Coastal Wave Modelling:

General Engineering Usage and Areas for Improved Research

30 July 2014

Nigel Bunn
HR Wallingford - History

1947 Government forms Hydraulics Research Organisation

1951 The Hydraulics Research Station comes to Wallingford in Oxfordshire

1982 Privatisation to create Hydraulics Research

1991 Company becomes HR Wallingford
HR Wallingford - Now

- Consultancy – water
- Limited by guarantee, non profit distributing, independent
- Turnover £22 million
- Over 250 staff including world leading experts
- Work worldwide
Need for waves in port design

Site selection & layout optimisation

Extreme design & operational criteria

Approach channel & manoeuvring area design & optimisation

Design & optimise breakwaters, coast protection & terminals

Dredging design, maintenance & disposal

Coastal and environmental impact studies

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Coastal defence structures – need for waves

- Stability of armour units
- Overtopping of sea defences
- Beach movement and scour
Wave climate
Fatigue assessment
Planning construction / maintenance
Annual and seasonal

Extreme waves
Design conditions \((H_s,H_{\text{max}},T_z,T_p)\)
Joint probability (with water level)
Wave crest elevations

Forecasts
For construction and maintenance
Parameterisation of waves

Many design formulae require

- Description of sea-states (for different return periods)
  - Random waves – energy spectrum
  - Significant wave height (Hs)
  - Peak wave period (Tp)
- Mean Direction

Engineers also interested in:

- Wave climate (probability distribution of seastates)
- Hs v Dir, Hs v Tp

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Mean wave direction bands (°N).

-15 15 45 75 105 135 165 195 225 255 285 315

Parts per thousand for each direction

0.00000 108 117 79 75 59 47 42 82 106 66 66 93
Many ocean wave models linked to global atmospheric models

- Mainly use WAVEWATCH III or WAM
- Run in forecast model but also need long term hindcast (eg 30 years)
- Validate against measurements

- UK Met Office
- NOAA’s CFSR hindcast
- European Centre for Medium-range Weather Forecasting (ECMWF)
Need local models to resolve bathymetry

Offshore wind farms often built on shallow banks – Need local models
Spectral area wave modelling

- Cover large spatial area
- Consider shallow water processes
- Transform complete, random wave spectra
- Run for large number of seastates to build up complete wave climate
Developed by TU Delft

Fully spectral representation of the wave action balance equation

Processes

- Refraction
- Linear shoaling
- Wind generation
- Breaking
- White capping
- Friction
- Reflection
- Current interaction
- Wave-wave interaction (quadruplet and triad)
- Diffraction – far field approximation
Phase-resolving models

- Elliptic Mild Slope Equation models
- Boussinesq equation models

Need to consider

- Partial reflections
- Wave diffraction and interference
- Harbour resonance
- Long Waves

Further work

- Introduce moored vessels into Boussinesq model
  Including effect of mooring lines and fenders
Physical modelling
What do we still use physical models for

Wave-structure interaction
- Stability of breakwaters
- Wave overtopping
- Forces on caissons

Vessel response

Scour
- New larger scale facility
Moored vessel response

Must represent complexity of:
- Mooring line forces
- Fender forces
- Random waves (directional spectrum)
- Long waves
- Wind and current forces
- Full 6 degrees of freedom movement
Armour stability tests

- Random Waves
- Armour stability
- Overtopping

- Good data sets for validation of numerical models

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New Fast Flow Facility

Dual channel flume for wave-current-sediment modelling

- Foundation stability and scour
- Wave-current interaction
- Capabilities for research
  - Main working channel size of 70 m by 4 m
  - Water depth range 0.5 m to 2 m
  - 1 m deep (16 m³) test pit for sediment studies
  - Significant wave heights up to 0.5 m and maximum wave height 1.0 m
Wave-structure interaction

Wave forces on structures

eg Caisson breakwaters or offshore wind turbine

- Non-linearity of waves
- Free-surface elevation
- Differential wave pressures
- Wave crest elevations

Can use Boussinesq models
Wave crest elevations

Not designed for wave uplift forces!

Hurricane Katrina

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Non-linear shoaling of long swell

Breaking waves can only be parameterised in Boussinesq model.

Can link with NLSW equation model to model breaking through shock wave theory
More detailed modelling - Numerical flume

CFD- OPENFOAM

- Solve Navier Stokes equations, VOF method for air/water interface
More detailed modelling - Numerical flume

**CFD- OPENFOAM**

- Impulsive wave overtopping

Less severe overtopping sequence
Why don’t we use this type of CFD modelling all the time?

- Computationally expensive
- Usually run for a short profile or over a small area
- Often only for a few individual waves
- Time consuming to run even for 2000 wave periods to adequately represent a single random sea seastate, let alone considering a whole range of seastates or a complete wave climate

Lagrangian methods (SPH)

- Represent individual particles
- Naturally handle free surface flows and wetting drying processes
- Even more computationally expensive
Full particle PIC (Particle in Cell) model

Hybrid model: Functionality of pure Lagrangian (SPH) with efficiency of Eulerian (grid-based) techniques


Numerical Approach: The PICIN Algorithm

1. Transfer particle velocities to the grid, tracking water surface

2. On the grid:
   • Add body forces (e.g. gravity)
   • Diffuse velocities (diffusion step)
   • Solve Poisson equation subject to BCs
   • Project the velocity field onto the nearest divergence free field (using pressure as Lagrange multiplier) to ensure incompressibility
   • Subtract the new grid velocities from the saved grid velocities

3. Transfer the difference in velocity from the grid to increment the particle velocity (bi-linear interpolation).

4. Advect particles and their associated velocities through the grid velocity field.
Example Results: Viscous Free Surface Flow Around a Circular Cylinder

- Vertical mixing
Two-Way Fluid Structure Interaction

- Solve Navier Stokes equations everywhere (pretend solid doesn’t exist)
- Account for relative density and forces on solid
- Enforce rigidity of body
- Velocity of body calculated through conservation of momentum
Full particle PIC (Particle in Cell) model

Rock cuttings sucked into a dredger pipe
More development / research needed

Interesting topics
Bridge the gap between parameterised models and detailed CFD/SPH
- More efficient surf zone model, wave-structure interaction, overtopping
- Moored vessel response models
- Long (infra-gravity) waves: free and bound waves

Statistical/Probabilistic topics
- Extreme waves (is the climate stationary ?)
- Clustering and cumulative response of storms: not just extreme design storm
Coastal Wave Modelling

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