Analysis and Design of Marine Structures

Editors:
C. Guedes Soares
R.A. Shenoi

CRC Press
Taylor & Francis Group
A BALKEMA BOOK

PROCEEDINGS OF THE 5TH INTERNATIONAL CONFERENCE ON MARINE STRUCTURES (MARSTRUCT 2015), SOUTHAMPTON, UK, 25–27 MARCH 2015

Analysis and Design of Marine Structures

Editors

C. Guedes Soares
Instituto Superior Técnico, University of Lisbon, Portugal

R.A. Shenoi
University of Southampton, UK

CRC Press
Taylor & Francis Group
Boca Raton London New York Leiden

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

A BALKEMA BOOK

CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informa business

Typeset by V Publishing Solutions Pvt Ltd., Chennai, India
Printed and bound in Great Britain by CPI Group (UK) Ltd, Croydon, CR0 4YY

Published by: CRC Press/Balkema
P.O. Box 11320, 2301 EH Leiden, The Netherlands
e-mail: Pub.NL@taylorandfrancis.com
www.crcpress.com – www.taylorandfrancis.com

ISBN: 978-1-138-02789-3 (Hbk + CD-ROM)
ISBN: 978-1-315-68505-2 (eBook PDF)

Analysis and Design of Marine Structures – Guedes Soares & Shenoi (Eds)
© 2015 Taylor & Francis Group, London, ISBN 978-1-138-02789-3

Organisation

CONFERENCE CHAIRMAN

Prof. R.A. Shenoi, *University of Southampton, UK*

TECHNICAL PROGRAMME COMMITTEE

Prof. C. Guedes Soares, *IST, University of Lisbon, Portugal* (Chair)
Prof. R.A. Shenoi, *University of Southampton, UK*
Prof. M. Biot, *University of Trieste, Italy*
Prof. L. Domnisoru, *University "Dunarea de Jos" at Galati, Romania*
Prof. R.S. Dow, *University of Newcastle-upon-Tyne, UK*
Prof. W. Fricke, *Technical University Hamburg-Harburg, Germany*
Prof. Y. Garbatov, *IST, University of Lisbon, Portugal*
Prof. J.M. Gordo, *IST, University of Lisbon, Portugal*
Prof. J. Parunov, *University of Zagreb, Croatia*
Prof. P. Rigo, *University of Liège, Belgium*
Prof. J. Ringsberg, *Chalmers University of Technology, Sweden*
Prof. E. Rizzuto, *University of Genova, Italy*
Prof. Jani Romanoff, *Aalto University, Finland*
Prof. M. Samuelidis, *NTUA, Greece*
Prof. M. Taczala, *West Pomeranian University of Technology, Poland*
Prof. P. Temarel, *University of Southampton, UK*
Dr. H. von Selle, *DNV GL, Germany*
Dr. A. Vredeveldt, *TNO, The Netherlands*

ADVISORY COMMITTEE

Prof. F. Brennan, *Cranfield University, UK*
Prof. X. Chen, *CSSRMT, Wuxi, China*
Dr. F. Cheng, *Lloyd's Rregister, UK*
Prof. S.R. Cho, *University of Ulsan, Korea*
Prof. Y.S. Choo, *National University of Singapore, Singapore*
Prof. M. Collette, *Univesity of Michigan, USA*
Prof. W.C. Cui, *CSSRC, China*
Prof. M. Fujikubo, *Osaka University, Japan*
Prof. T. Fukasawa, *Osaka Prefecture University, Japan*
Prof. C.-F. Hung, *National Taiwan University, Taiwan ROC*
Prof. H.W. Leheta, *Alexandria University, Egypt*
Prof. N.R. Mandal, *Indian Institute of Technology, Kharagpur, India*
Dr. Y. Ogawa, *National Maritime Research Institute, Japan*
Dr. N.G. Pegg, *DND, Canada*
Prof. R. Sundaravadivelu, *Indian Institute of Technology, Madras, India*
Dr. H. Thorkildsen, *Det Norske Veritas, Norway*
Dr. G. Wang, *American Bureau of Shipping, USA*
Prof. L. Zhu, *Wuhan University of Technology, China*
Dr. N. Yamamoto, *NKK, Japan*

Analysis and Design of Marine Structures – Guedes Soares & Shenoi (Eds)

Table of contents

Wave loads and responses

Hydroelasticity

Vibrations

Analysis and Design of Marine Structures – Guedes Soares & Shenoi (Eds)
© 2015 Taylor & Francis Group, London, ISBN 978-1-138-02789-3

Smoothed Particle Hydrodynamics (SPH) method for modelling 2-dimensional free surface hydrodynamics

M.Z. Ramli, P. Temarel & M. Tan
Fluid Structure Interaction Group, University of Southampton, Southampton, UK

ABSTRACT: The main goal of the current research is to implement Smoothed Particle Hydrodynamics (SPH) for the prediction of wave-induced motions and loads within the framework of 3D modelling. In this paper, the focus is twofold. First, implementation of possible additional terms to the standard Incompressible SPH (ISPH) method with reference to generating/propagating regular waves in 2D domain, using a piston wave maker. Improvements to the prediction of pressure and velocity fields are then carried out with kernel renormalization technique and shifting technique without increasing the computational cost. The arc method is employed to improve the accuracy of free surface recognition, i.e. "noise-free" free surface. In addition, the Weakly Compressible (WCSPH) is also applied to the problem of 2D regular wave generation. Comparisons of predicted free surfaces, their kinematic and dynamic characteristics between ISPH, WCSPH and analytical solutions for a range of frequencies are carried out. The second focus of the paper is the 2D radiation problem due to forced sinusoidal oscillation of a rectangular section floating on calm water. The predicted hydrodynamic actions and coefficients in sway by WCSPH are then compared against available experimental measurements.

1 INTRODUCTION

Smoothed Particle Hydrodynamic (SPH) which is purely Lagrangian method developed during the seventies was an attempt to model continuum physics to overcome the limitations of finite difference methods. The Lagrangian method is a meshfree method whereby the computational domain is represented by a set of interpolation points called particles rather than grid cells. Each particle carries an individual mass, position, velocity, internal energy and any other physical quantity which evolves in time according to the governing equations. All particles have a kernel function to define their range of interaction, while the hydrodynamic variables are determined by integral approximations. These methods, where the main idea is to substitute the grid by a set of arbitrarily distributed particles, are expected to be more adaptable and versatile than the conventional grid-based methods, especially for those applications with severe discontinuities in free surface. Shao and Lo (2003) developed the ISPH method based on a strict hydrodynamic formulation and two-step semi-implicit solution process. Compared with the standard SPH, it has been demonstrated that the ISPH approach can improve the computational efficiency and pressure stability (Lee et al. 2008) and thus will be further developed for free-surface flow in this paper.

However, the prediction of free surface hydrodynamics in propagating waves is very difficult for standard SPH formulations, in the case of hydrodynamic actions and coefficients that depend on the wave force and wave damping which affect the wave characteristics around a rigid body (Vugts 1968). The application of SPH to free surface flows can be dated back to 1996, when Monaghan use Weakly Compressible SPH (WCSPH) to perform 2D simulations of wave propagation onto a shallow beach, followed by comparison of SPH with published experimental results in Scott Russel wave generator. Since then, improvements have been made for WCSPH formulation including treating 2D interfacial flows with different fluids (Colagrossi & Landrini 2003), integrating Large Eddy Simulation (LES) scheme and modelling the free surface flows with consideration of complex turbulent flows. Important development of Riemann solution by Vila (1999) has the most significant impact on the free surface prediction in terms of suppressing the pressure fluctuations (Gao et al. 2012, He et al. 2013). In ISPH, other works have been done to improve accuracy near free surface boundaries by employing corrective or additional terms (Shao 2010, Li et al. 2012, Colagrossi et al. 2013).

In the present work, ISPH with divergence-free velocity field is used to study the propagation of 2D waves generated by a piston wave maker into a wave tank. The wave maker is located at the upstream boundary of the tank and an artificial damping layer on the other side. The kernel summation of standard SPH formulation is observed to be insufficiently accurate in obtaining the velocity and pressure fields, thus does not perform well when simulating free surface hydrodynamics. In order to exploit fully particles inside kernel domain, the accuracy of gradient estimation is improved up to second order with kernel renormalization technique. Highly distorted particle spacing around free surface which cause instability is smoothed out by collision control and particle shifting. Then, the arc method is applied for fast and accurate boundary recognition. The numerical model built in this paper is validated through comparison between ISPH, WCSPH and potential flow solution. Comparisons of predicted free surfaces, their kinematic and dynamic characteristics for a range of frequencies are carried out. The work is then extended to investigate the 2D radiation problem due to forced sway motion of a rectangular section on calm water surface using WCSPH. The predicted hydrodynamic forces in swaying are compared against available experimental measurements.

2 SPH METHODOLOGY

2.1 *SPH interpolation*

In SPH, the approximate integral form of a function at any given position vector is

$$\langle f(\mathbf{x})\rangle = \int_{\Omega} f(\mathbf{x}')\, \omega(\mathbf{x}-\mathbf{x}', h)\, d\mathbf{x}' \tag{1}$$

where $\omega(\mathbf{x} - \mathbf{x}', h)$ is a smoothing function, $\mathbf{x}'$ is another arbitrary position vector in the domain of integration Ω, and h is the smoothing length.

As the entire system in SPH method is represented by particles which carry individual mass and occupy individual space, integral representation in Eq. (1) can be written in the form of particle approximation.

$$\langle f(x)\rangle = \sum_{j=1}^{N} \frac{m_j}{\rho_j} f(x_j)\, \omega(x - x_j, h) \tag{2}$$

where x_j is the position vector of particle j within the support domain of x, and N is the total number of particles.

For a particle i, Eq. (2) is written as

$$\langle f(x_i)\rangle = \sum_{j=1}^{N} \frac{m_j}{\rho_j} f(x_i)\, \omega_{ij} \tag{3}$$

where m_j and ρ_j are the mass and density of particle j, respectively, within the support domain of particle i, $\omega_{ij} = \omega(x_i - x_j, h)$.

Following the same integral representation and particle approximation, the derivative of a function for particle i can be written as

$$\langle \nabla \cdot f(x_i)\rangle = \sum_{j=1}^{N} \frac{m_j}{\rho_j} f(x_j) \cdot \nabla_i \omega_{ij} \tag{4}$$

where

$$\nabla_i \omega_{ij} = \frac{x_i - x_j}{r_{ij}} \frac{\partial \omega_{ij}}{\partial r_{ij}} \tag{5}$$

and r_{ij} is the distance between particle i and j.

Using Eq. (3) and Eq. (4), the continuity and pressure contribution to the momentum conservation equations can be written as

$$\frac{D\rho_i}{Dt} = \rho_i \sum_{\rho_j}^{m_j} \mathbf{v}_{ij} \frac{\partial \omega_{ij}}{\partial x_i} \tag{6}$$

$$\frac{D\mathbf{v}_i}{Dt} = -\sum_{j=1}^{N} m_j \left[\frac{P_i}{\rho_i^2} + \frac{P_j}{\rho_j^2}\right] \frac{\partial \omega_{ij}}{\partial x_i} + F \tag{7}$$

where P is the pressure and F is the acceleration due to gravity.

In ISPH, incompressibility is enforced in the projection method by a pressure Poisson equation. In this paper a quartic smoothing kernel is used for all SPH interpolations. A smoothing length of $h = 1.3dx$ is used, where dx is the initial particle spacing.

2.2 *Boundary conditions*

In SPH, three methods are, in general, widely used, the repulsive force method, the mirror particle method and the dummy particle method (Shao and Lo 2003, Lee et al. 2008). It is very difficult to build some boundary conditions, such as the homogeneous Neumann boundary for the pressure, with the repulsive boundary force method. In this paper, the dummy particles, which have the physical properties of inner fluid particles, are used for the treatment of wall boundary condition.

In this 2D model, the solid boundaries are simulated by three layers of boundary particles similar to the fluid particles which balance the pressure of inner fluid particles and prevent them from penetrating the wall. These boundary particles are forced to satisfy the same equations as the fluid particles. Thus, they follow the same momentum and continuity equations. The physical properties of all boundary particles, except velocity and position, evolve with time. However, for moving boundaries, such as the solid boundaries of a moving rectangular box and the wave maker paddle, velocities and

Analysis and Design of Marine Structures contains the papers presented at MARSTRUCT 2015, the 5th International Conference on Marine Structures (Southampton, UK, 25-27 March 2015).

The MARSTRUCT series of conferences started in Glasgow, UK in 2007, the second event of the series took place in Lisbon, Portugal (2009), while the third was in Hamburg, Germany (2011), and the fourth in Espoo, Finland (2013). This conference series deals with Ship and Offshore Structures, addressing the following topics:

- Methods and Tools for Loads and Load Effects
- Methods and Tools for Strength Assessment
- Experimental Analysis of Structures
- Materials and Fabrication of Structures
- Methods and Tools for Structural Design and Optimisation
- Structural Reliability, Safety and Environmental Protection

This book is essential reading for academics, engineers and all professionals involved in the area of design of marine and offshore structures.

ISBN 978-1-138-02789-3

9 781138 027893

an **informa** business

CRC Press
Taylor & Francis Group
an **informa** business
www.crcpress.com

6000 Broken Sound Parkway, NW
Suite 300, Boca Raton, FL 33487
Schipholweg 107C
2316 XC Leiden, NL
2 Park Square, Milton Park
Abingdon, Oxon OX14 4RN, UK