Journal of Coastal Research | 11 | 4 | 1108–1124 | Fort Lauderdale, Florida | Fall 1995

Automated Tools for Coastal Engineering

David A. Leenknecht, Ann R. Sherlock and Andy Szuwalski

Coastal Engineering Research Center
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180, U.S.A.

ABSTRACT

LEENKNECHT, D.A.; SHERLOCK, A.R., and SZUWALSKI, A., 1995. Automated tools for coastal engineering. *Journal of Coastal Research*, 11(4), 1108–1124. Fort Lauderdale (Florida), ISSN 0749-0208.

Coastal Engineering practice encompasses a substantial diversity of technologies varying in sophistication and origin. The U.S. Army Corps of Engineers requires interactive computer based design capabilities for this purpose. An overview is presented of the contents, history, usage and issues relative to a widely used collection of automated technologies for a variety of coastal engineering topics.

ADDITIONAL INDEX WORDS: *Computer programs; wind adjustment; wave growth, theory, and transformation; structural design, runup, transmission, overtopping; littoral and inlet processes.*

INTRODUCTION

In the last decade, several important trends have emerged which impact the procedures and cost of coastal engineering studies. While not unique to this discipline, one trend has been a significant increase in the development and adaptation of engineering technologies to the desktop computing environment, with measurable benefits. Starting in 1987, the Coastal Engineering Research Center (CERC) of the U.S. Army Engineer Waterways Experiment Station (WES) actively pursued the creation of a system of coastal engineering technologies entitled the Automated Coastal Engineering System. The thrust of the effort was to provide software, documentation and training on a broad spectrum of coastal engineering topics for use by coastal experts within the U.S. Army Corps of Engineers (CE). Since its creation, the ACES suite of software has been applied by the CE, private industry, and foreign governments for various levels of design and analysis. In addition, the ACES has become a popular educational supplement in academic institutions. Information about the ACES has largely been limited to CE publications (LEENKNECHT *et al.*, 1992a,b). This paper presents an overview of the contents, history, and description of the ACES package for the wider coastal research community.

BACKGROUND

The Water Resource Development Act of 1986 mandated a change in cost sharing mechanisms and planning procedures for CE projects, resulting in a critical need for more cost-effective engineering design procedures. Within the CE coastal engineering community, it was felt that readily available computer-based interactive design and analysis tools were required to facilitate design and lower project costs. The CERC was charged by the Chief of Engineers to provide automated design capabilities to CE coastal designers. Through a combination of regional CE workshops and committee deliberations, it was decided to implement an interactive microcomputer-based set of tools embodying a broad selection of coastal engineering design and analysis technologies. The development of such a product represented a non-traditional area of endeavor for CERC which assembled a team of coastal engineers and computer specialists to pursue the effort.

The first version of the ACES was completed in July 1987. It was subsequently expanded in successive releases, and in 1992 the last version 1.07 was completed. Since then, the ACES package has been in a maintenance mode with efforts directed towards correction, consulting and distribution activities. Early versions were employed

---

94158 received and accepted in revision 4 August 1994.

within the CE. Later versions (currently v1.07e) were made available to the coastal field at large.

DESIGN PARAMETERS

Software design goals included a user-friendly interface made relatively uniform between the various technologies incorporated within the ACES. The interface provided an intuitive procedure for usage, and obscured the underlying technologies in the computational areas of the package. A principal goal of the endeavor was to facilitate improved CE project estimates using more sophisticated technologies at earlier levels of investigation.

A common misconception of the ACES has been that it represents an implementation of traditional hand-computations presented within the widely referenced Shore Protection Manual SPM (1984). While some technologies within the system fit this description, a significant portion represent more complex numerical procedures. The early decision to couch the ACES within a PC/DOS/FORTRAN environment precluded the implementation of multidimensional numerical models of useful size. However, some one-dimensional similitude and finite difference models have been included which use some intense numerical algorithms. For example, the Fourier series wave theory application applies Newton's method to solve the Jacobian of a matrix of maximum rank 60. Part of the procedure for estimating wave transmission through porous breakwaters involves the solution of a ratio of integrals containing Bessel functions as part of an iterative solution with other simultaneous equations. Selected library routines from Morris (1981) and LINPACK (Dongarra *et al.*, 1979) are embedded in the computational areas of the software. These features in a desktop environment offer significant advances over SPM approaches, and cannot be accurately described as hand methods. Further, many technologies embedded within the ACES post-date the SPM and involve non-CE developed methods not found in traditional CE guidance.

A philosophy for evaluating alternative conditions by rapidly solving permutations of ranges or sets of physical parameters (depth, winds, waves, *etc.*) was included as an option in most of the technologies within the ACES. With expansion of the package, some in-line graphics capabilities were also added for analysis. While not tightly coupled, additional CE PC-based wave and wind data bases were concurrently being implemented on some of the same computer systems within the CE. McAneny (1994) offered driving data for some of the processes represented within the ACES.

Table 1. *ACES organization and contents.*

Functional Area	Application Name
Wave Prediction	Windspeed Ajustment and Wave Growth Beta-Rayleigh Distribution Extremal Significant Wave Height Analysis Constituent Tide Record Generation
Wave Theory	Linear Wave Theory Cnoidal Wave Theory Fourier Series Wave Theory
Wave Transformation	Linear Wave Theory with Snell's Law Irregular Wave Transformation Diffraction and Reflection by Vertical Wedge
Structural Design	Breakwater Design/Hudsons Equations Toe Protection Design Nonbreaking Wave Forces at Vertical Walls Rubble-Mound Revetment Design
Wave Runup, Transmission, and Overtopping	Irregular Wave Runup on Beaches Runup and Overtopping of Structures Transmission over Structures Transmission of Permeable Structures
Littoral Processes	Longshore Sediment Transport Time-Dependent Beach and Dune Erosion Composite Grain-Size Distribution Beach Nourishment Overfill Ratio and Volume
Inlet Processes	Spatially Integrated Inlet Hydraulics

ORGANIZATION AND CONTENTS

A tabular summary of the organization and contents is presented in Table 1. Methodologies in the ACES are diverse in topic, sophistication and origin, and reflect the nature of coastal engineering practice. To aid in implementing and navigating the various technologies, called "applications," a simple organization based upon technical area is employed within the package. An application is often a composite of several separate methodologies used in combination. For example,

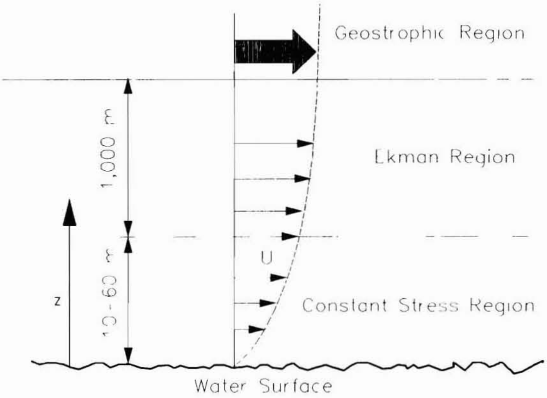

Figure 1. Idealized atmospheric boundary layer over water.

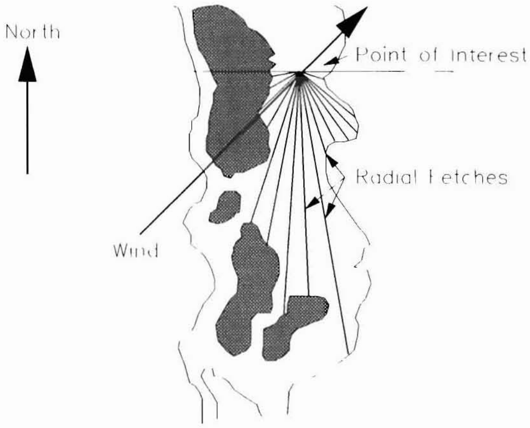

Figure 2. Restricted fetch wind wave growth.

linear wave theory is available as a separate application, but it is also embedded within many other applications. Another grouping of technologies is an application which combines a vertical planetary boundary layer model to estimate near surface wind velocities with simplified wave growth equations in various settings. Such combinations of technologies were not implemented early in the development of the package but were refined through successive iterations and revised as additional relationships were incorporated.

The following sections contain brief descriptions of the applications and parallel the organization within the ACES. The details for all applications are presented in the system technical documentation (LEENKNECHT *et al.*, 1992a), while herein, only major references are provided.

Wave Prediction

Applications within this technical area of ACES include wave and water level estimates by numerical, simple predictive and statistical techniques.

Windspeed Adjustment and Wave Growth

A steady-state parameterized model of the planetary boundary layer (Figure 1) is used to adjust observed winds of varying character and location to a 10 m elevation windspeed under neutral stability conditions. Synoptic scale events are the focus of this technology which utilizes low level observations near the surface or geostrophic winds as the principal driving inputs. Iterative solution until convergence of simultaneous relations based on relatively simple generalizations of the atmospheric boundary layer physics form the computational framework of this portion of the application. Additional factors such as ship motion, observation elevation, stability, location, fetch length, and averaging times are also considered. The methodology is described elsewhere (CARDONE, 1969; RESIO *et al.*, 1982; THOMPSON and LEENKNECHT, 1994). The winds produced are targeted for simplified wave growth formulas, and supercede those of the SPM (1984).

First-order estimates for spectrally derived wind-generated wave growth in open water and restricted fetch environments (Figure 2) are provided in deep and shallow water. Assumptions of constant wind speed and direction are significant. In deep water, estimates include the effect of wind fetch, and duration, and are bounded by fully developed spectral forms. In restricted fetch scenarios, off-wind direction wave growth, and the basin geometry is also considered. Shallow water forms have the greatest uncertainty and consider only fetch-limited assumptions. The complex temporal and spatially dependent nature of wind-wave growth is only approximately estimated by these expressions. The most relevant background is in VINCENT (1984), SMITH (1991) and SPM (1984).

This combined application of windspeed adjustment and wind-generated wave growth receives the most use (and mis-use) within the ACES framework.

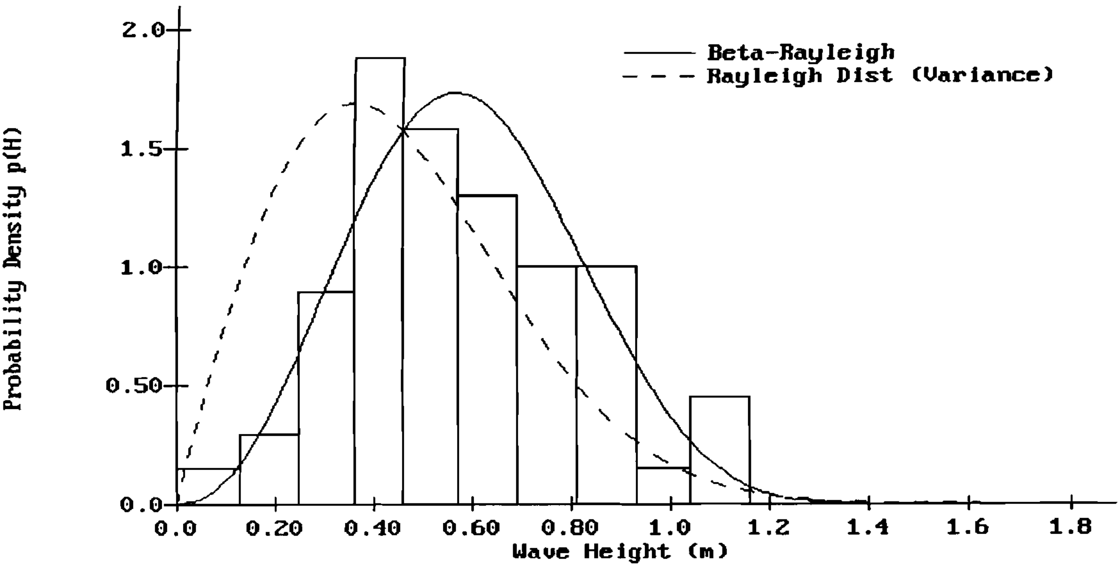

Figure 3. Beta-Rayleigh individual wave height distribution (Hmo = 0.72 m, Tp = 10.9 sec, d = 1.63 m).

Beta-Rayleigh Distribution

LONGUET-HIGGINS (1952) demonstrated the applicability of Rayleigh's distribution function from acoustics to individual wave height distributions in a deep water sea state. HUGHES and BORGMAN (1987) proposed the Beta-Raleigh distribution, providing bounds on the distribution corresponding to breaking wave height in shallow water, and the Rayleigh distribution in deep water. The application requires specification of energy-based spectral wave height, peak spectral wave period, and still water depth, and provides estimates for root-mean-square and median wave height as well as other frequently utilized wave height estimates for design and analysis. The distribution is also presented graphically (Figure 3) for a variety of analyses.

Extremal Significant Wave Height Analysis

Given a partial duration series of maximum significant wave heights (Hs) from observed or hindcast events and other parameters characterizing the length and completeness of the series, this application estimates Hs for various return periods with the expected bounds of a specified confidence interval. Five separate candidate distributions recommended by GODA (1988) are fitted using least squares analysis. Fisher-Tippet Type I and Weibull (using 4 unique shape factors) distributions are considered. Correlation coefficients, residual measures from the analysis, and comparison plots of the data with the distributions are also provided. The application uses procedures recommended in GODA (1988) and a representative plot is in Figure 4.

Constituent Tide Record Generation

DARWIN (1898) presented a first approximation describing tidal phenomena. Harmonic tide analysis and prediction has been accomplished by hand computations using published tables, by mechanisms using cams and gears, and more recently using computers. In this application, tide elevation predictions at a station are provided from a maximum of 37 traditional harmonic phase and amplitude constituents. Databases of constituents for various locations are becoming more abundant in recent decades from traditional sources maintaining long-term stations (NOAA, USACE, academic institutions) and from site studies for shorter durations. A comprehensive manual for harmonic analysis and prediction was provided by SCHUREMAN (1971). A recent database of elevation and velocity constituents at fine resolution along the U.S. Atlantic and Gulf Coasts

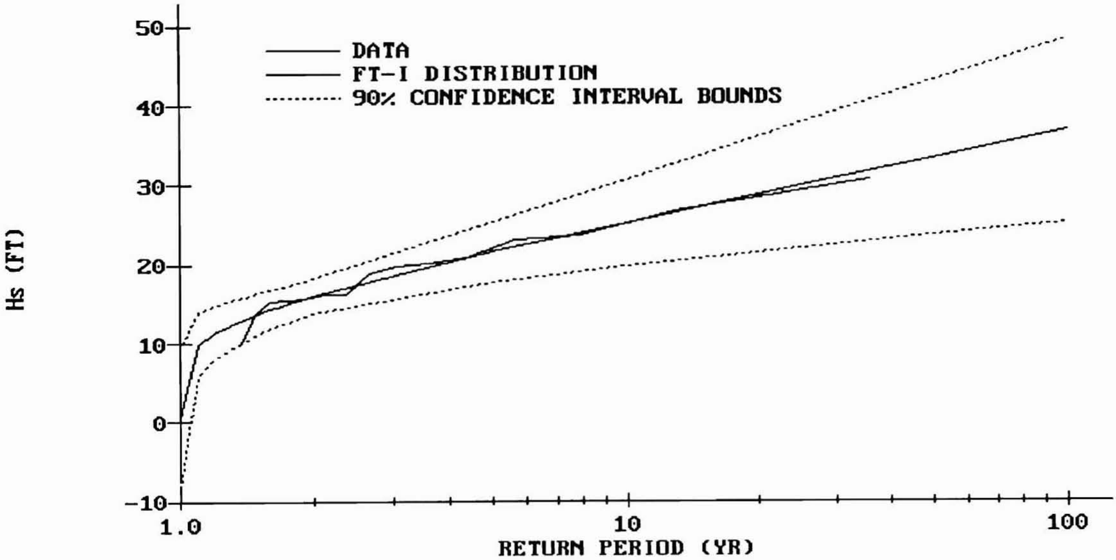

Figure 4. Extremal significant wave height analysis (Fisher-Tippett distribution).

was developed using a long-wave model (WESTERINK *et al.*, 1993).

While provided as a separate application within the ACES framework, this technology is also used internally within the package to generate elevations as boundary conditions for other models and applications requiring such information. Standalone utilization of this technology is useful for planning, operational, construction and maintenance activities in tidally influenced areas.

Wave Theory

This collection of technologies includes linear and some finite amplitude wave theories commonly applied in coastal practice. Principal uses of the applications are to obtain basic engineering properties, integral wave properties and kinematics associated with waves assumed to be of permanent form. The theories considered differ in complexity, accuracy, capability (celerity assumptions and co-flowing currents), basic formulation (velocity potential versus stream function), philosophies of solution (analytic versus purely numeric), and range of applicability. All share a common subset of basic assumptions, which include two-dimensional progressive waves of permanent form in the x–z plane (Figure 5), smooth horizontal bed of constant depth, movement in the positive x-direction, inviscid and incompressible fluid, irrotational flow, no surface tension, and datum at the still water surface. They represent solution of the 2-D Laplace equation with bottom, kinematic and dynamic free surface boundary conditions and periodicity as the basic problem statement. Table 2 provides a comparison of the three wave theories available within the ACES framework.

Linear Wave Theory

Based upon the assumption of small wave height (H) relative to wavelength and depth (d), the free surface boundary conditions become linear and are applied at the still water level. These assumptions contribute to a very mathematically tractable solution. As a result, linear theory is the most widely used wave theory applied in a stand alone context or assumed as an underlying principle in more complex processes. The transcendental dispersion relation is solved with a 9 term Pade approximation, allowing very rapid solution of remaining variables of interest.

Because of common utilization of first order approximations offered by linear wave theory, it is included as a separate application in the pack-

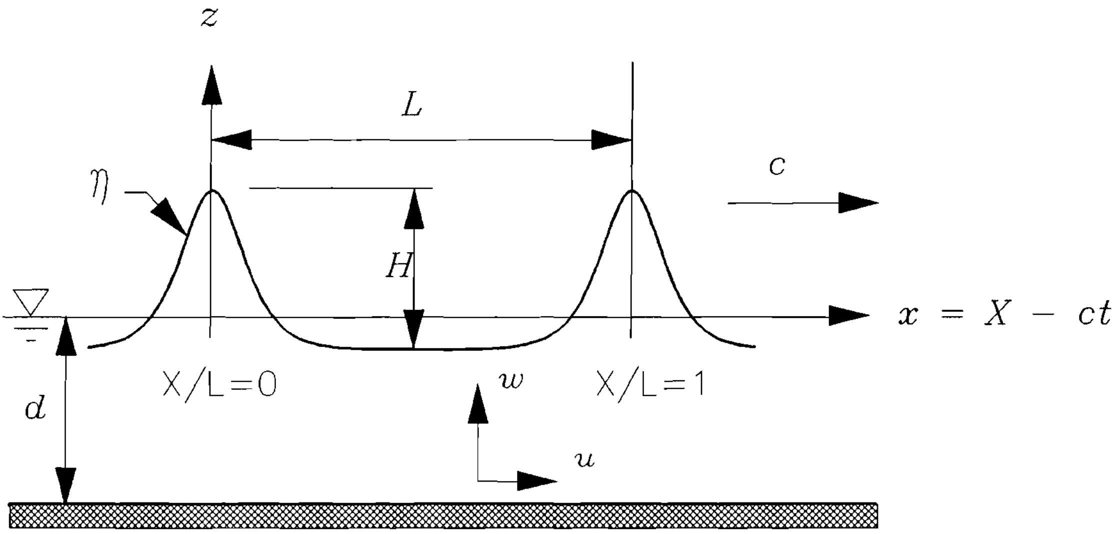

Figure 5. Progressive wave.

age and used throughout the software within other applications in library form. The ACES implementation is formulated in velocity potential form, with major references of AIRY (1845), DEAN and DALRYMPLE (1984), SARPKAYA and ISAACSON (1981), and HUNT (1979).

Cnoidal Wave Theory

Shallow water applications make the small amplitude assumption of linear theory less appropriate, and finite amplitude theories, especially cnoidal, are often more applicable. The ACES framework offers first- and second-order versions of cnoidal theory formulated in stream function form and assumes a moving coordinate system having the same velocity as wave celerity employing Stokes second definition of celerity (zero average mass flux). The solution is based on the perturbation method using the ratio of (H/d) as the perturbation parameter and modulus of the elliptic integral (κ) as the secondary parameter. Many derivations and variations of cnoidal theory are available since original work by KORTEWEG and DE VRIES (1895). The principal formulation of this application follows HARDY and KRAUS (1987), and ISOBE and KRAUS (1983). ABRAMOWITZ and STEGUN (1972) provide standard methods used to solve the various relationships in terms of Jacobian elliptic functions.

Fourier Series Wave Theory

Numerical wave theories have become increasingly more applicable in recent years. Their principle advantages include substitution of computational effort for lengthy analytic derivations and broader domains of applicability than theories based on perturbation methods (higher order Stokes or cnoidal). Fourier approximation wave theory is tractable at very high order and offers robust, accurate engineering tools for the steady wave problem. The ACES application includes the methodology of FENTON (1988a,b) and in-

Table 2. *Wave theory features included in ACES.*

	Linear	Cnoidal	Fourier Series
Realm of application	varies	shallow	deep–shallow
Order of theory	1	1, 2	1–25
Underlying current	none	none	specify
Celerity definition	zero mean current	zero mass transport	mean current, or mass transport
Integral parameters	yes	yes	yes
Kinematic estimates	yes	yes	yes
Approach	analytic	analytic	numerical
Graphics features	none	some	max

cludes revised derivations for wave properties by SOBEY (1988) and KLOPMAN (1990).

Based on a stream function formulation, Fenton's methodology offers the inclusion of a uniform, underlying current, specification of STOKES (1847) first (time-mean Eulerian velocity) or second (mass transport velocity) definition of celerity and, as applied here, up to 25th order accuracy. It appears that 15th to 20th order is adequate to resolve even highly nonlinear waves at PC-based machine precision. The solution is obtained by numerically computing N Fourier coefficients to satisfy a system of simultaneous equations consisting of the free surface boundary conditions (evaluated at $N + 1$ evenly spaced points) and the dispersion relation. Input for this application includes the wave height, period, water depth, and either celerity definition and observed velocity. The system of equations is solved iteratively using Newton's method and double precision LINPACK (DONGARRA *et al.*, 1979) routines for matrix algebra up to rank 60 at each iteration. A ramping mechanism is provided to achieve the fundamental solution (avoiding higher odd harmonics) at slight additional computational expense. Graphic displays are also provided for displaying the free surface and wave kinematics within the waveform.

Wave Transformation

This class of applications includes simple wave transformation methods for monochromatic and irregular waves and estimates of reflection and diffraction in the vicinity of structures.

Linear Wave Transformation with Snell's Law

The simplest wave transformation processes include refraction predicted by Snell's law and shoaling using linear wave theory. Rather limiting assumptions require that mild slope depth contours be straight and parallel. Given incident wave height, period, depth, and direction, wave estimates in deepwater and at a different specified depth are predicted. Several bulk wave parameters are provided, with limiting empirical relations checked for wave breaking and steepness as functions of nearshore slope and deepwater conditions.

Irregular Wave Transformation

The transformation of irregular waves over a smooth absorbant beach having straight and parallel depth contours is treated in this application. Work by GODA (1975, 1984) and SHUTO (1974) provides the basis and assumes a Rayleigh distribution of wave heights in the nearshore zone and a narrow-banded (Bretschneider-Mitsuyasu) type spectrum. Processes modeled include wave refraction, shoaling, breaking, setup and surf beat. It is assumed that irregular wave shoaling may be approximated by the shoaling of monochromatic waves, and the probability distribution of broken wave heights is proportional to the unbroken wave heights. Input to this application include incident significant deepwater wave height parameters and water depth of interest. Results from the methodology at the depth of interest include significant, mean, maximum, and a number of common design wave heights, as well as a cumulative probability distribution of exceedance for wave height. Shoaling and effective refraction coefficients, estimates of setup and surf beat, and deepwater exceedance probability distribution are also provided.

Diffraction and Reflection by a Vertical Wedge

CHEN (1987) presented an analytic solution for monochromatic wave height modification in the vicinity of a simple structure. The methodology assumes linear, monochromatic, unidirectional waves and constant water depth, and predicts diffraction and reflection of waves by a wedge shaped structure with vertical walls. The analytic solution uses Bessel functions of the first kind and provides estimates up to about 10 wavelengths from the structure tip. Routines from MORRIS (1981) are used for the special math functions. Given the incident wave parameters, wedge angle, and a point or array of points of interest (Figure 6), the model provides estimates of the modified wave height and phase.

Structural Design

Estimates of material or forces on coastal structures are often required for design or analysis needs. This class of applications provides common estimates for rubble and other armor materials, and forces upon vertical walls. Methodologies embodied here consist mostly of semi-empirical and analytic techniques for structures subject to normally-incident nonbreaking wave action.

Breakwater Design

For decades, HUDSON'S work (1953, 1959, 1961a,b) on armor unit stability and derived quantities for crest width, armor layer thickness,

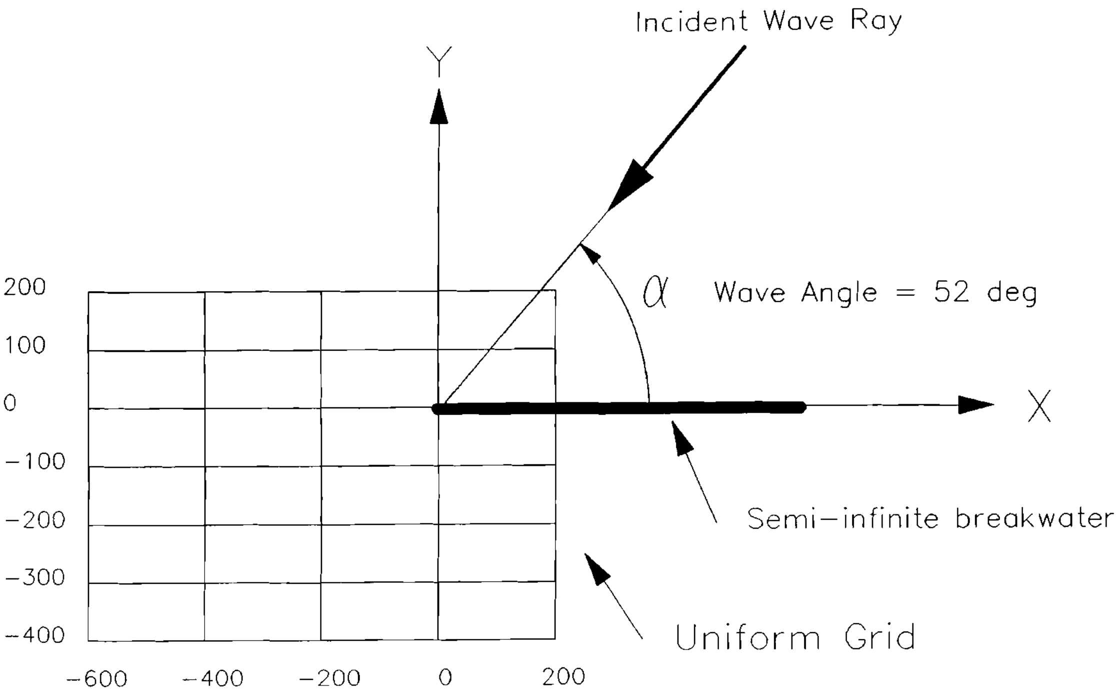

Figure 6. Diffraction and reflection near structure.

and placement density has remained in wide practice. This application embodies these rather classic empirical formulas and are most representative of SPM (1984) style guidance within the ACES framework. On-line databases of reported empirical coefficients are also provided.

Toe Protection Design

Scour of bottom material can often be a serious problem near structures subject to wave action. Tanimoto *et al.* (1982) formulated a semi-empirical approach to consider the stability and threshold of movement of a submerged stone subjected to standing waves at a specified distance and depth near a vertical wall (Figure 7). Linear wave theory is used for kinematic estimates and lab measurements provide material stability estimates. This analysis was combined with simple suggestions for apron width to match CE accepted practice. This application provides first-order estimates for threshold toe protection material weights, cast in the form of Hudson's (1959) expression for stone weight.

Nonbreaking Wave Forces upon Vertical Walls

Force and moment loadings on the face of vertical structures in fetch-limited or protected regions represent common design problems. The methods of Sainflou (1928) and Miche (1944) modified by Rundgren (1958) based on partial second-order wave theory are included in this application (Figure 8). Forces and moments per unit length of wall are determined as functions of nonbroken wave and hydrostatic pressure loading assumptions. External loads from soil pressures, tiebacks and other supports are ignored. Sainflou's method assumes full reflection, while Miche-Rundgren incorporates a reflection coefficient less than unity. Estimates from both methods and recommendations are provided.

Rubble Mound Revetment Design

The durability, affordability, and availability of quarrystone as armor material are important factors contributing to their widespread use in revetments subject to wave attack. Much research

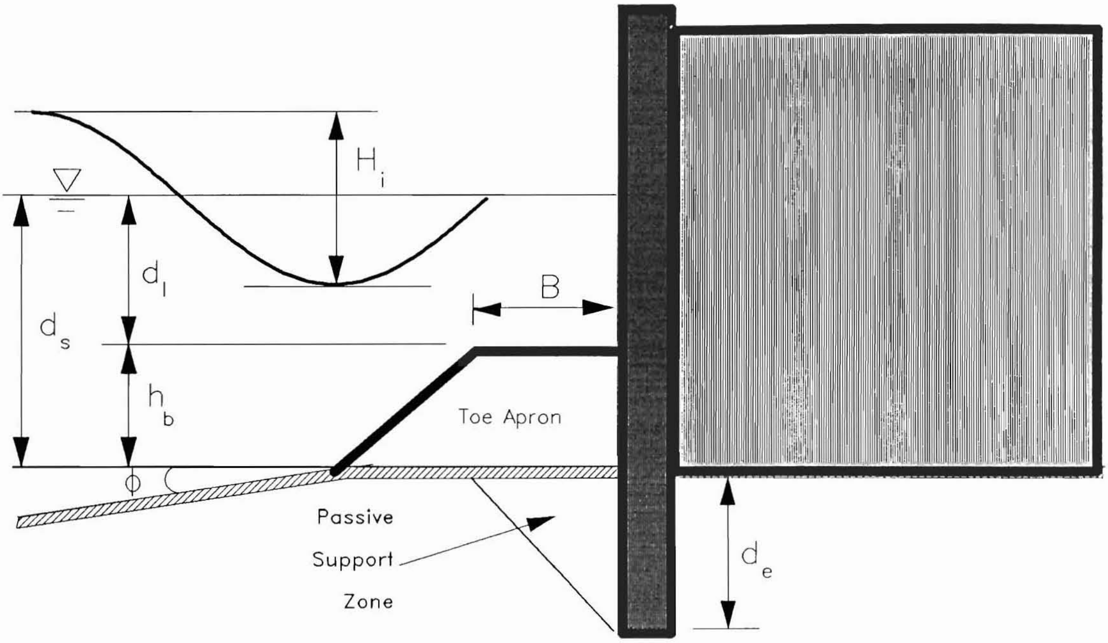

Figure 7. Toe protection at vertical bulkhead.

has been reported on the analysis and design of such structures: AHRENS (1975a,b, 1981), BRODERICK (1982, 1983), and VAN DER MEER (1987, 1988a,b). Physical modeling studies remain the principal design and analysis approach for such structures, and empirical formulas based upon such studies are at best first-order guidance. Refined estimates include factors such as perme-

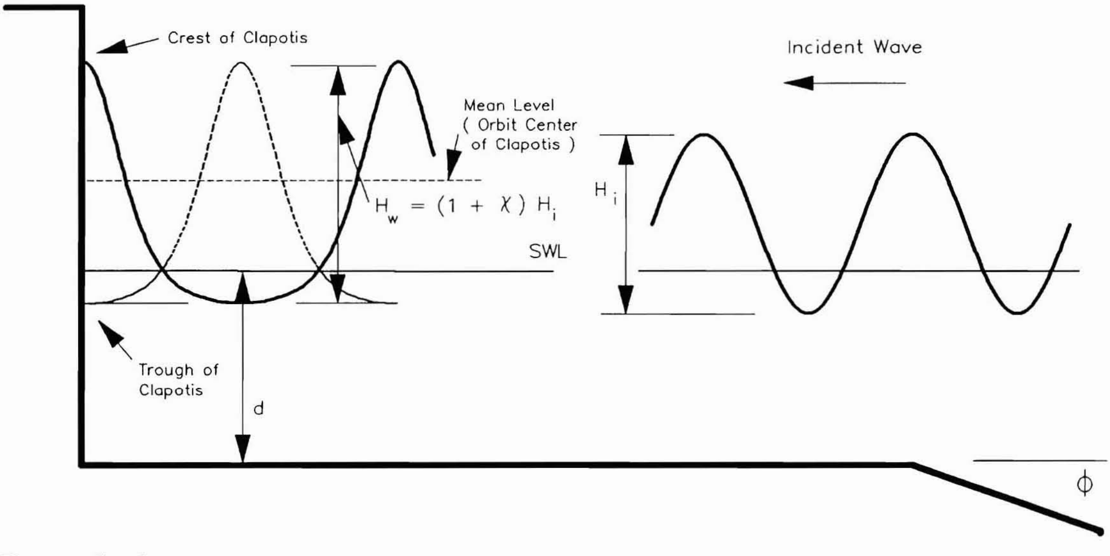

Figure 8. Standing waves at vertical walls.

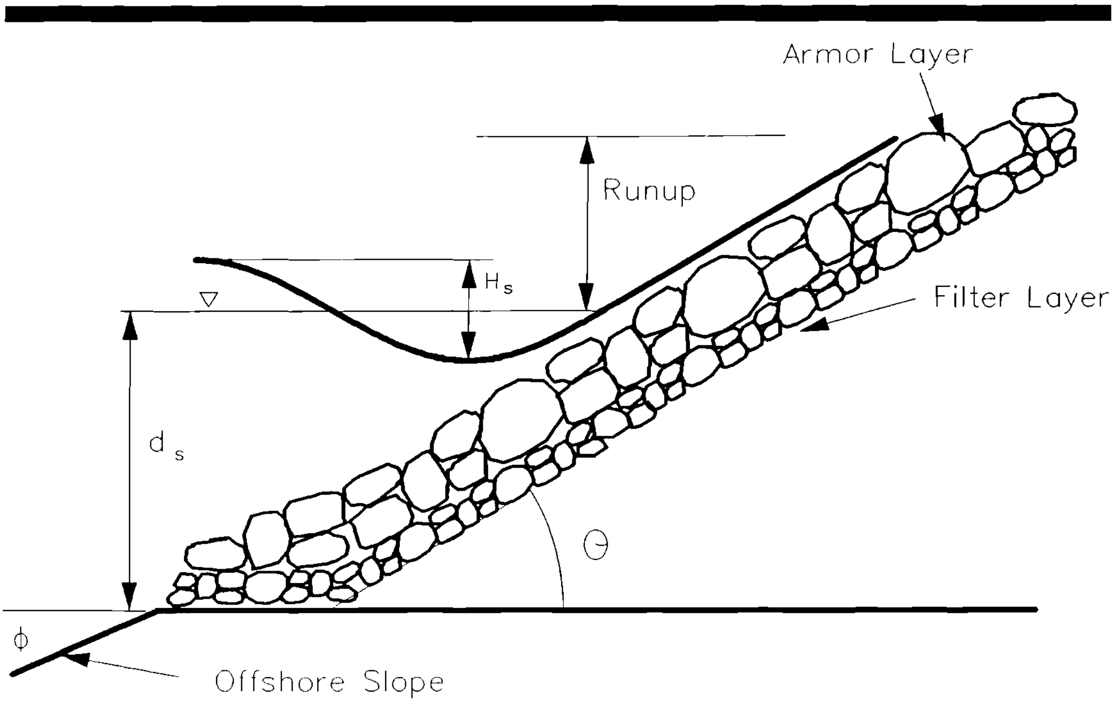

Figure 9. Rubble mound revetments.

ability, wave period, wave action (plunging *versus* surging), structure slope, damage level, and event length (number of waves) in the assessment of the structure stability. This application offers guidance for armor unit weight, armor and filter layer thickness, gradations and runup estimates on rubble mound (Figure 9).

Runup, Transmission and Overtopping

This class of applications is concerned with estimates of wave-structure interactions in the context of runup, transmission, and volumetric overtopping rates (Figure 10). Estimates are based upon empirical formulas as functions of the Iribarren number obtained from lab or field measurements. The treatment of permeable structures is more analytic in content. Normally incident nonbreaking wave assumptions are common to the methods.

Irregular Wave Runup on Beaches

Laboratory data on irregular wave runup on smooth slope linear beaches has been reported by MASE and IWAGAKI (1984), and MASE (1989). Theoretical approaches remain limited, and statistical runup estimates are provided as a function of deepwater significant wave height, wave period, beach foreshore slope, and empirical coefficients.

Runup and Overtopping of Structures

Estimates of wave runup and volumetric overtopping rates on rough and smooth linear slope structures are often required for design and analysis. Physical modeling studies remain the most reliable approach, and numerical models have also been developed in recent years. First-order estimates derived from empirical results suggested by AHRENS and MCCARTNEY (1975), and AHRENS and TITUS (1985) are used in this application for predicting runup of monochromatic waves as a function of incident wave parameters at the structure location, structure slope, and material properties.

Volumetric overtopping rates are computed using the method suggested by WEGGEL (1976). Guidance is provided for estimating some of the empirical coefficients. Irregular waves are represented by a Rayleigh distribution based upon significant wave height, and overtopping rates are

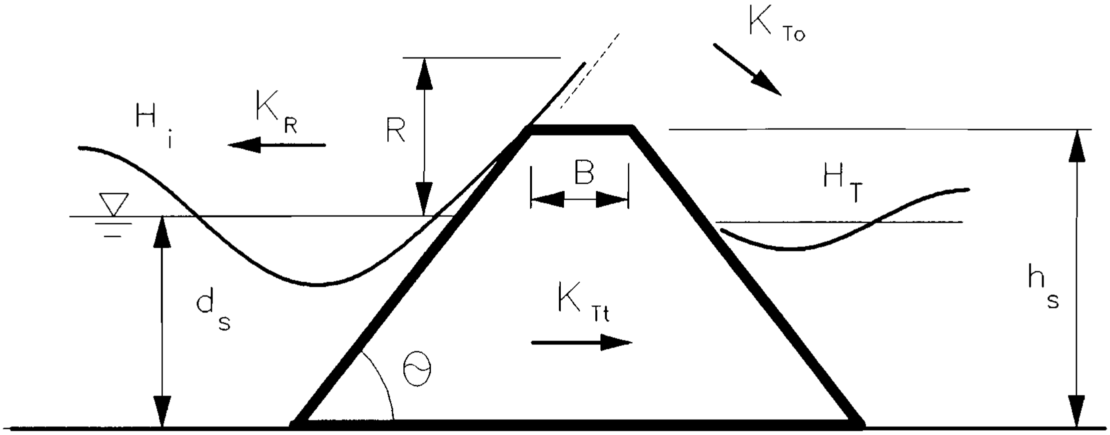

Figure 10. Wave runup, overtopping, and transmission.

determined from the summation of contributions of individual wave heights in the distribution.

Transmission over Structures

Wave transmission of protective structures is an important facet of harbor design and operation. Similar to runup and volumetric overtopping analysis problems, physical models furnish traditional wave transmission design information. Some empirical formulations have been derived from lab measurements and are first-order accurate. Methods reported by CROSS and SOLLITT (1971) and SEELIG (1980) for transmission by overtopping of simple linear slope structures as a function of wave height, water depth, runup, and structure dimensions are used in this ACES application. Runup estimates are made using the previous methodology.

Transmission over vertical or composite breakwaters is based on the work of GODA *et al.* (1967, 1969) and SEELIG (1976). Factors considered include wave height, water depth, and structure geometry, type, and dimensions.

The above methods for runup, overtopping, and transmission are highly empirical and based solely on curve fits to laboratory data. Estimates provided are considered only first-order accurate.

Transmission Through Permeable Structures

MADSEN and WHITE (1976) studied wave transmission through porous rubble mound structures of quarrystone and provided an analytic (and semi-empirical) solution of the wave equation through porous media. Factors considered include size, porosity, and placement of breakwater materials, seaward slope, structure geometry, water depth and viscosity, and normally incident wave height and period. The method assumes that the process of reflection and transmission through a structure may be determined by separately partitioning the incident wave energy between reflected, transmitted, and dissipated wave fields.

The computational method consists of iterative simultaneous solutions of the linear long wave equations within and outside the structure. Dissipation mechanisms within the internal porous media and the seaward slope are represented by friction terms in the one-dimensional momentum equations. Analytic solutions to the continuity and momentum equations in the complex domain are utilized, matched at structure boundaries, and synthesized into a composite solution yielding estimates of wave transmission, reflection, and runup on the structure. The solution involves iterative numerical integration of ratios of integrals of Bessel functions. Mainframe library routines from MORRIS (1981) have been modified to produce solutions in a reasonable timeframe in the desktop environment.

Littoral Processes

Several technologies are included which address processes or procedures in the littoral environment. First-order estimates of long-shore

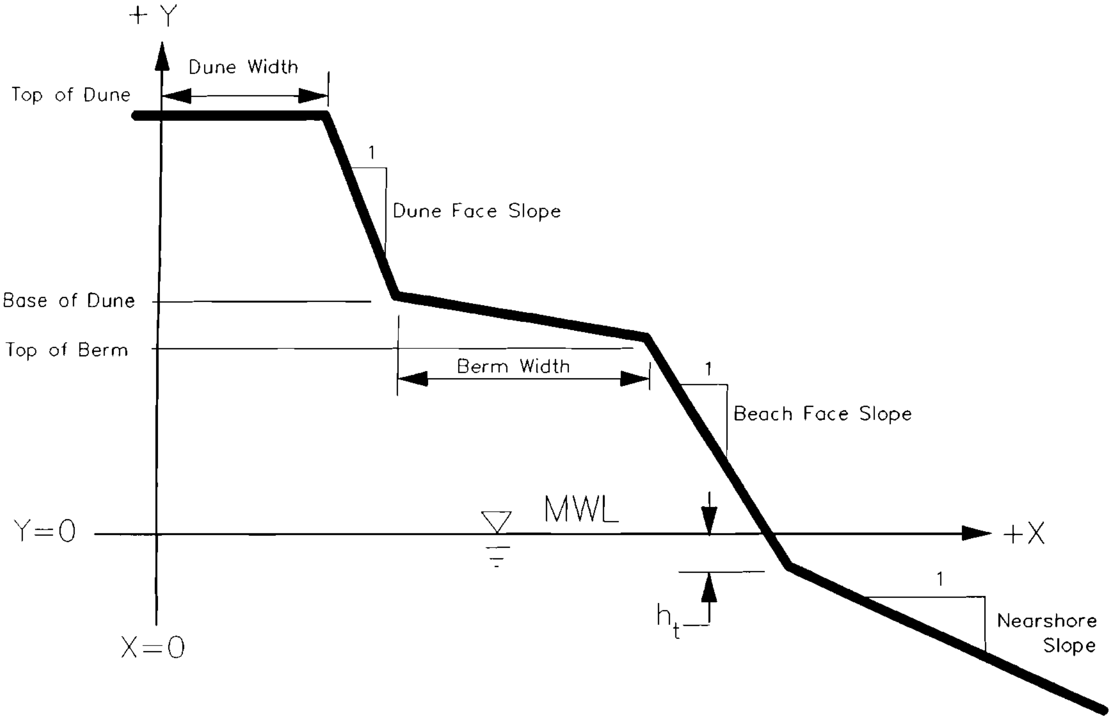

Figure 11. Idealized beach profile.

transport are included, as are methods for estimating profile change in response to cross-shore transport, methods for estimating a composite grain size distribution, sand overfill ratios, and renourishment factors.

Longshore Sediment Transport

Estimates of potential longshore transport rates caused by wave action are based on the longshore component of wave energy flux and immersed weight of sand moved described by GALVIN (1979). Variations offered in this application include estimates from sustained wave heights and directions in deepwater, at breaking, or time series of hindcast data (GRAVENS, 1988) from databases such as those described in MCANENY (1994). Methods are considered first order approximate and considered in greater complexity in models reported in HANSEN and KRAUS (1988).

Time Dependent Beach and Dune Erosion

Time-dependent cross-shore sediment transport and beach and dune erosion is considered in this application. It consists of a one-dimensional explicit finite difference approach applied to the evolution of an equilibrium beach profile shape as a function of uniform wave energy dissipation per unit volume of water in the surf zone under breaking waves as described by DEAN (1977). The application accepts actual or idealized profiles (Figure 11), and astronomical tides plus actual storm elevations as boundary conditions. General characteristics of the model are similar to those reported by KRIEBEL (1982, 1984a,b, 1986). It was provided as an interim model and in CE usage has been succeeded by a model reported by LARSON and KRAUS (1989).

Composite Grain Size Distribution

A major concern in the design of a sediment sampling plan for beach-fill purposes is the determination of composite grain-size characteristics of both native and potential borrow site material. In this implementation, a maximum of 144 separate samples containing a maximum of 56 sand weights in each sample distribution can be processed into the composite distribution. The

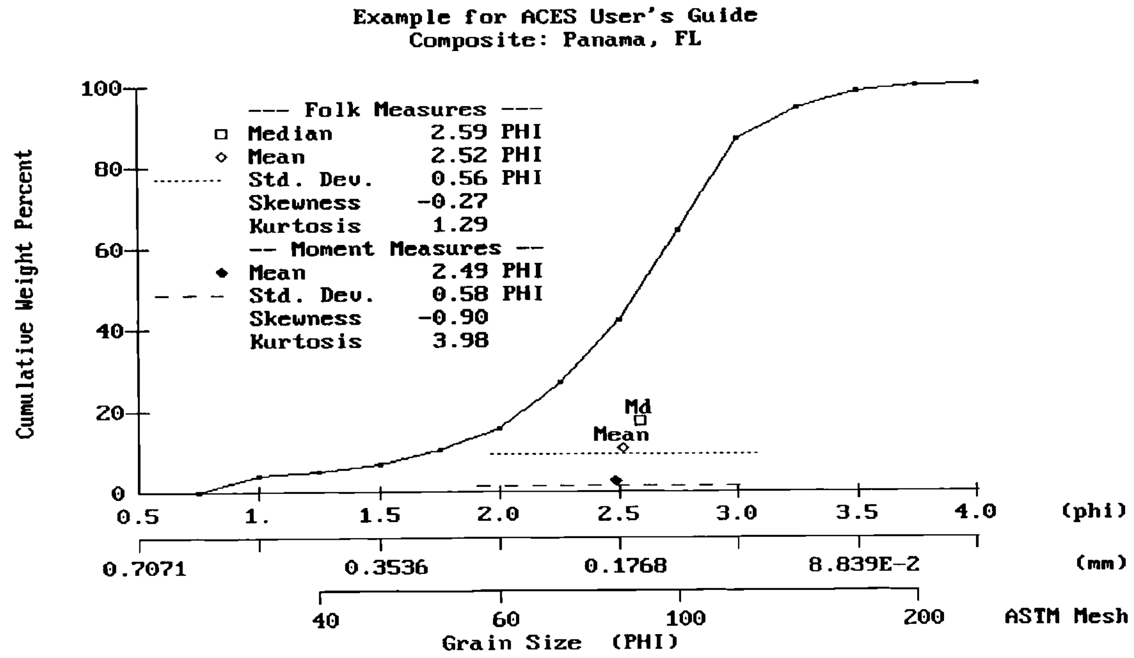

Figure 12. Composite grain size distribution.

Folk graphic method (Folk, 1974) and method of moments (Moussa, 1977) are utilized to obtain statistical parameters of the composite distribution. The composite grain size distribution is reported in ASTM mesh sizes, millimeters, phi units, and percent weight. Various weight-based statistical plots are also provided for the composite distribution (Figure 12). Major references also include the work of Krumbein (1957) and Hobson (1977).

Beach Nourishment Overfill Ratio and Volume

The planning and design of beach nourishment projects constitutes a large contemporary workload in the CE. Simple formulae are often used to provide first order estimates of material overfill ratios and renourishment factors. The two estimates are physically unrelated; and they address the different problems in determining nourishment requirements when fill material which is different than native sediments is to be used (overfill ratio) and in predicting how quickly a particular fill will erode (renourishment factor). Detailed discussion of the methods are in James (1975) and SPM (1984).

Inlet Processes

The only methodology currently available in the ACES for inlet processes is a numerical model providing estimates of water velocities within an inlet and average bay water levels as a function of time-dependent sea level fluctuations (Figure 13). Inlet hydraulic processes are approximated by simultaneous solution of the one-dimensional spatially integrated momentum equation yielding flow in the inlet, with a mass continuity equation relating the bay and sea levels to inlet discharge. Seaward boundary conditions include predicted astronomical tides, or measured elevations as a function of time. River inflows to the bay are considered. The numerical technique uses a fourth order Runge-Kutta-Gill method for the solution of simultaneous differential equations. The model theory was reported by Seelig *et al.* (1977).

USAGE AND ISSUES

Levels of Applicability

The technologies in the ACES package vary widely in complexity and applicability. All ACES methodologies may be applicable to reconnaissance level studies, while final project designs may

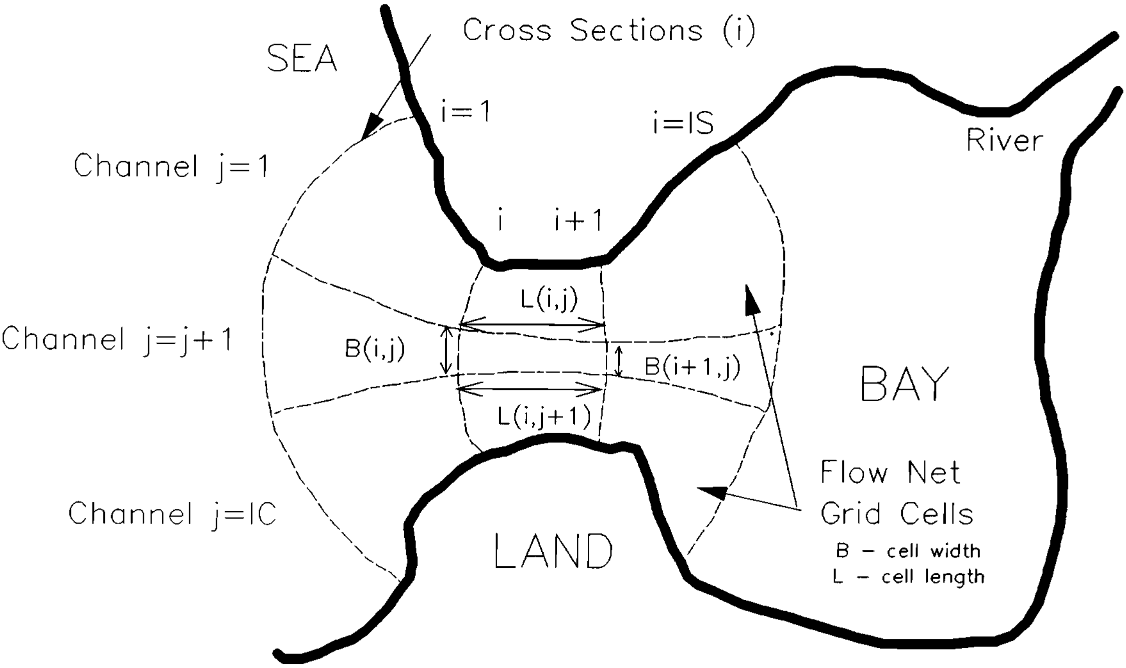

Figure 13. Idealized one-dimensional inlet discretization.

require more comprehensive technologies. The ACES has been used in all levels of CE coastal projects, often supplemented with other tools and methods. Information from CE offices indicate 50 major projects will be at least partially designed using this package in the upcoming two year period.

This package is presently utilized as a teaching supplement in several courses taught by CERC and WES. Use of the package within the academic community has also increased in recent years.

Technical Responsibility

Closely coupled with the issue of applicability is the issue of technical responsibility. The ACES package has been assembled as a diverse set of tools and designed for use on common desktop computers. This endeavor precluded any attempt at absolute or ultimate guidance in any particular specialty area of coastal engineering. The premise and goal was to provide rapid and convenient solutions to common problems encountered in CE coastal practice. Efforts were made to ensure that methodologies and software were useful and implemented with a reasonable measure of quality control. Technical and instruction documentation has been continually part of the effort (LEENKNECHT *et al.,* 1992a,b). Workshops have been conducted focusing on theory and application and extended use has substantially aided quality control issues.

However, the authors wish to strongly emphasize that methodologies here (and elsewhere) are no better than underlying assumptions and limitations and ultimate responsibility for use of the package must lie with the end-user. The importance of familiarity and understanding of applied technologies cannot be overemphasized, and ease of use cannot substitute for careful thought, experience, good judgment and quality data.

Sector Distribution

Initially, the ACES was prepared for CE coastal specialists, but implementation has spread within other federal, private, and academic sectors. Coincident with the addition of methodologies over time, usage and distribution increased from 50 individuals in 1987, to over 700 for the latest version by June of 1994. Figure 14 shows the current distribution in the various sectors.

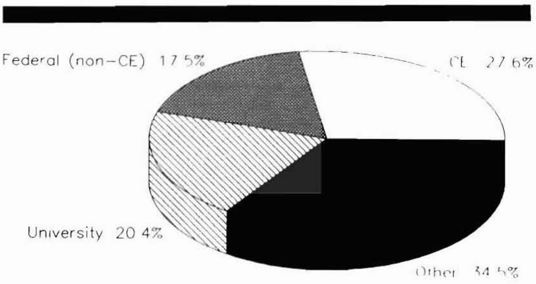

Figure 14. ACES sector distribution (742 total, June 1994).

SUMMARY

A brief overview of one set of automated tools covering diverse topics in coastal engineering has been presented. Topics have included the contents, history, usage and relevant issues.

ACKNOWLEDGEMENTS

This work was conducted at the Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station, under the Coastal Research Program. The Automated Coastal Engineering System work unit supported the effort. In addition to the authors, many current and former CERC and WES employees participated in the actual development of the system: J.P. Ahrens, W.A. Brandon, M.R. Byrnes, P.L. Crawford, L.K. Fields, M.E. George, D.W. Hyde, R.E. Jensen, J.M. Kaihatu, E.F. Thompson, and K.A. Turner. The authors also thank E.F. Thompson and Z. Demirbilek (CERC) for review of this document. Permission was granted by the Chief of Engineers to publish this information.

LITERATURE CITED

ABRAMOWITZ, M. and STEGUN, I.A., 1972. *Handbook of Mathematical Functions.* New York: Dover, 1,046p.

AHRENS, J.P., 1975. Large wave tank tests of riprap stability. *CERC Technical Memorandum 51.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

AHRENS, J.P., 1981. Design of riprap revetments for protection against wave attack. *CERC TP 81-5.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

AHRENS, J.P. and MCCARTNEY, B.L., 1975. Wave period effect on the stability of riprap. *Proceedings of Civil Engineering in the Oceans/III* (American Society of Civil Engineers, ASCE), pp. 1019–1034.

AHRENS, J.P. and TITUS, M.F., 1985. Wave runup formulas for smooth slopes. *Journal of Waterway, Port, Coastal and Ocean Engineering* (ASCE), 111(1), 128–133.

AIRY, G.B., 1845. Tides and waves. *Encyclopaedia Metropolitana,* 192, 241–396.

BRODERICK, L.L., 1983. Riprap stability, a progress report. *Proceedings of the Coastal Structures '83 Conference.* American Society of Civil Engineers, Arlington, Virginia, pp. 320–330.

BRODERICK, L.L. and AHRENS, J.P., 1982. Riprap stability scale effects. *CERC TP 82-3.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

CARDONE, V.J., 1969. Specification of the wind distribution in the marine boundary layer for wave forecasting. *TR-69-1.* Geophysical Sciences Laboratory, Department of Meteorology and Oceanography, School of Engineering and Science, New York University, New York.

CHEN, H.S., 1987. Combined reflection and diffraction by a vertical wedge. *Technical Report CERC-87-16.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

CROSS, R. and SOLLITT, C., 1971. Wave transmission by overtopping. *Technical Note No. 15.* Massachusetts Institute of Technology, Ralph M. Parsons Laboratory, Boston, Massachusetts.

DARWIN, G.H., 1898. *The Tides and Kindred Phenomena in the Solar System.* New York: Houghton Mifflin.

DEAN, R.G., 1977. Equilibrium beach profiles: U.S. Atlantic and Gulf Coasts. *Ocean Engineering Report No. 12.* Department of Civil Engineering, University of Delaware, Newark, Delaware.

DEAN, R.G. and DALRYMPLE, R.A., 1984. *Water Wave Mechanics for Engineers and Scientists.* Englewood Cliffs, New Jersey: Prentice-Hall, pp. 41–86.

DONGARRA, J.J.; MOLER, C.B.; BUNCH, J.R., and STEWART, G.W., 1979. *LINPACK User's Guide.* Philadelphia: S. I. A. M.

DOUGLASS, S.L., 1986. Review and comparison of methods for estimating irregular wave overtopping rates. *Technical Report CERC-86-12.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, pp. 6–14.

FENTON, J.D., 1988a. The numerical solution of steady water wave problems. *Computers and Geoscience,* 14(3), 357–368.

FENTON, J.D., 1988b. Discussion of nonuniqueness in stream function wave theory. *Journal of Waterway, Port, Coastal and Ocean Division* (American Society of Civil Engineers), 114(1), 110–112.

FOLK, R.L., 1974. *Petrology of Sedimentary Rocks.* Austin, Texas: Hemphill, 183p.

GODA, Y., 1969. Reanalysis of laboratory data on wave transmission over breakwaters. *Report of the Port and Harbour Research Institute,* 8(3).

GODA, Y., 1975. Irregular wave deformation in the surf zone. *Coastal Engineering in Japan,* 18, 13–26.

GODA, Y., 1984. *Random Seas and Design of Maritime Structures.* Tokyo, Japan: University of Tokyo Press, pp. 41–46.

GODA, Y., 1988. On the methodology of selecting design wave heights. *Proceedings, Twenty-first Coastal Engineering Conference* (ASCE, Costa del Sol-Malaga, Spain), pp. 899–913.

GODA, Y.; TAKEDA, H., and MORIYA, Y., 1967. Laboratory investigation of wave transmission over breakwaters. *Report of the Port and Harbour Research Institute, No. 13.*

Gravens, M.B., 1988. Use of hindcast wave data for estimation of longshore sediment transport. *Proceedings of the Symposium on Coastal Water Resources.* American Water Resources Association, Wilmington, North Carolina, pp. 63–72.

Hansen, H. and Kraus, N.C., 1989. GENESIS: Generalized model for simulating shoreline change. *Technical Report CERC-89-19.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Hardy, T.A. and Kraus, N.C., 1987. A numerical model for shoaling and refraction of second-order cnoidal waves over an irregular bottom. *Miscellaneous Paper CERC-87-9.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Headquarters, Department of the Army, 1985. Design of coastal revetments, seawalls, and bulkheads. *Engineer Manual 1110-2-1614.* Washington, D.C., Chapter 2, pp. 15–19.

Hobson, R.D., 1977. Review of design elements for beach fill evaluation. *Technical Paper 77-6.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Hudson, R.Y., 1958. Design of quarry stone cover layers for rubble mound breakwaters. *Research Report 2-2.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Hudson, R.Y., 1959. Laboratory investigations of rubble-mound breakwaters. *Proceedings of the American Society of Civil Engineers.* (ASCE, Waterways and Harbors Division), 85 (WW3), Paper No. 2171.

Hudson, R.Y., 1961a. Laboratory investigation of rubble-mound breakwaters. *Transactions of the American Society of Civil Engineers* (ASCE), 126, Pt. IV.

Hudson, R.Y., 1961b. Wave forces on rubble-mound breakwaters and jetties. *Miscellaneous Paper 2-453.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Hughes, S.A. and Borgman, L.E., 1987. Beta-Rayleigh distribution for shallow water wave heights. *Proceedings of the American Society of Civil Engineers Specialty Conference on Coastal Hydrodynamics* (ASCE), pp. 17–31.

Hunt, J.N., 1979. Direct solution of wave dispersion equation. *Journal of Waterway, Port, Coastal and Ocean Division* (American Society of Civil Engineers), 105 (WW4), 457–459.

Isobe, M. and Kraus, N.C., 1983. Derivation of a second-order cnoidal wave theory. *Hydraulics Laboratory Report No. YNU-HY-83-2.* Department of Civil Engineering, Yokohama National University, 43p.

James, W.R., 1975. Techniques in evaluating suitability of borrow material for beach nourishment. *Technical Memorandum No. 60.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Klopman, G., 1990. A note on integral properties of periodic gravity waves in the case of a non-zero mean Eulerian velocity. *Journal of Fluid Mechanics,* 211, 609–615.

Korteweg, D.J. and de Vries, G., 1895. On the change of form of long waves advancing in a rectangular canal, and on a new type of long stationary waves. *Philosophy Magazine,* 5(39), 422–443.

Kriebel, D.L., 1982. Beach and Dune Response to Hurricanes. M.S. Thesis, Department of Civil Engineering, University of Delaware, Newark, New Jersey.

Kriebel, D.L., 1984a. Beach erosion model (EBEACH) users manual, volume I: Description of computer model. *Beach and Shores Technical and Design Memorandum No. 84-5-I.* Division of Beaches and Shores, Florida Department of Natural Resources, Tallahassee, Florida.

Kriebel, D.L., 1984b. Beach erosion model (EBEACH) users manual, volume II: Theory and background. *Beach and Shores Technical and Design Memorandum No. 84-5-II.* Division of Beaches and Shores, Florida Department of Natural Resources, Tallahassee, Florida.

Kriebel, D.L., 1986. Verification study of a dune erosion model. *Shore and Beach,* 54(3), 13–21.

Krumbein, W.C., 1957. A method for specification of sand for beach fills. *Technical Memorandum No. 102.* Beach Erosion Board, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Larson, M. and Kraus, N.C., 1989. SBEACH: Numerical model for simulating storm-induced change. *Technical Report CERC-89-9.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Leenknecht, D.A.; Szuwalski, A.S., and Sherlock, A., 1992a. *Automated Coastal Engineering System, Technical Reference, Version 1.07.* U.S. Army Waterways Experiment Station, Vicksburg, Mississippi.

Leenknecht, D.A.; Szuwalski, A.S., and Sherlock, A., 1992b. *Automated Coastal Engineering System, User Guide, Version 1.07.* U.S. Army Waterways Experiment Station, Vicksburg, Mississippi.

Longuet-Higgins, M.S., 1952. On the statistical distributions of the heights of sea waves. *Journal of Maritime Research,* IX(3), 245–266.

Madsen, O.S. and White, S.M., 1976. Reflection and transmission characteristics of porous rubble-mound breakwaters. *CERC MR 76-5.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Mase, H., 1989. Random wave runup height on gentle slopes. *Journal of the Waterway, Port, Coastal, and Ocean Engineering Division* (ASCE), 115(5), 649–661.

Mase, H. and Iwagaki, Y., 1984. Runup of random waves on gentle slopes. *Proceedings of the 19th International Conference on Coastal Engineering* (Houston, Texas, ASCE), pp. 593–609.

McAneny, D.S., 1995. Regional coastal databases for corps of engineers districts. *Journal of Coastal Research,* 11, in press.

Miche, R., 1944. Mouvements ondulatoires de la mer en profondeur constante ou decroissante. *Annales des Ponts et Chaussees* (Paris), 114.

Morris, A.H., 1981. *NSWC/DL Library of Mathematics Subroutines, NSWC-TR-81-410.* Naval Surface Weapons Center, Dahlgren, Virginia.

Moussa, T.M., 1977. Phi mean and phi standard deviation of grain-size distribution in sediments: Method of moments. *Journal of Sedimentary Petrology,* 47(3), 1295–1298.

Resio, D.T.; Vincent, C.L., and Corson, W.D., 1982. Objective specification of Atlantic Ocean wind fields from historical data. *Wave Information Study Report*

No. 4. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

RUNDGREN, L., 1958. Water wave forces. *Bulletin No. 54.* Royal Institute of Technology, Division of Hydraulics, Stockholm, Sweden.

SAINFLOU, M., 1928. Essay on Vertical Breakwaters. *Annals des Ponts et Chaussees,* Paris (HATCH, C.R., (tr.), Western Reserve University, Cleveland, Ohio).

SARPKAYA, T. and ISAACSON, M., 1981. *Mechanics of Wave Forces on Offshore Structures.* New York: Van Nostrand Reinhold, pp. 150–168.

SCHUREMAN, P., 1971 (reprinted). Manual of Harmonic Analysis and Prediction of Tides. *Coast and Geodetic Survey Special Publication No. 98,* Revised (1940) Edition. U.S. Government Printing Office, Washington, D.C.

SEELIG, W.N., 1976. A simplified method for determining vertical breakwater crest elevation considering wave height transmitted by overtopping. *CERC CDM 76-1.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

SEELIG, W.N., 1980. Two-dimensional tests of wave transmission and reflection characteristics of laboratory breakwaters. *CERC TR-80-1.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

SEELIG, W.N.; HARRIS, D.L., and HERCHENRODER, B.E., 1977. A spatially integrated numerical model of inlet hydraulics. *CERC GITI Report 14.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

SHUTO, N., 1974. Nonlinear long waves in a channel of variable section. *Coastal Engineering in Japan,* 17, 1–12.

SMITH, J.M., 1991. Wind-wave generation on restricted fetches. *Miscellaneous Paper CERC-91-2.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

SOBEY, R.J., 1988. Discussion of nonuniqueness in stream function wave theory. *Journal of Waterway, Port, Coastal and Ocean Division* (ASCE), 114(1), 112–114.

STOKES, G.G., 1847. On the theory of oscillatory waves. *Transactions of the Cambridge Philosophical Society,* 8, 441–455.

THOMPSON, E.F. and LEENKNECHT, D.A., 1994. Wind estimation for coastal modeling applications. *Journal of Coastal Research,* 10(3), 628–636.

U.S. ARMY CORPS OF ENGINEERS, 1984. *Shore Protection Manual.* U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, US Government Printing Office, Washington, D.C., Chapter 3, 4th ed., 2 Vols., pp. 24–66.

VAN DER MEER, J.W., 1988a. Deterministic and probabilistic design of breakwater armor layers. *Journal of Waterways, Port, Coastal, and Ocean Engineering* (ASCE), 114(1), 66–80.

VAN DER MEER, J.W., 1988b. Rock Slopes and Gravel Beaches Under Wave Attack. Ph.D. Thesis, Department of Civil Engineering, Delft Technical University; also Delft Hydraulics Communication No. 396, Delft, The Netherlands.

VAN DER MEER, J.W. and PILARCZYK, K.W., 1987. Stability of breakwater armor layers deterministic and probabilistic design. *Delft Hydraulics Communication No. 378.* Delft, The Netherlands.

VINCENT, C.L., 1984. Deepwater wind wave growth with fetch and duration. *Miscellaneous Paper CERC-84-13.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

WEGGEL, J.R., 1976. Wave overtopping equation. *Proceedings of the 15th Coastal Engineering Conference* (American Society of Civil Engineers, Honolulu, Hawaii), pp. 2737–2755.

WESTERINK, J.J.; LUETTICH, R.A., and SCHEFFNER, N., 1993. ADCIRC: An advanced three-dimensional circulation model for shelves, coasts, and estuaries, Report 3, development of a tidal constituent database for the western North Atlantic and Gulf of Mexico. *Technical Report DRP-92-6.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.