CHANGE IN DEPTH.
41100      DO 47 J=1,JMAX+1
41200      DUM=-BERM/2.O
41300      IF(J.NE.1) DUM=DEEP(I,J-1)
41400      DELH=O.5*(DEEP(I,J+1)+DEEP(I,J))-O.5*(DEEP(I,J)+DUM)
41500      PSLOP=DELH/(Y(I,J+1)-Y(I,J))
41600      47 SANGLE(J)=ATAN(PSLOP)
41700      C*FIND THE MIN NEG SLOPE ANGLE OR THEN THE POS SLOPE>REPOSE OR FORGET IT
41800      ASLOPM=-1.OE5O
41900      ASLOPP=O.O
42000      DO 46 J=1,JMAX+1
42100      IF(SANGLE(J).GT.O.O) GO TO 45
42200      IF(SANGLE(J).GT.ASLOPM)ASLOPM=SANGLE(J)
42300      IF(ASLOPM.EQ.SANGLE(J)) JM=J
42400      GO TO 46
42500      45 IF(SANGLE(J).GT.REPOSE.AND.SANGLE(J).GT.ASLOPP)ASLOPP=SANGLE(J)
42600      IF(ASLOPP.EQ.SANGLE(J)) JP=J
42700      46 CONTINUE
42800      IF(ASLOPM.EQ.-1.OE5O.AND.ASLOPP.EQ.O.O) GO TO 42
42900      IF(ASLOPM.EQ.-1.OE5O) GO TO 44
43000      DUM=-BERM/2.
43100      IF(JM.NE.1) DUM=DEEP(I,JM-1)
43200      ALTER=((O.5/SLOPEM*(DEEP(I,JM+1)-DUM))-(Y(I,JM+1)-Y(I,JM)))/
43300      * (1.O+((DEEP(I,JM+1)-DEEP(I,JM))/(DEEP(I,JM)-DUM)))
43400      Y(I,JM+1)=Y(I,JM+1)+ALTER

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43500      Y(I,JM)=Y(I,JM)-(ALTER*(DEEP(I,JM+1)-DEEP(I,JM))/(DEEP(I,JM)-DUM))
43600      QYEXP(I,JM+1)=QYEXP(I,JM+1)+DX/DELTA*ALTER*(DEEP(I,JM+1)-DEEP(I,JM)
43700      * )
43800      GO TO 43
43900      44 CONTINUE
44000      DUM=-BERM/2.
44100      IF(JP.NE.1) DUM=DEEP(I,JP-1)
44200      ALTER=((O.5/SLOPEM*(DEEP(I,JP+1)-DUM))-(Y(I,JP+1)-Y(I,JP)))/
44300      * (1.O+((DEEP(I,JP+1)-DEEP(I,JP))/(DEEP(I,JP)-DUM)))
44400      Y(I,JP+1)=Y(I,JP+1)+ALTER
44500      Y(I,JP)=Y(I,JP)-(ALTER*(DEEP(I,JP+1)-DEEP(I,JP))/(DEEP(I,JP)-DUM))
44600      QYEXP(I,JP+1)=QYEXP(I,JP+1)+DX/DELTA*ALTER*(DEEP(I,JP+1)-DEEP(I,JP)
44700      * )
44800      GO TO 43
44900      42 WEQ(I,JMAX+1)=Y(I,JMAX+1)-Y(I,JMAX)
45000      48 CONTINUE
45100      C*IF WE GET SENT HERE, LOOP 444 WILL CATCH THE CROSSED CONTOURS.
45200      41 CONTINUE
45300      C*NOW WE CAN COMPUTE QX'S AND QY'S!
45400      DO 318 I=2,IMAX
45500      C*ALL IMPLIC AND EXPLIC MOVEMENT OF YZERO WILL BE TAKEN CARE OF HERE
45600      QY(I,1)=-BERM*QX*(Y(I,1)-YOLD(I,1))/DELT
45700      YZERO(I)=YZERO(I)+(Y(I,1)-YOLD(I,1))
45800      319 DO 318 J=1,JMAX
45900      QX(I,J)=RHS1(I,J)-S3(I,J)*YIMP(I,J)+S3(I,J)*YIMP(I-1,J)
46000      318 QY(I,J+1)=CONST6(I,J+1)*(O.5*(YIMP(I,J)+YOLD(I,J)-YIMP(I,J+1)
46100      * -YOLD(I,J+1))+WEQ(I,J+1))
46200      DO 323 J=1,JMAX
46300      QX(I,J)=QX(2,J)
46400      323 QX(IMAX+1,J)=QX(IMAX,J)
46500      C*TOTAL QYS WILL BE COMP FROM IMPLIC AND EXPLIC VALUES.THEN ZERO QYEXP
46600      DO 39 I=1,IMAX+1
46700      DO 39 J=1,JMAX+3
46800      QY(I,J)=QY(I,J)+QYEXP(I,J)
46900      39 QYEXP(I,J)=O.O
47000      C*THIS CHECK WILL BOMB THINGS OUT IF CONTOURS HAVE CROSSED.
47100      DO 444 II=1,IMAX
47200      DO 444 JJ=1,JMAX
47300      C*IF CONTOURS CROSS AT ANY TIME WANT PROGRAM TO STOP!
47400      IF(Y(II,JJ).LT.Y(II,JJ+1)) GO TO 444
47500      WRITE(6,103)
47600      WRITE(6,*) NUNIV
47700      DO 150 J=1,JMAX
47800      150 WRITE(6,100) (QX(I,J),I=1,IMAX)
47900      DO 151 J=1,JMAX
48000      151 WRITE(6,101) (QY(I,J),I=1,IMAX)
48100      DO 152 J=1,JMAX
48200      152 WRITE(6,100) (Y(I,J),I=1,IMAX)
48300      103 FORMAT(2X,'THE CONTOURS HAVE CROSSED AND SOMETHING IS WRONG',/)
48400      DO 19 J=1,JMAX
48500      19 WRITE(6,100) (YOLD(I,J),I=1,IMAX)
48600      GO TO 445
48700      444 CONTINUE
48800      WRITE(6,*) NUNIV
48900      C*THE FOLLOWING STATEMENT DETERMINES AT WHAT FREQ EVERYTHING IS WRITTEN!
49000      IF(MOD(NUNIV,10).NE.O) GO TO 1
49100      C*LET'S WRITE ALL OF IT OUT.
49200      WRITE(6,926) NUNIV
49300      926 FORMAT(2X,'THE TOTAL ELAPSED NUMBER OF TIME-STEPS. NUNIV= ',I5,/)
49400      800 FORMAT(2X,'(F8.4)')
49500      C* DO 900 I=1,IMAX
49600      C*900 WRITE(6,800) (THETA(I,J),J=1,JMAX)
49700      C* DO 903 J=1,JMAX+1
49800      C*903 WRITE(6,801) DEEP(1,J)
49900      C* DO 906 I=1,IMAX
50000      C*906 WRITE(6,800) (H(I,J),J=1,JMAX)
50100      C* DO 755 J=1,JMAX
50200      C*755 WRITE(6,800) (CONST6(I,J),I=1,IMAX)
50300      801 FORMAT(2X,'(F8.2)')
50400      WRITE(6,107)
50500      107 FORMAT(/,2X,'THE LONGSHORE TRANSPORTS,QX, FOLLOW')
50600      DO 15 J=1,JMAX
50700      15 WRITE(6,100) (QX(I,J),I=1,IMAX)

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50800      WRITE(6,108)
50900      108 FORMAT(/,2X,'THE ON-OFFSHORE TRANSPORTS, QY, FOLLOW')
51000      DO 17 J=1,JMAX
51100      17   WRITE(6,101)      (QY(I,J),I=1,IMAX)
51200      WRITE(6,109)
51300      109 FORMAT(/,2X,'THE NEW CONTOUR VALUES, Y, FOLLOW')
51400      DO 18 J=1,JMAX
51500      18   WRITE(6,100)      (Y(I,J),I=1,IMAX)
51600      100  FORMAT(2X,13(F9.3))
51700      101  FORMAT(2X,13(F9.4))
51800      1    CONTINUE
51900      RETURN
52000      GO TO 446
52100      445 STOP
52200      446 CONTINUE
52300      END
52400      C*****
52500      SUBROUTINE QTRAN
52600      C*THIS SUBROUTINE CALCS THE BREAKER HEIGHT FOR EACH
52700      C*OF THE I GRID LINES. METHOD--FINDS Y-LOCATIONS BEFORE AND AFTER
52800      C*BREAKING HAS OCCURRED BY 'REFRAC', THEN USES SHOALING TO GET THE
52900      C*HBQ. SNELL'S LAW IS USED FOR REFRACTION OVER THE SHORT DIST TO BREAKING
53000      C* QX(I,J) IS THE TRANS BETWEEN(I-1,J) AND (I,J) AT THE BLOCKCENT
53100      COMMON/A/ C(60,20),RK(60,20),Y(60,20),DEEP(60,20),ALPHAS(60,20)
53200      COMMON/AA/YZERO(60)
53300      COMMON/B/ THETA(60,20),QXTOT(60), OLDDANG(60,20), DY(60,20)
53400      COMMON/C/ H(60,20),CG(60,20),HOLD(60,20),HB(60,20),YB(60)
53500      COMMON/N USED/JUSE,T,CG,CGEN,CGGEN,ANGGEN,DX,BERM,THETAQ(10),MMAX
53600      COMMON/D/SIGMA,G,ELO,JMAX,IMAX,PI,TWOPI,PIO2,HGEN,IJET(10),SJETTY
53700      COMMON/G/IBREAK(60),HNONBR(20)
53800      COMMON/E/RHO,RHOS,POROS,CONST,TKSI
53900      COMMON/P/HBQ(60),DEEPB(60)
54000      CAPP=0.78
54100      DO 1 I=2,IMAX
54200      DO 2 JJ=1,JMAX
54300      J=JMAX-JJ+1
54400      HDUM=(H(I,J)+H(I-1,J))*0.5
54500      HBDUM=(HB(I,J)+HB(I-1,J))*0.5
54600      C*CAN ONLY USE COND ON ONE SIDE OF STRUCT. CAN'T AVG HERE!
54700      IF(SJETTY.EQ.0.0) GO TO 4
54800      DO 4 M=1,MMAX
54900      IF(I.NE.IJET(M)+1) GO TO 4
55000      IF(THETAQ(M).GE.0.0) ISIDE=IJET(M)
55100      IF(THETAQ(M).LT.0.0) ISIDE=IJET(M)+1
55200      C**B.C. AT STRUCT TIP ASSUMES QX COMP AS IF NO STRUCT IS PRESENT.
55300      YSEA=0.5*(Y(ISIDE,J)+Y(ISIDE,J+1))
55400      IF(YSEA.GT.SJETTY) GO TO 3
55500      HDUM=H(ISIDE,J)
55600      HBDUM=HB(ISIDE,J)
55700      GO TO 3
55800      4 CONTINUE
55900      3 IF(HDUM.LE.HBDUM) GO TO 2
56000      DEEPB(I)=((0.5*(H(I,J+1)+H(I-1,J+1)))*((0.5*(DEEP(I,J+1)
56100      * +DEEP(I-1,J+1)))*0.25)/CAPP)*0.8
56200      HBQ(I)=CAPP*DEEPB(I)
56300      C*HBQ(I) AND DEEPB(I) WILL BE COMPUTED ACCORDING TO THE WAVE DIR.
56400      C** AT THE STRUCTURE TIP,THETAQ.
56500      IF(SJETTY.EQ.0.0) GO TO 1
56600      DO 6 M=1,MMAX
56700      IF(I.NE.IJET(M)+1) GO TO 6
56800      C**THE TRANSPORTING WAVES WILL BE COMPUTED USING THE WAVE TO PROP SIDE.
56900      IF(THETAQ(M).GE.0.0) GO TO 11
57000      DEEPB(I)=(H(IJET(M)+1,J+1)*DEEP(IJET(M)+1,J+1))*0.25/CAPP)*0.8
57100      IBREAK(I)=IBREAK(IJET(M)+1)
57200      GO TO 12
57300      11 DEEPB(I)=(H(IJET(M),J+1)*DEEP(IJET(M),J+1))*0.25/CAPP)*0.8
57400      IBREAK(I)=IBREAK(IJET(M))
57500      12 HBQ(I)=DEEPB(I)*CAPP
57600      GO TO 1
57700      6 CONTINUE
57800      GO TO 1
57900      2 CONTINUE
58000      1 CONTINUE

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58100 C*IF THE OFFSHORE WAVE HT IS ZERO, NEVER GET TO HERE.
58200 C*HOWEVER IF THE H IS SUCH THAT IT WOULD BREAK INSHORE OF Y(I,2)
58300 C*DEEPB(I) WOULD STILL BE ZERO AND DISTR(I,J) WOULD BLOW-UP.
58400 DO 20 I=1,IMAX
58500 IF(DEEPB(I).GT.O.O) GO TO 20
58600 DEEPB(I)=(H(I,1)*DEEP(I,1)**O.25/CAPPA)**O.8
58700 HBQ(I)=CAPPA*DEEPB(I)
58800 20 CONTINUE
58900 HBQ(1)=HBQ(2)
59000 HBQ(IMAX+1)=HBQ(IMAX)
59100 DEEPB(1)=DEEPB(2)
59200 DEEPB(IMAX+1)=DEEPB(IMAX)
59300 RETURN
59400 END
59500 C*****
59600 SUBROUTINE BREAK(IMAX,JMAX)
59700 C*ROUTINE WILL DETERMINE HB AND DEEPB ON THE GRID LINES RATHER
59800 C* THAN BETWEEN THEM. REQ'D FOR COFF BEYOND SURF ZONE.
59900 COMMON/A/ C(60,20),RK(60,20),Y(60,20),DEEP(60,20),ALPHAS(60,20)
60000 COMMON/C/ H(60,20),CG(60,20),HOLD(60,20),HB(60,20),YB(60)
60100 COMMON/MP/ RKB(60),HBI(60),DEEPBI(60)
60200 CAPPA=O.78
60300 DO 1 I=2,IMAX
60400 DO 2 JJ=1,JMAX
60500 J=JMAX-JJ+1
60600 IF(H(I,J).LT.HB(I,J)) GO TO 2
60700 DEEPBI(I)=((H(I,J+1)*DEEP(I,J+1)**O.25)/CAPPA)**O.8
60800 HBI(I)=CAPPA*DEEPBI(I)
60900 C***ONCE THE HEIGHT & DEPTH AT BREAKING ARE FOUND, GO TO NEXT GRID-LINE.
61000 GO TO 1
61100 2 CONTINUE
61200 1 CONTINUE
61300 DO 20 I=1,IMAX
61400 IF(DEEPBI(I).GT.O.O) GO TO 20
61500 DEEPBI(I)=(H(I,1)*DEEP(I,1)**O.25/CAPPA)**O.8
61600 HBI(I)=CAPPA*DEEPBI(I)
61700 20 CONTINUE
61800 DEEPBI(1)=DEEPBI(2)
61900 DEEPBI(IMAX+1)=DEEPBI(IMAX)
62000 HBI(1)=HBI(2)
62100 HBI(IMAX+1)=HBI(IMAX)
62200 RETURN
62300 END
62400 C*****
62500 SUBROUTINE REFRAC(JBEGIN,JEND,NPTS,IBEGIN,IEND,ISTART,M)
62600 COMMON/A/ C(60,20),RK(60,20),Y(60,20),DEEP(60,20),ALPHAS(60,20)
62700 COMMON/AA/ YZERO(60)
62800 COMMON/B/ THETA(60,20),QXTOT(60), OLDANG(60,20), DY(60,20)
62900 COMMON/C/ H(60,20),CG(60,20),HOLD(60,20),HB(60,20),YB(60)
63000 COMMON/N USED/JUSE, T,CO,CGEN,CGGEN,ANGGEN,DX,BERM,THETAO(10),MMAX
63100 COMMON/D/SIGMA,G,ELO,JMAX,IMAX,PI,TWOPI,PIO2,HGEN,IJET(10),SJETTY
63200 COMMON/G/IBREAK(60),HNONBR(20)
63300 COMMON/ZZZ/NTIME
63400 DIMENSION JBEGIN(60),JEND(60)
63500 C***** THIS SUBROUTINE WILL DETERMINE H AND
63600 C***** THETA AT THE MID PT OF Y VALUES.
63700 C***TAU IS THE FACTOR WHICH RECOUPLES THE REFRACTION EQS.SEE ABBOTT
63800 TAU=O.25
63900 C*MUST PRESCRIBE THE WAVE ANGLE AT THE OUTERMOST CONTOUR BOX
64000 C*SNELL'S LAW WILL BE USED TO START THINGS OFF.
64100 C*THETA(I,J) WILL BE AT AREA'S CENTER AND WILL USE Y(I,J) IN NEG Y-DIR
64200 C*WILL INITIALIZE ALL THETA'S USING SNELL'S LAW.
64300 DO 206 I=IBEGIN,IEND
64400 C*INITIALIZE TWO J-VALUES BEYOND JMAX,IF IN REGION 1.
64500 IF(JEND(I).EQ.JMAX) JINIT=2
64600 IF(JEND(I).NE.JMAX) JINIT=O
64700 DO 206 J=JBEGIN(I),JEND(I)+JINIT
64800 C*MUST CORRECT FOR THE CONTOUR ORIENTATION, ALPHAS.
64900 IF(I.NE.IBEGIN) GO TO 960
65000 ALPHAS(I,J)=ATAN((O.5*(Y(I+1,J)+Y(I+1,J+1))-O.5*(Y(I,J)
65100 * +Y(I,J+1)))/DX)
65200 GO TO 962

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65300      960 IF(I.NE.IEND) GO TO 961
65400      ALPHAS(I,J)=ATAN((0.5*(Y(I,J)+Y(I,J+1))-0.5*(Y(I-1,J)
65500      * +Y(I-1,J+1)))/DX)
65600      GO TO 962
65700      961 ALPHAS(I,J)=ATAN((0.5*(Y(I+1,J)+Y(I+1,J+1))-0.5*
65800      * (Y(I-1,J)+Y(I-1,J+1)))/(2.*DX))
65900      962 DALPHA=ANGGEN-ALPHAS(I,J)
66000      THETA(I,J)=ARSIN((C(I,J)/CGEN)*SIN(DALPHA))
66100      C*MUST GET THETA WRT THE X-AXIS.
66200      THETA(I,J)=THETA(I,J)+ALPHAS(I,J)
66300      206 CONTINUE
66400      C*NOW, WE MUST COMP THE BOUN WAVE HTS SO THE HTS CAN BE COMPUTED.
66500      C*WILL USE THE EQ. ***** DEL DOT (E*CG)=0.0
66600      C*NOW WE WILL CORRECT THE HT FOR SHOALING AND REFRACTION TO THE B.C.
66700      C*WILL ALSO INITIALIZE H'S WITH THESE EQUATIONS FOR ENTIRE ARRAY.
66800      DO 500 I=IBEGIN,IEND
66900      C*INITIALIZE TWO J-VALUES BEYOND JMAX IF IN REGION 1.
67000      IF(JEND(I).EQ.JMAX) JINIT=2
67100      IF(JEND(I).NE.JMAX) JINIT=0
67200      DO 500 J=JBEGIN(I),JEND(I)+JINIT
67300      H(I,J)=HGEN*SQRT(CGGEN/CG(I,J))*SQRT(COS(ANGGEN)/COS(THETA(I,
67400      * J)))
67500      IF(HB(I,J).LT.H(I,J)) H(I,J)=HB(I,J)
67600      500 CONTINUE
67700      C*-----
67800      C*****
67900      C*LET'S FILL THE DY ARRAY.
68000      C*DY WILL BE INDEXED AS THE THETA TO WHICH WE ARE GOING.
68100      DO 209 I=IBEGIN,IEND
68200      DO 209 J=JBEGIN(I)+1,JEND(I)
68300      DY(I,J-1)=0.5*(Y(I,J-1)+Y(I,J))-0.5*(Y(I,J)+Y(I,J+1))
68400      209 CONTINUE
68500      NITERS=100
68600      DO 100 NITER=1,NITERS
68700      SUMANG=0.0
68800      C*DO "60 LOOP" GOES FROM 2 TO IMAX IF ISTART =IBEGIN
68900      C*DO "60 LOOP" GOES FROM IMAX-1 TO 1 IF ISTART=IEND
69000      DO 60 II=IBEGIN,IEND
69100      C*MUST HAVE IT SET UP SO THAT THE KNOWN BOUNDARIES ANGLES AREN'T RECOMP
69200      IF(ISTART.EQ.IBEGIN) I=II
69300      IF(ISTART.EQ.IBEGIN .AND. I.EQ.IBEGIN) GO TO 60
69400      IF(ISTART.EQ.IEND) I=IEND-II+IBEGIN
69500      IF(ISTART.EQ.IEND .AND. I.EQ.IEND) GO TO 60
69600      C*ADX EQUALS ACTUAL DELTA X ACROSS SPACE STEP.
69700      C*ONLY ON BOUNDARIES WHERE FORWARD OR BACKWARD DIFFERENCING.
69800      IF(I.NE.IBEGIN) GO TO 6
69900      ADX=DX
70000      IP=I+1
70100      IM=I
70200      GO TO 12
70300      6 IF(I.NE.IEND) GO TO 10
70400      ADX=DX
70500      IP=I
70600      IM=I-1
70700      GO TO 12
70800      10 ADX=2.0*DX
70900      IP=I+1
71000      IM=I-1
71100      12 CONTINUE
71200      DO 40 J=JBEGIN(I),JEND(I)-1
71300      C*WILL GO FROM (JMAX-1) TO 1 BECAUSE THAT'S THE DIR WAVE COMES IN FROM.
71400      JJ=JEND(I)-1-J+JBEGIN(I)
71500      OLDANG(I,JJ)=THETA(I,JJ)
71600      C*LOCATE MIDPOINT BETWEEN TWO ADJACENT BLOCK CENTERS
71700      C*BECAUSE THETA'S JJ-VALUE IS THE SAME AS THE FIRST SHOREWARD Y VALUE
71800      C*MUST USE JJ, JJ+1, AND JJ+2 TO COMPUTE YBAR.
71900      YBAR=0.25*(Y(I,JJ)+2.0*Y(I,JJ+1)+Y(I,JJ+2))
72000      C*LOCATE APPROPRIATE INDICES ON IP AND IM GRID LINES.
72100      IMINUS=-1
72200      IPLUS=+1
72300      CALL LOC(IM,JJ,JOIM,JSIM,YBAR,IMINUS)
72400      CALL LOC(IP,JJ,JOIP,JSIP,YBAR,IPLUS)
72500      C*NOW USE THE CONSERVATION OF WAVES EQUATION.....

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72600      PART1C=RK(I,JJ+1)*SIN(THETA(I,JJ+1))
72700      PART2=-DY(I,JJ)/ADX
72800      C*WILL LINEARLY INTERPOLATE TO DETERMINE RK*COS(THETA) AT I+1 AND I-1.
72900      C*IF NO ADJ SHOREWARD PT EXISTS, PUT IN ZERO FOR TERMS IN GOV. EQ.
73000      IF(JSIM.NE.O) GO TO 301
73100      PART3B=O.O
73200      GO TO 302
73300      301 TOPIM=RK(IM,JOIM-1)*COS(THETA(IM,JOIM-1))
73400      BOTIM=RK(IM,JSIM)*COS(THETA(IM,JSIM))
73500      TOTALB=O.5*(Y(IM,JOIM)+Y(IM,JOIM-1))-O.5*(Y(IM,JSIM+1)+Y(IM,JSIM))
73600      DUMB=O.5*(Y(IM,JOIM)+Y(IM,JOIM-1))-YBAR
73700      PART3B=((TOTALB-DUMB)*(TOPIM-BOTIM)/TOTALB)+BOTIM
73800      302 IF(JSIP.NE.O) GO TO 303
73900      PART3A=O.O
74000      GO TO 304
74100      303 TOPIP=RK(IP,JOIP-1)*COS(THETA(IP,JOIP-1))
74200      BOTIP=RK(IP,JSIP)*COS(THETA(IP,JSIP))
74300      TOTALA=O.5*(Y(IP,JOIP)+Y(IP,JOIP-1))-O.5*(Y(IP,JSIP+1)+Y(IP,JSIP))
74400      DUMA=O.5*(Y(IP,JOIP)+Y(IP,JOIP-1))-YBAR
74500      PART3A=((TOTALA-DUMA)*(TOPIP-BOTIP)/TOTALA)+BOTIP
74600      304 PART3=PART3A-PART3B
74700      C*NOW MUST FIND RK*SIN(THETA) FOR I+1 AND I-1 AT J+1
74800      YBARP=O.25*(Y(I,JJ+1)+2.*Y(I,JJ+2)+Y(I,JJ+3))
74900      CALL LOC(IM,JJ+1,JPOIM,JPSIM,YBARP,IMINUS)
75000      CALL LOC(IP,JJ+1,JPOIP,JPSIP,YBARP,IPLUS)
75100      IF(JPSIM.NE.O) GO TO 305
75200      PART1B=O.O
75300      GO TO 306
75400      305 TOPM=RK(IM,JPOIM-1)*SIN(THETA(IM,JPOIM-1))
75500      BOTM=RK(IM,JPSIM)*SIN(THETA(IM,JPSIM))
75600      TOTB=O.5*(Y(IM,JPOIM)+Y(IM,JPOIM-1))-O.5*(Y(IM,JPSIM+1)+
75700      * Y(IM,JPSIM))
75800      DUMPB=O.5*(Y(IM,JPOIM)+Y(IM,JPOIM-1))-YBARP
75900      PART1B=((TOTB-DUMPB)*(TOPM-BOTM)/TOTB)+BOTM
76000      306 IF(JPSIP.NE.O) GO TO 307
76100      PART1A=O.O
76200      GO TO 308
76300      307 TOPP=RK(IP,JPOIP-1)*SIN(THETA(IP,JPOIP-1))
76400      BOTP=RK(IP,JPSIP)*SIN(THETA(IP,JPSIP))
76500      TOTA=O.5*(Y(IP,JPOIP)+Y(IP,JPOIP-1))-O.5*(Y(IP,JPSIP+1)+Y(IP,JPSIP
76600      * ))
76700      DUMPA=O.5*(Y(IP,JPOIP)+Y(IP,JPOIP-1))-YBARP
76800      PART1A=((TOTA-DUMPA)*(TOPP-BOTP)/TOTA)+BOTP
76900      308 PART1=TAU*PART1B+(1.-2.*TAU)*PART1C+TAU*PART1A
77000      IF(JPSIM.EQ.O)PART1=(1.-TAU)*PART1C+TAU*PART1A
77100      IF(JPSIP.EQ.O)PART1=TAU*PART1B+(1.-TAU)*PART1C
77200      ARG=((PART1+PART2+PART3)/RK(I,JJ))
77300      C*IF THE ROUTINE IS TO BLOWUP,USE SNELLS LAW.
77400      IF(ABS(ARG).LE.1.O) GO TO 41
77500      ARG=(C(I,JJ)/C(I,JJ+1))*SIN(THETA(I,JJ+1))
77600      IF(ARG.GT.1.O) ARG=1.O
77700      THETA(I,JJ)=ARSIN(ARG)
77800      GO TO 42
77900      41 THETA(I,JJ)=ARSIN(ARG)
78000      42 THETA(I,JJ)=O.5*(THETA(I,JJ)+OLDANG(I,JJ))
78100      SUMANG=SUMANG+(ABS(THETA(I,JJ)-OLDANG(I,JJ)))
78200      40 CONTINUE
78300      60 CONTINUE
78400      C*MUST EJECT IF WE HAVE REACHED AN ACCEPTABLE ITERATION ERROR
78500      C*IF THE SUM OF THE ABSOLUTE VALUE OF ANGLE CHANGES DURING AN ITERATION
78600      C* AVERAGES LESS THAN O.O2 DEGREES PER GRID ITS CLOSE ENOUGH.
78700      IF(SUMANG.LT.(NPTS*O.O035)) GO TO 215
78800      IF(NITER.GE.50) GO TO 215
78900      100 CONTINUE
79000      WRITE(6,803)
79100      215 CONTINUE
79200      C*ITERATION LOOP FOR THE WAVE HEIGHT.
79300      DO 501 NITER=1,NITERS
79400      SUMH=O.O
79500      DO 510 I1=IBEGIN,IEND
79600      C*MUST HAVE IT SET UP SO THAT THE KNOWN BOUNDARIES HTS. AREN'T RECOMP
79700      IF(I1START.EQ.IBEGIN) I=I1
79800      IF(I1START.EQ.IBEGIN .AND. I1.EQ.IBEGIN) GO TO 510

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79900      IF(ISTART.EQ.IEND)   I=IEND-II+IBEGIN
80000      IF(ISTART.EQ.IEND .AND. I.EQ.IEND)   GO TO 510
80100 C*ADX EQUALS ACTUAL DELTA X ACROSS SPACE STEP.
80200 C*ONLY ON BOUNDARIES WHERE FORWARD OR BACKWARD DIFFERENCING.
80300      IF(I.NE.IBEGIN)   GO TO 503
80400      ADX=DX
80500      IP=I+1
80600      IM=I
80700      GO TO 505
80800 503      IF(I.NE.IEND)   GO TO 504
80900      ADX=DX
81000      IP=I
81100      IM=I-1
81200      GO TO 505
81300 504      ADX=2.0*DX
81400      IP=I+1
81500      IM=I-1
81600 505      CONTINUE
81700      DO 502 J=JBEGIN(I),JEND(I)-1
81800      JJ=JEND(I)-1-J+JBEGIN(I)
81900      HOLD(I,JJ)=H(I,JJ)
82000      YBAR=0.25*(Y(I,JJ)+2.0*Y(I,JJ+1)+Y(I,JJ+2))
82100      CALL LOC(IM,JJ,JOIM,JSIM,YBAR,IMINUS)
82200      CALL LOC(IP,JJ,JOIP,JSIP,YBAR,IPLUS)
82300      PART13=(H(I,JJ+1)**2.)*CG(I,JJ+1)*COS(THETA(I,JJ+1))
82400      PART2=DY(I,JJ)/ADX
82500      IF(JSIM.NE.O)   GO TO 311
82600      PART4B=O.O
82700      GO TO 312
82800 311      TOPIMH=(H(IM,JOIM-1)**2.)*CG(IM,JOIM-1)*(SIN(THETA(IM,JOIM-1)))
82900      BOTIMH=(H(IM,JSIM)**2.)*CG(IM,JSIM)*SIN(THETA(IM,JSIM))
83000      TOTALB=O.5*(Y(IM,JOIM)+Y(IM,JOIM-1))-O.5*(Y(IM,JSIM+1)+Y(IM,JSIM))
83100      DUMB=O.5*(Y(IM,JOIM)+Y(IM,JOIM-1))-YBAR
83200      PART4B=((TOTALB-DUMB)*(TOPIMH-BOTIMH)/TOTALB)+BOTIMH
83300 312      IF(JSIP.NE.O)   GO TO 313
83400      PART4A=O.O
83500      GO TO 314
83600 313      TOPIPH=(H(IP,JOIP-1)**2.)*CG(IP,JOIP-1)*SIN(THETA(IP,JOIP-1))
83700      BOTIPH=(H(IP,JSIP)**2.)*CG(IP,JSIP)*SIN(THETA(IP,JSIP))
83800      TOTALA=O.5*(Y(IP,JOIP)+Y(IP,JOIP-1))-O.5*(Y(IP,JSIP+1)+Y(IP,JSIP))
83900      DUMA=O.5*(Y(IP,JOIP)+Y(IP,JOIP-1))-YBAR
84000      PART4A=((TOTALA-DUMA)*(TOPIPH-BOTIPH)/TOTALA)+BOTIPH
84100 314      PART4=PART4A-PART4B
84200      YBARP=O.25*(Y(I,JJ+1)+2.*Y(I,JJ+2)+Y(I,JJ+3))
84300      CALL LOC(IM,JJ+1,JPOIM,JPSIM,YBARP,IMINUS)
84400      CALL LOC(IP,JJ+1,JPOIP,JPSIP,YBARP,IPLUS)
84500      IF(JPSIM.NE.O)   GO TO 315
84600      PART12=O.O
84700      GO TO 316
84800 315      TOPMH=(H(IM,JPOIM-1)**2)*CG(IM,JPOIM-1)*COS(THETA(IM,JPOIM-1))
84900      BOTMH=(H(IM,JPSIM)**2)*CG(IM,JPSIM)*COS(THETA(IM,JPSIM))
85000      TOTB=.5*(Y(IM,JPOIM)+Y(IM,JPOIM-1))-.5*(Y(IM,JPSIM+1)+Y(IM,JPSIM))
85100      DUMPB=O.5*(Y(IM,JPOIM)+Y(IM,JPOIM-1))-YBARP
85200      PART12=((TOTB-DUMPB)*(TOPMH-BOTMH)/TOTB)+BOTMH
85300 316      IF(JPSIP.NE.O)   GO TO 317
85400      PART11=O.O
85500      GO TO 318
85600 317      TOPPH=(H(IP,JPOIP-1)**2)*CG(IP,JPOIP-1)*COS(THETA(IP,JPOIP-1))
85700      BOTPH=(H(IP,JPSIP)**2)*CG(IP,JPSIP)*COS(THETA(IP,JPSIP))
85800      TOTA=.5*(Y(IP,JPOIP)+Y(IP,JPOIP-1))-.5*(Y(IP,JPSIP+1)+Y(IP,JPSIP))
85900      DUMPA=O.5*(Y(IP,JPOIP)+Y(IP,JPOIP-1))-YBARP
86000      PART11=((TOTA-DUMPA)*(TOPPH-BOTPH)/TOTA)+BOTPH
86100 318      PART1H=TAU*PART12+(1.-2.*TAU)*PART13+TAU*PART11
86200      IF(JPSIM.EQ.O)PART1H=(1.-TAU)*PART13+TAU*PART11
86300      IF(JPSIP.EQ.O)PART1H=TAU*PART12+(1.-TAU)*PART13
86400      ARG=((PART1H+PART2*PART4)/(CG(I,JJ)*COS(THETA(I,JJ))))
86500 C*IF THERE IS TO BE AN INVALID SQRT,USE LINEAR SHOALING.
86600      IF(ARG.GE.O.)   GO TO 44
86700      ARG=(CG(I,JJ+1)*COS(THETA(I,JJ+1)))/(CG(I,JJ)*COS(THETA(I,JJ)))
86800      IF(ARG.LT.O.O)   ARG=O.O
86900      H(I,JJ)=H(I,JJ+1)*SQRT(ARG)
87000      GO TO 45

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87100      44  H(I,JJ)=SQRT(ARG)
87200      45  H(I,JJ)=O.5*(H(I,JJ)+HOLD(I,JJ))
87300      HNONBR(JJ)=H(I,JJ)
87400  C*IBREAK(I)=JJ, THEREFORE JJ WILL BE LEEWARD SIDE OF GRID AT INIT BREAK
87500      IF(HB(I,JJ).LT.H(I,JJ).AND.HB(I,JJ+1).GE.HNONBR(JJ+1))
87600      *      IBREAK(I)=JJ
87700      IF(HB(I,JJ).LT.H(I,JJ))  H(I,JJ)=HB(I,JJ)
87800      SUMH=SUMH+ABS(H(I,JJ)-HOLD(I,JJ))
87900  502  CONTINUE
88000  510  CONTINUE
88100      IBREAK(IEND)=IBREAK(IEND-1)
88200      IBREAK(IBEGIN)=IBREAK(IBEGIN+1)
88300      IF(SUMH.LT.(NPTS*O.O1))  GO TO 507
88400      IF(NITER.GE.50)  GO TO 507
88500  501  CONTINUE
88600      WRITE(6,803)
88700  507  CONTINUE
88800      802  FORMAT(2X,4(F15.5),////)
88900      803  FORMAT(2X,"AFTER NITERS ITERATIONS, CONVERGENCE WAS NOT REACHED")
89000      804  FORMAT(2X,"THE WAVE HT. ROUTINE CONVERGED IN, NITER= ",I5.//)
89100      805  FORMAT(2X,"THIS IS MY CHECKING WRITE STATEMENT")
89200      806  FORMAT(2X,"THE WAVE ANGLE ROUTINE CONVERGED IN, NITER= ",I5.//)
89300      RETURN
89400      END
89500  C*****
89600      SUBROUTINE DIFF(RHOND,THETA0,ANGLE,AMP)
89700  C****DIFFRACTION ABOUT SEMI INFINITE BREAKWATER (PENNEY-PRICE)
89800      PI=3.14159265
89900      ABSS=SIN(O.5*(ANGLE-THETA0))
90000      ABSP=SIN(O.5*(ANGLE+THETA0))
90100      ABC=COS(ANGLE-THETA0)
90200      ABC1=COS(ANGLE+THETA0)
90300      XX=RHOND*ABC
90400      XXC=COS(XX)
90500      XXS=SIN(XX)
90600      XX1=RHOND*ABC1
90700      XXC1=COS(XX1)
90800      XXS1=SIN(XX1)
90900      AL=SQRT(RHOND/PI)
91000      SIG=2.O*AL*ABSS
91100      SIGP=-2.O*AL*ABSP
91200      CALL FRES(SIG,C,S,FR,FI)
91300      CALL FRES(SIGP,CP,SP,FRP,FIP)
91400      SUM1=XXC*FR+XXS*FI+XXC1*FRP+XXS1*FIP
91500      SUM2=XXC*FI-XXS*FR+XXC1*FIP-XXS1*FRP
91600      AMP=SQRT(SUM1**2+SUM2**2)
91700      RETURN
91800      END
91900  C*****
92000      SUBROUTINE FRES(A,C,S,FR,FI)
92100  C*FRESNEL INTEGRAL SUBROUTINE***AFTER ABROMOWITZ AND STEGUN.
92200      Z=ABS(A)
92300      P02=1.5707963
92400      FZ=(1.O+O.926*Z)/(2.O+1.792*Z+3.104*Z*Z)
92500      GZ=1.O/(2.O+4.142*Z+3.492*Z*Z+6.670*Z*Z*Z)
92600      XX=P02*Z*Z
92700      CZ=COS(XX)
92800      SZ=SIN(XX)
92900      C=O.5-GZ*CZ+FZ*SZ
93000      S=O.5-FZ*CZ-GZ*SZ
93100      IF(A.GT.O.O)  GO TO 50
93200      C=-C
93300      S=-S
93400      50  FR=O.5*(1.O+C+S)
93500      FI=-O.5*(S-C)
93600      RETURN
93700      END
93800  C*****
93900      SUBROUTINE PREDIF
94000      COMMON/A/ C(60,20),RK(60,20),Y(60,20),DEEP(60,20),ALPHAS(60,20)
94100      COMMON/AA/YZERO(60)
94200      COMMON/B/ THETA(60,20),QXTOT(60),OLDANG(60,20),DY(60,20)
94300      COMMON/C/ H(60,20),CGC(60,20),HOLD(60,20),HB(60,20),YB(60)

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94400      COMMON/N USED/JUSE,T,CO,CGEN,CGGEN,ANGGEN,DX',BERM,THETAO(10),MMAX
94500      COMMON/D/SIGMA,G,ELO,JMAX,IMAX,PI,TWOPI,PIO2,HGEN,IJET(10),SJETTY
94600      COMMON/G/IBREAK(60),HNONBR(20)
94700      DIMENSION J1(60),J2(60),J1REF(60),J3REF(60)
94800      C*THIS SUB CALCS WHERE DIFFRACTION GOVERNS AND WHERE REFRACT GOVERNS.
94900      C*IT WILL CALL REFRAC FOR OFFSHORE AREA(OFF TIP OF STRUCTURE).
95000      C*THEN IT WILL DO THE SHADOW ZONE USING DIFF(IF THETAO.NE.O.O)
95100      C* IT WILL THEN FINISH THE OTHERS USING REFRAC AGAIN.
95200      C*LET'S ZERO-OUT THE DIMENSIONED ARRAYS.
95300          DO 1000 I=1,IMAX+2
95400              J1(I)=0.0
95500              J2(I)=0.0
95600              J1REF(I)=0.0
95700          1000 J3REF(I)=0.0
95800      C*NOW, LETS FIND C,CG,RK,HB, AND WVNUM.
95900          DO 202 I=1,IMAX
96000          DO 202 J=1,JMAX+2
96100              DEPTH=DEEP(I,J)
96200              CALL WVNUM(DEPTH,T,DUMK)
96300              RK(I,J)=DUMK
96400              C(I,J)=C0*TANH(RK(I,J)*DEEP(I,J))
96500              EN=0.5*(1.0+((2.*RK(I,J)*DEEP(I,J))/SINH(2.*RK(I,J)*DEEP(I,J))))
96600              CG(I,J)=EN*C(I,J)
96700              HB(I,J)=0.78*DEEP(I,J)
96800          202 CONTINUE
96900      C*WILL ATTRIB AN EQUAL REACH TO EACH SIDE OF EACH M-GROIN.
97000          DO 200 M=1,MMAX
97100              IDUML=1
97200              IF(M.NE.1) IDUML=(IJET(M)+IJET(M-1))/2
97300              IDUMR=IMAX
97400              IF(M.NE.MMAX) IDUMR=(IJET(M)+IJET(M+1))/2
97500              NPTS=0
97600              DO 1 I=IDUML,IDUMR
97700              DO 2 J=1,JMAX
97800                  IF(Y(I,J).LT.SJETTY) GO TO 14
97900                  J1(I)=J
98000                  J2(I)=JMAX
98100                  GO TO 15
98200              14 CONTINUE
98300              2 CONTINUE
98400              15 CONTINUE
98500      C*IF NO STRUCT IS PRESENT(SJETTY=0.0), DO REFRAC THRUOUT GRID SYSTEM
98600          IF(SJETTY.EQ.0.0) J1(I)=1
98700          1 CONTINUE
98800          DO 16 I=IDUML,IDUMR
98900      C* 'REFRAC' STARTS ON THE NEXT TO LAST J-CONTOUR,NOT THE LAST!
99000          DO 16 J=J1(I),J2(I)-1
99100          16 NPTS=NPTS+1
99200      C*WILL NOW DO THE REFRACT FOR THE REGION 1 AREA.
99300      C*ISTART REPRESENTS THE DIRECTION THE SWEEPS WILL BEGIN FROM.
99400      C*WILL USE DUMMY IMAX,IJET,IJET+1 IN CALL STTS SO IBEGIN,IEND, AND
99500      C***ISTART WON'T CHANGE THEM.MUST RESET AFTER EACH CALL REFRAC.
99600          IMAXT=IDUMR
99700          IJETT=IJET(M)
99800          IJETP=IJET(M)+1
99900          IDUMLL=IDUML
100000      IF(ANGGEN.GE.0.0) CALL REFRAC(J1,J2,NPTS,IDUMLL,IMAXT,IDUMLL,M)
100100      IF(ANGGEN.LT.0.0) CALL REFRAC(J1,J2,NPTS,IDUMLL,IMAXT,IMAXT,M)
100200          IMAXT=IDUMR
100300          IJETT=IJET(M)
100400          IJETP=IJET(M)+1
100500          IDUMLL=IDUML
100600          JDUMN=J1(IJET(M))
100700          JDUMS=J1(IJET(M)+1)
100800          XDISTN=(IJET(M)-1.0)*DX+DX/2.
100900          ELTIP=T*0.5*(C(IJET(M),JDUMN)+C(IJET(M)+1,JDUMS))
101000      C*NOW MUST CHECK THE ANGLE AT THE STRUCTURE'S TIP TO SEE WHERE SHAD ZONE
101100      C*IF NO STRUCT PRESENT(SJETTY=0.0), FUTHER REFRAC/DIFF UNNECESSARY.
101200          IF(SJETTY.EQ.0.0) GO TO 13
101300          THETAO(M)=0.5*(THETA(IJET(M),JDUMN)+THETA(IJET(M)+1,JDUMS))
101400          HINC=0.5*(H(IJET(M),JDUMN)+H(IJET(M)+1,JDUMS))
101500          IF(THETAO(M))10,11,12
101600      C*THIS SECTION HANDLES REFRAC/DIFF IF THETAO<0.0.

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101700      10  CONTINUE
101800      C*FIRST ALL OF REGION 2 WILL GET REFRACTED.
101900          NPTS=0
102000          DO 100 I=IJET(M)+1, IDUMR
102100              J2(I)=J1(I)
102200          100  J1(I)=1
102300          DO 101 I=IJET(M)+1, IDUMR
102400              DO 101 J=J1(I), J2(I)-1
102500          101  NPTS=NPTS+1
102600              IMAXT=IDUMR
102700              IDUMLL=IDUML
102800              IJETT=IJET(M)
102900              IJETP1=IJET(M)+1
103000              CALL REFRAC(J1, J2, NPTS, IJETP1, IMAXT, IMAXT, M)
103100              IMAXT=IDUMR
103200              IJETT=IJET(M)
103300              IJETP1=IJET(M)+1
103400              IDUMLL=IDUML
103500      C*NOW MUST DO REGION 3 OF NEG THETA0 CASE-SHADOW ZONE.
103600          DO 102 I=IDUML, IJET(M)
103700              J2(I)=J1(I)
103800          102  J1(I)=1
103900          DO 103 I=IDUML, IJET(M)
104000              J1REF(I)=1
104100              DO 104 J=J1(I), J2(I)+1
104200                  XCOORD=(I-1.0)*DX
104300                  YCOORD=0.5*(Y(I, J)+Y(I, J+1))
104400                  ANGLE=ATAN((XDISTN-XCOORD)/(SJETTY-YCOORD))
104500                  IF(YCOORD.GT.SJETTY) ANGLE=PI+ANGLE
104600      C*IF MOST SHOREWARD PT OUT OF SHAD ZONE, SO ARE THE OTHERS FOR THAT I.
104700          IF(ABS(ANGLE).GT.ABS(THETA0(M))) GO TO 105
104800          RAD=SQRT((XDISTN-XCOORD)**2+(SJETTY-YCOORD)**2)
104900          RHOND=RAD*TWOPI/ELTIP
105000      C*DIFFRACTION TREATS THE POS THETA0 CASE.
105100          THE=ABS(THETA0(M))
105200          CALL DIFF(RHOND, THE, ANGLE, AMP)
105300          H(I, J)=AMP*HINC
105400          ANGRAD=-ANGLE
105500      C*WILL NOW REFRACT DIFF WAVES IN THE SHAD ZONE USING SNELL'S.
105600          CTIP=ELTIP/T
105700          ALPHAS(I, J)=ATAN((0.5*(Y(I+1, J)+Y(I+1, J+1))-0.5*
105800              * (Y(I-1, J)+Y(I-1, J+1)))/(2.*DX))
105900          IF(I.EQ.IJET(M))ALPHAS(I, J)=ATAN((0.5*(Y(I, J)+Y(I, J+1))-0.5*(Y(I-1
106000              * J)+Y(I-1, J+1)))/DX)
106100          DALPHA=ANGRAD-ALPHAS(I, J)
106200          THETA(I, J)=ARSIN((C(I, J)/CTIP)*SIN(DALPHA))
106300          THETA(I, J)=THETA(I, J)+ALPHAS(I, J)
106400      C*MUST CHECK TO SEE IF WAVE WOULD HAVE BROKEN.
106500          IF(HB(I, J).LE.H(I, J).AND.HB(I, J+1).GT.H(I, J+1))IBREAK(I)=J
106600          IF(HB(I, J).LT.H(I, J)) H(I, J)=HB(I, J)
106700          104  CONTINUE
106800              GO TO 103
106900          105  J1REF(I)=J
107000          103  CONTINUE
107100      C*NOW MUST DO REFRACTION FOR REGION 4.
107200          NPTS=0
107300          DO 106 I=IDUML, IJET(M)
107400              DO 106 J=J1REF(I), J2(I)-1
107500          106  NPTS=NPTS+1
107600              IDUMLL=IDUML
107700              IMAXT=IDUMR
107800              IJETT=IJET(M)
107900              IJETP1=IJET(M)+1
108000              CALL REFRAC(J1REF, J2, NPTS, IDUMLL, IJETT, IDUMLL, M)
108100              IDUMLL=IDUML
108200              IMAXT=IDUMR
108300              IJETT=IJET(M)
108400              IJETP1=IJET(M)+1
108500              GO TO 13
108600      C*THIS HANDLES REFRACT/DIFF IF THETA0 IS 0.0.
108700      C*FOR THIS CASE, ONLY THREE REGIONS EXIST.
108800          11  CONTINUE
108900          NPTS=0

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109000      DO 120 I=IDUML,IJET(M)
109100      J2(I)=J1(I)
109200      120 J1(I)=1
109300      DO 121 I=IDUML,IJET(M)
109400      DO 121 J=J1(I),J2(I)-1
109500      121 NPTS=NPTS+1
109600      IMAXT=IDUMR
109700      IDUMLL=IDUML
109800      IJETT=IJET(M)
109900      IJETP1=IJET(M)+1
110000      CALL REFRAC(J1,J2,NPTS,IDUMLL,IJETT,IDUMLL,M)
110100      IMAXT=IDUMR
110200      IJETT=IJET(M)
110300      IJETP1=IJET(M)+1
110400      IDUMLL=IDUML
110500      DO 122 I=IJET(M)+1,IDUMR
110600      J2(I)=J1(I)
110700      122 J1(I)=1
110800      NPTS=0
110900      DO 123 I=IJET(M)+1,IDUMR
111000      DO 123 J=J1(I),J2(I)-1
111100      123 NPTS=NPTS+1
111200      IMAXT=IDUMR
111300      IDUMLL=IDUML
111400      IJETT=IJET(M)
111500      IJETP1=IJET(M)+1
111600      CALL REFRAC(J1,J2,NPTS,IJETP1,IMAXT,IMAXT,M)
111700      IMAXT=IDUMR
111800      IJETT=IJET(M)
111900      IJETP1=IJET(M)+1
112000      IDUMLL=IDUML
112100      GO TO 13
112200      C*THIS SECTION HANDLES REFRACT/DIFF IF THETA0>0.0
112300      12 CONTINUE
112400      C*FIRST, REGION 2- ALL REFRACTION.
112500      NPTS=0
112600      DO 110 I=IDUML,IJET(M)
112700      J2(I)=J1(I)
112800      110 J1(I)=1
112900      DO 111 I=IDUML,IJET(M)
113000      DO 111 J=J1(I),J2(I)-1
113100      111 NPTS=NPTS+1
113200      IMAXT=IDUMR
113300      IDUMLL=IDUML
113400      IJETT=IJET(M)
113500      IJETP1=IJET(M)+1
113600      CALL REFRAC(J1,J2,NPTS,IDUMLL,IJETT,IDUMLL,M)
113700      IMAXT=IDUMR
113800      IJETT=IJET(M)
113900      IJETP1=IJET(M)+1
114000      IDUMLL=IDUML
114100      C*NOW WILL DO REGION 3 OF THE POS THETA0 CASE.
114200      DO 112 I=IJET(M)+1,IDUMR
114300      J2(I)=J1(I)
114400      112 J1(I)=1
114500      DO 113 I=IJET(M)+1,IDUMR
114600      J1REF(I)=1
114700      C*WILL GO ONE PT. BEYOND J2(I) TO MAKE SURE OUTOF DIFF ZONE.
114800      DO 114 J=J1(I),J2(I)+1
114900      XCOORD=(I-1.0)*DX
115000      YCOORD=0.5*(Y(I,J)+Y(I,J+1))
115100      ANGLE=ATAN((XCOORD-XDISTN)/(SJETT-YCOORD))
115200      IF(YCOORD.GT.SJETT) ANGLE=PI+ANGLE
115300      C*IF LEAST J-VALUE IS OUT OF SHAD ZONE,SO ARE OTHER J'S.(FOR EACH I)
115400      IF(ANGLE.GT.ABS(THETA0(M))) GO TO 115
115500      RAD=SQRT((XCOORD-XDISTN)**2+(SJETT-YCOORD)**2)
115600      RHOND=RAD*TWOP/ELTIP
115700      THE=THETA0(M)
115800      CALL DIFF(RHOND,THE,ANGLE,AMP)
115900      ANGRAD=ANGLE
116000      C*WILL NOW REFRACT DIFFRACTED WAVES IN SHAD ZONE USING SNELL'S.
116100      CTIP=ELTIP/T
116200      ALPHAS(I,J)=ATAN((0.5*(Y(I+1,J)+Y(I+1,J+1))-0.5*

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116300      * (Y(I-1,J)+Y(I-1,J+1)))/(2.*DX))
116400      IF(I.EQ.IJET(M)+1)ALPHAS(I,J)=ATAN((0.5*(Y(I+1,J)+Y(I+1,J+1))-0.5*
116500      * (Y(I,J)+Y(I,J+1)))/DX)
116600      DALPHA=ANGRAD-ALPHAS(I,J)
116700      THETA(I,J)=ARSIN((C(I,J)/CTIP)*SIN(DALPHA))
116800      THETA(I,J)=THETA(I,J)+ALPHAS(I,J)
116900      H(I,J)=HINC*AMP
117000  C*MUST CHECK TO SEE IF WAVE WOULD HAVE BROKEN.
117100      IF(HB(I,J).LE.H(I,J).AND.HB(I,J+1).GT.H(I,J+1))IBREAK(I)=J
117200      IF(HB(I,J).LT.H(I,J)) H(I,J)=HB(I,J)
117300      114 CONTINUE
117400      GO TO 113
117500      115 J1REF(I)=J
117600      113 CONTINUE
117700  C*NOW MUST DO REFRAC FOR REGION 4.
117800      NPTS=0
117900      DO 116 I=IJET(M)+1,IDUMR
118000      DO 116 J=J1REF(I),J2(I)-1
118100      116 NPTS=NPTS+1
118200      IMAXT=IDUMR
118300      IDUMLL=IDUML
118400      IJETT=IJET(M)
118500      IJETP1=IJET(M)+1
118600      CALL REFRAC(J1REF,J2,NPTS,IJETP1,IMAXT,IMAXT,M)
118700      IMAXT=IDUMR
118800      IJETT=IJET(M)
118900      IJETP1=IJET(M)+1
119000      IDUMLL=IDUML
119100      13 CONTINUE
119200      200 CONTINUE
119300      RETURN
119400      END
119500  C*****
119600      SUBROUTINE LOC(IM,JJ,JOIM,JSIM,YBAR,IDUM)
119700      COMMON/A/ C(60,20),RK(60,20),Y(60,20),DEEP(60,20),ALPHAS(60,20)
119800      COMMON/AA/YZERO(60)
119900      COMMON/B/ THETA(60,20),QXTOT(60), OLDANG(60,20), DY(60,20)
120000      COMMON/C/ H(60,20),CG(60,20),HOLD(60,20),HB(60,20),YB(60)
120100      COMMON/N USED/JUSE,T,CQ,CGEN,CGGEN,ANGGEN,DX,BERM,THETA0(10),MMAX
120200      COMMON/D/SIGMA,G,ELQ,JMAX,IMAX,PI,TWOPI,PI02,HGEN,IJET(10),SJETTY
120300  C*SUBROUTINE LOC FINDS J-VALUES WHICH ARE GREATER AND LESS THAN YBAR.
120400      JOIM=2
120500      2 AA=0.5*(Y(IM,JOIM)+Y(IM,JOIM-1))
120600      IF(AA.GT.YBAR) GO TO 4
120700      JOIM=JOIM+1
120800  C*THE FOLLOWING IS REQ'D SO THAT DY/DX>0.5
120900  C*WILL DETERMINE K SIN THETA ON IM-LINE AT A DIST YBAR.
121000  C*WILL CALL THIS POINT JUSE+1
121100      IF(JOIM.LE.JUSE) GO TO 2
121200      JOIM=JUSE+1
121300      Y(IM,JOIM)=YBAR
121400  C* DEPTH AT THIS POINT WILL BE COMP ASSUMING CONST BEACH SLOPE ON I=IM
121500      DEL=.5*(Y(IM,JOIM-1)+Y(IM,JOIM-2))- .5*(Y(IM,JOIM-2)+Y(IM,JOIM-3))
121600      BSLOPE=(DEEP(IM,JOIM-2)-DEEP(IM,JOIM-3))/DEL
121700      DEEP(IM,JOIM-1)=DEEP(IM,JOIM-2)+BSLOPE*(Y(IM,JOIM)-Y(IM,JOIM-1))
121800      DEPTH=DEEP(IM,JOIM-1)
121900      CALL WVNUM(DEPTH,T,DUMK)
122000      RK(IM,JOIM-1)=DUMK
122100      C(IM,JOIM-1)=CO*TANH(RK(IM,JOIM-1)*DEEP(IM,JOIM-1))
122200      EN=0.5*(1.0+((2.0*RK(IM,JOIM-1)*DEEP(IM,JOIM-1))/SINH(
122300      * 2.*RK(IM,JOIM-1)*DEEP(IM,JOIM-1))))
122400      CG(IM,JOIM-1)=C(IM,JOIM-1)*EN
122500  C*WILL USE SNELL'S LAW TO DETERMINE THE WAVE ANGLE HERE
122600  C*ANGLE OF CONTOUR WILL BE ASSUME TO BE THE SAME AS THE JMAX+1 CONTOUR
122700      IF(IDUM.EQ.1)ALPH=ATAN((Y(IM,JOIM-1)-Y(IM-1,JOIM-1))/DX)
122800      IF(IDUM.EQ.-1)ALPH=ATAN((Y(IM+1,JOIM-1)-Y(IM,JOIM-1))/DX)
122900      DALPHA=ANGGEN-ALPH
123000      THETA(IM,JOIM-1)=ARSIN((C(IM,JOIM-1)/CGEN)*SIN(DALPHA))
123100      THETA(IM,JOIM-1)=THETA(IM,JOIM-1)+ALPH
123200      4 JSIM=JMAX-1
123300      6 AA=0.5*(Y(IM,JSIM)+(Y(IM,JSIM+1)))
123400      IF(AA.LT.YBAR) GO TO 8
123500      JSIM=JSIM-1

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123600 C*IF JSIM=0,THERE IS NO ADJ PT, SUB REFRAC CAN HANDLE IT.
123700 IF(JSIM.EQ.0) GO TO 8
123800 GO TO 6
123900 8 RETURN
124000 END
124100 C*****
124200 SUBROUTINE WVNUM(DEPTH,T,RK)
124300 G=32.17
124400 EPS=0.001
124500 TWOPI=6.283185307
124600 SIGMA=TWOPI/T
124700 RK=TWOPI/(T*SQR(T*G*DEPTH))
124800 DO 100 IT=1,20
124900 ARG=RK*DEPTH
125000 EK=(G*RK*TANH(ARG))-(SIGMA**2)
125100 EKPR=G*(ARG*((SECH(ARG))**2)+TANH(ARG))
125200 RKNEW=RK-EK/EKPR
125300 IF(ABS(RKNEW-RK).LE.ABS(EPS*RKNEW)) GO TO 120
125400 RK=RKNEW
125500 100 CONTINUE
125600 WRITE(6,1000) IT,DEPTH,RK
125700 1000 FORMAT(///,10X,"ITERATION FOR K FAILED TO CONVERGE AFTER"
125800 * ,3X,13,"ITERATION",/,"OUTPUT: DEPTH, RK",3X,2F13.5)
125900 CALL EXIT
126000 120 RK=RKNEW
126100 IF(RK.GT.0.0) GO TO 140
126200 WRITE(6,1020) DEPTH,RK
126300 1020 FORMAT(///,10X," RK IS NEG",/," OUTPUT DEPTH,RK",3X,2F13.5)
126400 CALL EXIT
126500 140 RETURN
126600 END
126700 C*****
126800 SUBROUTINE SMOOTH(THETA,IMAX,UMAX,IJET,SJETTY,MMAX,Y)
126900 C*THIS WILL SMOOTH THE WAVE ANGLE FIELD TO ACCT FOR DIFF(ARTIFICIALLY)
127000 DIMENSION TEMP(60,20),Y(60,20),THETA(60,20),IJET(10)
127100 C*(MMAX+1) IS REQ'D BECAUSE M-GROINS HAVE M+1 REACHES OF SHORELINE.
127200 DO 10 M=1,MMAX+1
127300 IF(M.NE.1) GO TO 3
127400 ILEFT=2
127500 IRIGHT=IJET(1)
127600 GO TO 5
127700 3 IF(M.NE.MMAX+1) GO TO 4
127800 ILEFT=IJET(MMAX)+1
127900 IRIGHT=IMAX-1
128000 GO TO 5
128100 4 ILEFT=IJET(M-1)+1
128200 IRIGHT=IJET(M)
128300 5 CONTINUE
128400 DO 1 J=1,UMAX-1
128500 DO 1 I=ILEFT,IRIGHT
128600 IF(I.NE.ILEFT.AND.I.NE.IRIGHT) GO TO 15
128700 C*TO GET HERE, MUST BE ON BOUN OR ADJ TO A STRUCTURE.
128800 IF(I.EQ.2.OR.I.EQ.IMAX-1) GO TO 15
128900 C*TO GET HERE,ADJ TO A STRUCT AND CAN BE ILEFT OR IRIGHT.
129000 IF(Y(I,J).GE.SJETTY) GO TO 15
129100 C*IF HERE, WITHIN JETTY AND ADJ TO EITHER SIDE.
129200 IF(I.EQ.ILEFT)TEMP(I,J)=0.5*(THETA(I,J)+THETA(I+1,J))
129300 IF(I.EQ.IRIGHT)TEMP(I,J)=0.5*(THETA(I,J)+THETA(I-1,J))
129400 GO TO 1
129500 15 TEMP(I,J)=0.25*THETA(I-1,J)+0.50*THETA(I,J)+0.25*THETA(I+1,J)
129600 1 CONTINUE
129700 10 CONTINUE
129800 DO 2 J=1,UMAX-1
129900 DO 2 I=2,IMAX-1
130000 2 THETA(I,J)=TEMP(I,J)
130100 RETURN
130200 END
130300 C*****
130400 FUNCTION SECH(A)
130500 SECH=1.0/COSH(A)
130600 RETURN
130700 END
130800 C****HERE IS WHERE THE IMSL ROUTINES MUST GO!

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APPENDIX C

CONTOURS AND SCHEMATIC ILLUSTRATIONS

This appendix presents tables of the original contours at Oregon Inlet and the final contours for the eight numerical simulations (Tables C-1 to C-9). Also included are schematic illustrations of sediment volumes transported from the nourished region (Figs. C-1 to C-8).

Table C-1. Initial bathymetry for all simulations (prior to any sediment addition).

[illegible]

Table C-2. Final contours, case 2.a.

THE NEW CONTOUR VALUES, Y, FOLLOW																			
220.000	219.421	218.843	218.266	217.691	217.119	216.550	215.985	215.425	214.871	214.322	213.779	213.240							
212.716	212.137	211.557	210.974	210.393	209.812	209.231	208.650	208.069	207.488	206.907	206.326	205.745							
208.148	207.567	206.986	206.405	205.824	205.243	204.662	204.081	203.500	202.919	202.338	201.757	201.176							
202.506	201.925	201.344	200.763	200.182	199.601	199.020	198.439	197.858	197.277	196.696	196.115	195.534							
231.623	231.042	230.461	229.880	229.299	228.718	228.137	227.556	226.975	226.394	225.813	225.232	224.651							
244.407	243.826	243.245	242.664	242.083	241.502	240.921	240.340	239.759	239.178	238.597	238.016	237.435							
238.468	237.887	237.306	236.725	236.144	235.563	234.982	234.401	233.820	233.239	232.658	232.077	231.496							
234.401	233.820	233.239	232.658	232.077	231.496	230.915	230.334	230.753	230.172	229.591	229.010	228.429							
309.443	308.862	308.281	307.700	307.119	306.538	305.957	305.376	304.795	304.214	303.633	303.052	302.471							
292.300	291.719	291.138	290.557	290.976	290.395	289.814	289.233	288.652	288.071	287.490	286.909	286.328							
296.400	295.819	295.238	294.657	294.076	293.495	292.914	292.333	291.752	291.171	290.590	290.009	289.428							
292.114	291.533	290.952	290.371	289.790	289.209	288.628	288.047	287.466	286.885	286.304	285.723	285.142							
402.028	401.447	400.866	400.285	399.704	399.123	398.542	397.961	397.380	396.799	396.218	395.637	395.056							
434.911	434.330	433.749	433.168	432.587	432.006	431.425	430.844	430.263	429.682	429.101	428.520	427.939							
429.014	428.433	427.852	427.271	426.690	426.109	425.528	424.947	424.366	423.785	423.204	422.623	422.042							
424.696	424.115	423.534	422.953	422.372	421.791	421.210	420.629	420.048	419.467	418.886	418.305	417.724							
684.758	684.177	683.596	683.015	682.434	681.853	681.272	680.691	680.110	679.529	678.948	678.367	677.786							
677.735	677.154	676.573	675.992	675.411	674.830	674.249	673.668	673.087	672.506	671.925	671.344	670.763							
667.700	667.119	666.538	665.957	665.376	664.795	664.214	663.633	663.052	662.471	661.890	661.309	660.728							
984.726	984.145	983.564	982.983	982.402	981.821	981.240	980.659	980.078	979.497	978.916	978.335	977.754							
973.574	972.993	972.412	971.831	971.250	970.669	970.088	969.507	968.926	968.345	967.764	967.183	966.602							
967.779	967.198	966.617	966.036	965.455	964.874	964.293	963.712	963.131	962.550	961.969	961.388	960.807							
953.379	952.798	952.217	951.636	951.055	950.474	949.893	949.312	948.731	948.150	947.569	946.988	946.407							
1270.414	1269.833	1269.252	1268.671	1268.090	1267.509	1266.928	1266.347	1265.766	1265.185	1264.604	1264.023	1263.442							
1262.470	1261.889	1261.308	1260.727	1260.146	1259.565	1258.984	1258.403	1257.822	1257.241	1256.660	1256.079	1255.498							
1256.402	1255.821	1255.240	1254.659	1254.078	1253.497	1252.916	1252.335	1251.754	1251.173	1250.592	1250.011	1249.430							
1252.739	1252.158	1251.577	1250.996	1250.415	1249.834	1249.253	1248.672	1248.091	1247.510	1246.929	1246.348	1245.767							
1702.228	1701.647	1701.066	1700.485	1700.904	1699.823	1698.742	1697.661	1696.580	1695.499	1694.418	1693.337	1692.256							
1694.342	1693.761	1693.180	1692.599	1692.018	1691.437	1690.856	1690.275	1689.694	1689.113	1688.532	1687.951	1687.370							
1686.915	1686.334	1685.753	1685.172	1684.591	1684.010	1683.429	1682.848	1682.267	1681.686	1681.105	1680.524	1679.943							
1684.279	1683.698	1683.117	1682.536	1681.955	1681.374	1680.793	1680.212	1679.631	1679.050	1678.469	1677.888	1677.307							

Table C-3. Final contours, case 2.b.

THE NEW CONTOUR VALUES, Y, FOLLOW																			
220.000	219.039	218.880	218.321	217.765	217.210	216.659	216.112	215.568	215.029	214.495	213.967	213.436	212.904	212.371	211.838	211.305	210.772	210.239	209.706
218.931	218.424	217.917	217.413	216.910	216.406	215.903	215.400	214.897	214.394	213.891	213.388	212.885	212.382	211.879	211.376	210.873	210.370	209.867	209.364
207.032	206.643	206.253	205.864	205.475	205.086	204.697	204.308	203.919	203.530	203.141	202.752	202.363	201.974	201.585	201.196	200.807	200.418	200.029	199.640
202.637	202.394	202.151	201.908	201.665	201.422	201.179	200.936	200.693	200.450	200.207	199.964	199.721	199.478	199.235	198.992	198.749	198.506	198.263	198.020
251.623	251.065	250.508	249.954	249.401	248.850	248.302	247.757	247.216	246.679	246.148	245.621	245.101	244.581	244.061	243.541	243.021	242.501	241.981	241.461
248.588	248.062	247.536	247.010	246.484	245.958	245.432	244.906	244.380	243.854	243.328	242.802	242.276	241.750	241.224	240.698	240.172	240.046	239.520	239.000
238.788	238.317	237.846	237.375	236.904	236.433	235.962	235.491	235.020	234.549	234.078	233.607	233.136	232.665	232.194	231.723	231.252	230.781	230.310	229.839
236.337	235.952	235.567	235.182	234.797	234.412	234.027	233.642	233.257	232.872	232.487	232.102	231.717	231.332	230.947	230.562	230.177	230.000	229.523	229.046
309.443	308.891	308.341	307.793	307.246	306.698	306.150	305.602	305.054	304.506	303.958	303.410	302.862	302.314	301.766	301.218	300.670	300.122	300.000	299.523
302.469	301.966	301.471	300.985	300.500	300.015	299.530	299.045	298.560	298.075	297.590	297.105	296.620	296.135	295.650	295.165	294.680	294.195	293.710	293.225
296.628	296.234	295.840	295.446	295.052	294.658	294.264	293.870	293.476	293.082	292.688	292.294	291.900	291.506	291.112	290.718	290.324	290.000	289.523	289.046
292.226	291.938	291.653	291.369	291.087	290.807	290.530	290.257	290.000	289.750	289.500	289.250	289.000	288.750	288.500	288.250	288.000	287.750	287.500	287.250
482.028	481.480	480.934	480.388	479.844	479.300	478.756	478.212	477.668	477.124	476.580	476.036	475.492	474.948	474.404	473.860	473.316	472.772	472.228	471.684
435.163	434.864	434.564	434.264	433.964	433.664	433.364	433.064	432.764	432.464	432.164	431.864	431.564	431.264	430.964	430.664	430.364	430.064	429.764	429.464
425.398	424.997	424.596	424.195	423.794	423.393	422.992	422.591	422.190	421.789	421.388	420.987	420.586	420.185	419.784	419.383	418.982	418.581	418.180	417.779
424.947	424.533	424.119	423.705	423.291	422.877	422.463	422.049	421.635	421.221	420.807	420.393	419.979	419.565	419.151	418.737	418.323	417.909	417.495	417.081
684.758	684.237	683.717	683.196	682.676	682.156	681.635	681.114	680.591	680.069	679.548	679.029	678.516	677.999	677.482	676.965	676.448	675.931	675.414	674.897
678.011	677.515	677.032	676.561	676.104	675.660	675.228	674.806	674.392	673.982	673.574	673.166	672.756	672.346	671.936	671.526	671.116	670.706	670.296	669.886
672.344	671.933	671.524	671.124	670.735	670.361	670.004	669.665	669.343	669.034	668.735	668.441	668.150	667.859	667.568	667.277	666.986	666.695	666.404	666.113
667.852	667.553	667.248	666.938	666.625	666.311	665.997	665.685	665.375	665.066	664.758	664.451	664.148	663.845	663.542	663.240	662.937	662.635	662.332	662.030
980.67	980.191	979.657	979.122	978.587	978.050	977.513	976.975	976.438	975.899	975.363	974.833	974.309	973.785	973.262	972.738	972.214	971.690	971.166	970.642
973.735	973.292	972.850	972.408	971.968	971.528	971.088	970.648	970.208	969.768	969.328	968.888	968.448	968.008	967.568	967.128	966.688	966.248	965.808	965.368
968.087	967.678	967.275	966.882	966.502	966.140	965.795	965.468	965.157	964.859	964.571	964.283	964.000	963.717	963.434	963.151	962.868	962.585	962.302	962.019
963.718	963.428	963.133	962.835	962.533	962.230	961.927	961.624	961.321	961.018	960.715	960.412	960.109	959.806	959.503	959.200	958.897	958.594	958.291	957.988
1270.414	1269.827	1269.239	1268.653	1268.069	1267.487	1266.907	1266.332	1265.760	1265.194	1264.634	1264.081	1263.536	1262.991	1262.446	1261.901	1261.356	1260.811	1260.266	1259.721
1263.000	1262.474	1261.959	1261.456	1260.964	1260.485	1260.018	1259.562	1259.117	1258.683	1258.259	1257.844	1257.440	1256.991	1256.546	1256.101	1255.656	1255.211	1254.766	1254.321
1257.000	1256.661	1256.322	1255.983	1255.644	1255.305	1254.966	1254.627	1254.288	1253.949	1253.610	1253.271	1252.932	1252.593	1252.254	1251.915	1251.576	1251.237	1250.898	1250.559
1252.921	1252.660	1252.401	1252.142	1251.883	1251.624	1251.365	1251.106	1250.847	1250.588	1250.329	1250.070	1249.811	1249.552	1249.293	1249.034	1248.775	1248.516	1248.257	1248.000
1702.228	1701.600	1701.000	1700.428	1699.886	1699.386	1698.904	1698.444	1697.986	1697.544	1697.104	1696.664	1696.224	1695.784	1695.344	1694.904	1694.464	1694.024	1693.584	1693.144
1694.339	1693.851	1693.315	1692.741	1692.229	1691.780	1691.293	1690.820	1690.361	1689.915	1689.483	1689.065	1688.660	1688.264	1687.868	1687.472	1687.076	1686.680	1686.284	1685.888
1686.270	1685.933	1685.596	1685.260	1684.924	1684.588	1684.252	1683.916	1683.580	1683.244	1682.908	1682.572	1682.236	1681.900	1681.564	1681.228	1680.892	1680.556	1680.220	1679.884
1684.336	1684.104	1683.876	1683.659	1683.445	1683.236	1683.030	1682.827	1682.626	1682.427	1682.228	1682.029	1681.830	1681.631	1681.432	1681.233	1681.034	1680.835	1680.636	1680.437

Table C-4. Final contours, case 2.c1.

LINE AREA CONTOUR VALUES. Y. FOLLOW									
200.000	222.852	225.555	228.459	231.234	233.970	236.655	239.278	241.828	244.294
250.000	254.964	256.685	258.239	259.618	260.810	261.805	262.594	263.168	263.520
262.600	261.791	260.740	259.459	257.953	256.229	254.495	252.160	249.834	247.327
235.725	232.492	229.151	225.714	222.193	218.602	214.951	211.253	207.519	203.764
251.623	254.652	257.687	260.718	263.712	266.652	269.545	272.386	275.145	277.820
207.319	209.369	291.215	292.907	294.439	295.772	296.865	297.605	298.008	298.694
201.935	297.079	295.672	294.634	293.068	291.265	289.216	286.935	284.449	281.778
201.535	266.119	262.565	258.909	255.172	251.353	247.456	243.493	239.492	235.520
307.443	313.514	317.595	321.665	325.688	329.646	333.542	337.363	341.075	344.657
357.618	360.390	362.951	365.314	367.461	369.345	370.917	372.171	373.126	373.788
373.330	372.334	371.011	369.385	367.455	365.207	362.937	359.769	356.641	353.573
337.760	333.404	328.673	324.214	319.450	314.581	309.523	304.600	299.541	294.083
402.028	407.543	413.038	418.495	423.895	429.219	434.449	439.566	444.553	449.390
506.062	510.658	514.183	517.414	520.328	522.901	525.111	526.937	528.362	529.371
529.189	528.019	526.558	524.870	522.061	519.142	516.025	512.428	508.470	504.176
408.171	478.590	472.617	468.668	460.760	454.511	448.146	441.690	435.170	428.608
684.75	693.500	702.203	710.628	719.341	727.712	735.913	743.920	751.708	759.253
786.463	792.381	797.887	802.950	807.539	811.626	815.180	818.172	820.578	822.373
823.139	821.676	819.544	816.751	813.310	809.242	804.571	799.127	793.544	787.556
757.770	749.480	740.882	732.003	722.672	713.521	703.986	694.304	684.514	674.654
980.726	997.388	1014.001	1030.517	1046.688	1063.067	1079.004	1095.102	1110.953	1128.857
1179.27	1191.248	1202.442	1212.761	1222.200	1230.635	1238.024	1244.309	1249.436	1253.359
1256.285	1253.726	1249.649	1244.675	1238.258	1230.584	1221.770	1211.959	1200.921	1189.030
1153.523	1117.612	1101.693	1085.097	1068.088	1050.725	1033.071	1015.185	997.127	978.954
1270.414	1275.696	1280.964	1286.207	1291.410	1296.559	1301.640	1306.637	1311.533	1316.308
1333.786	1337.633	1341.221	1344.522	1347.511	1350.162	1352.051	1354.354	1356.050	1356.922
1356.712	1355.509	1353.852	1351.750	1349.218	1346.273	1342.938	1339.236	1335.192	1330.832
1310.715	1305.234	1299.529	1293.683	1287.717	1281.649	1275.498	1269.263	1263.020	1256.744
1702.228	1701.697	1701.166	1700.636	1700.109	1699.584	1699.062	1698.544	1698.030	1697.521
1695.54	1695.061	1694.589	1694.123	1693.664	1693.213	1692.764	1692.321	1691.878	1691.462
1689.654	1689.484	1689.082	1688.705	1688.335	1687.972	1687.614	1687.263	1686.917	1686.577
1685.268	1684.952	1684.640	1684.331	1684.025	1683.722	1683.420	1683.121	1682.822	1682.528

Table C-5. Final contours, case 2.c2.

THE NEW CONTOUR VALUES, Y, FOLLOW

220.000	222.574	225.142	227.698	230.232	232.755	235.198	237.610	239.962	242.243	244.443	246.550	248.554
250.442	252.202	253.622	255.220	256.531	257.720	258.660	259.402	259.937	260.256	260.355	260.237	259.869
259.280	258.601	257.414	256.185	254.659	252.665	251.073	248.994	246.739	244.321	241.751	239.043	236.209
233.260	230.209	227.068	223.848	220.560	217.215	213.824	210.398	206.946	203.477	200.000		
251.623	254.387	257.181	259.990	262.787	265.552	268.275	270.949	273.563	276.104	278.562	280.926	283.187
285.327	287.332	289.187	290.877	292.388	293.708	294.821	295.716	296.332	296.681	296.995	297.264	296.589
295.985	295.117	293.992	292.618	291.000	289.148	287.075	284.796	282.337	279.602	276.675	273.917	270.824
267.614	264.301	260.896	257.407	253.846	250.224	246.555	242.849	239.119	235.374	231.623		
309.443	312.369	315.475	318.666	321.824	324.931	327.987	330.992	333.933	336.779	339.523	342.195	344.810
347.324	349.679	351.847	353.825	355.606	357.172	358.504	359.591	360.427	361.022	361.390	361.498	361.247
360.580	359.556	358.265	356.739	354.956	352.905	350.596	348.053	345.302	342.360	339.231	335.913	332.433
328.655	325.228	321.524	317.726	313.833	309.864	305.835	301.742	297.600	293.549	289.543		
482.028	485.538	489.186	492.859	496.485	500.091	503.669	507.192	510.631	513.936	517.076	520.140	523.249
503.470	502.557	500.893	499.043	496.955	494.589	491.946	489.038	485.882	482.495	478.884	475.030	470.940
466.773	462.654	458.548	454.299	449.861	445.303	440.687	436.037	431.362	426.686	422.028		
684.758	693.580	702.347	711.058	719.730	728.360	736.919	745.379	753.715	761.903	769.943	780.355	795.635
813.210	830.484	847.336	863.718	879.584	894.889	909.591	923.619	936.984	949.588	961.432	972.431	977.454
971.427	959.366	946.416	932.695	918.235	903.074	887.251	870.809	853.788	836.240	818.222	799.793	781.024
764.526	752.893	743.635	734.202	724.578	714.804	704.920	694.953	684.921	674.849	664.758		
980.726	996.141	1011.526	1026.650	1042.081	1057.184	1072.120	1086.848	1101.319	1115.484	1129.283	1146.126	1169.417
1195.18	1221.161	1248.980	1270.014	1293.157	1315.340	1337.771	1340.535	1350.556	1359.797	1368.228	1375.820	1379.114
1374.609	1365.793	1356.149	1345.701	1334.479	1322.518	1305.427	1281.933	1257.273	1231.821	1205.553	1178.508	1150.882
1126.103	1107.752	1095.429	1076.727	1060.706	1044.422	1027.926	1011.265	994.484	977.624	960.726		
1270.414	1273.892	1277.367	1280.834	1284.289	1287.728	1291.146	1294.535	1297.888	1301.196	1304.445	1307.622	1310.710
1313.688	1316.535	1319.224	1321.730	1324.022	1326.073	1327.834	1329.316	1330.536	1331.537	1332.329	1332.929	1333.429
1379.410	1370.594	1360.950	1350.502	1339.280	1327.319	1314.694	1301.671	1288.254	1274.439	1259.225	1243.641	1227.913
1293.650	1289.698	1285.451	1280.117	1273.804	1267.428	1260.994	1254.602	1248.154	1241.654	1235.104	1228.504	1221.913
1702.228	1701.684	1701.140	1700.596	1700.054	1699.513	1698.974	1698.438	1697.906	1697.377	1696.854	1696.336	1695.825
1695.321	1696.824	1694.336	1691.856	1689.385	1686.923	1684.469	1682.023	1679.586	1677.156	1674.734	1672.319	1669.912
1689.513	1686.122	1682.368	1678.504	1674.640	1670.797	1666.950	1663.116	1659.286	1655.461	1651.646	1647.831	1644.016
1685.055	1684.759	1684.467	1684.178	1683.893	1683.611	1683.331	1683.051	1682.771	1682.502	1682.228		

Table C-6. Final contours, case 2.c3.

THE NEW CONTOUR VALUES. Y, FOLLOW																			
220.000	221.845	223.683	225.509	227.313	229.089	230.826	232.523	234.167	235.753	237.272	238.716	240.077							
241.348	242.519	243.583	244.530	245.353	246.044	246.595	247.099	247.550	247.944	248.277	248.554								
246.101	245.308	244.519	243.498	242.328	241.012	239.554	237.957	236.227	234.369	232.393	230.308	228.125							
225.855	223.507	221.082	218.409	215.071	211.380	207.443	203.168	198.562	193.636	188.376	182.690	176.588							
231.623	233.498	235.392	237.293	239.177	241.030	242.846	244.621	246.350	248.025	249.639	251.186	252.660							
274.050	275.345	276.533	277.605	278.550	279.355	280.008	280.498	280.816	280.956	280.915	280.693	280.287							
279.700	278.935	278.094	276.914	275.671	274.278	272.735	271.046	269.215	267.249	265.161	262.964	260.672							
258.303	255.866	253.369	250.814	248.203	245.537	242.819	240.057	237.263	234.447	231.623									
309.443	311.420	313.526	315.697	317.843	319.940	321.993	324.009	325.987	327.907	329.763	331.568	333.333							
335.036	336.608	338.135	339.505	340.744	341.834	342.746	343.458	343.962	344.255	344.343	344.224	343.875							
343.258	342.373	341.244	339.974	338.519	336.896	335.104	333.146	331.029	328.772	326.388	323.865	321.286							
318.625	315.921	313.167	310.354	307.487	304.568	301.600	298.590	295.551	292.498	289.443									
442.028	445.418	448.680	452.348	455.794	459.206	462.618	466.027	469.418	472.725	475.932	479.175	482.503							
486.080	489.479	492.681	495.692	498.535	501.184	503.567	505.609	507.274	508.581	509.611	510.162	510.567							
509.676	508.291	506.130	503.646	500.898	497.879	494.580	491.005	487.184	483.176	479.013	474.675	470.194							
465.732	461.411	457.144	452.802	448.382	443.943	439.518	435.114	430.730	426.368	422.028									
684.758	696.120	706.490	716.309	726.334	736.809	747.685	758.888	770.505	782.655	796.988	813.373	831.732							
852.453	874.788	897.290	919.475	941.503	962.353	982.069	1001.785	1019.395	1035.244	1048.852	1058.086	1061.185							
1057.956	1048.151	1033.428	1016.170	997.242	977.029	955.202	933.448	910.379	886.753	862.903	839.272	816.819							
796.596	779.055	764.002	750.342	737.126	724.257	711.804	699.726	687.912	676.278	664.758									
946.726	965.702	1015.781	1032.198	1048.818	1066.111	1083.912	1101.890	1120.103	1139.021	1159.881	1183.592	1210.260							
1239.961	1271.244	1302.237	1329.025	1366.090	1378.627	1393.615	1407.198	1419.140	1429.286	1436.598	1439.352								
1436.553	1428.600	1417.146	1403.578	1388.502	1372.372	1355.913	1337.697	1319.213	1289.330	1256.251	1223.058	1190.661							
1161.109	1136.338	1115.348	1095.497	1075.419	1055.263	1035.010	1016.077	997.673	979.099	960.726									
1270.414	1233.743	1217.935	1219.784	1282.576	1285.699	1289.080	1292.438	1295.774	1299.326	1303.099	1306.958	1311.005							
1315.456	1320.326	1325.416	1333.836	1350.891	1367.461	1383.248	1398.116	1411.999	1423.941	1434.087	1441.399	1444.153							
1431.354	1433.401	1427.917	1406.377	1393.303	1377.173	1360.214	1342.498	1324.014	1315.513	1309.511	1303.673	1298.513							
1293.516	1284.477	1284.093	1279.828	1275.396	1270.916	1266.612	1262.487	1258.424	1254.393	1250.414									
1702.228	1701.647	1701.066	1700.481	1699.896	1699.317	1698.746	1698.179	1697.615	1697.057	1696.506	1695.961	1695.430							
1694.894	1694.377	1693.869	1693.366	1692.875	1692.393	1691.923	1691.467	1691.019	1690.579	1690.149	1689.733	1689.330							
1686.934	1688.549	1688.173	1687.806	1687.449	1687.104	1686.769	1686.446	1686.131	1685.825	1685.527	1685.238	1684.956							
1684.684	1684.418	1684.161	1683.910	1683.660	1683.413	1683.170	1682.932	1682.696	1682.461	1682.228									

Table C-7. Final contours, case 2.c4.

THE NEW CONTOUR VALUES. Y, FOLLOW														
220.000	221.049	223.694	225.532	227.357	229.164	230.947	232.699	234.414	236.083	237.699	239.252	240.734		
242.133	243.440	244.642	245.728	246.680	247.511	248.186	248.704	249.057	249.234	249.244	249.067	248.706		
248.163	247.434	246.522	245.433	244.170	242.740	241.153	239.418	237.595	235.585	233.430	231.211	228.899		
226.504	224.034	221.504	219.010	216.286	213.617	210.920	208.203	205.473	202.737	200.000				
251.023	251.692	252.355	253.015	253.674	254.331	254.984	255.634	256.281	256.925	257.566	258.205	258.841		
278.176	275.526	276.771	277.898	278.896	279.753	280.459	281.004	281.391	281.583	281.605	281.437	281.075		
280.520	279.777	278.647	277.734	276.443	274.982	273.359	271.585	269.671	267.629	265.471	263.208	260.853		
258.420	255.916	253.349	250.728	248.061	245.356	242.622	239.864	237.096	234.348	231.623				
309.443	311.024	314.207	316.594	318.982	321.367	323.741	326.099	328.431	330.730	332.986	335.188	337.320		
339.366	341.307	343.135	344.802	346.317	347.652	348.789	349.712	350.485	350.858	351.058	350.994	350.662		
350.065	349.197	348.071	346.688	345.061	343.202	341.126	338.753	336.091	333.790	331.038	328.166	325.192		
322.133	319.003	315.814	312.579	309.309	306.014	302.702	299.380	296.058	292.744	289.443				
482.028	485.709	489.391	493.072	496.753	498.429	499.098	499.671	500.133	500.495	500.758	500.921	500.986		
488.632	491.756	494.710	497.464	499.986	502.246	504.214	505.862	507.163	508.095	508.641	508.786	508.522		
507.847	506.762	505.276	503.402	501.157	498.564	495.646	492.432	488.951	485.214	481.309	477.208	472.956		
468.585	464.11	459.566	454.960	450.309	445.628	440.926	436.211	431.487	426.758	422.011				
684.758	689.616	714.513	729.483	744.557	759.753	775.078	790.525	806.069	821.667	837.259	852.857	868.494		
903.921	920.812	953.321	976.995	999.774	1021.498	1042.110	1061.104	1078.824	1094.873	1109.216	1121.782	1127.320		
1120.607	1106.869	1091.341	1073.105	1053.289	1034.889	1013.156	989.193	966.194	941.196	915.473	889.135	862.324		
937.770	918.190	901.075	883.899	866.720	849.579	832.498	815.486	798.536	781.634	764.758				
980.726	1000.366	1020.022	1039.705	1059.422	1079.168	1099.927	1118.668	1138.343	1157.890	1177.226	1197.224	1220.739		
1260.672	1291.908	1322.298	1351.684	1379.324	1399.434	1404.547	1410.545	1431.322	1442.782	1452.850	1461.468	1465.130		
1460.350	1450.611	1439.418	1426.823	1412.903	1397.747	1381.461	1364.160	1339.492	1308.613	1276.690	1243.078	1210.323		
1179.637	1155.019	1134.309	1112.934	1091.375	1069.696	1047.905	1026.156	1004.356	982.538	960.726				
1270.914	1275.657	1280.936	1286.285	1291.736	1297.314	1303.040	1308.927	1314.976	1321.182	1327.523	1333.970	1340.476		
1346.987	1353.432	1359.731	1365.801	1371.825	1378.355	1384.385	1390.348	1396.348	1402.348	1408.348	1414.348	1420.348		
1465.151	1455.412	1444.219	1431.684	1417.704	1402.398	1386.262	1368.961	1351.282	1330.198	1312.912	1295.469	1277.947		
1320.413	1312.922	1305.514	1299.250	1291.055	1284.025	1271.123	1270.336	1263.641	1257.011	1250.414				
1702.228	1701.608	1701.008	1700.491	1699.917	1699.307	1698.702	1698.169	1697.671	1697.127	1696.591	1696.063	1695.545		
1695.036	1694.536	1694.007	1693.567	1693.096	1692.636	1692.185	1691.743	1691.310	1690.886	1690.471	1690.064	1689.665		
1689.275	1688.892	1688.517	1688.151	1687.792	1687.441	1687.097	1686.762	1686.433	1686.113	1685.800	1685.494	1685.195		
1684.902	1684.616	1684.335	1684.060	1683.789	1683.523	1683.260	1682.999	1682.741	1682.484	1682.228				

Table C-8. Final contours, case 3 (17 weeks plus sediment addition).

220.000	219.071	217.236	216.342	215.470	214.625	213.812	213.033	212.291	211.589	210.926	210.303
209.719	209.172	208.660	208.180	207.729	207.305	206.903	206.522	206.158	205.817	205.473	205.147
204.816	204.497	204.201	203.936	203.692	203.465	203.255	203.066	202.895	202.741	202.603	202.479
200.950	200.773	200.616	200.480	200.363	200.265	200.185	200.121	200.071	200.033	200.000	
251.623	250.708	249.802	248.909	248.035	247.187	246.370	245.589	244.848	244.150	243.495	242.884
241.792	241.367	240.957	240.560	240.180	239.822	239.483	239.163	238.873	238.615	238.379	238.165
237.089	236.767	236.461	236.170	235.895	235.635	235.392	235.166	234.964	234.784	234.625	234.485
232.909	232.676	232.467	232.282	232.119	231.978	231.860	231.766	231.696	231.651	231.623	
309.443	308.558	307.680	306.817	305.980	305.175	304.411	303.694	303.027	302.414	301.855	301.349
300.762	300.131	299.608	299.117	298.649	298.209	297.799	297.416	297.058	296.730	296.434	296.168
290.761	290.423	290.042	289.640	289.220	288.784	288.336	287.883	287.429	286.979	286.541	286.118
291.353	291.013	290.703	290.422	290.167	289.936	289.735	289.578	289.478	289.400	289.343	
442.028	441.318	440.621	439.951	439.321	438.745	438.232	437.789	437.421	437.129	436.913	436.696
436.693	436.722	436.798	436.899	437.013	437.127	437.225	437.289	437.302	437.252	437.136	436.952
436.373	435.968	435.482	434.916	434.270	433.576	432.822	432.026	431.198	430.354	429.508	428.667
427.138	426.422	425.644	424.814	423.968	423.108	422.235	421.353	420.463	419.568	418.668	417.764
684.758	684.608	684.472	684.364	684.297	684.263	684.331	684.408	684.639	684.907	685.250	685.665
686.652	687.264	687.876	688.502	689.122	689.717	690.266	690.747	691.140	691.424	691.591	691.659
691.160	690.696	690.068	689.284	688.352	687.289	686.110	684.837	683.490	682.091	680.661	679.221
674.378	675.004	673.675	672.398	671.175	670.006	668.887	667.813	666.774	665.760	664.758	
980.726	991.845	1002.983	1014.160	1025.389	1036.678	1048.028	1059.430	1070.864	1082.300	1093.693	1105.129
1150.760	1179.183	1203.166	1226.603	1249.386	1271.402	1292.545	1312.709	1331.801	1349.717	1366.447	1381.880
1381.020	1364.718	1347.118	1326.266	1308.222	1287.065	1264.885	1240.782	1217.863	1193.239	1168.019	1142.510
1091.293	1077.103	1064.242	1051.598	1038.315	1025.327	1012.356	999.412	986.497	973.605	960.726	
1270.414	1267.593	1264.812	1262.106	1259.506	1257.036	1254.706	1252.516	1250.450	1248.476	1246.543	1244.658
1463.017	1449.303	1435.137	1420.383	1405.097	1389.355	1373.161	1356.524	1339.450	1321.946	1305.004	1287.634
1689.958	1641.451	1608.760	1568.974	1527.783	1485.291	1441.617	1396.892	1351.254	1304.845	1257.603	1209.527
1397.684	1379.718	1365.183	1350.630	1336.109	1321.650	1307.270	1292.970	1278.740	1264.563	1250.414	
1702.228	1701.147	1700.070	1699.001	1697.903	1696.800	1695.676	1694.534	1693.374	1692.209	1691.043	1690.292
1689.728	1688.702	1687.666	1686.613	1685.548	1684.474	1683.390	1682.298	1681.198	1680.091	1678.968	1677.828
1690.821	1689.609	1688.001	1686.001	1683.613	1680.841	1677.691	1674.167	1670.270	1666.001	1661.455	1656.634
1681.226	1681.280	1681.309	1681.331	1681.323	1681.266	1681.170	1681.047	1680.894	1680.711	1680.500	1680.268
2160.943	2176.761	2176.582	2177.412	2176.254	2175.111	2173.988	2172.898	2171.845	2170.771	2169.760	2168.744
2160.949	2165.094	2165.282	2164.516	2163.797	2163.125	2162.501	2161.925	2161.399	2160.919	2160.487	2160.102
2159.468	2159.217	2159.008	2158.840	2158.710	2158.617	2158.559	2158.533	2158.539	2158.573	2158.634	2158.719
2158.956	2159.103	2159.267	2159.445	2159.636	2159.830	2160.040	2160.264	2160.480	2160.715	2160.943	

Table C-9. Final contours, case 4.

THE NEW CONTOUR VALUES, Y, FOLLOW

220.000	221.426	222.652	223.967	225.270	226.555	227.817	229.050	230.248	231.406	232.517	233.575	234.573
235.500	236.361	237.136	237.823	238.415	238.908	239.284	239.549	239.693	239.711	239.601	239.358	238.982
236.471	237.026	237.609	238.103	238.510	238.957	239.348	239.688	239.971	240.207	240.392	240.522	240.592
231.121	231.972	232.169	232.110	232.032	231.910	231.768	231.608	231.441	231.268	231.092	230.915	230.738
236.941	237.584	238.081	238.529	238.926	239.276	239.576	239.836	239.967	239.983	239.893	239.698	239.408
306.068	307.101	308.048	308.893	309.634	310.260	310.736	311.140	311.368	311.456	311.395	311.181	310.812
291.207	292.056	292.853	293.598	294.293	294.938	295.533	296.080	296.587	297.054	297.481	297.868	298.215
472.161	473.070	473.957	474.822	475.667	476.492	477.297	478.082	478.847	479.592	480.317	481.022	481.707
482.518	483.183	483.818	484.423	484.998	485.543	486.058	486.543	486.998	487.423	487.818	488.183	488.518
458.938	459.323	459.678	459.993	460.268	460.503	460.698	460.853	460.968	461.043	461.078	461.083	461.068
571.553	572.760	573.967	575.174	576.381	577.588	578.795	579.992	581.189	582.386	583.583	584.780	585.977
637.553	638.760	639.967	641.174	642.381	643.588	644.795	645.992	647.189	648.386	649.583	650.780	651.977
651.950	653.157	654.364	655.571	656.778	657.985	659.192	660.399	661.606	662.813	663.920	665.027	666.134
605.307	606.240	607.173	608.106	609.039	609.972	610.905	611.838	612.771	613.704	614.637	615.570	616.503
736.953	738.160	739.367	740.574	741.781	742.988	744.195	745.402	746.609	747.816	749.023	750.230	751.437
817.756	819.201	820.646	822.091	823.536	824.981	826.426	827.871	829.316	830.761	832.206	833.651	835.096
721.847	723.477	725.107	726.737	728.367	729.997	731.627	733.257	734.887	736.517	738.147	739.777	741.407
902.091	904.036	905.981	907.926	909.871	911.816	913.761	915.706	917.651	919.596	921.541	923.486	925.431
857.866	859.811	861.756	863.701	865.646	867.591	869.536	871.481	873.426	875.371	877.316	879.261	881.206
1001.281	1003.226	1005.171	1007.116	1009.061	1011.006	1012.951	1014.896	1016.841	1018.786	1020.731	1022.676	1024.621
902.478	904.423	906.368	908.313	910.258	912.203	914.148	916.093	918.038	920.033	922.028	924.023	926.018
937.092	939.037	940.982	942.927	944.872	946.817	948.762	950.707	952.652	954.597	956.542	958.487	960.432
1054.990	1056.935	1058.880	1060.825	1062.770	1064.715	1066.660	1068.605	1070.550	1072.495	1074.440	1076.385	1078.330
1068.650	1070.595	1072.540	1074.485	1076.430	1078.375	1080.320	1082.265	1084.210	1086.155	1088.100	1090.045	1091.990
1027.128	1029.073	1031.018	1032.963	1034.908	1036.853	1038.798	1040.743	1042.688	1044.633	1046.578	1048.523	1050.468
1270.414	1272.359	1274.304	1276.249	1278.194	1280.139	1282.084	1284.029	1285.974	1287.919	1289.864	1291.809	1293.754
1266.353	1268.298	1270.243	1272.188	1274.133	1276.078	1278.023	1279.968	1281.913	1283.858	1285.803	1287.748	1289.693
1281.695	1283.640	1285.585	1287.530	1289.475	1291.420	1293.365	1295.310	1297.255	1299.200	1301.145	1303.090	1305.035
1252.600	1254.545	1256.490	1258.435	1260.380	1262.325	1264.270	1266.215	1268.160	1270.105	1272.050	1273.995	1275.940

Case 2.a.

Period Considered: Twelve months, January through December, using 1975
WIS wave hindcasts

Sediment Budget Summary:

Amount of sediment added:	None
Amount of sediment transported shoreward from nourished region:	992 yd ³
Amount of sediment transported seaward from nourished region:	96 yd ³
Net amount of sediment transported alongshore from nourished region:	10,444 yd ³
Total amount of sediment transported from nourished region:	-9,356 yd ³

Figure C-1. Schematic illustration of sediment volumes transported from region, case 2.a.

Case No. 2b.

Period considered: Twelve months, January through December, using 1975
WIS wave hindcasts, but wave angle always set equal
to 0°.

Sediment Budget Summary:

Amount of sediment added:	None
Amount of sediment transported shoreward from nourished region:	1,624 yd ³
Amount of sediment transported seaward from nourished region:	132 yd ³
Net amount of sediment transported alongshore from nourished region:	-15,904 yd ³
Total amount of sediment transported from nourished region:	-14,148 yd ³

Figure C-2. Schematic illustration of sediment volumes transported from region, case 2.b.

Case 2.c1.

Period considered: Twelve months, January through December, using 1975
WIS wave hindcasts.

Sediment Budget Summary:

Amount of sediment added:	1,452,000 yd ³ (on 7- and 11-ft contours)
Amount of sediment transported shoreward from nourished region:	460,264 yd ³ (31.7pct)
Amount of sediment transported seaward from nourished region:	27,808 yd ³ (1.9pct)
Net amount of sediment transported alongshore from nourished region:	403,944 yd ³ (27.8pct)
Total amount of sediment transported from nourished region:	892,016 yd ³ (61.4pct)

Figure C-3. Schematic illustration of sediment volumes transported from nourished region, case 2.c1.

Case 2.c2.

Period considered: Twelve months, April through March, using 1975
WIS wave hindcasts.

Sediment Budget Summary:

Amount of sediment added:	1,452,000 yd ³ (on 7- and 11-ft contours)
Amount of sediment transported shoreward from nourished region:	466,260 yd ³ (32.1pct)
Amount of sediment transported seaward from nourished region:	28,920 yd ³ (2.0 pct)
Net amount of sediment transported alongshore from nourished region:	421,428 yd ³ (29.0pct)
Total amount of sediment transported from nourished region:	916,608 yd ³ (63.1pct)

Figure C-4. Schematic illustration of sediment volumes transported from nourished region, case 2.c2.

Case 2.c3.

Period considered: Twelve months, July through June, using 1975
WIS wave hindcasts.

Sediment Budget Summary:

Amount of sediment added:	1,452,000 yd ³ (on 7- and 11-ft contour)
Amount of sediment transported shoreward from nourished region:	415,784 yd ³ (28.6 pct)
Amount of sediment transported seaward from nourished region:	23,728 yd ³ (1.6 pct)
Net amount of sediment transported alongshore from nourished region	330,400 yd ³ (22.8pct)
Total amount of sediment transported from nourished region:	769,912 yd ³ (53.0pct)

Figure C-5. Schematic illustration of sediment volumes transported from nourished region, case 2.c3.

Case 2.c4.

Period considered: Twelve months, October through September, using 1975
WIS wave hindcasts.

Sediment Budget Summary:

Amount of sediment added: 1,452,000 yd³ (on 7- and 11-ft contours).

Amount of sediment transported shoreward from nourished region: 395,556 yd³ (27.2 pct)

Amount of sediment transported seaward from nourished region: 28,452 yd³ (2.0 pct)

Net amount of sediment transported alongshore from nourished region: 348,144 yd³ (24.0 pct)

Total amount of sediment transported from nourished region: 772,152 yd³ (53.2 pct)

Figure C-6. Schematic illustration of sediment volumes transported from nourished region, case 2.c4.

Case 3.

Period considered: Four months, January through April, using 1975
WIS wave hindcasts.

Sediment Budget Summary:

Amount of sediment added 363,000 yd³ (on 11- and 14-ft contours).

Amount of sediment transported shoreward from nourished region: 32,164 yd³ (8.9pct)

Amount of sediment transported seaward from nourished region: 4,112 yd³ (1.1pct)

Net amount of sediment transported alongshore from nourished region: 43,708 yd³ (12.0pct)

Total amount of sediment transported from nourished region: 79,984 yd³ (22.0pct)

Figure C-7. Schematic illustration of sediment volumes transported from nourished region, case 3.

Period considered: Twelve months, January through December, using 1975
WIS wave hindcasts.

Sediment Budget Summary:

Amount of sediment added: 1,452,000 yd³ (on 7-, 8-, 9-, and 10-ft contours).

Amount of sediment transported shoreward from nourished region: 275,796 yd³ (19.0pct)

Amount of sediment transported seaward from nourished region: 392,000 yd³ (27.0pct)

Net amount of sediment transported alongshore from nourished region: 96,679 yd³ (6.7pct)

Total amount of sediment transported from nourished region: 764,475 yd³ (52.6pct)

Figure C-8. Schematic illustration of sediment volumes transported from nourished region, case 4.

APPENDIX D

METHODOLOGY AND PROGRAM LISTING OF COMPUTER PROGRAM WHICH CONVERTS BATHYMETRIC DATA INTO MONOTONICALLY DECREASING DEPTH CONTOURS

In order to simulate prototype shorelines (and in this case to help verify the numerical model via Channel Islands Harbor data), the (x, y, z) data points must be transformed into a form suitable for use in the model (i.e., bars can not be present). First, the bathymetric data have to be put into a form with fixed longshore and offshore spacings (i.e., Δx and Δy equal constants). This can be accomplished using one of the many available canned programs which do the interpolation. The problem is then one of finding the most suitable value of the constant, A, in the equation $h = Ay^{2/3}$. However, as is usually the case, the exact location of the shoreline ($h = 0$) is unknown. In addition, one requires the added constraint is required that the volumes of sediment (or conversely, the water above the profiles) balance. The problem is solved using LaGrange Multipliers and the Newton Raphson technique for non linear equations.

The equation to be minimized is

$$F(A, ydel_1, ydel_2, \dots, ydel_{IMAX}) = \sum_{i=1}^{IMAX} \sum_{j=1}^{IMAX} (h_{meas_{i,j}} - h_{pred_{i,j}})^2 \quad (D-1)$$

where A is the scale parameter in the equilibrium beach profile, $ydel_i$ are the locations of the shoreline for the IMAX profiles, h_{meas} is the interpolated depth from the survey, and h_{pred} is the depth predicted by the equation

$$h_{pred_{i,j}} = A(y_{i,j} - ydel_i)^{2/3} \quad (D-2)$$

The constraint equation is as follows

$$g(A, ydel_1, \dots, ydel_{IMAX}) = V_{pred} = \sum_{i=1}^{IMAX} \Delta x \left\{ \int_{ydel_i}^y A(y - ydel_i)^{2/3} dy \right\} \\ = \sum_{i=1}^{IMAX} \frac{3}{5} \Delta x A(y_f - ydel_i)^{5/3} = V_{meas} \quad (D-3)$$

where V_{pred} is the predicted volume of water above the profile to the reference datum, V_{meas} is the measured volume computed from the survey, Δx is the longshore distance between onshore-offshore profiles, and y_f is the distance offshore to the last point on each of the measured profiles (it was a constant after the interpolation routine was used).

LaGrange Multipliers procedure says to form the quantify F^* as

$$F^* = F - \lambda g \quad (D-4)$$

take the total differential of equation (D-4)

$$\begin{aligned} dF^* = dF - \lambda dg = & \left(\frac{dF}{dA} dA + \frac{dF}{d(y_{del1})} d(y_{del1}) + \dots \frac{dF}{d(y_{delIMAX})} d(y_{delIMAX}) \right) \\ & - \lambda \left(\frac{dg}{dA} dA + \frac{dg}{d(y_{del1})} d(y_{del1}) + \dots \frac{dg}{d(y_{delIMAX})} d(y_{delIMAX}) \right) \end{aligned} \quad (D-5)$$

Rearranging

$$0 = dF^* = \left(\frac{dF}{dA} - \lambda \frac{dg}{dA} \right) dA + \left(\frac{dF}{d(y_{del1})} - \lambda \frac{dg}{d(y_{del1})} \right) d(y_{del1}) + \dots \quad (D-6)$$

It is clear that the terms in brackets in equation (D-6) must individually equal zero, however this leaves $(IMAX + 2)$ unknown ($y_{del i}$ = to $IMAX$, A , and λ) and only $(IMAX + 1)$ Equations. The $(IMAX + 2)$ th equation is taken as equation (D-3). The following system of equation then results:

$$\begin{aligned} 0 = \frac{dF}{dA} - \lambda \frac{dg}{dA} = & \sum_{i=1}^{IMAX} \sum_{j=1}^{JMAX} [-2(h_{meas_{i,j}} - A(y_{i,j} - y_{del i})^{2/3})(y_{i,j} - y_{del i})^{2/3}] \\ & - \lambda \sum_{i=1}^{IMAX} \frac{3}{5} \Delta x (y_f - y_{del i})^{5/3} \end{aligned} \quad (D-7-1)$$

$$\begin{aligned}
0 &= \frac{dF}{d(y_{del1})} - \lambda \frac{dg}{d(y_{del1})} = \sum_{j=1}^{JMAX} \left[2(h_{meas1,j} - A(y_{1,j} - y_{del1})^{2/3}) \right. \\
&\quad \left. * (2/3 A(y_{1,j} - y_{del1})^{-1/3}) + \lambda \Delta x A(y_f - y_{del1})^{2/3} \right] \\
&\quad \vdots \\
0 &= \frac{dF}{d(y_{delIMAX})} - \lambda \frac{dg}{d(y_{delIMAX})} = \sum_{j=1}^{JMAX} \left[2(h_{measIMAX,j} - A(y_{IMAX,j} - y_{delIMAX})^{2/3}) \right. \\
&\quad \left. * (2/3 A(y_{IMAX,j} - y_{delIMAX})^{-1/3}) + \lambda \Delta x A(y_f - y_{delIMAX})^{2/3} \right] \\
&\quad (D-7-(IMAX+1)) \\
V_{meas} &= \sum_{i=1}^{IMAX} (3/5 \Delta x A(y_f - y_{del1})^{5/3}) \\
&\quad (D-7-(IMAX+2))
\end{aligned}$$

Because Equations (D-7) is a system of nonlinear equations, it can not be written in matrix form as a $[D][x] = [E]$ system of equations (the brackets denote matrices). To solve the equations, a Newton-Raphson Iteration technique for nonlinear equations was used. This is done by differentiating each of the $(IMAX + 2)$ equations with respect to each of the unknowns, the resulting equations are then linear in terms of Δa , Δy_{del1} , . . . $\Delta y_{delIMAX}$, $\Delta \lambda$. The resulting matrix is inverted to obtain the Δ (unknown) and the quantities are added to the original estimates to produce a better estimate. This iterative procedure is continued until the changes become acceptably small. The solution converged rapidly. Generally, the first row of the matrix to be inverted is (a_{11} represents the k^{th} row and the l^{th} column of the matrix).

$$a_{11} = \sum_{i=1}^{IMAX} \sum_{j=1}^{JMAX} 2(y_{i,j} - y_{del1})^{4/3}$$

$$a_{1,2} = \sum_{j=1}^{JMAX} \frac{4}{3} (y_{1,j} - y_{del1})^{-1/3} (h_{meas1,j} - 2A(y_{1,j} - y_{del1})^{2/3})$$

$$a_{1,IMAX+1} = \sum_{j=1}^{JMAX} \left[\frac{4}{3} (y_{IMAX,j} - y_{del_{IMAX}})^{-1/3} (h_{meas_{IMAX,j}} - 2A(y_{IMAX,j} - y_{del_{IMAX}})^{2/3}) \right]$$

$$a_{1,IMAX+2} = \sum_{i=1}^{IMAX} \left[\frac{3}{5} \Delta x (y_f - y_{del_1})^{5/3} \right] \quad (D-8)$$

The second row of the matrix is as follows:

$$a_{2,1} = \sum_{j=1}^{JMAX} \left[\frac{4}{3} h_{meas_{1,j}} (y_{1,j} - y_{del_1})^{-1/3} - \frac{8}{3} A (y_{1,j} - y_{del_1})^{1/3} \right] + \lambda \Delta x (y_f - y_{del_1})^{2/3}$$

$$a_{2,2} = \sum_{j=1}^{JMAX} \left[\frac{4}{9} A h_{meas_{i,j}} (y_{1,j} - y_{del_1})^{-4/3} + \frac{4}{9} A^2 (y_{1,j} - y_{del_1})^{-2/3} \right] - \lambda (2/3) \Delta x A (y_f - y_{del_1})^{-1/3}$$

$$a_{2,3} = 0$$

$$\vdots$$

$$a_{2,IMAX+1} = 0$$

$$a_{2,IMAX+2} = \Delta x A (y_f - y_{del_1})^{2/3} \quad (D-9)$$

The third row is simply these elements repeated except that the ones on the right-hand side of the first and last elements are changed to twos, and the $a_{3,3}$ element is similar to the $a_{2,2}$ except the ones on the right hand side become twos. The remaining column elements (i.e., those when the $k = 1$) are zeroes. This process is continued to fill the array, except for the last row.

The $(IMAX+2)^{th}$ row is as follows:

$$a_{IMAX+2,1} = \sum_{i=1}^{IMAX} \frac{3}{5} \Delta x (y_f - y_{del_i})^{5/3}$$

$$a_{IMAX+2,2} = -\Delta x A (y_f - y_{del_1})^{2/3}$$

$$\vdots$$

$$a_{IMAX+2, IMAX+1} = -\Delta x A (y_f - y_{del_{IMAX}})^{2/3}$$

$$a_{IMAX+2, IMAX+2} = 0 \quad (D-10)$$

The E matrix in the [D] [x] = [E] system of equations is

$$E_1 = - \sum_{i=1}^{IMAX} \sum_{j=1}^{JMAX} - 2(h_{meas_{i,j}} - A(y_{i,j} - y_{del_i})^{2/3})(y_{i,j} - y_{del_i})^{2/3}$$

$$- \lambda \sum_{i=1}^{IMAX} \left(\frac{3}{5} \right) \Delta x (y_f - y_{del_i})^{5/3}]$$

$$E_2 = - \left[\sum_{j=1}^{JMAX} 2(h_{meas_{i,j}} - A(y_{1,j} - y_{del_1})^{2/3}) \left(\left(\frac{2}{3} \right) A (y_{1,j} - y_{del_1})^{-1/3} \right) \right.$$

$$\left. + \lambda (\Delta x A (y_f - y_{del_1})^{2/3}) \right]$$

$$E_{IMAX+1} = - \left[\sum_{j=1}^{JMAX} 2(h_{meas_{IMAX,j}} - A(y_{IMAX,j} - y_{del_{IMAX}})^{2/3}) \right.$$

$$\left. * \left(\left(\frac{2}{3} \right) A (y_{1,j} - y_{del_1})^{-1/3} \right) + \lambda (\Delta x A (y_f - y_{del_1})^{2/3}) \right]$$

$$E_{IMAX+2} = - \left[\sum_{i=1}^{IMAX} \left(\left(\frac{3}{5} \right) \Delta x A (y_f - y_{del_i})^{5/3} \right) - v_{meas} \right] \quad (D-11)$$

The $[D] [x] = [E]$ system of equations was then solved, as explained previously, by solving the x column vector (which represents the changes in the unknowns, $\Delta A, \Delta y_{del1} \dots \Delta y_{delIMAX}, \Delta \lambda$), adding these changes to the respective variables and iterating until a final solution is obtained.

The computer program which did these calculations for the Channel Island Harbor simulation follows. A user-supplied matrix inversion routine is required (Line 37,200).

```

100 $RESET FREE
200 C*****PROGRAM CIH/BVALUE1
300 FILE 5(KIND=PACK,TITLE="CIH42076A",FILETYPE=7)
400 FILE 6(KIND=REMOTE)
500 C*THIS PROGRAM USES THE INTERPOLATED PROFILES OF CIH.
600 C*IT FINDS THE LOCATION OF THE SHORELINE, YOEL AND THE BEST
700 C*FIT LEAST SQUARES "B" VALUE FOR H=BY**2/3
800 C*USES LAGRANGE MULTIPLIERS TO CONSTRAIN THE VOLUMES(SO THEY ARE EQUAL)
900 C*THEN IT USES NEWTON-RAPHSON ITER FOR NON-LIN EQS
1000 DIMENSION X(40)
1100 DIMENSION WKAREA(600),AMATRX(23,23),BMATRX(23,1)
1200 DIMENSION Y(40,20),Z(40,20),YOEL(40),JBEGIN(40),YOELI(40)
1300 DIMENSION DYTWO(40,20),DYONE(40,20),DYMTWO(40,20),DYMONE(40,20)
1400 DIMENSION DYMFOR(40,20),DYFOR(40,20),YDONE(40,20),YDMTWO(40,20)
1500 DIMENSION YDMONE(40,20),YETWO(40),YEONE(40),YEMONE(40)
1600 DIMENSION YEMTWO(40),YEMFOR(40),YEFIVE(40)
1700 EXPON=2./3.
1800 THIRO=0.3333333333333333
1900 C*FIRST READ IN THE PROFILES FROM DISKPACK.
2000 DO 1 I=1,34
2100 DO 1 J=1,15
2200 1 READ(5,100) X(I),Y(I,J),Z(I,J)
2300 100 FORMAT(14X,F6.0,F5.0,F5.0)
2400 C*NOW WE MUST GET A FIRST APPROX FOR YDEL
2500 C*WE WILL USE LINEAR INTERPOLATION TO DETERMINE IT.
2600 IBEGIN=1
2700 IMAX=21
2800 JMAX=15
2900 C*CHANGE PROFILE TO SPAN 1 TO IMAX(IF ALREADY DONE,WON'T HARM THINGS)
3000 ITEMPI=1
3100 ITEMPI=IMAX-IBEGIN+1
3200 K=-1
3300 DO 777 I=1,ITEMPI
3400 K=K+1
3500 DO 777 J=1,JMAX
3600 Y(I,J)=Y(IBEGIN+K,J)
3700 777 Z(I,J)=Z(IBEGIN+K,J)
3800 IMAX=ITEMPI
3900 DX=100.00
4000 DO 2 I=1,IMAX
4100 DO 3 J=1,JMAX
4200 IF(Z(I,J).GE.0.0) GO TO 3
4300 C*FIRST NEG POINT ON THE PROFILE IS SEAWARD OF Z=0.0
4400 C* WE MUST ALSO REMEMBER THIS LOCATION.
4500 C*IF Z(I,1)<0.,CHOOSE ARBITRARY PT. ROUTINE ITERATES TO SOLN.
4600 ZOUM=1.0
4700 IF(J.NE.1) ZOUM=Z(I,J-1)
4800 YDUM=Y(I,J)-50.0
4900 IF(J.NE.1) YDUM=Y(I,J-1)
5000 DELY=ZOUM/((ZOUM-Z(I,J))/(Y(I,J)-YDUM))
5100 YDEL(I)=YDUM+DELY
5200 JBEGIN(I)=J
5300 GO TO 2
5400 3 CONTINUE
5500 2 CONTINUE
5600 C*THE VALUES FOR Z ARE NEG ON FILE, MUST NOW MAKE POS.
5700 C*THE Z VALUES ARE ALSO *10.
5800 DO 35 I=1,IMAX
5900 DO 35 J=JBEGIN(I),JMAX
6000 35 Z(I,J)=-Z(I,J)/10.0
6100 C*MUST INITIALIZE "B" SO WILL MAKE A FIRST GUESS.
6200 C*MUST ALSO GUESS LAMBDA (XLAMB)
6300 B=0.30
6400 XLAMB=-2.0
6500 DO 10 ITER=1,100
6600 C*LET'S CALCULATE THE VOL OF WATER ABOVE THE PROFILE,VMEAS.
6700 C*ITS OUR CONSTRAINT,BUT SINCE YOEL IS NOT KNOWN,A PRIORI,IT WILL CHANGE
6800 VMEAS=0.0
6900 DO 200 I=1,IMAX
7000 DO 200 J=JBEGIN(I),JMAX
7100 IF(J.NE.JBEGIN(I)) GO TO 201

```



```

7200      VMEAS=VMEAS+DX*Z(I,J)*(0.5*(Y(I,J)+Y(I,J+1))-YDEL(I))
7300      GO TO 200
7400      201 IF(J.EQ.JMAX)      GO TO 202
7500      VMEAS=VMEAS+DX*0.5*(Y(I,J+1)-Y(I,J-1))*Z(I,J)
7600      GO TO 200
7700      202 VMEAS=VMEAS+DX*Z(I,J)*(Y(I,J)-0.5*(Y(I,J)+Y(I,J+1)))
7800      200 CONTINUE
7900      C*PRIOR TO EQS, COMPUTE AND STORE SEVERAL VALUES WE NEED OVER AND OVER
8000      C*BECAUSE COMPUTER CAN'T RAISE A NEG VALUE TO AN EXPONENT
8100      C*MUST PRESERVE THE SIGN.
8200      DO 400 II=1,IMAX
8300      DO 401 JJ=JBEGIN(II),JMAX
8400      ARG1=Y(II,JJ)-YDEL(II)
8500      DYSIGN=SIGN(1.,ARG1)
8600      DY=ABS(Y(II,JJ)-YDEL(II))
8700      DYTWO(II,JJ)=DY**EXPON
8800      DYONE(II,JJ)=DYSIGN*DY**THIRO
8900      DYM TWO(II,JJ)=DY**(-EXPON)
9000      DYMONE(II,JJ)=DYSIGN*DY**(-THIRO)
9100      DYMFOR(II,JJ)=DY**(-2.*EXPON)
9200      DYFOR(II,JJ)=DY**(-2.*EXPON)
9300      401 CONTINUE
9400      ARG2=1400.-YDEL(II)
9500      DSIGN=SIGN(1.,ARG2)
9600      DYE=ABS(ARG2)
9700      YETWO(II)=DYE**EXPON
9800      YEONE(II)=DSIGN*DYE**THIRO
9900      YEMONE(II)=DSIGN*DYE**(-THIRO)
10000      YEMTWO(II)=DYE**(-EXPON)
10100      YEMFOR(II)=DYE**(-2.*EXPON)
10200      YEFIVE(II)=DSIGN*DYE**(5.*THIRO)
10300      400 CONTINUE
10400      C*LET'S INPUT THE FIRST ROW OF THE MATRIX. A
10500      SUM1B=0.0
10600      DO 300 II=1,IMAX
10700      DO 300 JJ=JBEGIN(II),JMAX
10800      300 SUM1B=SUM1B+2.*DYFOR(II,JJ)
10900      AMATRX(1,1)=SUM1B
11000      SUMLAM=0.0
11100      DO 305 K=1,IMAX
11200      SUM1K=0.0
11300      DO 306 JJ=JBEGIN(K),JMAX
11400      306 SUM1K=SUM1K+2.*EXPON*DYMONE(K,JJ)*(Z(K,JJ)-2.*B*
11500      * DYTWO(K,JJ))
11600      SUMLAM=SUMLAM-0.6*DX*YEFIVE(K)
11700      305 AMATRX(1,K+1)=SUM1K
11800      AMATRX(1,IMAX+2)=SUMLAM
11900      C*NOW THE MIDDLE ROWS OF THE AMATRX.
12000      DO 410 LROW=2,IMAX+1
12100      SUM2B=0.0
12200      II=LROW-1
12300      DO 415 JJ=JBEGIN(II),JMAX
12400      415 SUM2B=SUM2B+2.*EXPON*Z(II,JJ)*DYMONE(II,JJ)-4.*EXPON*
12500      * B*DYONE(II,JJ)
12600      AMATRX(LROW,1)=SUM2B+XLAMB*DX*YETWO(II)
12700      DO 430 II=1,IMAX
12800      SUM2Y=0.0
12900      DO 425 JJ=JBEGIN(II),JMAX
13000      425 SUM2Y=SUM2Y+2.*EXPON*THIRO*B*Z(II,JJ)*DYMFOR(II,JJ)+THIRO*EXPON
13100      * 2.*B*B*DYM TWO(II,JJ)
13200      IF((II+1).EQ.LROW)      GO TO 431
13300      AMATRX(LROW,II+1)=0.0
13400      GO TO 430
13500      431 AMATRX(LROW,II+1)=SUM2Y+XLAMB*EXPON*DX*B*YEMONE(II)
13600      430 CONTINUE
13700      410 AMATRX(LROW,IMAX+2)=DX*B*YETWO(LROW-1)
13800      C*NOW THE LAST ROW OF THE MATRIX A
13900      SUMFB=0.0
14000      DO 450 II=1,IMAX
14100      450 SUMFB=SUMFB+0.6*DX*YEFIVE(II)
14200      AMATRX(IMAX+2,1)=SUMFB

```

```

14300      DO 453  II=1,IMAX
14400      453  AMATRX(IMAX+2,II+1)=-DX*B*YETWO(II)
14500      AMATRX(IMAX+2,IMAX+2)=O.O
14600      C*NOW MUST INPUT THE BMATRX.
14700      SUMF1A=O.O
14800      SUMF1B=O.O
14900      DO 455  II=1,IMAX
15000      SUMF1B=SUMF1B+XLAMB*O.6*DX*YEFIVE(II)
15100      DO 455  JJ=JBEGIN(II),JMAX
15200      455  SUMF1A=SUMF1A-2.*(Z(II,JJ)-B*DYTWO(II,JJ))*DYTWO(II,JJ)
15300      BMATRX(1,1)=- (SUMF1A-SUMF1B)
15400      DO 460  II=1,IMAX
15500      SUMFII=O.O
15600      DO 462  JJ=JBEGIN(II),JMAX
15700      462  SUMFII=SUMFII+2.*(Z(II,JJ)-B*DYTWO(II,JJ))*EXPON*B*DYMONE(II,JJ)
15800      SUMFII=SUMFII+XLAMB*DX*B*YETWO(II)
15900      460  BMATRX(II+1,1)=-SUMFII
16000      SUMV=O.O
16100      DO 465  II=1,IMAX
16200      465  SUMV=SUMV+O.6*DX*B*YEFIVE(II)
16300      BMATRX(IMAX+2,1)=- (SUMV-VMEAS)
16400      C*NEXT LET'S CALL THE MATRIX INVERSION ROUTINE VIA IMSL
16500      CALL LEQT2F(AMATRX,1,IMAX+2,23,BMATRX,3,WKAREA,IER)
16600      C*THE SOLN IS RETURNED IN THE VECTOR BMATRX
16700      C*FINALLY, WE MUST UPDATE THE X VECTOR IN AX=B.
16800      B=B+BMATRX(1,1)
16900      XLAMB=XLAMB+BMATRX(IMAX+2,1)
17000      DO 470  II=1,IMAX
17100      470  YDEL(II)=YDEL(II)+BMATRX(II+1,1)
17200      C*CHECK THE CRITERION FOR COMPLETION
17300      SUMVEC=O.O
17400      DO 475  II=1,IMAX
17500      475  SUMVEC=SUMVEC+ABS(BMATRX(II,1))
17600      IF(SUMVEC.LT.(O.1*(IMAX+2))) GO TO 11
17700      WRITE(6,*) B,ITER,(I,YDEL(I),I=1,IMAX),XLAMB
17800      10  CONTINUE
17900      11  CONTINUE
18000      C*LET'S WRITE IT ALL OUT.
18100      WRITE(6,*) ITER,B.(I,YDEL(I),I=1,IMAX)
18200      STOP
18300      END

```

APPENDIX E

USER DOCUMENTATION AND INPUT AND OUTPUT FOR PROGRAM VERIFICATION

The computer program presented in Appendix B was run on a Burroughs B-7700 computer. The B7000/B6000 series FORTRAN language was designed so several existing programs written in FORTRAN would be compatible with minimal changes. It was designed to be compatible with Fortran IV, H level and to contain ANSI X3.9-1966 Standard FORTRAN as a subset.

Line 37,200 of the coding (see App. B) requires a subroutine from the IMSL subroutine package, LEQT1B and its associated subroutines. If the user's computing center has access to this package of subroutine programs they need only bind them to the program (note: copyright laws prohibited the inclusion of the IMSL coding). If not, a substitute subroutine must be user supplied. It must facilitate the solution of a banded storage mode matrix.

The program input will be described here using a card deck set-up, however, the use of diskpack or magnetic tape input follows directly. Lines 3100, 4100, 5500, 5900, 6800, 7500, and 12,900 are read statements. The cards used for the simulation presented in this appendix are shown in Figure E-1. The first card contains the value of WDEPTH, the depth of water (in meters) to which the input wave conditions are to be transformed (a partial list of variables used in the program is presented beginning on page A-8 of Appendix A). The format statements are obviously in the program coding.

The second data input card is read by line 4100 where the variables SJETTY, BERM, SFACE, and DIAM are required (length of the structure, berm height, shore face slope, and sediment diameter, respectively).

Lines 5500 reads MMAX, the number of structures to be simulated (as set-up here, a maximum of 10 structures can be modeled, however, appropriate changes in array dimensions would allow additions (structures). Line 5900, which is in a "DO" loop reads the lesser I grid value adjacent to where the structure is desired. The number of structures, MMAX, determines the number of data cards required here; 3 structures require 3 cards with the 3 I grid locations (note, the present configuration of the refraction and diffraction subroutines requires evenly spaced structures, however this can be altered if necessary).

The parameter ADEAN, which represents the value of A in the equilibrium profile used is the next value input (line 6800). As mentioned previously, whenever possible a site-specific value should be used. The space-step and time-step (DX and DELT in the coding) are input next (line 7500).

The last input values are the wave data, HS, T, ALPWIS read by line 12,900. This statement is in a loop made by the unconditional GO TO statement (line 16,400) and the read statement. There is an action specifier included in the read statement to transfer the program to statement 1000, thereby stopping execution of the program once all the wave climate data have been used. The number of data cards required for this read statement is dictated by the length of the simulation and the time-step used.

The input file and output for program verification follow.

100		10.000		
200		5.000		0.220
300	1			
400	25			
500		0.1500		
600		100.00		
700		21600.00		
800		5.0	8.0	3.0
900		5.0	8.0	3.0
1000		5.0	8.0	3.0
1100		5.0	8.0	3.0
1200		5.0	8.0	3.0
1300		5.0	8.0	3.0
1400		5.0	8.0	3.0
1500		5.0	8.0	3.0
1600		5.0	8.0	3.0
1700		5.0	8.0	3.0
1800		5.0	8.0	3.0
1900		5.0	8.0	3.0
2000		5.0	8.0	3.0
2100		5.0	8.0	3.0
2200		5.0	8.0	3.0
2300		5.0	8.0	3.0
2400		5.0	8.0	3.0
2500		5.0	8.0	3.0
2600		5.0	8.0	3.0
2700		5.0	8.0	3.0
2800		5.0	8.0	3.0
2900		5.0	8.0	3.0
3000		5.0	8.0	3.0
3100		5.0	8.0	3.0
3200		5.0	8.0	3.0
3300		5.0	8.0	3.0
3400		5.0	8.0	3.0
3500		5.0	8.0	3.0
3600		5.0	8.0	3.0

```

.....
TO WHAT DEPTH ARE THE WAVES TO BE TRANSFORMED .....
THE DEPTH (IN FT.) WAVES TRANSFORMED TO, WDEPTH= 32 808
.....
ITS TIME FOR SUEITY, BROW, SEACE, AND DIAM .....
.....
THE LENGTH OF THE STRUCTURE, SUEITY= 300 000
THE HEIGHT OF THE BERM, BERM= 5 000
THE SLOPE OF THE BEACH FACE, SEACE= 0 0500
.....
THE SEDIMENT DIAMETER, DIAM= 0 220
.....
THE NUMBER 1 GROUT IS LOCATED AT GRID 28
.....
NOW ENTER THE VALUE OF ADEAN
THE VALUE OF ADEAN= 0 1500 IN THE EQ HAY=2/3
READ IN THE SPACE STEP, TIME STEP
.....
THE VALUE OF THE LONGSHORE SPACE STEP, D% 100 000
THE TIME STEP IN SECONDS, DELT= 21600 000
.....
THE BOUNDARY Y-VALUES, I=1, IMAX ARE AS FOLLOWS
.....
0 00 31 62 68 01 137 71 252 38 464 76 760 73 1050 41 1656 50 2674 85
0 00 31 62 68 01 137 71 252 38 464 76 760 73 1050 41 1656 50 2674 85
.....
THE DEPTHS BETWEEN CONTOURS ARE AS FOLLOWS
.....
1 00 2 00 3 00 5 00 7 00 11 00 14 00 17 00 25 00 32 81
.....
NNIV+1,
NNIV+2,
NNIV+3,
NNIV+4,
NNIV+5,
NNIV+6,
NNIV+7,
NNIV+8,
NNIV+9,
NNIV+10,
THE TOTAL ELAPSED NUMBER OF TIME STEPS, NNIV= 10
.....
THE LONGSHORE TRANSFURTS, Q%, FOLLOW
0 000 0 000 0 000 0 000 0 000 0 000 0 000 0 000 0 000 0 000
0 000 0 000 0 000 0 000 0 000 0 000 0 000 0 000 0 000 0 000
0 000 0 000 0 000 0 000 0 000 0 000 0 000 0 000 0 000 0 000

```


THE NEW FORTIOR VALUES, Y, FOLLOW																			
	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
31 644	31 623	31 623	31 623	31 623	31 623	31 623	31 623	31 623	31 623	31 623	31 623	31 623	31 623	31 623	31 623	31 623	31 623	31 623	31 636
29 950	30 402	30 817	31 708	31 758	31 815	31 872	31 929	32 000	32 071	32 142	32 213	32 284	32 355	32 426	32 497	32 568	32 639	32 710	32 781
3 619	3 619	3 619	3 619	3 619	3 619	3 619	3 619	3 619	3 619	3 619	3 619	3 619	3 619	3 619	3 619	3 619	3 619	3 619	3 619
68 187	68 041	68 042	68 043	68 044	68 045	68 046	68 047	68 048	68 049	68 050	68 051	68 052	68 053	68 054	68 055	68 056	68 057	68 058	68 059
63 226	63 405	65 413	66 176	66 715	67 107	67 388	67 648	67 888	68 109	68 310	68 491	68 652	68 803	68 944	69 075	69 196	69 307	69 408	69 509
67 989	68 014	68 024	68 031	68 035	68 038	68 041	68 043	68 045	68 047	68 049	68 051	68 053	68 055	68 057	68 059	68 061	68 063	68 065	68 067
137 706	137 711	137 717	137 724	137 731	137 737	137 744	137 751	137 757	137 764	137 771	137 778	137 785	137 792	137 799	137 806	137 813	137 820	137 827	137 834
138 778	139 016	139 322	139 628	140 000	140 358	140 704	141 039	141 365	141 683	142 000	142 308	142 606	142 895	143 175	143 446	143 708	143 961	144 205	144 440
137 454	137 528	137 581	137 619	137 647	137 666	137 679	137 689	137 693	136 693	136 491	136 801	137 038	137 218	137 354	137 454	137 538	137 608	137 668	137 718
252 982	253 029	253 036	253 065	253 097	253 133	253 174	253 222	253 277	253 332	253 387	253 442	253 497	253 552	253 607	253 662	253 717	253 772	253 827	253 882
250 848	250 916	251 075	251 225	251 366	251 507	251 648	251 789	251 930	252 071	252 212	252 353	252 494	252 635	252 776	252 917	253 058	253 199	253 340	253 481
252 552	252 675	252 798	252 921	253 044	253 167	253 290	253 413	253 536	253 659	253 782	253 905	254 028	254 151	254 274	254 397	254 520	254 643	254 766	254 889
464 753	464 763	464 764	464 764	464 759	464 759	464 759	464 759	464 759	464 759	464 759	464 759	464 759	464 759	464 759	464 759	464 759	464 759	464 759	464 759
464 756	464 756	464 757	464 757	464 757	464 757	464 757	464 757	464 757	464 757	464 757	464 757	464 757	464 757	464 757	464 757	464 757	464 757	464 757	464 757
760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726
760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726
760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726	760 726
1050 411	1050 411	1050 411	1050 411	1050 411	1050 411	1050 411	1050 411	1050 411	1050 411	1050 411	1050 411	1050 411	1050 411	1050 411	1050 411	1050 411	1050 411	1050 411	1050 411
1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414
1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414
1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414	1050 414
MINIV-11.																			
MINIV-12.																			
MINIV-13.																			
MINIV-14.																			
MINIV-15.																			
MINIV-16.																			
MINIV-17.																			
MINIV-18.																			
MINIV-19.																			
MINIV-20.																			
THE TOTAL ELAPSED NUMBER OF TIME-STEPS, MINIV= 20																			
THE LONGSHORE TRANSPORTS, OK, FOLLOW																			
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

THE NEW CONTOUR VALUES, Y_c , FOLLOW

0.177	0.227	0.293	0.377	0.011	0.016	0.022	0.029	0.038	0.050	0.064	0.083	0.107	0.137
-1.624	-1.422	-1.196	-0.978	-0.783	-0.618	-0.484	-0.383	-0.316	-0.196	-1.421	-1.624	-1.750	-1.751
-0.083	-0.064	-0.050	-0.038	-0.029	-0.022	-0.016	-0.011	-0.007	-0.003	-0.006	-0.013	-0.137	-0.106
31.621	31.642	31.663	31.685	31.706	31.728	31.749	31.771	31.811	31.860	31.918	31.990	32.077	32.184
32.110	32.167	32.230	32.298	32.370	32.447	32.528	32.613	32.702	32.795	32.892	32.993	33.098	33.207
32.310	32.487	32.668	32.864	33.070	33.285	33.513	33.755	34.020	34.309	34.623	34.962	35.326	35.714
31.257	31.328	31.387	31.435	31.475	31.508	31.537	31.561	31.581	31.598	31.604	31.623	31.663	31.170
31.680	31.701	31.715	31.723	31.727	31.728	31.726	31.722	31.716	31.707	31.695	31.680	31.662	31.641
69.580	69.892	70.264	70.706	71.231	71.854	72.572	73.382	74.283	75.275	76.358	77.533	78.807	80.179
58.945	60.376	61.580	62.614	63.523	64.353	65.154	65.884	66.598	67.251	67.898	68.501	69.066	69.598
67.172	67.378	67.567	67.741	67.892	67.999	68.064	68.094	68.094	68.064	67.999	67.898	67.741	67.567
140.320	140.828	141.379	141.945	142.516	143.083	143.645	144.202	144.754	145.301	145.843	146.380	146.912	147.439
140.342	140.920	141.473	142.114	142.856	143.716	144.710	145.860	147.192	148.718	150.542	152.766	155.490	158.714
124.860	126.687	128.213	129.547	130.699	131.694	132.554	133.298	133.939	134.493	134.971	135.384	135.740	136.046
136.048	136.315	136.547	136.748	136.926	137.082	137.222	137.350	137.468	137.568	137.651	137.718	137.770	137.806
254.982	253.115	253.244	253.372	253.501	253.630	253.758	253.886	254.014	254.142	254.269	254.396	254.522	254.647
254.814	254.969	255.120	255.268	255.415	255.561	255.706	255.850	255.993	256.135	256.276	256.416	256.554	256.691
250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000
250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000
250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000	250.000
464.758	464.761	464.763	464.765	464.766	464.766	464.766	464.766	464.766	464.766	464.766	464.766	464.766	464.766
464.785	464.786	464.786	464.786	464.786	464.786	464.786	464.786	464.786	464.786	464.786	464.786	464.786	464.786
464.749	464.744	464.739	464.735	464.732	464.730	464.729	464.728	464.727	464.726	464.725	464.724	464.723	464.722
464.735	464.737	464.739	464.742	464.744	464.746	464.748	464.750	464.752	464.754	464.756	464.758	464.760	464.762
760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726
760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726
760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726
760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726	760.726
1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414
1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414
1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414
1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414	1050.414

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