Preface

The modest number of topics on waves and wave forces that is reviewed comes primarily from three sources: (1) from four one-quarter in length (10 weeks) graduate courses taught at Oregon State University (OSU) in the USA; viz. (i) linear waves, (ii) nonlinear waves, (iii) random real ocean waves and (iv) wave forces on structures; (2) from Masters and PhD theses written for the Departments of Civil, Construction and Environmental Engineering and of Mathematics at OSU; and (3) from manuscripts co-authored by the author. Because of these limited resources for the topics reviewed, the topics are intended primarily as a reference for graduate classes on waves and wave loads; although it is hoped that some practicing coastal/ocean engineers may also find these topics of some value. The emphases are (1) on the fundamental physics of the dynamics of fluids and of semi-immersed Lagrangian solid bodies that are responding to wave induced loads; (2) on the scaling of dimensional equations and boundary value problems in order to determine a small dimensionless parameter, ϵ say, that may be evaluated to linearize the equations and the boundary value problems in order to obtain a linear system; (3) on the replacing of differential and integral calculus equations with algebraic equations that require only algebraic substitutions instead of differentiations and integrations; and (4) on the importance of comparing analytical and numerical computations with data from laboratories and/or nature. More extensive treatments of the topics reviewed here are given from the point of view of naval architecture by Wehausen and Laitone, *Surface Waves* in ***Handbook of Physics, Fluid Dynamics III*** (1960) and from the point of view of coastal and ocean engineering by Mei in ***The Applied Dynamics of Ocean Surface Waves*** (1989).

Chapter 1 introduces the topic of wave forces on coastal and ocean structures and attempts to motivate the reasons for studying the theories that are reviewed.

Chapter 2 reviews the mathematical methods employed in the remaining chapters; and is motivated by the format used by Morse and Ingard, ***Theoretical Acoustics*** (1968) Chapter 1.2. The pedagogy used by the author in the four graduate courses cited above is to formulate problems on waves and wave loads on coastal and ocean structures in generic mathematical nomenclature; and to then search the mathematical literature for the solutions to the generic mathematical problem formulated rather than associating a generic mathematical solution method to a particular wave or wave load problem on a specific topic or in a specific chapter. By this pedagogy, it is hoped that readers will look for generic mathematical solutions to wave and wave load problems in the mathematical literature where the solution methods are compactly archived by specific mathematical nomenclature. This will expedite solutions and make all problems on waves and wave loads generic to their mathematical solutions.

Chapter 3 reviews the fundamental laws for the conservation of mass, momentum and energy for an Eulerian fluid field by the differential element method in Cartesian coordinates. The derivations are limited to the differential element method in Cartesian coordinates; but the corresponding results from arbitrary integral control volumes and from tensor analyses are also included for completeness but without rigorous derivations. The similarities of non-uniqueness between the scaling of equations and dimensional analysis are included in order to stress the importance of analyses by both of these methods for numerical and analytical computations and by the subsequent essential comparison between numerical and analytical results with data from laboratories and/or nature.

Chapter 4 begins the surface gravity wave analyses by reviewing long-crested linear wave theory (LWT) applying real-valued elementary transcendental functions. Differential control volumes in Cartesian coordinates are employed for deriving the equations for the boundary value problem for long-crested linear waves and the subsequent solutions for the conservation of mass, momentum and energy flux for both progressive and standing linear waves. Algorithms for computing the propagating eigenvalue (wave number) for the well-posed Sturm-Liouville boundary value problem that is formulated in Chapter 2 are reviewed.

Chapter 5 reviews a variety of 2D and 3D wavemaker theories applying complex-valued elementary transcendental functions. The emphasis of the wavemaker theories reviewed is the application of the wavemaker theory to the radiation potential for computing forces and moments on large semi-immersed Lagrangian solid bodies that are reviewed in Chapter 8. There is a deliberate and repeated effort to connect this review to the radiation potential for large body forces and moments in Chapter 8. In addition, integral equations for the coefficients of the eigenfunctions, for the forces and moments on wavemakers and for computing wavemaker power are replaced by algebraic equations that only require algebraic substitutions and eliminate all integral computations. Two-dimensional planar and double-articulated wavemakers are analyzed; and algorithms for computing the evanescent (or "local" wave components, John, 1950, p. 48) eigenvalues are reviewed. Both amplitude-modulated (AM) and phase-modulated (PM) circular wavemakers are reviewed. Sloshing waves in 2D channels and directional wavemakers in 3D basins are reviewed. Finally, the mapping of 2D wavemakers by both conformal mappings and by domain mapping are reviewed.

Chapter 6 reviews several nonlinear wave theories. Stokes 2D nonlinear waves are reviewed first by the classical (but extremely tedious) Stokes method of successive approximations and, subsequently, by the traditional Stokes-Lindstedt-Poincare perturbation method. In the traditional Stokes-Lindstedt-Poincare perturbation method there are two methods that may be applied to suppress resonant forcing. One method is to expand the wave celerity C in a perturbation expansion according to $C = \sum_{m=0} \epsilon^m {}_{(m+1)}C$. Another option is to expand the radian wave frequency ω in a perturbation expansion according to $\omega = \sum_{n=0} \epsilon^n \omega_n$. Both of these methods are reviewed. Specifically, the first method of expanding the wave celerity C is applied in the traditional Stokes perturbation expansion in Chapter 6.3; and the second method of expanding the radian wave frequency ω is applied in the nonlinear planar wavemaker theory in Chapter 6.7. In particular, the review of the Stokes-Lindstedt-Poincare traditional perturbation method introduces the method of replacing differential calculus with algebraic substitutions. The numerous repeated term by term differentiations required in the boundary conditions (as many as 75 differentiations at fourth order!) are replaced by six relatively simple algebraic equations that many times are identically equal to zero! The more modern methods of multiple scales (MMS) and the numerical stream function theory are reviewed briefly. Wave breaking is also reviewed briefly. An extension of the 2D wavemaker theory to weakly nonlinear waves and to Stokes drift in 2D wave channels is included. An analysis of weakly damped cross-waves with surface tension is analyzed by the generalized Melnikov method for nonlinear nonautonomous Hamiltonian systems with contact (canonical) transformations computed by an extension of the Herglotz algorithm to nonautonomous transformations.

Chapter 7 begins the formal analyses of deterministic wave loads on structures by reviewing the dynamics of small Lagrangian solid bodies responding to loads computed from the Morison equation and from the Modified Wave Force equation (relative motion Morison equation). The parametric dependencies of the inertial C_m and drag C_d force coefficients in the Morison equation are reviewed and are connected to the scaling and dimensional analyses methods reviewed in Chapter 3. The linearized wave force equation (relative motion Morison equation) is applied to analyze both a single-degree-of-freedom (SDOF) articulated tower and a semi-immersed, three-degree-of-freedom (MDOF) double pontoon system. The linearization of the relative motion wave loads in these two examples makes it possible to separate the wave loads into terms proportional only to the body motions and to terms proportional only to loads on fixed bodies. Because of this linear decomposition of the wave loads, deterministic wave loads on fixed small bodies need not be treated as a separate topic in this review because the wave loads on fixed bodies are identical to the exciting wave loads on dynamically responding small bodies to the first linear approximation! Finally, the chapter concludes by reviewing the transverse lift forces on small bodies and the stability of bottom laid marine pipelines through the surf zone.

Chapter 8 reviews the deterministic dynamics of large Lagrangian solid bodies responding to linear wave loads computed by potential wave theory and the linear progressive wave potentials derived in Chapter 4. Similar to the analyses in Chapter 7, the linear decomposition of the wave loads on large bodies reduces to uncoupled boundary value problems for (1) a scattered wave potential that computes the exciting wave loads on a fixed large Lagrangian body and to (2) a radiated wave potential that computes the restoring or wavemaker loads on an oscillating (wavemaker) body in otherwise still water. This linear decomposition in two separate and uncoupled boundary value problems is the direct consequence of the equalitarian treatment of the kinematic and dynamic boundary conditions between the Eulerian fluid field and the large Lagrangian solid body. Because the independent variables of the Eulerian fluid field (viz. space and time) and of the Lagrangian solid body (viz. particle and time) are not the same, the two boundary conditions on the boundary between the Eulerian fluid field and on the Lagrangian solid body must be treated with care. Specifically, the kinematic boundary condition converts the Lagrangian particle velocities of the semi-immersed solid body to Eulerian field velocities by the vector dot product between the time-dependent Lagrangian body velocities and the spatially-dependent unit normal to the Lagrangian solid body. Then the spatial dependencies of the dynamic Eulerian pressure field are integrated around the submerged portions of the semi-immersed Lagrangian solid body so that the wave loads are transformed to only time-dependent Lagrangian variables in the Lagrangian dynamic boundary condition. The boundary value problem for the radiated wave potential is connected repeatedly to the wavemaker theories in Chapter 5. Froude-Kriloff approximations for wave loads in both Cartesian and circular cylindrical coordinates are reviewed as well as the MacCamy-Fuchs diffraction theory for a full draft vertical cylinder. Reviews of the reciprocity relations and the Green's functions as resolvent kernels in Fredholm integral equations are reviewed. Wave loads computed by the Finite Element Method (FEM) complete the chapter on wave loads on large Lagrangian solid bodies.

Chapter 9 reviews the non-deterministic wave theories and wave loads. Fourier analyses of stochastic processes are reviewed and an application of the finite Fourier transform (FFT) to measured wave data from Hurricane CARLA is given. Generic 4 parameter and multi-parameter wave spectra are reviewed. Gaussian and Rayleigh probability theories are applied to the time series of wave profiles and wave heights, respectively. Wave groups are analyzed by the Hilbert transform and then applied to a stability analysis of coastal rubble-mound breakwater structures with comparisons to laboratory data. This analysis requires an algorithm that is capable of resolving incident and reflected times series (with wave phases as well as wave amplitudes) in order to apply the Hilbert transform and to compute the groupiness of the incident time series. Algorithms for random wave simulations by digital computers for both deterministic spectral amplitude (DSA) and nonderministic spectral amplitude (NSA) random wave simulations are reviewed along with conditional random wave simulations. Random wave forces on a prototype space-frame structure in the Gulf of Mexico are computed by the linearized relative motion Morison equation from Chapter 7 applying nondeterministic random waves and are compared with data from Hurricane CARLA on the same space-frame structure. The structural model also includes a dynamic soil-spring response algorithm. Finally, the frequency domain transfer functions for Eulerian field variables and for Lagrangian body motions are reviewed.

A Bibliography that contains a relatively large number of references that are not cited explicitly in the main chapters concludes this review.

I have benefitted enormously over the past 30 years from my harmonious collaborations with my colleagues of the College of Engineering, the Department of Mathematics and the College of Oceanic and Atmospheric Sciences at OSU in the USA; from colleagues in laboratories and institutions in Indonesia, Japan, Korea, Poland, Spain and Taiwan; as well as graduate students in both the Department of Civil, Construction and Environmental Engineering and the Department of Mathematics at OSU. In addition, I must also acknowledge my mentors from many academic and governmental institutions that have educated me. Although I feel obligated to cite each of them individually for their contributions to this review; it would require another review of equal length; but I do wish to acknowledge and to express my sincere appreciation individually to each of them for their contributions. However, it is virtually impossible to eliminate all of the theoretical and typographical errors in a review with the number of equations and theories that are reviewed here; and I, alone, bear all of the responsibility for these errors. I have, however, made repeated efforts to proof both the theories and equations; and I apologize here in advance for those errors that have survived all of my scrutiny. In addition, some of the materials that are reviewed such as replacing differential and integral calculus with algebraic substitutions in Chapters 5 and 6 and the applications of the generalized Melnikov method as well as the generalized Herglotz algorithm to analyze chaotic cross-waves in Chapter 6 are relatively new ideas (at least to the author) that are among many others in this review that almost surely require further elaborations and/or clarifications. I solicit these elaborations, clarifications and corrections and I welcome all comments, criticisms, suggestions and corrections. The coastal and ocean waters that cover our planet are wonderful areas to enjoy both for recreation and to benefit from their productivity. May some of the readers of my modest efforts here benefit from these efforts and help all of us to enjoy the beauty and the productivity of our coastal and ocean waters.