HR Wallingford
Working with water

Coastal Wave Modelling:

General Engineering Usage and Areas for Improved Research

30 July 2014

Nigel Bunn

HR Wallingford - History

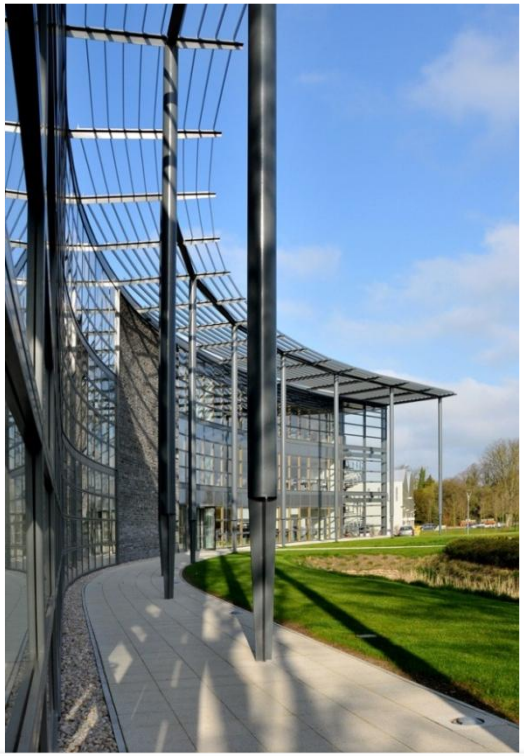
1947 Government forms Hydraulics Research Organisation

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

Water | Floods | Coasts | Maritime | Energy

Research

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

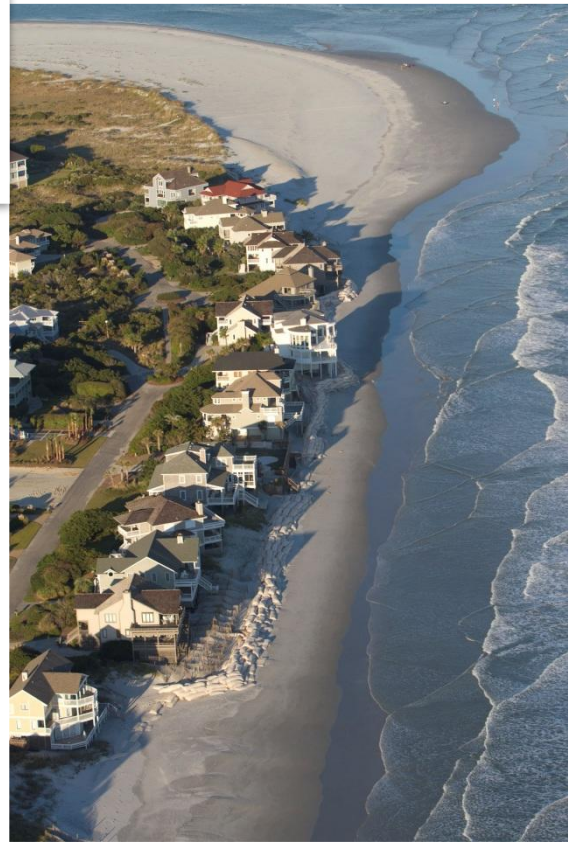
Dredging design, maintenance & disposal

Coastal and environmental impact studies

Coastal defence structures – need for waves

- Stability of armour units

- overtopping of sea defences



- Beach movement and scour

Offshore wind farms – Wave Requirements

Wave climate

Fatigue assessment

Planning construction / maintenance

Annual and seasonal

Extreme waves

Design conditions (Hs,Hmax,Tz,Tp)

Joint probability (with water level)

Wave crest elevations

Forecasts

For construction and maintenance

Parameterisation of waves

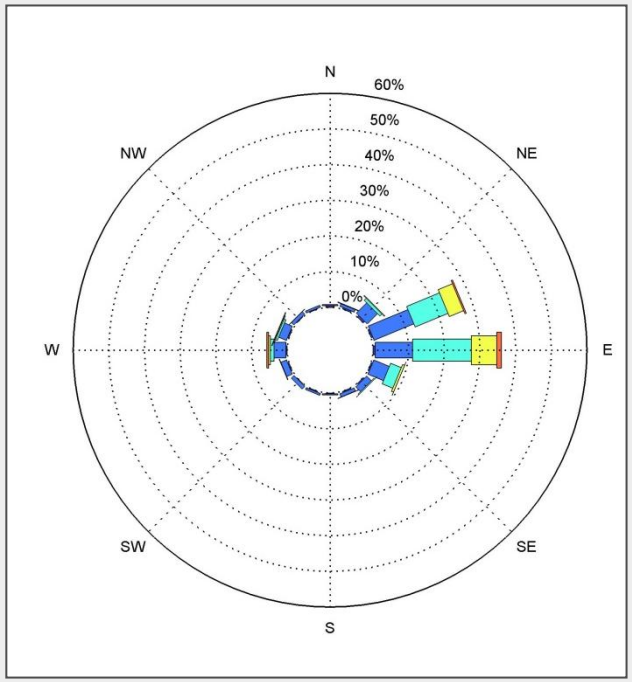
Many design formulae require

- 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

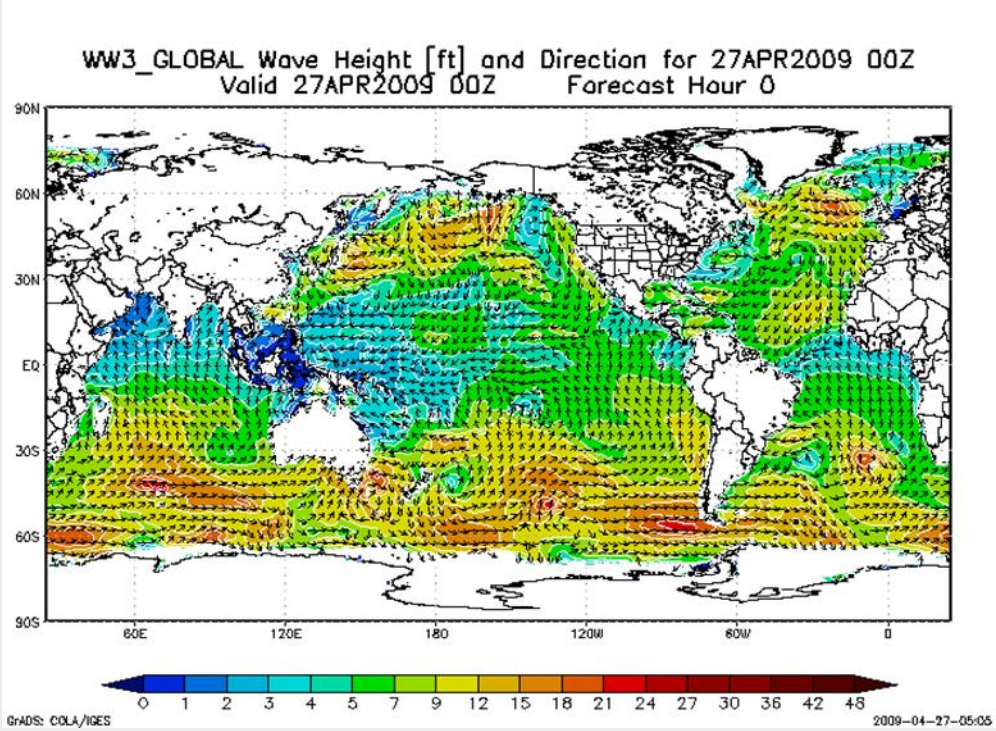
H1	H2	P(Hs>H1)	Mean wave direction bands (°N).											
			-15	15	45	75	105	135	165	195	225	255	285	315
			15	45	75	105	135	165	195	225	255	285	315	345
0.0	0.5	1.00000	1013	1042	875	906	826	878	773	1091	1349	930	889	950
0.5	1.0	0.88478	7054	5617	3390	3244	2840	1929	1738	3067	3907	2475	2552	3815
1.0	1.5	0.46849	4767	3136	2000	1833	1248	1075	1026	2497	3230	1788	1729	2198
1.5	2.0	0.20322	1966	939	831	671	645	485	463	1277	1646	889	756	1148
2.0	2.5	0.08605	976	551	499	486	254	269	178	269	354	340	450	609
2.5	3.0	0.03368	596	229	208	237	91	80	28	36	59	119	178	360
3.0	3.5	0.01147	279	117	78	72	19	12	4	0	12	20	62	152
3.5	4.0	0.00320	78	44	26	26	6	2	0	0	1	4	13	55
4.0	4.5	0.00067	19	18	6	4	3	1	0	0	0	1	1	6
4.5	5.0	0.00008	6	2	0	0	0	0	0	0	0	0	0	0
5.0	5.5	0.00000	0	0	0	0	0	0	0	0	0	0	0	0
5.5	6.0	0.00000	0	0	0	0	0	0	0	0	0	0	0	0
Parts per thousand for each direction			168	117	79	75	59	47	42	82	106	66	66	93



Global climate models

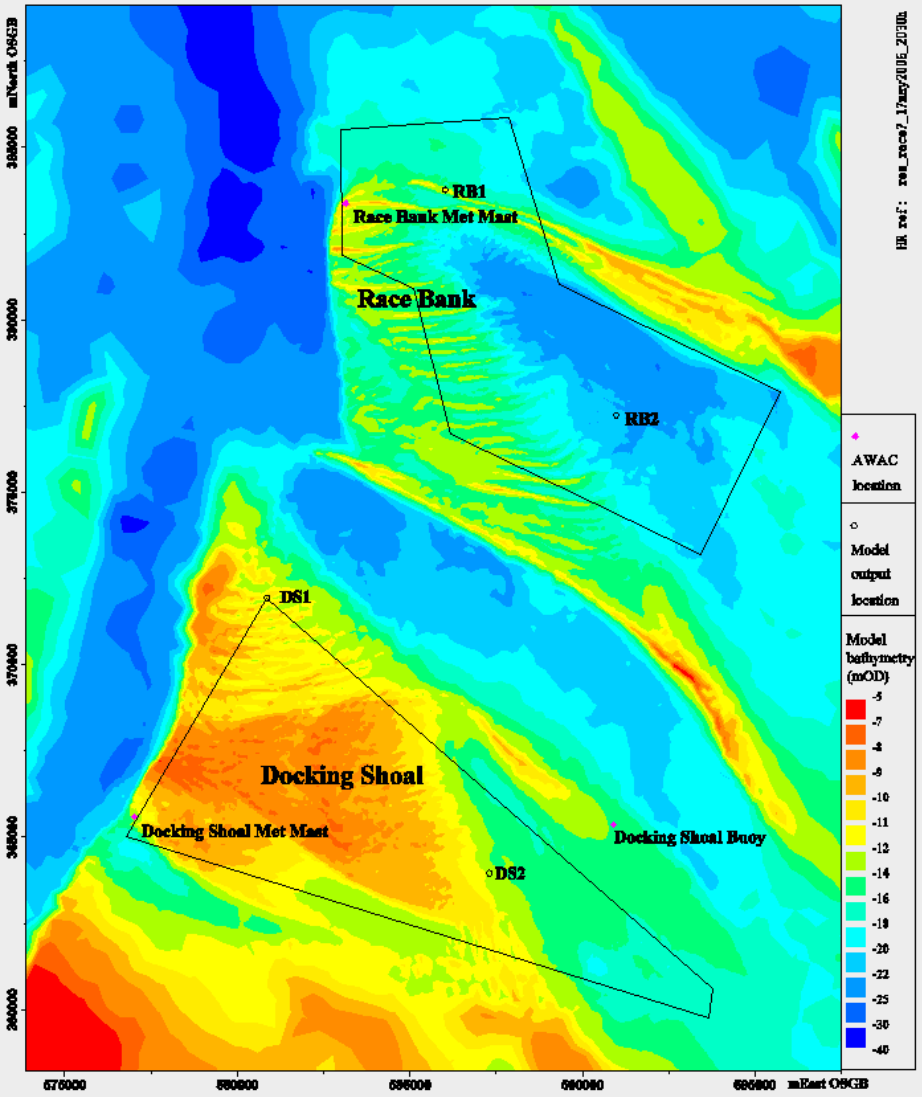
Many ocean wave models linked to global atmospheric models

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

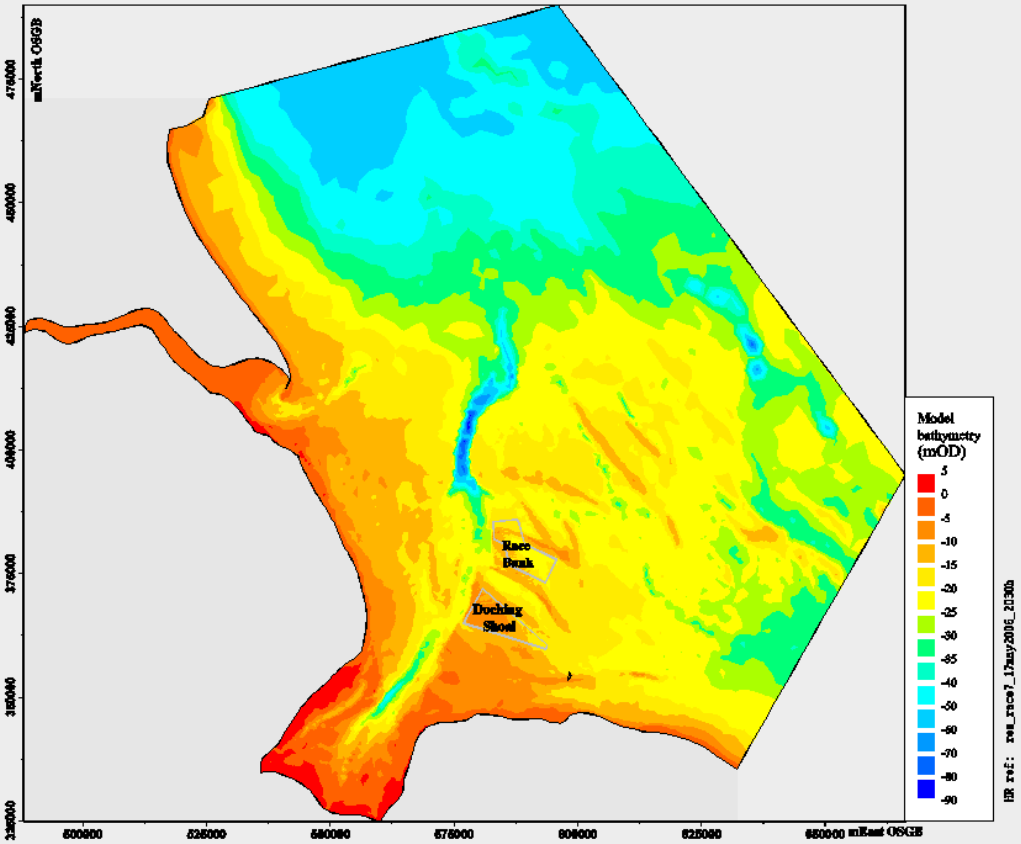


- UK Met Office
- NOAA's CFSR hindcast
- European Centre for Medium-range Weather Forecasting (ECMWF)

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

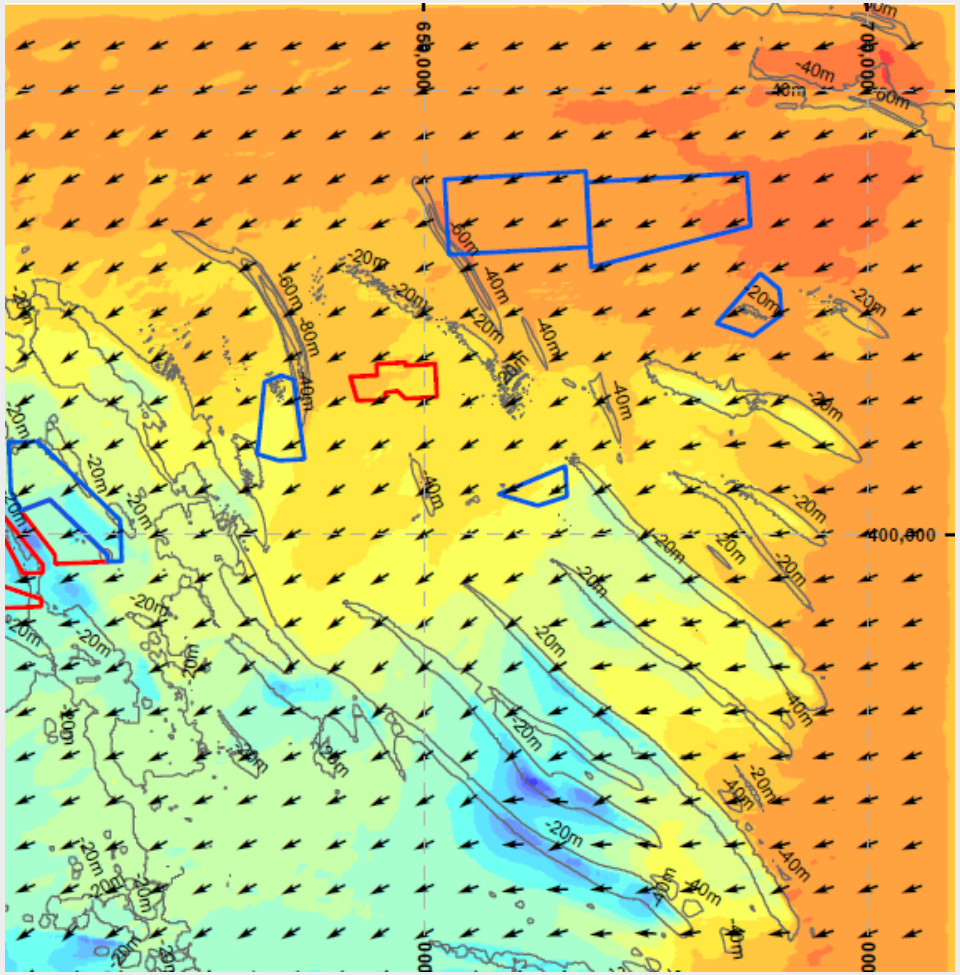
SWAN (Simulating Waves Nearshore) Model

Developed by TU Delft

Fully spectral representation of the wave action balance equation

Processes

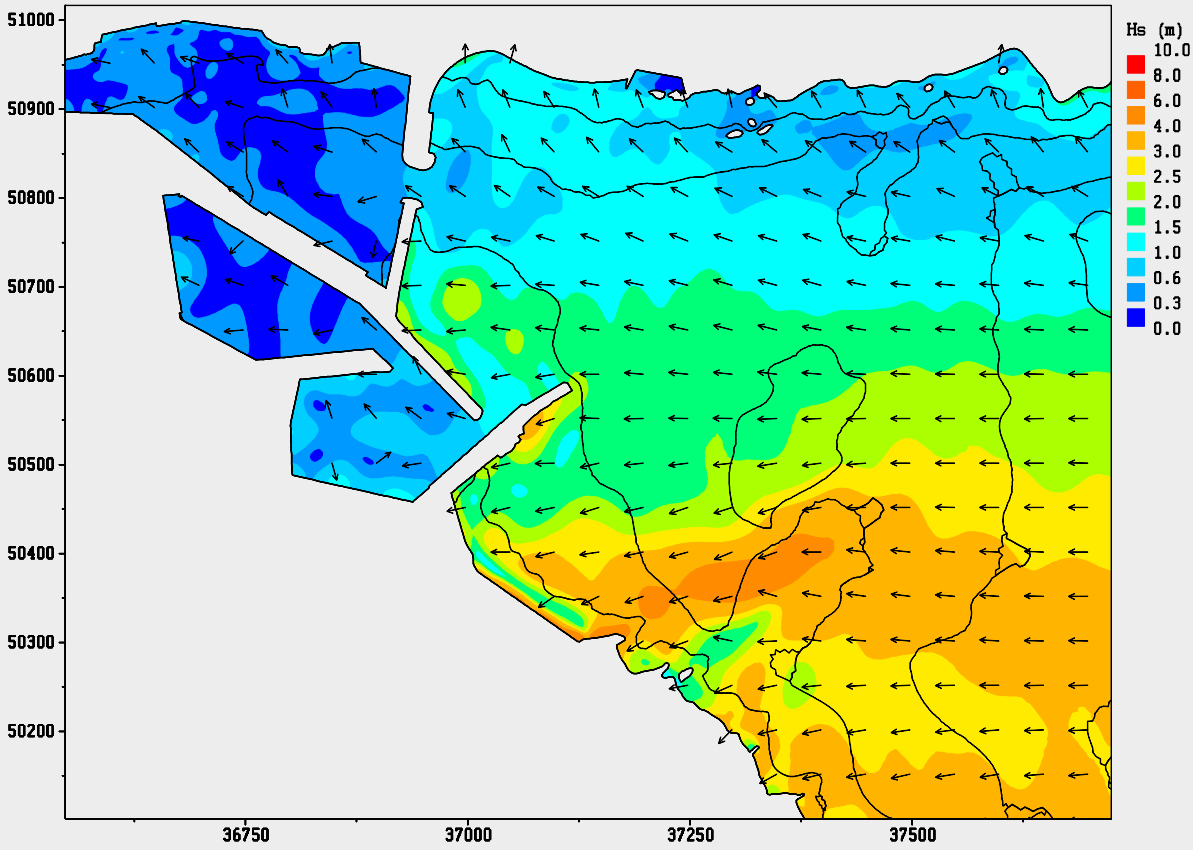
- Refraction
- Linear shoaling
- Wind generation
- Breaking
- White capping
- Friction
- Reflection
- Current interaction
- Wave-wave interaction (quadruplet and triad)
- Diffraction – far field approximation



Waves in Harbours

Phase-resolving models

- Elliptic Mild Slope Equation models
- Boussinesq equation models



Need to consider

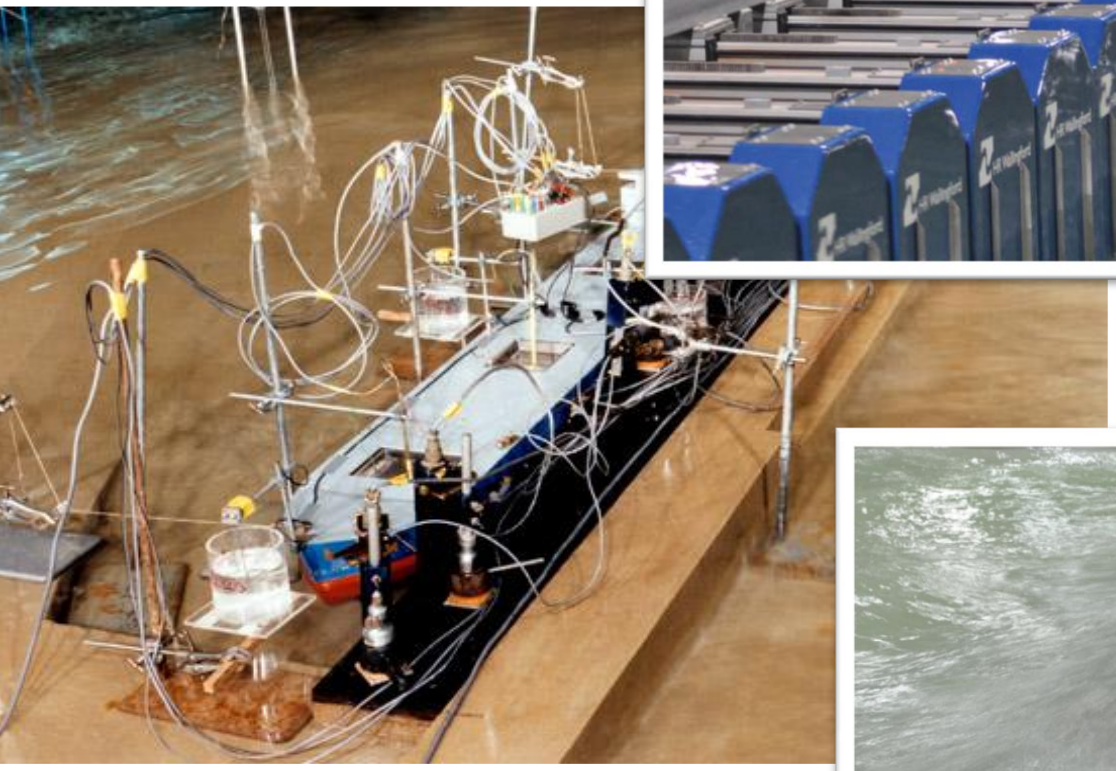
- Partial reflections
- Wave diffraction and interference
- Harbour resonance
- Long Waves

Further work

- Introduce moored vessels into Boussinesq model

Including effect of mooring lines and fenders

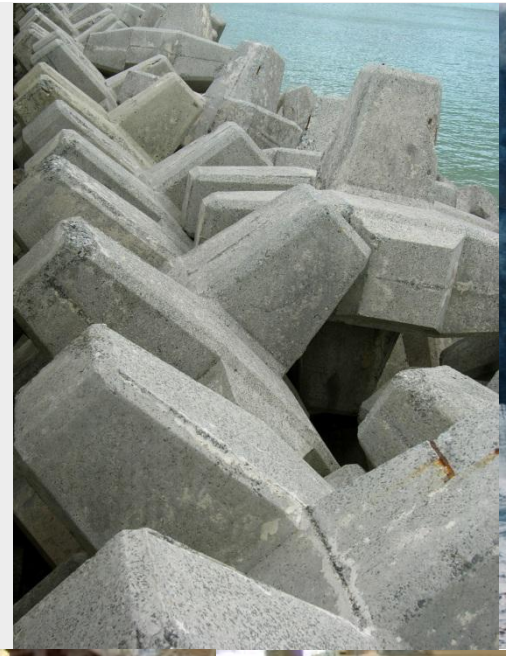
Physical modelling



What do we still use physical models for

Wave-structure interaction

- Stability of breakwaters
- Wave overtopping
- Forces on caissons



Vessel response

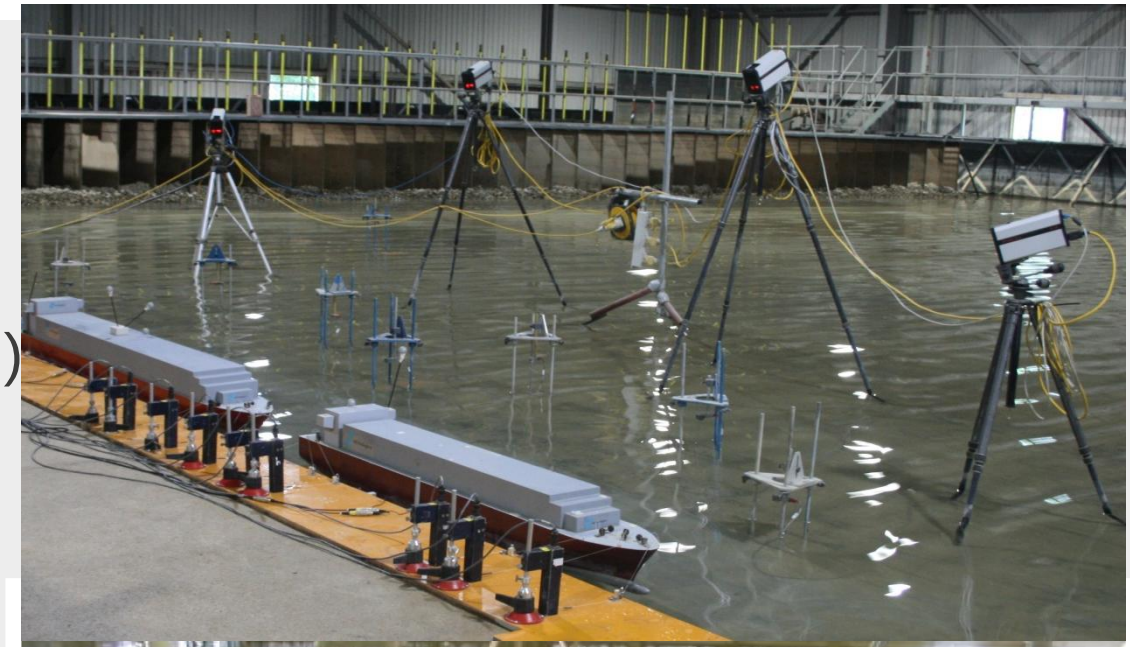
Scour

- New larger scale facility

Moored vessel response

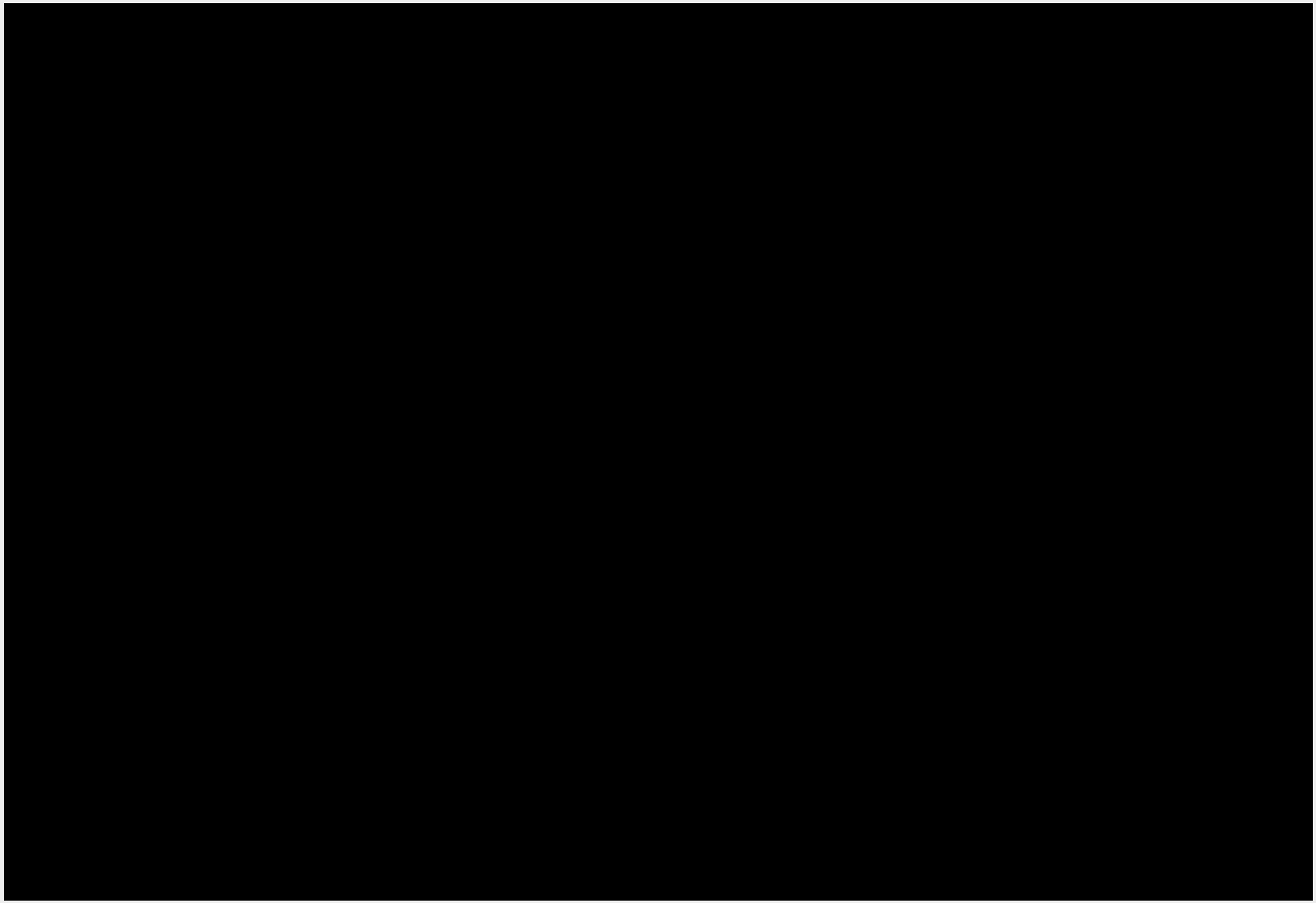
Must represent complexity of:

- Mooring line forces
- Fender forces
- Random waves (directional spectrum)
- Long waves
- Wind and current forces
- Full 6 degrees of freedom movement



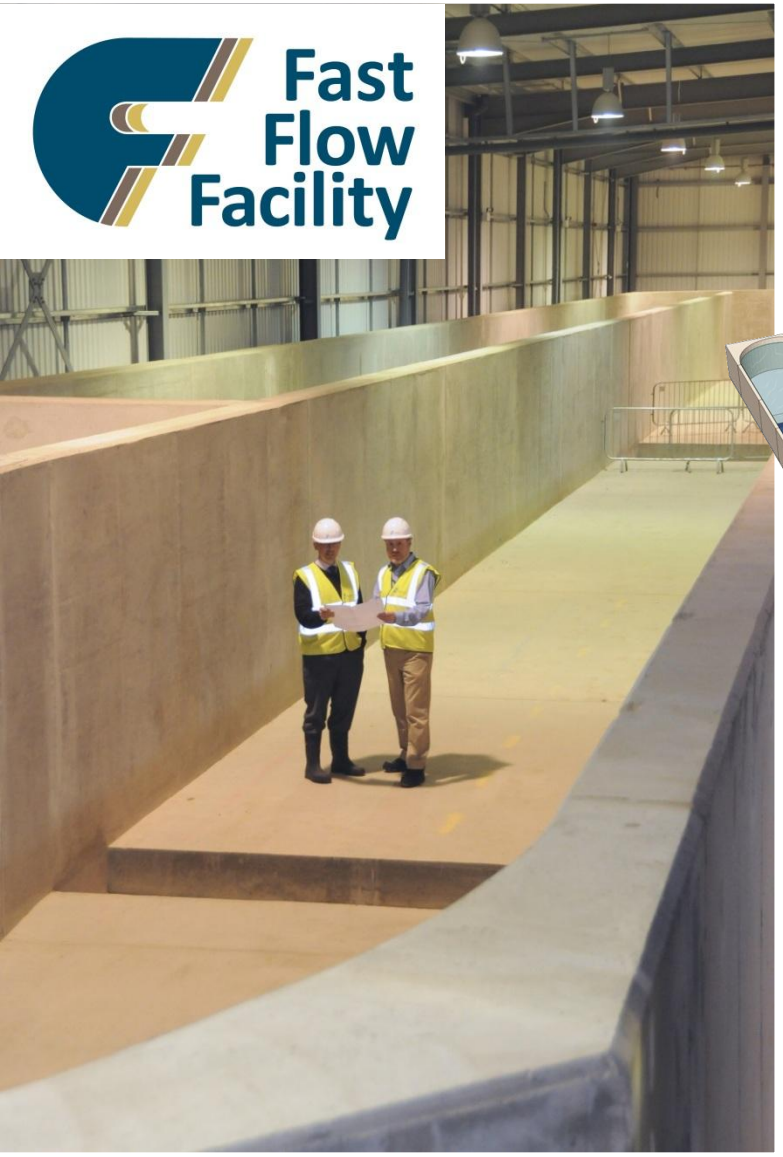
Armour stability tests

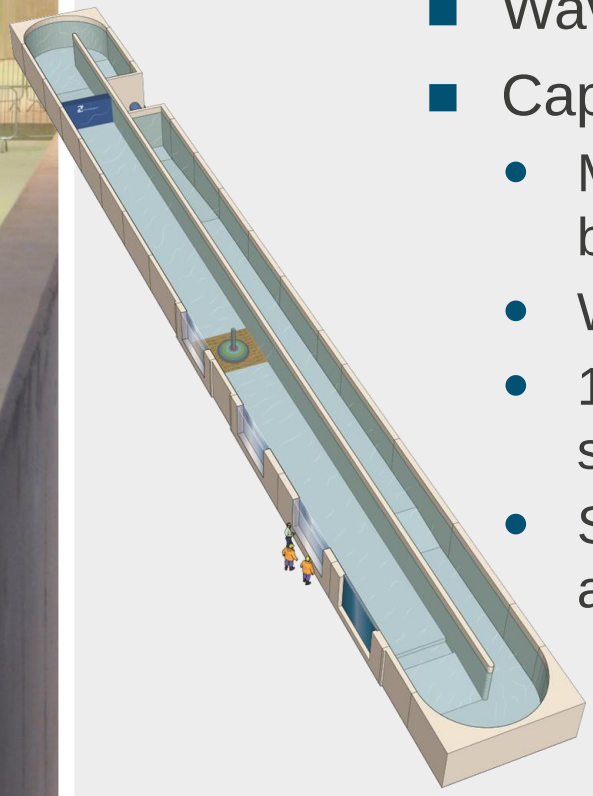
- Random Waves
- Armour stability
- Overtopping



- Good data sets for validation of numerical models

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

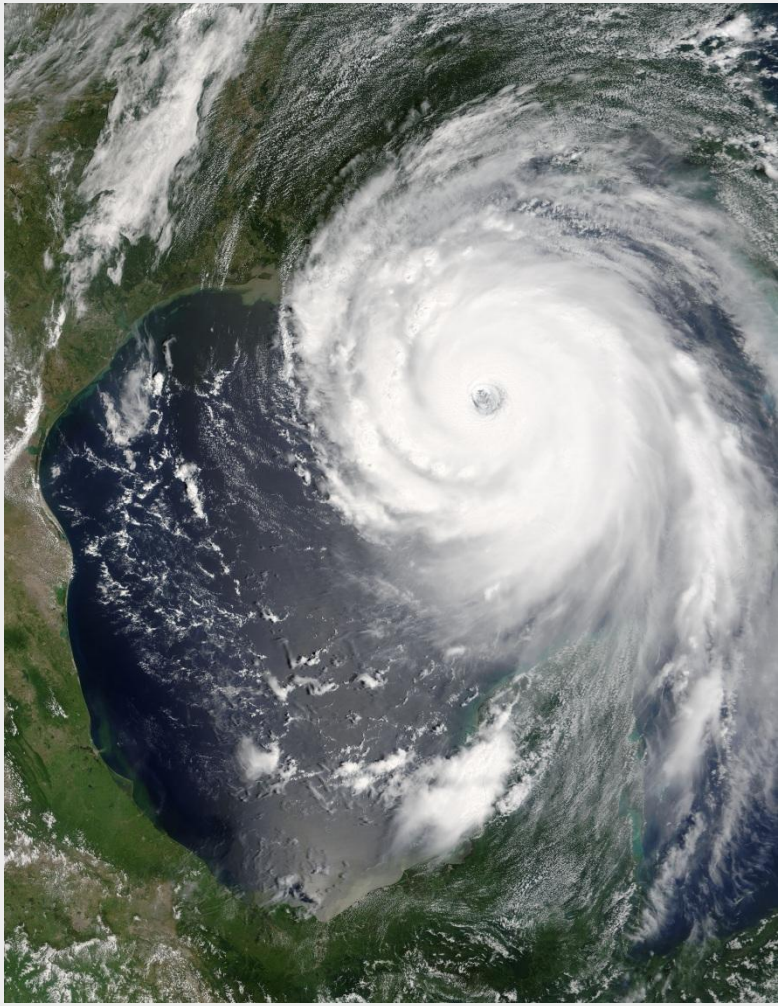
eg Caisson breakwaters or offshore wind turbine

- 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

More detailed modelling in surf zone

Non-linear shoaling of long swell

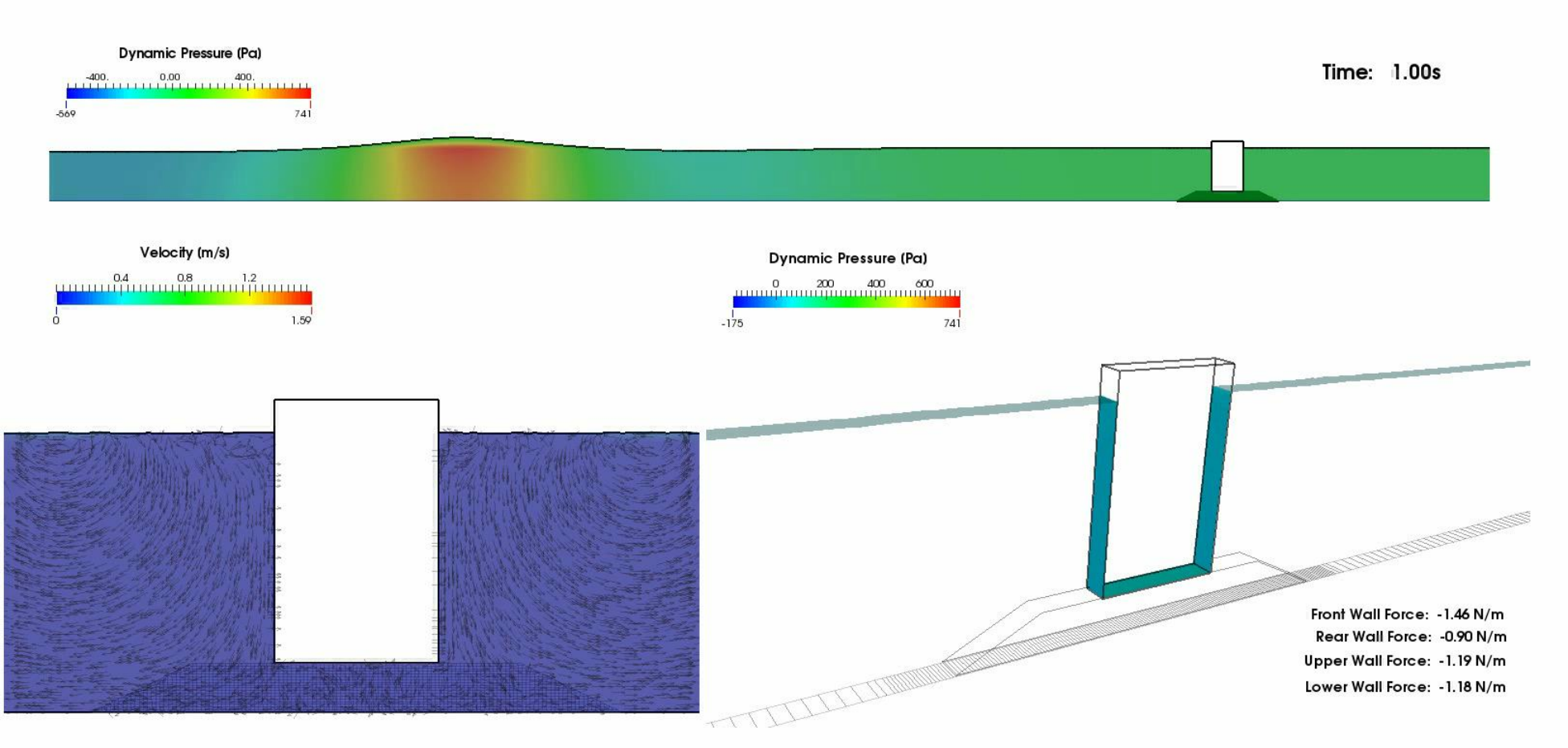
Breaking waves can only be parameterised in Boussinesq model.

Can link with NLSW equation model to model breaking through shock wave theory

More detailed modelling- Numerical flume

CFD- OPENFOAM

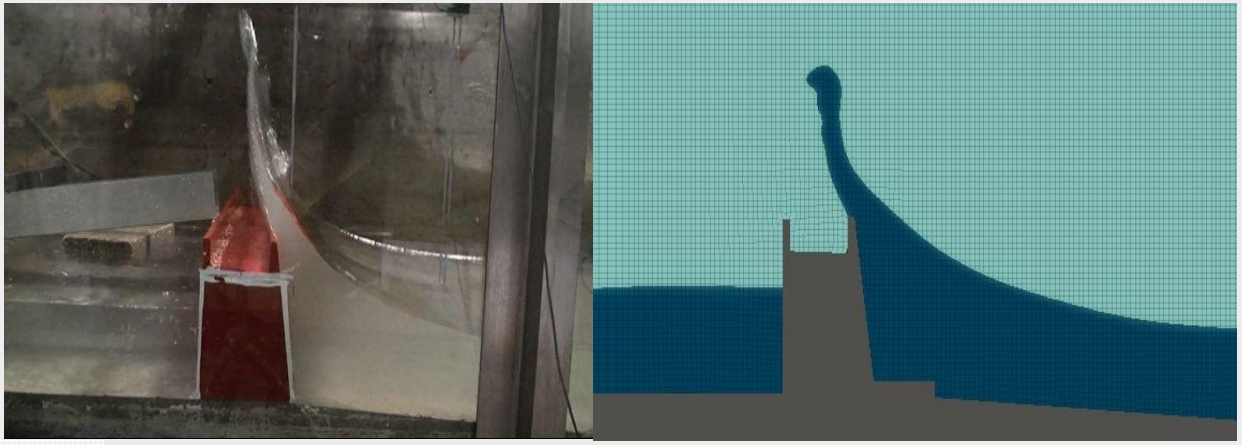
- Solve Navier Stokes equations, VOF method for air/water interface

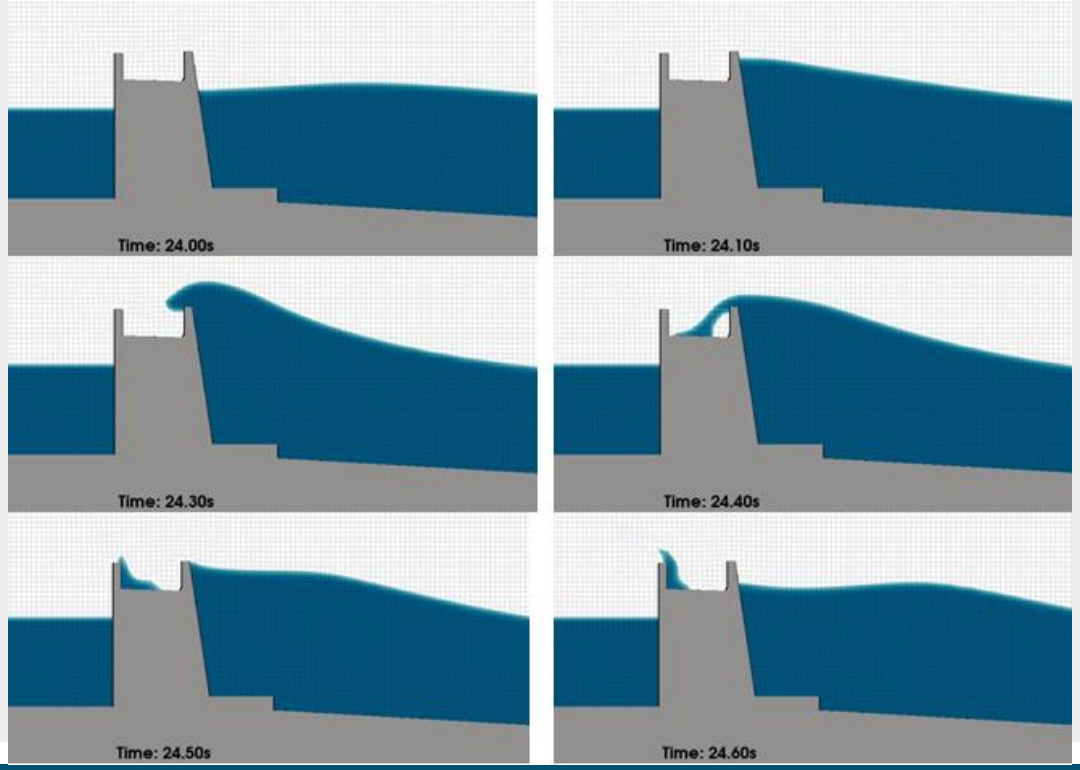


More detailed modelling- Numerical flume

CFD- OPENFOAM

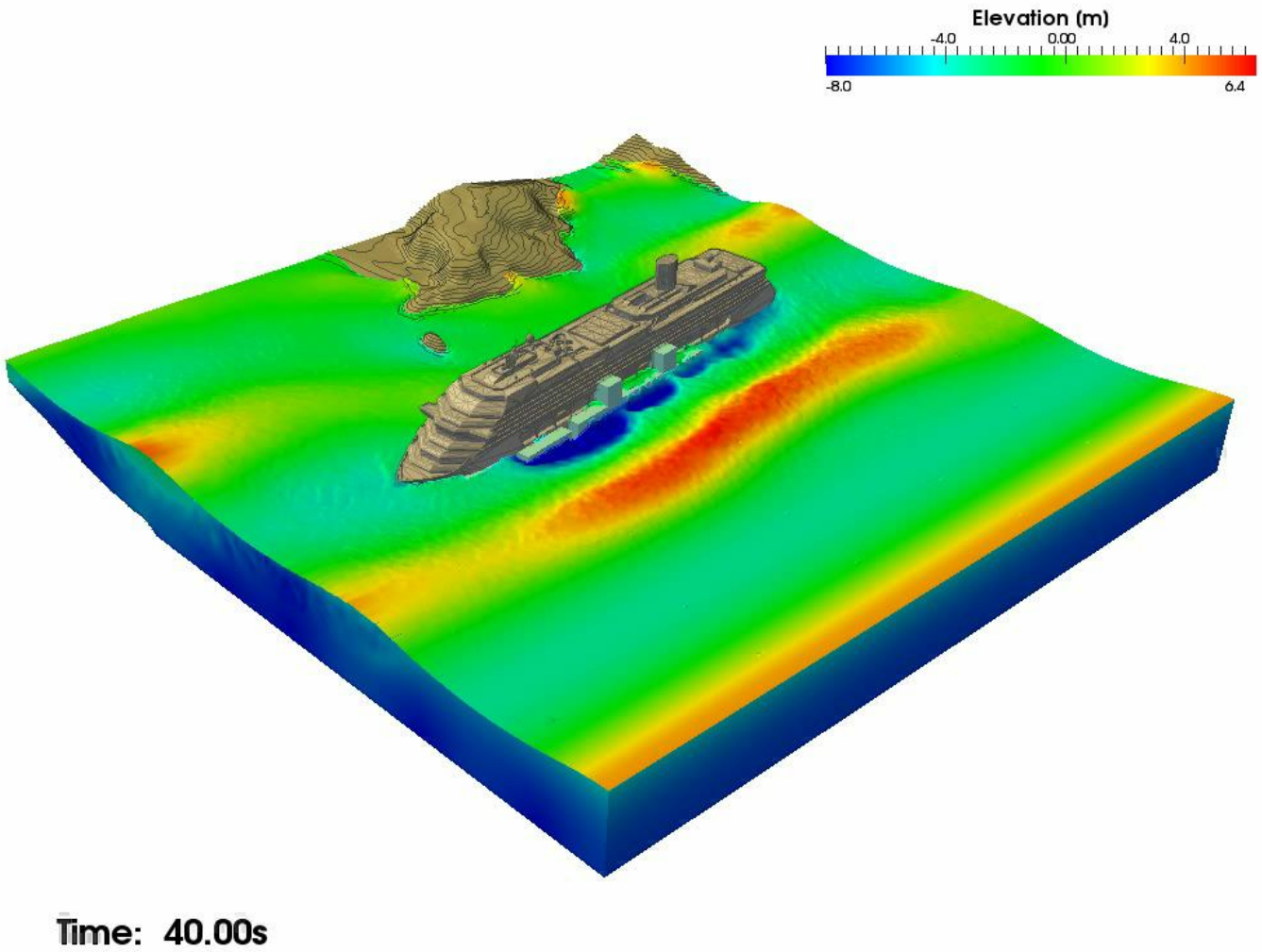
- Impulsive wave overtopping

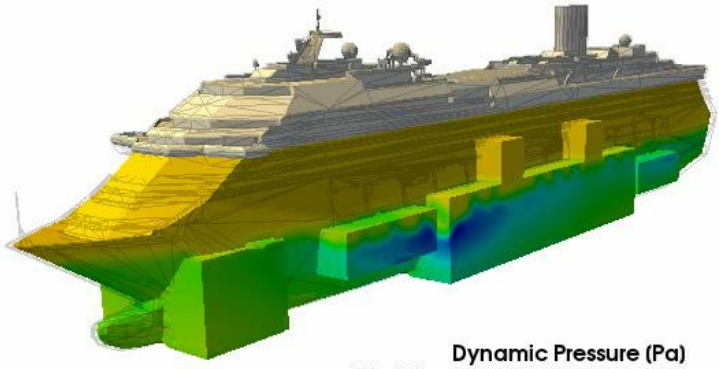


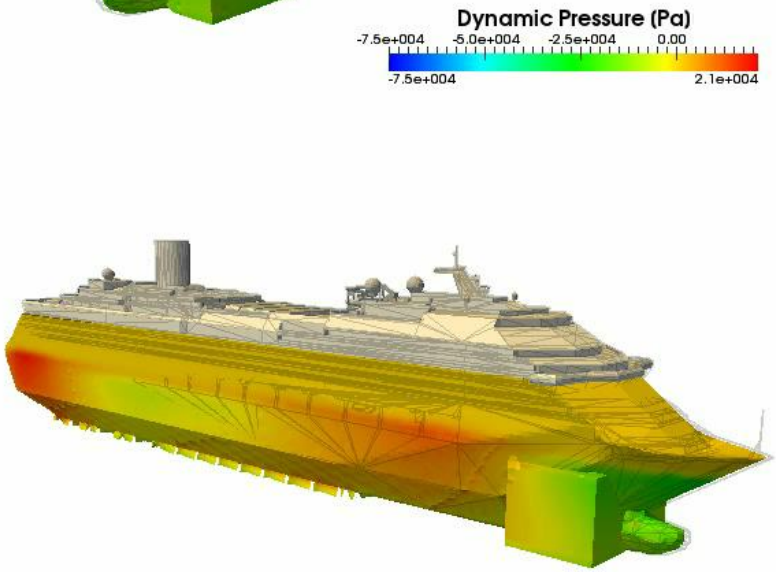


Less severe overtopping sequence

Costa Concordia salvage







More detailed modelling

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

- (Kelly, D.M, Chen, Q and Zang, J, 2014) “PICIN: A Particle-In-Cell Solver for Incompressible Free Surface Flows With Two-Way Fluid-Solid Coupling” Under consideration for publication in SIAM Journal on Scientific Computing (SISC)

- (Kelly D.M, 2012) “Full Particle PIC Modelling of the surf and swash zones” Coastal Engineering Conference 2012

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*

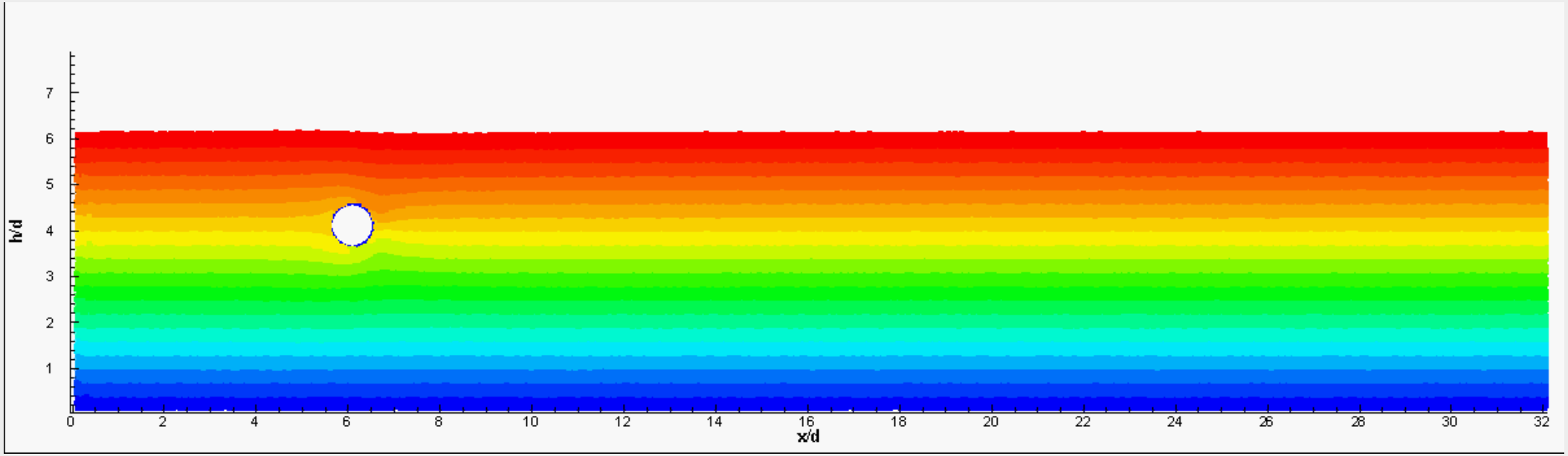
3. Transfer the difference in velocity from the grid to increment the particle velocity (bi-linear interpolation).

4. Advect particles and their associated velocities through the grid velocity field.

Full particle PIC (Particle in Cell) model

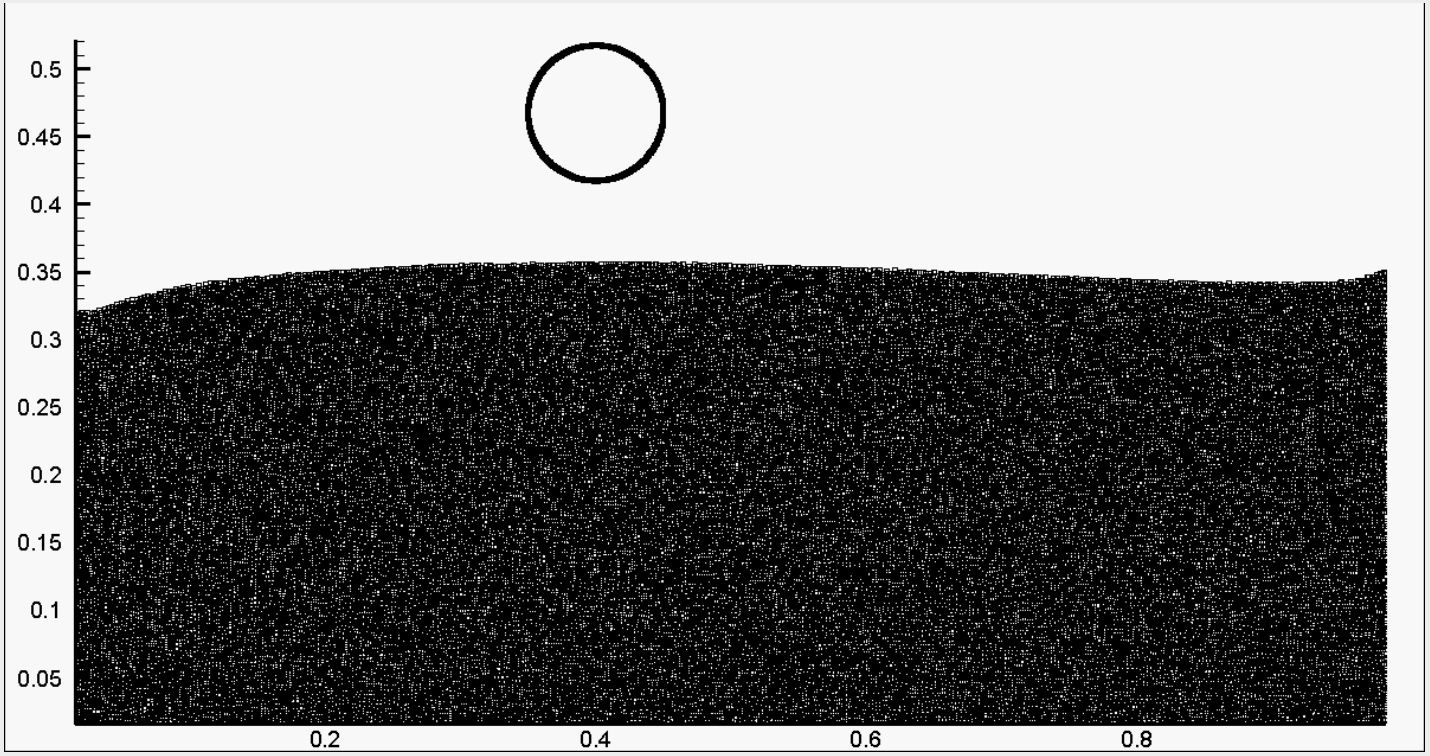
Example Results: Viscous Free Surface Flow Around a Circular Cylinder

- Vertical mixing



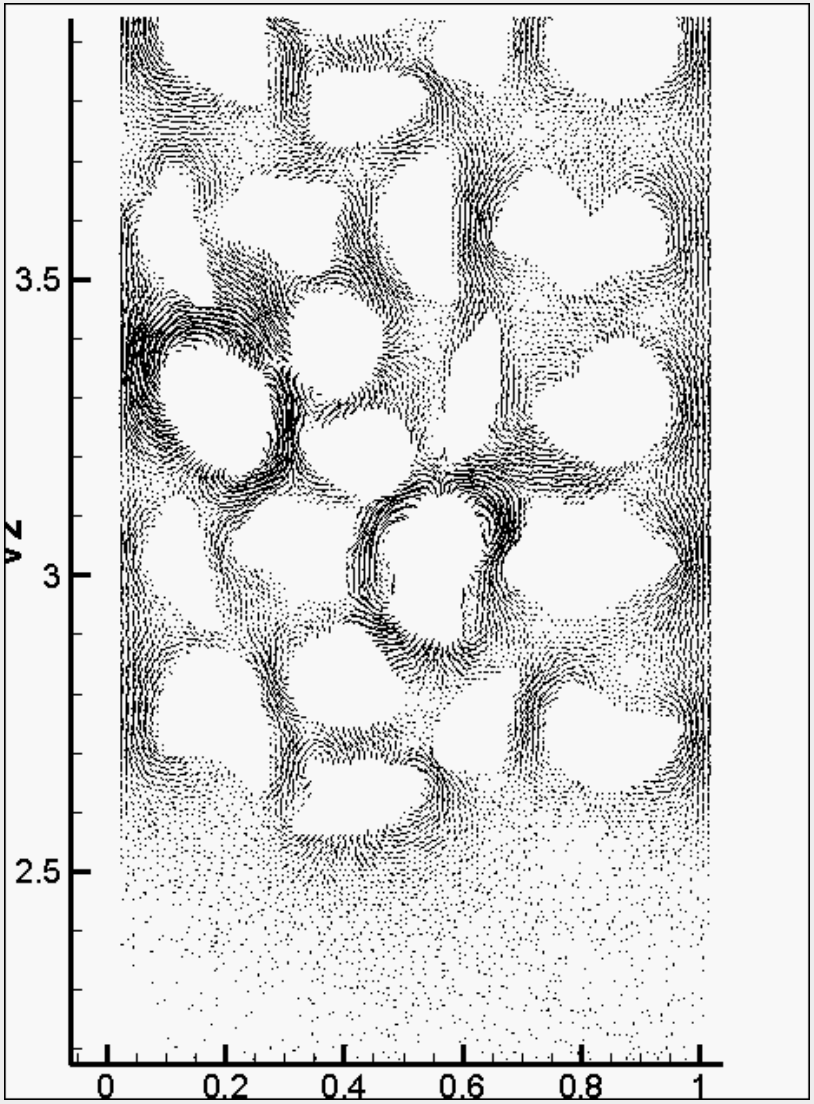
Two-Way Fluid Structure Interaction

- 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

HR Wallingford
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Coastal Wave Modelling

Nigel Bunn, HR Wallingford Ltd n.bunn@hrwallingford.com