The Collaborative Computational Project in Wave Structure Interaction: CCP-WSI+

Professor Deborah Greaves

University of Plymouth

Contents

CCP-WSI
a Collaborative Computational Project in Wave Structure Interaction

- **Introduction to CCP-WSI+**
- CCP-WSI Blind Test Workshops
- CCP-WSI+ Applications
- Coupling and Parallelisation

CCP-WSI+ Team

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Lee Margetts University of Manchester.

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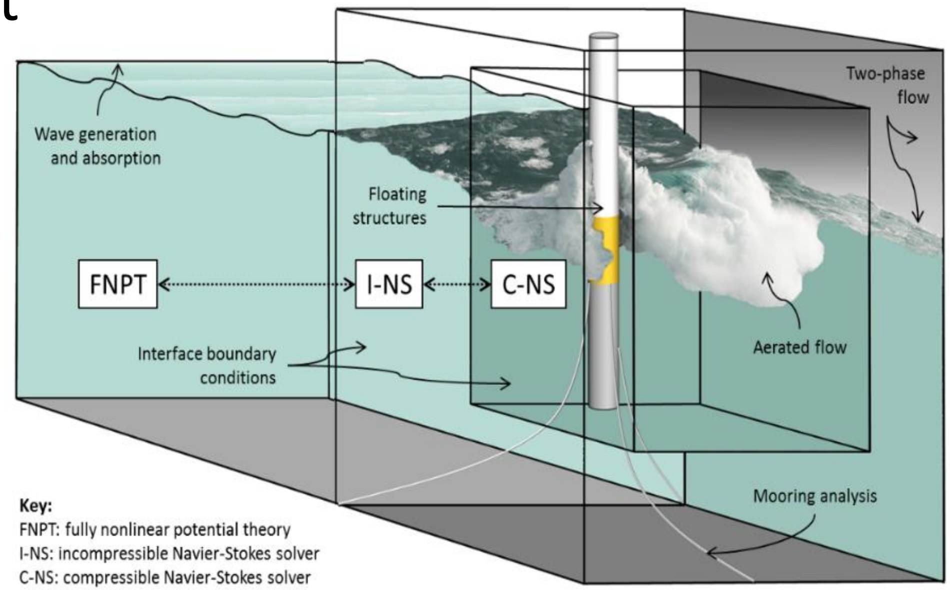
Stephen Longshaw STFC.

Xiaohu Guo STFC Daresbury Laboratory

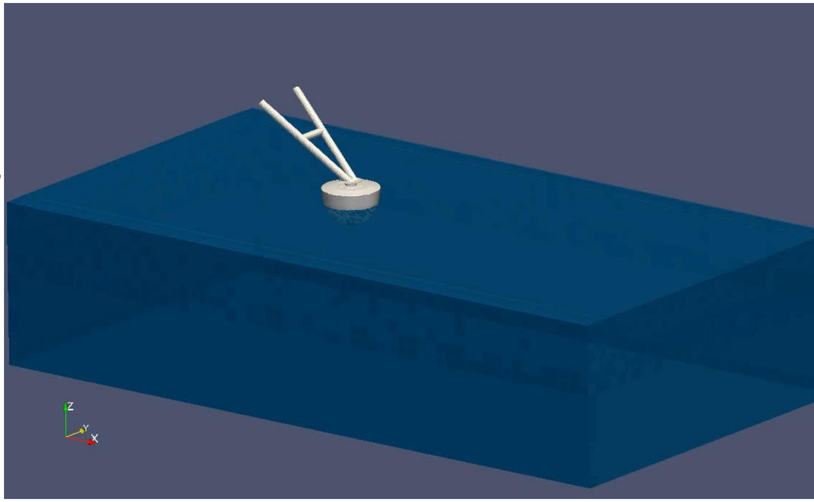
CCP-WSI+ Aims

- Develop and maintain a robust and efficient computational WSI modelling tool
- Build the community of researchers and developers around WSI
- Provide a focus for software development and code rationalisation
- *www.ccp-wsi.ac.uk*



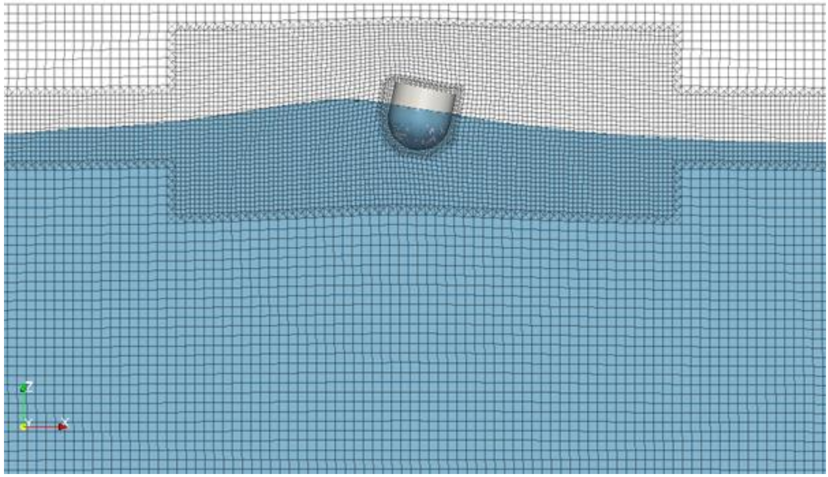
CCP-WSI+ Objectives

- Bring the Computational Fluid Dynamics (CFD) and Computational Solid Mechanics (CSM) communities together.
- Provide training and workshops to support community code development and co-creation.
- Extend the CCP-WSI blind test series.
- Support, investigate and develop code coupling methodologies.
- Support optimisation and parallel implementation on HPC architectures.
- Carry out a software audit on WSI, CFD and CSM; maintain CCP-WSI+ website and management of the code repository.



CCP-WSI+ networking activities

- WSI+ International Code developers' Workshops
- Focus group workshops and webinars
- Blind Test Workshops
- Hackathon: intensive week of coding and tuition
- WSI training courses
- CCP-WSI data Open source code repository
- CCP-WSI+ computation and experiment road mapping
- Industrial pilot projects and secondments
- Outreach activities



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CCP-WSI Blind Test Workshops

CCP-WSI a Collaborative Computational Project in Wave Structure Interaction

Format:

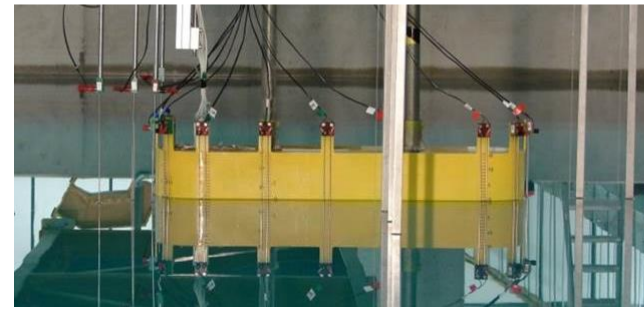
* Participants/volunteers are invited to demonstrate their codes through a series of blind WSI test cases, i.e. without the physical results being made available prior to submission
  * Solutions using any type of WSI model accepted
  * No enforced implementation strategy, e.g. free domain and mesh design

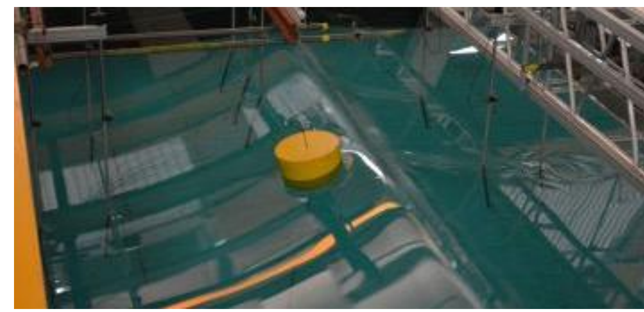
Aims:

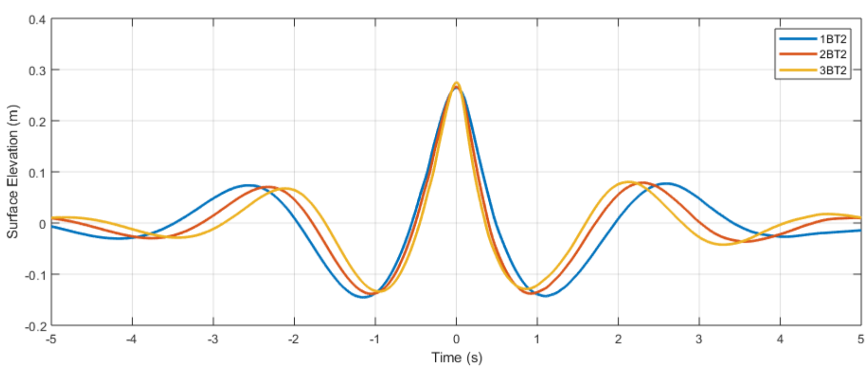
* To bring together numerical modellers within the WSI community
* To assess numerical codes currently in use (software audit)
* To provide a better understanding of the required level of model fidelity in WSI sims
* To help inform the development of future numerical modelling standards (to encourage the practical application of CFD/numerical tools)

Test cases:

* The CCP-WSI Blind Test Series 1
  * Focused wave interactions with a fixed FPSO-like structure
  * Waves of different steepness and incident angle
  * Surface elevation/run-up and pressure on hull
* The CCP-WSI Blind Test Series 2 & 3
  * Focused wave interactions with floating structures
  * Waves of different steepness
  * 2 different floater geometries (w. linear mooring)
  * Motion of floater and mooring line tension
  * Empty tank surface elevation (incident wave)

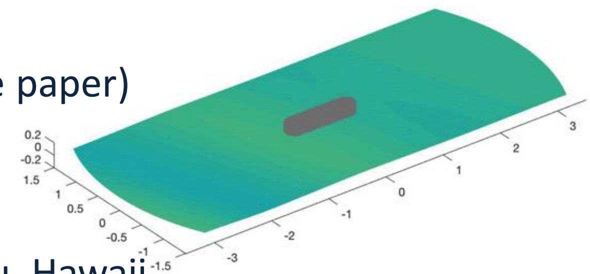






Participants/contributions:

- The CCP-WSI Blind Test Series 1
  - Held in conjunction with ISOPE 2018 (10-15 June 2018), Sapporo, Japan
  - 34 participants from 16 institutions/companies
  - 10 submissions -> 5 journal publications (incl. main comparative paper)
- The CCP-WSI Blind Test Series 2
  - Held in conjunction with EWTEC 2019 (3 September 2019), Naples, Italy
  - 30 participants from 13 institutions/companies
  - 11 submissions -> 10 journal publications (incl. main comparative paper) [in review]
- The CCP-WSI Blind Test Series 3
  - Held in conjunction with ISOPE 2019 (16-21 June 2019), Honolulu, Hawaii
  - 30 participants from 13 institutions/companies
  - 10 submissions -> 9 journal publications (incl. main comparative paper)



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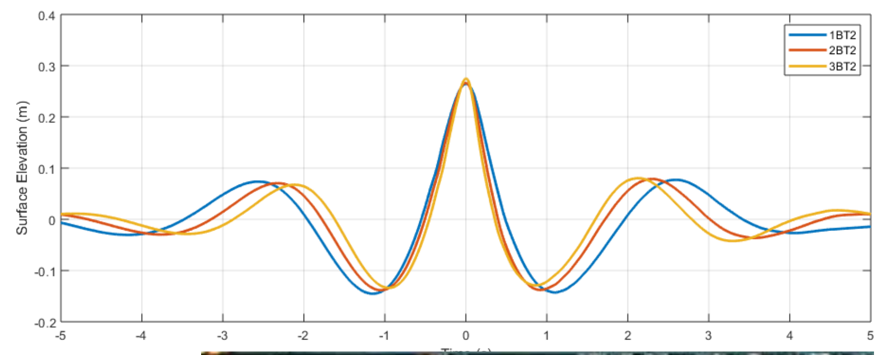
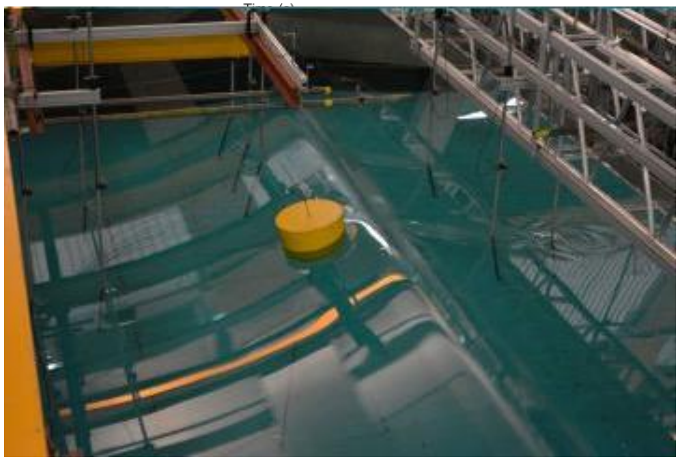
CCP-WSI Blind Tests Series 2: Codes

Code	Discretization scheme	Theory	Time stepping	Turbulence treatment	Free-surface treatment
PIC (in-house)	FDM+Meshless	NS	dynamic	laminar	MAC (1-phase)
Hybrid FNPT/NS (in-ho.)	FEM/FVM	FNPT/NS	dynamic	inviscid/laminar	1-phase/VOF
OpenFOAM (source)	FVM	NS	constant	laminar	VOF
LPT+WAMIT (in-house)	BEM	LPT	-	inviscid	linearised
Hybrid FNPT/SWENSE (in-h)	Spectral/FVM	FNPT/NS	constant	laminar	1-phase/VOF
OpenFOAM (overset)	FVM	NS	dyn.(Co 0.30)	RANS (SST)	VOF
StarCCM+	FVM	NS	constant	RANS (SST)	VOF
WECSim 1	BEM	LPT	constant	inviscid	-
Nonlinear Froude-Krylov	Analytical	LPT	const. (0.04s)	-	-
OpenFOAM (w2F)	FVM	NS	dyn.(Co 0.50)	laminar	VOF
WECSim 2	BEM	LPT	-	inviscid	-

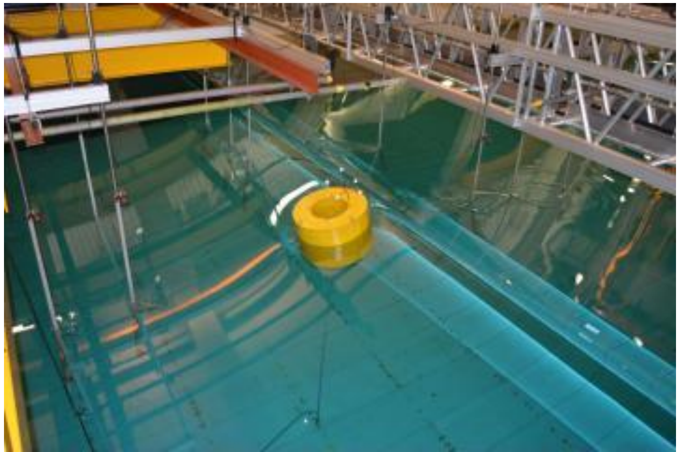
CCP-WSI Blind Tests Series 2: Test Cases



* Incident waves
  * 3 focused wave (NewWave) groups
  * COAST Laboratory Ocean Basin
  * Water depth, h = 3m
  * Steepness, kA = 0.129 – 0.193 (nonbreaking)
  * Fixed crest height (An = 0.25m), different peak frequency (PM spectrum, 0.358 < fp < 0.438 Hz, Hs = 0.274m)

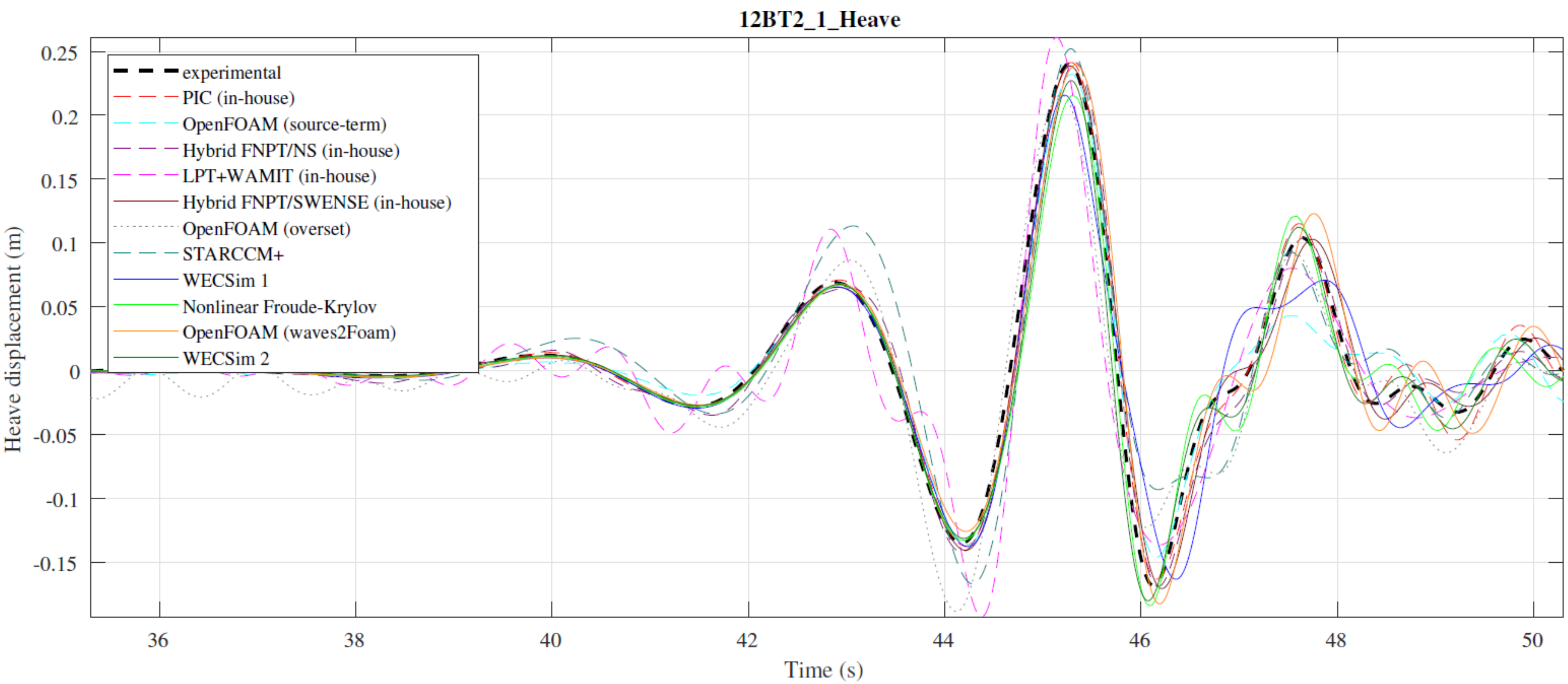


* Release Data
  * Time series data of surface elevation in the empty tank, i.e. no structure
  * 13 wave probe locations
  * Structure and mooring properties



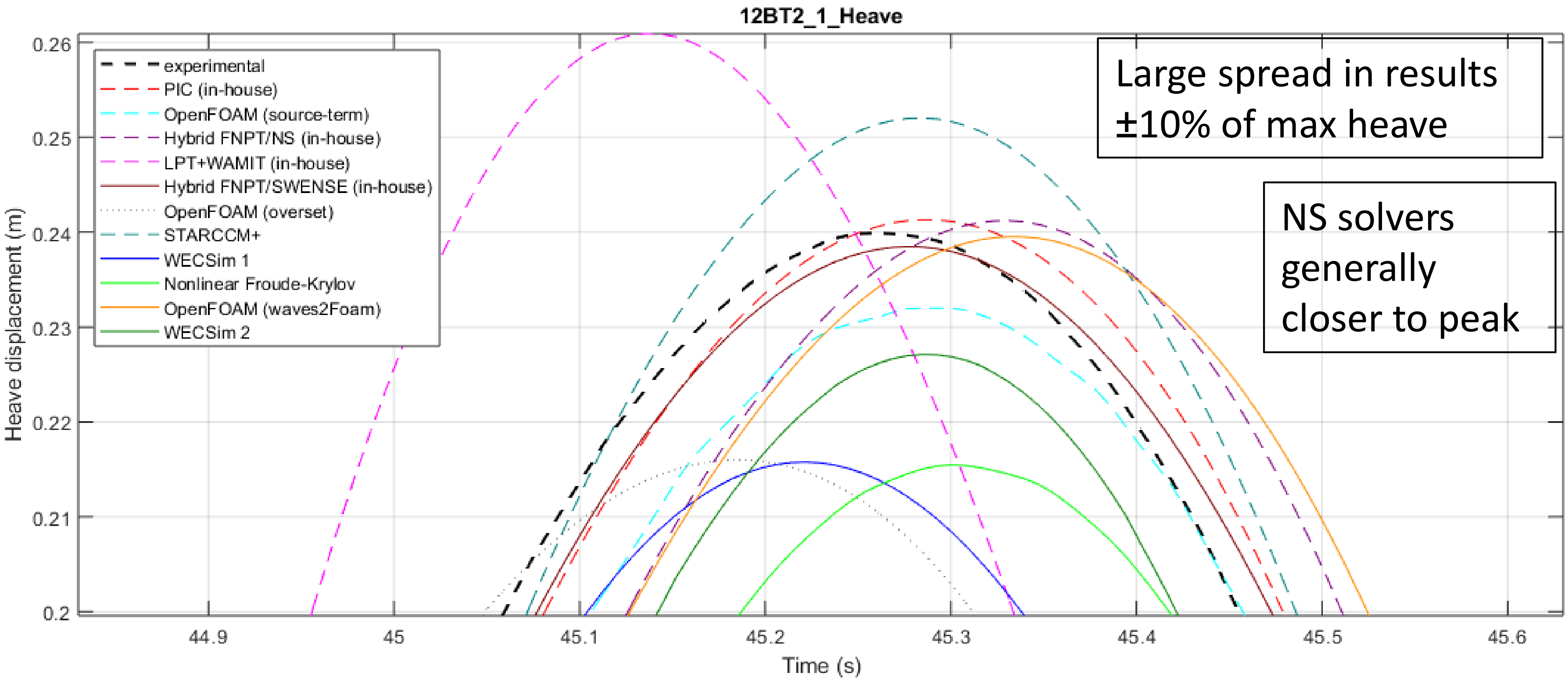
Submissions: Heave Response (blind)

* Heave response (time series) of Geometry 1 (hemispherical-bottomed)



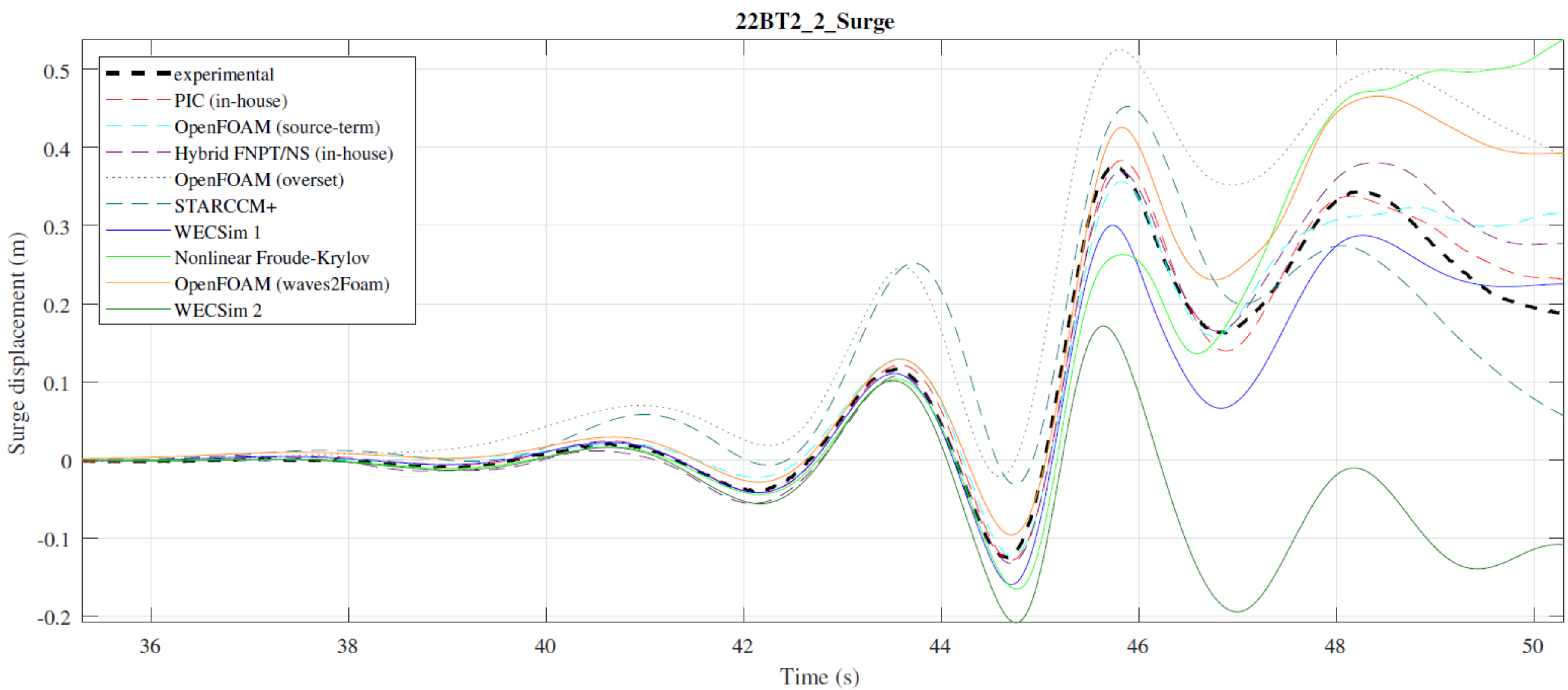
Submissions: Heave Response (blind)

* Heave response (time series) of Geometry 1 (hemispherical-bottomed)



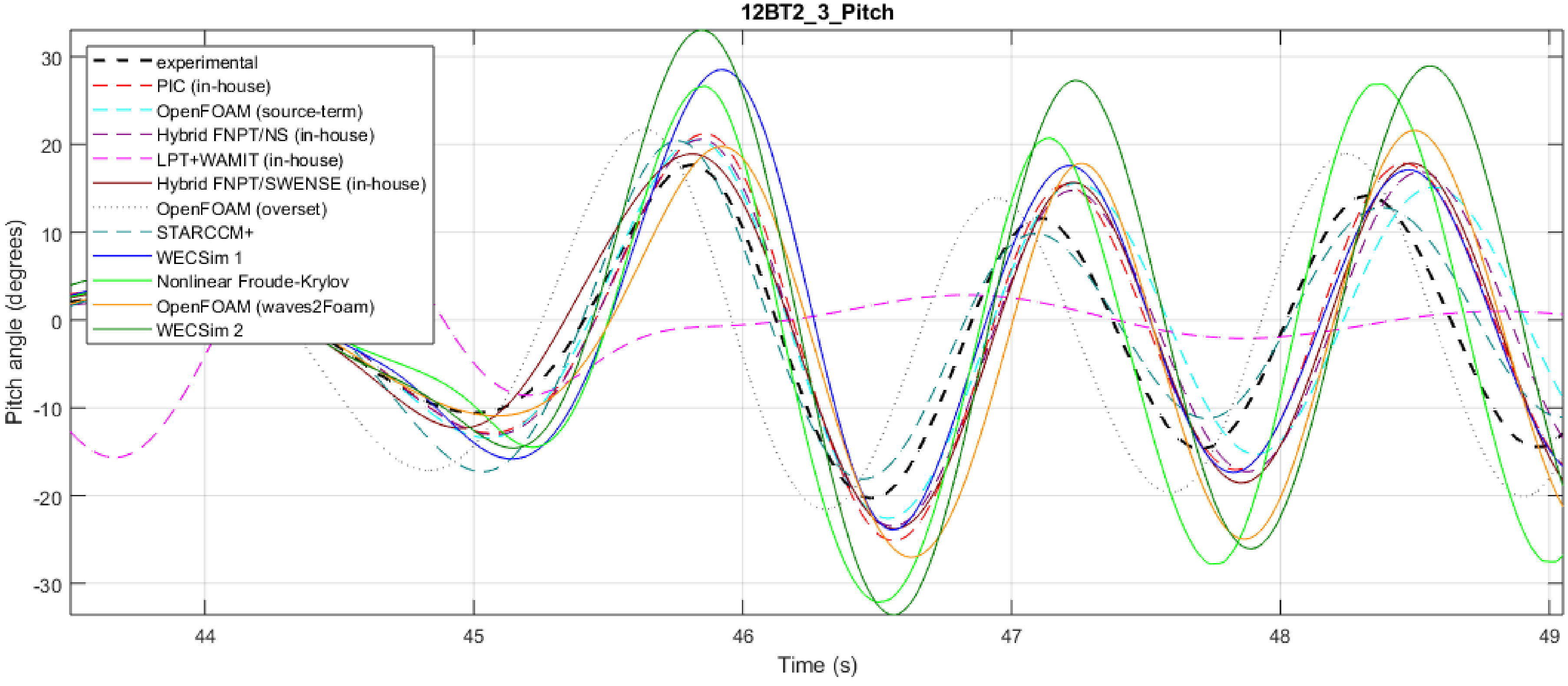
Submissions: Surge Response (blind)

* Surge response (time series) of Geometry 2 (moon-pool buoy)



Submissions: Pitch Response (blind)

* Pitch response (time series) of Geometry 1 (hemispherical-bottomed)



Conclusions:

* Coordinating these studies needs careful planning to achieve a parametric (useful) understanding of numerical capability
  * Need very well defined test cases
  * Meaningful comparisons require careful reduction in variables (needs agreed standardisation)
* Considerable scatter in the solutions from ‘similar’ models dominates
* To find a distinction between numerical models of different fidelity, the test cases need to span a step-change in physical phenomena
* Quantifying predictive capability is not trivial either
* Surrogate models, i.e. lower-fidelity methods ‘informed’ by higher-fidelity methods may be the best compromise between accuracy and speed
  * For example, viscous drag coefficients in a model based on linear potential theory informed by solutions using a NS solver

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ParaFEM

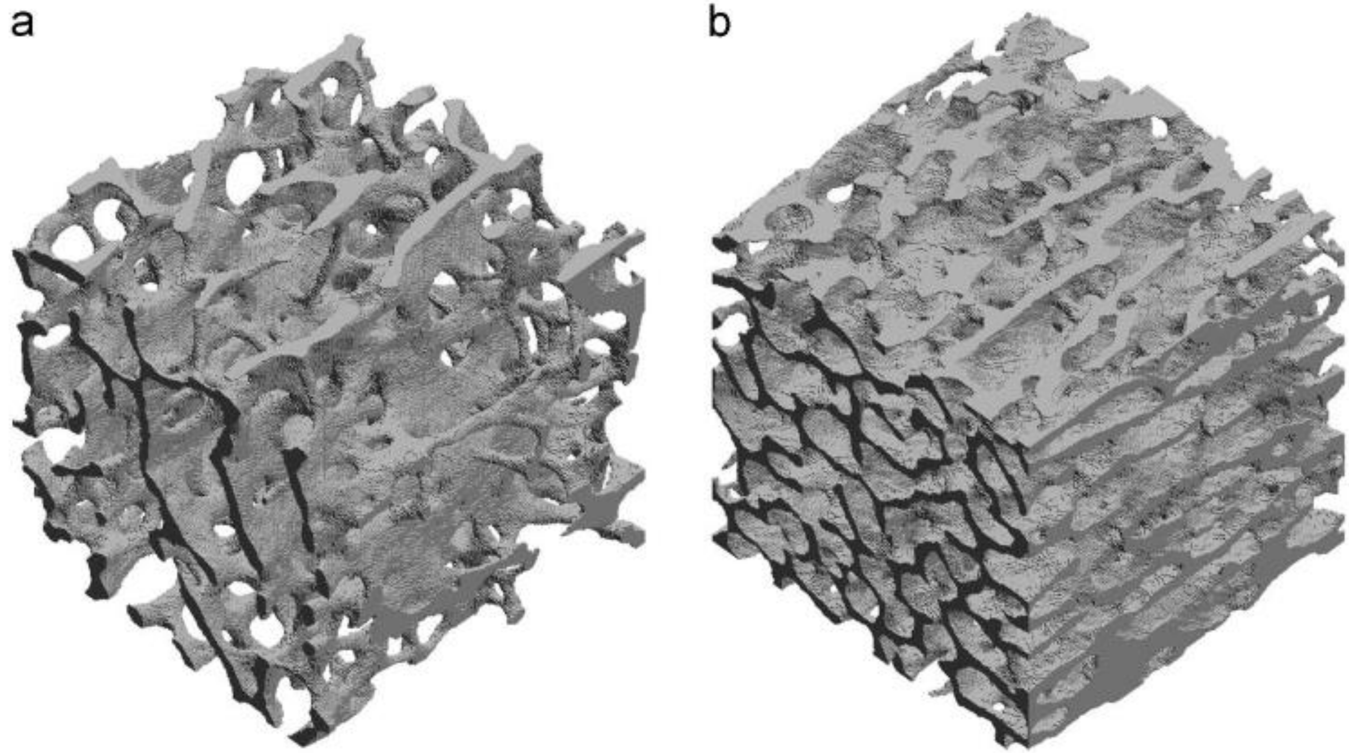

Figure 3: *FE meshes of (a) porous and (b) dense bone (Levrero et al., 2016)*

Create constitutive models for materials that have undergone degradation (here disease) …

Using ParaFEM to solve problems with ½ billion degrees of freedom on >10,000 cores on ARCHER

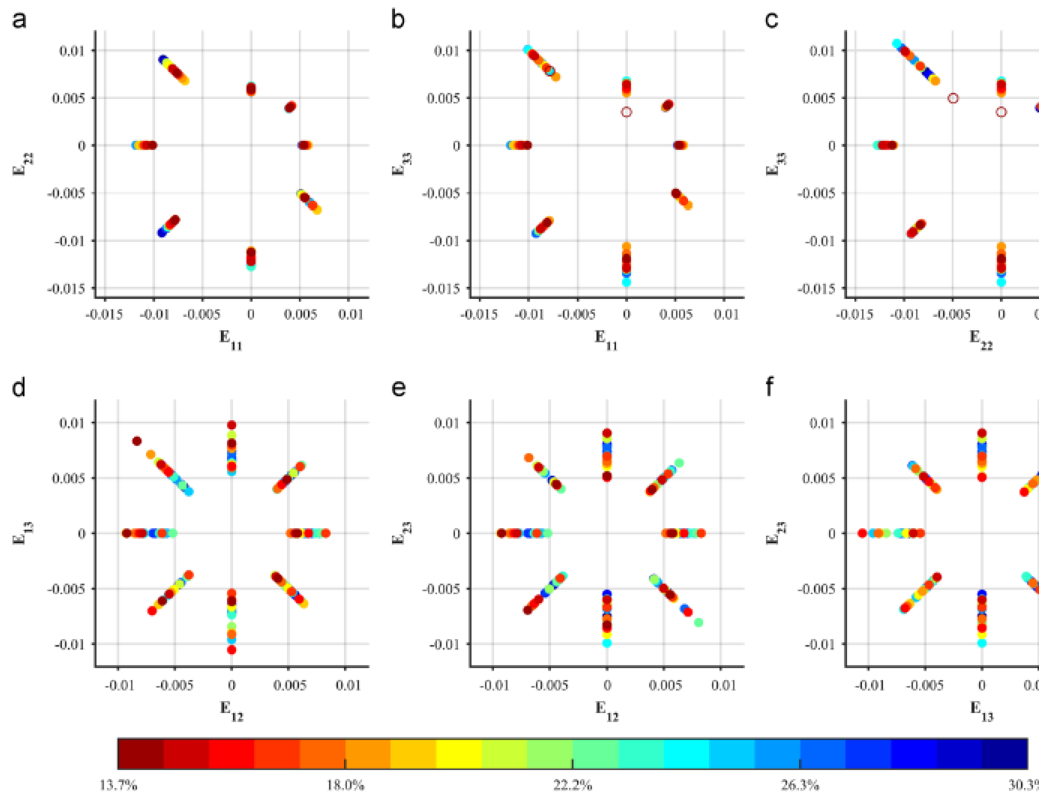

Figure 4: Macroscopic yield points (Levrero et al., 2016)

The same methodology can be applied to corroded or damaged engineering materials …

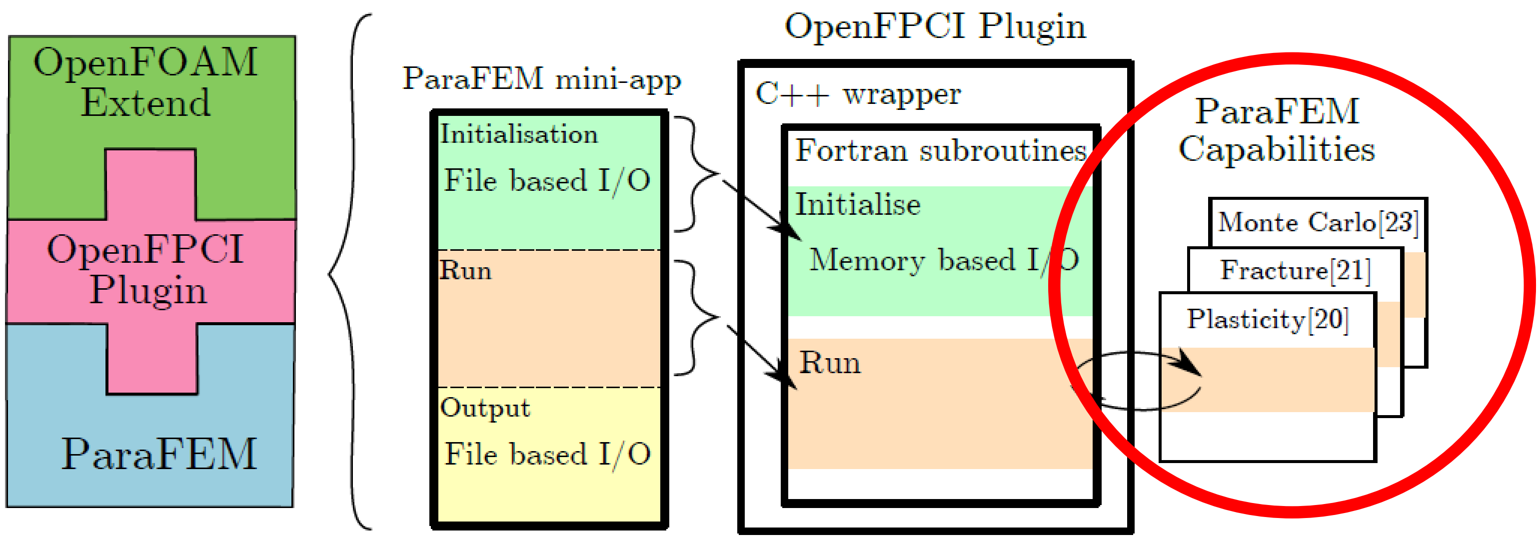

Figure 1: Summary of an OpenFPCI plugin, highlighting the decomposition of a ParaFEM mini-app into two subroutines, initialise and run. In the development of a new OpenFPCI plugin only the run routine needs to be swapped and an example of ParaFEM's capabilities are shown for possible mini-app developments

Framework enables solid mechanics innovations in ParaFEM to be used in FSI…

Extreme loading n FOWTs

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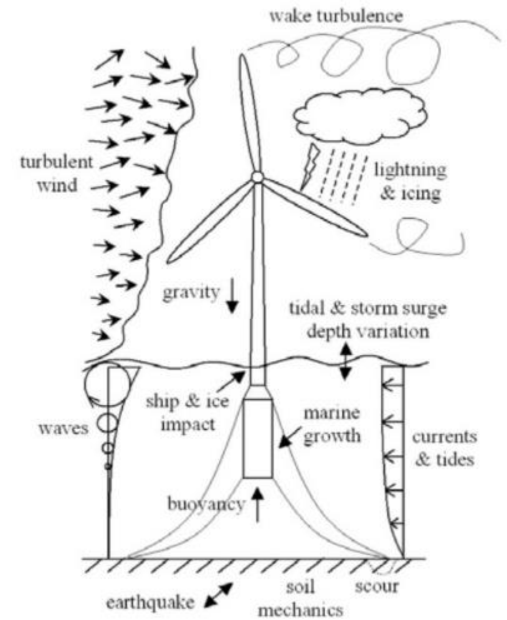
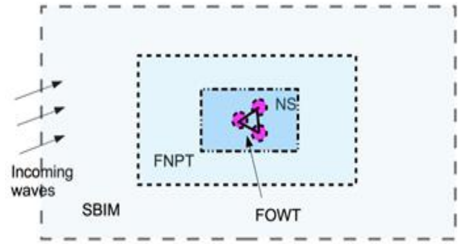
* Funded by EPSRC for three years (Oct 2019 – Oct 2022) with a total value of £1.46M (FEC);
* Five project partners and supported by eight industrial partners;
* To evaluate extreme loading on and the survivability of FOWTs;
* A programme of joint numerical and experimental work;
* Integrated approach to the analysis of aerodynamic and hydrodynamic loads on FOWTs.



Environmental loads on FOWTs



Domain decomposition

Manchester Metropolitan University
MARINE SCIENCE & ENGINEERING WITH PLYMOUTH UNIVERSITY
CITY UNIVERSITY LONDON
UKRI Science and Technology Facilities Council
Lancaster University

Dynamic response of FOWT under focused waves

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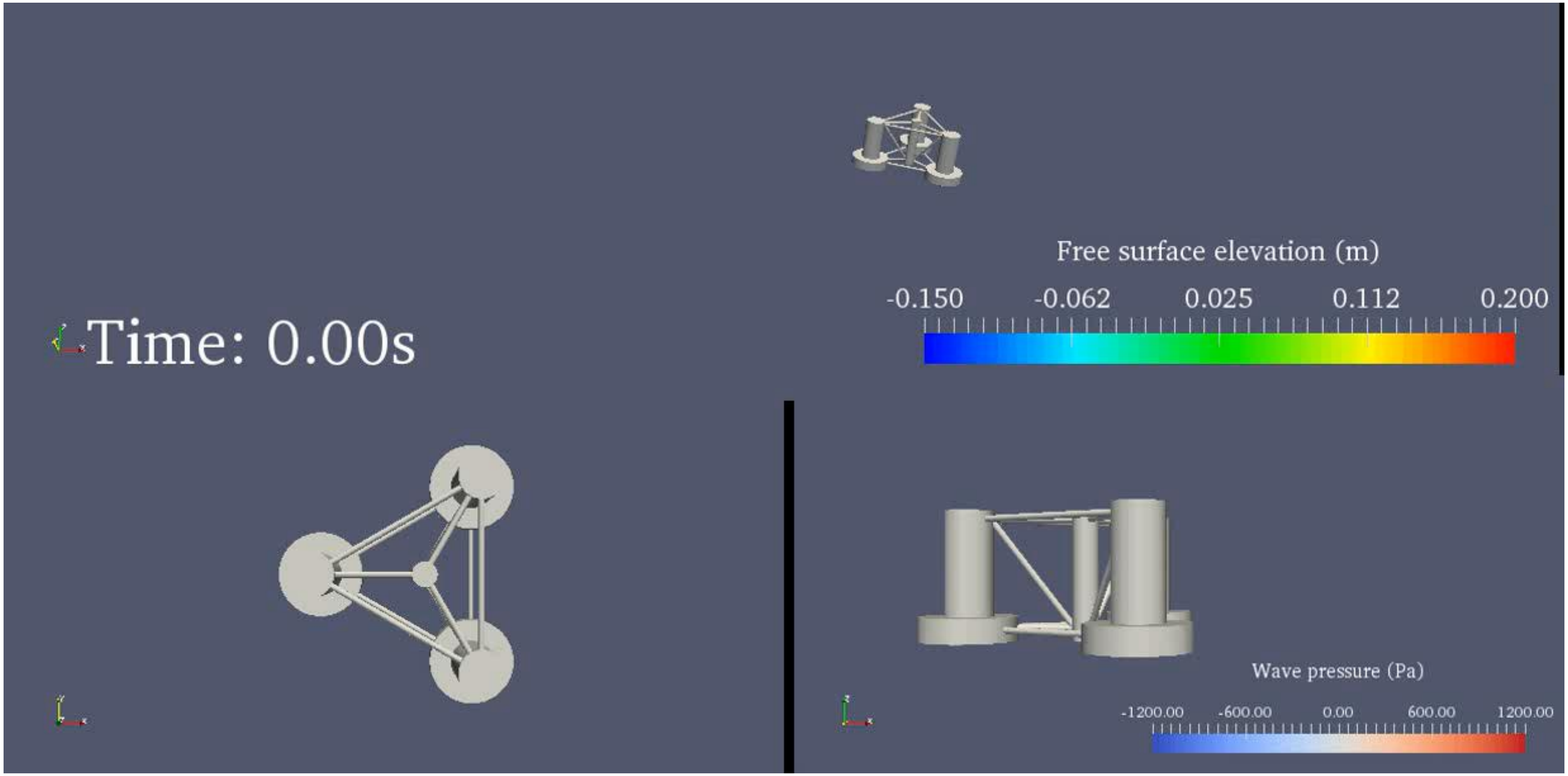
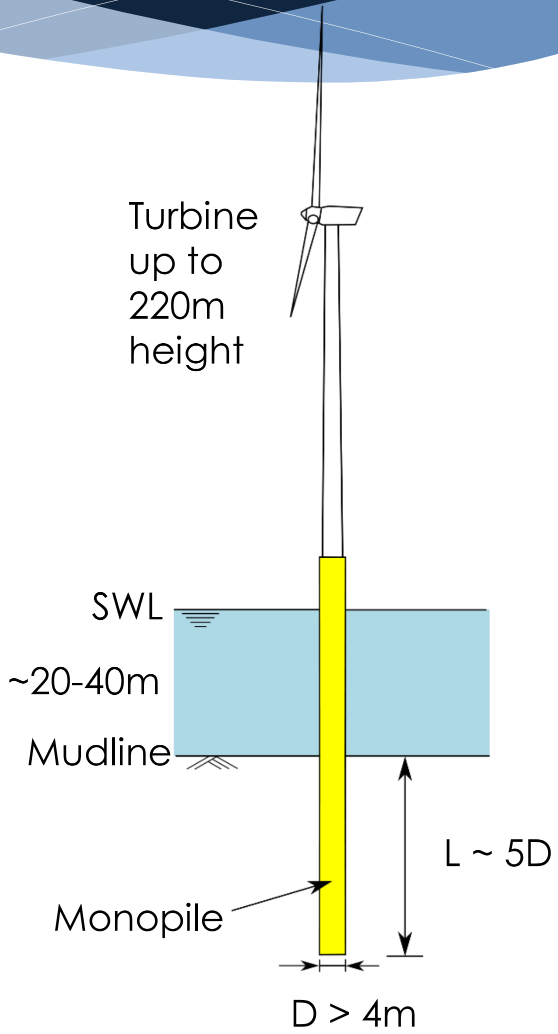
Focused waves: NewWave theory + Pierson-Moskowitz spectrum



Manchester Metropolitan University

Monopiles

- Monopiles are the most **popular foundation type** for offshore wind turbines (OWTs)
- Account for 81.5% of all installed OWT foundations in Europe, 74.5% in 2018 [Wind Europe, 2018]
- Design governed by **deformation and stiffness**
- **Cyclic loading** a particular concern in offshore environment

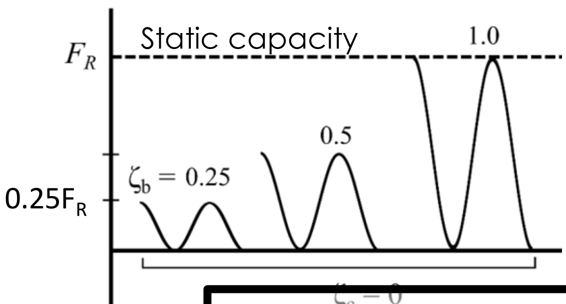


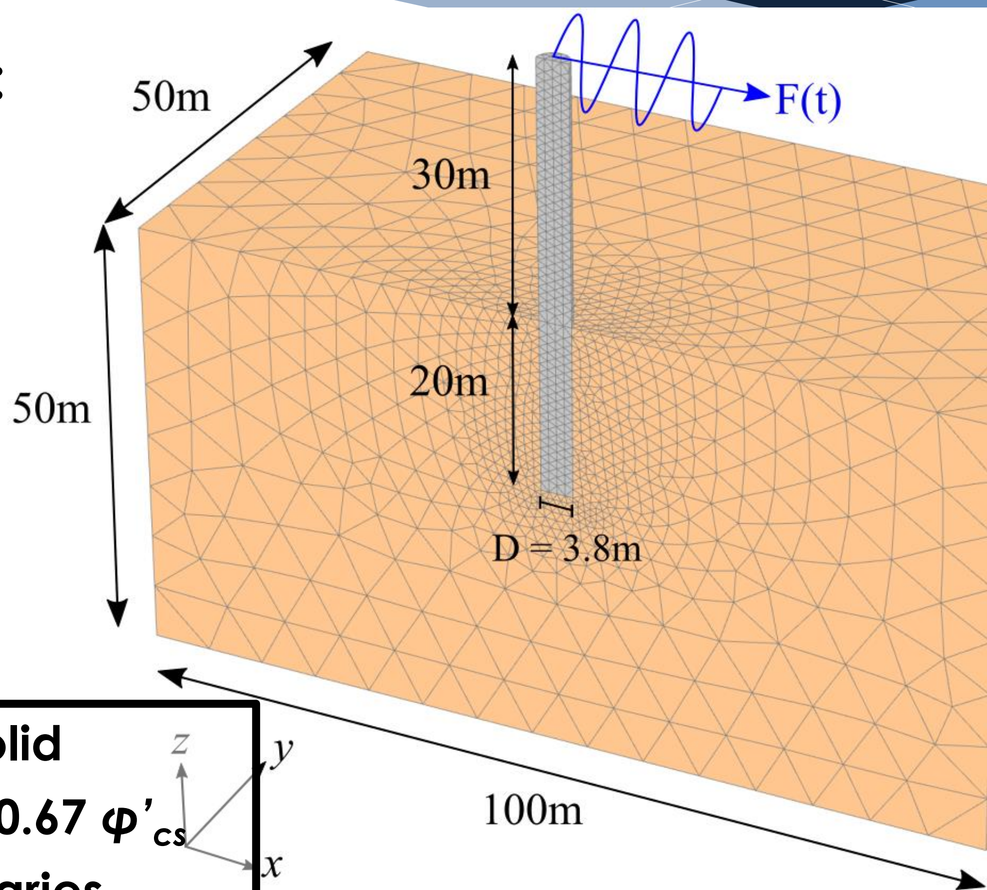
Finite element model

- **Cyclic loading:**

ζ_b = F_{max} / F_R = 0.18

ζ_c = F_{min} / F_{max} = 0





Monopile: LE solid

Interface: $\varphi' = 0.67\ \varphi'_{cs}$

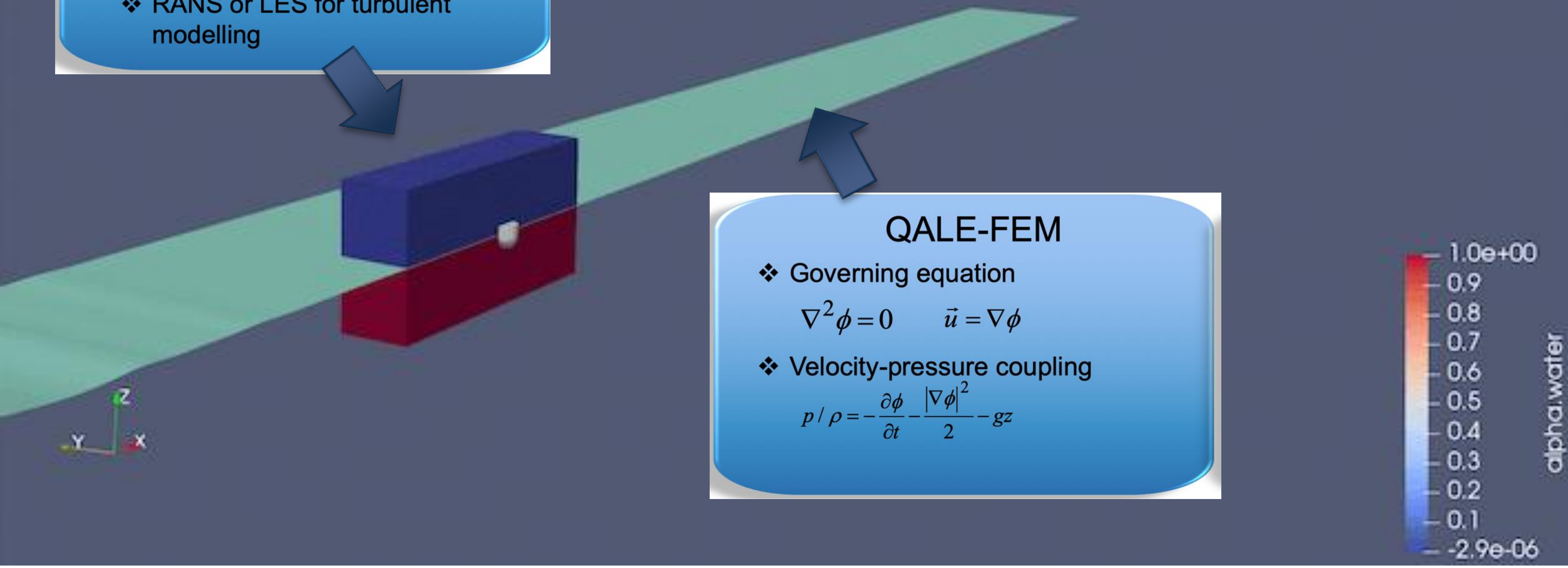
Viscous boundaries

Undrained

qaleFOAM

OpenFOAM

- Continuity equation
- Two-phase incompressible/compressible NS
- FVM
- Volume of Fraction (VOF)
- RANS or LES for turbulent modelling



QALE-FEM

- Governing equation

$$\nabla^2 \phi = 0 \qquad \vec{u} = \nabla \phi$$

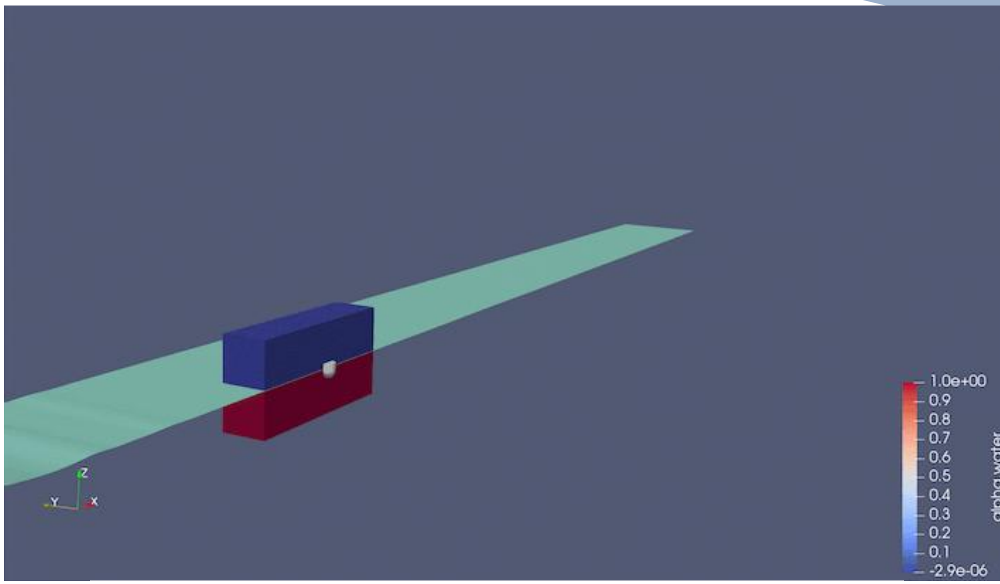
- Velocity-pressure coupling

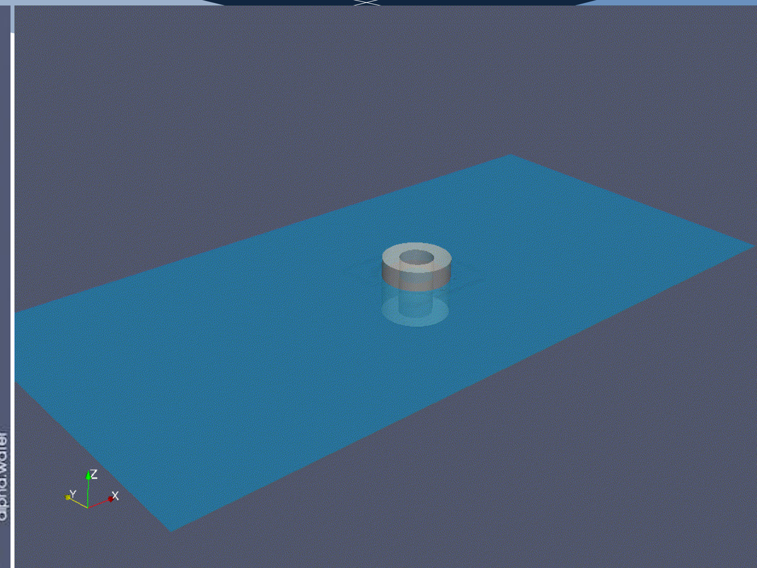
$$p/\rho = -\frac{\partial \phi}{\partial t} - \frac{|\nabla \phi|^2}{2} - gz$$

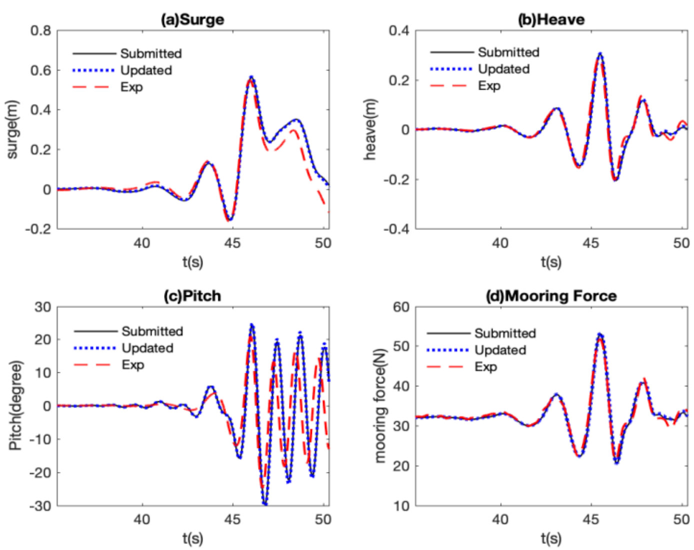
- Near the structure: viscous/turbulent effects, breaking wave impact, multi-phase/aeration may be important → requires NS models
- Away from the structure: insignificant viscous effects, wave may be highly nonlinear in extreme sea → FNPT is the most robust model

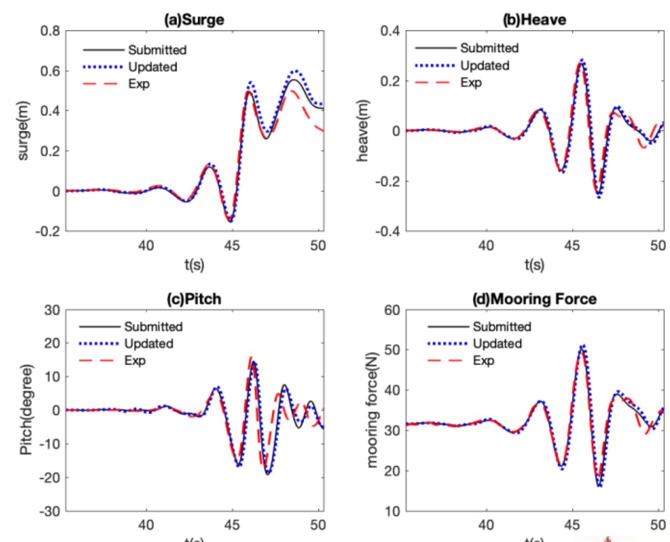
qaleFOAM Application: 6DoF motions

* CCP-WSI Blind Test 2/3









Motion responses and mooring loads

qaleFOAM: FOWT in extreme sea

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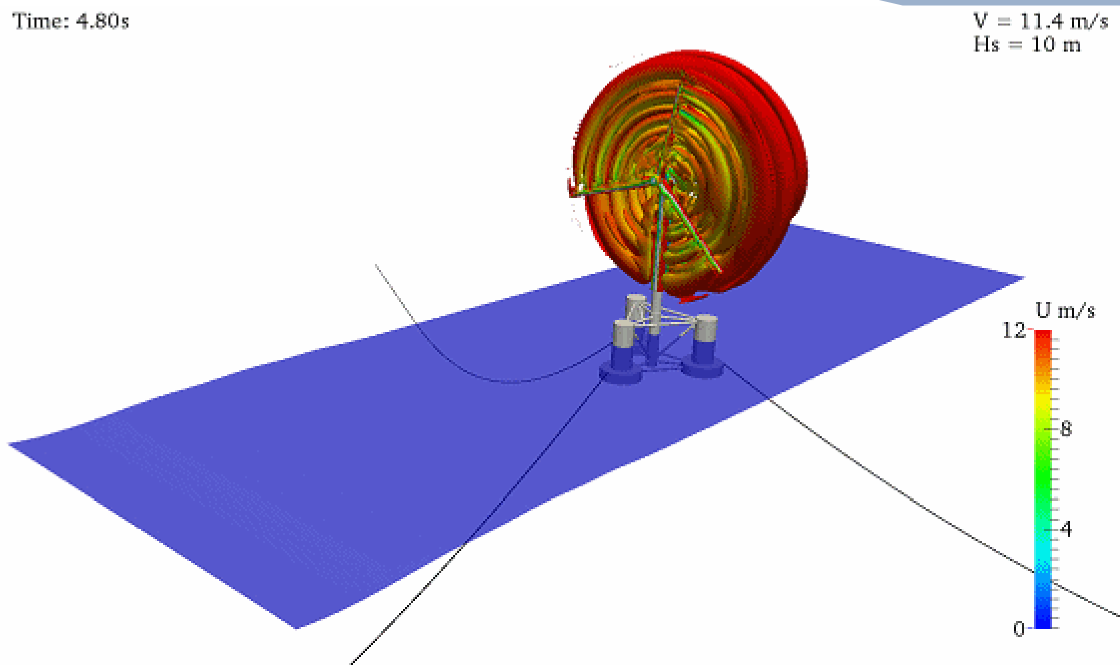

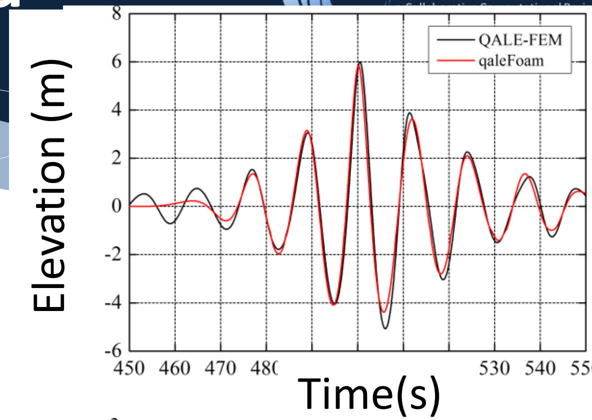

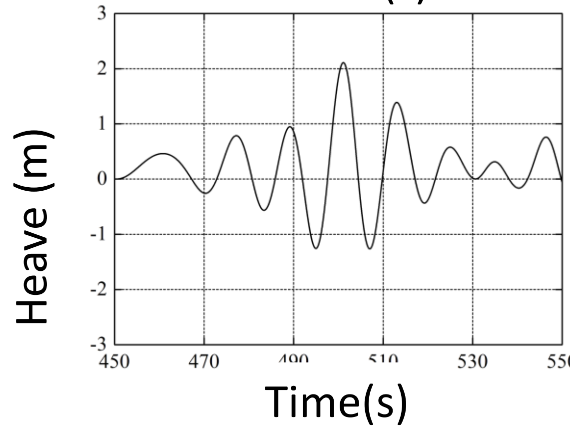

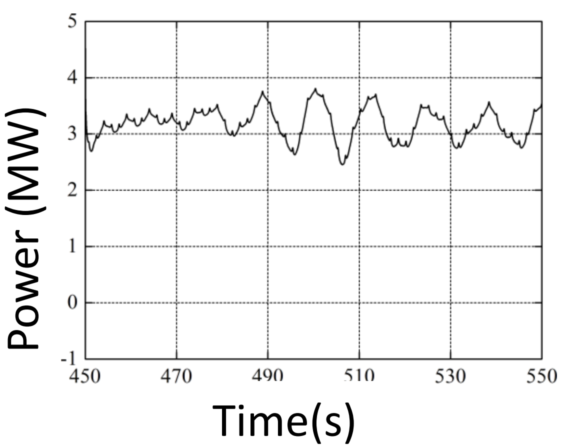

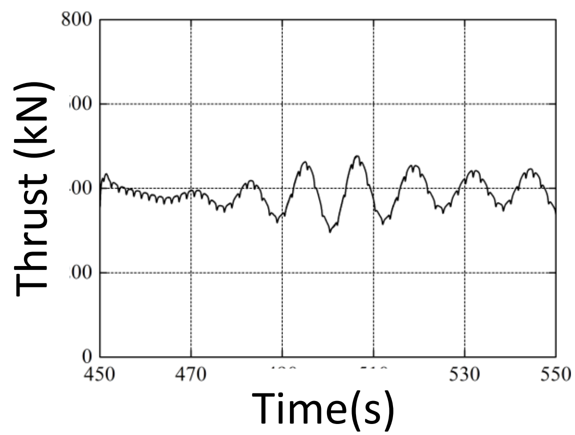

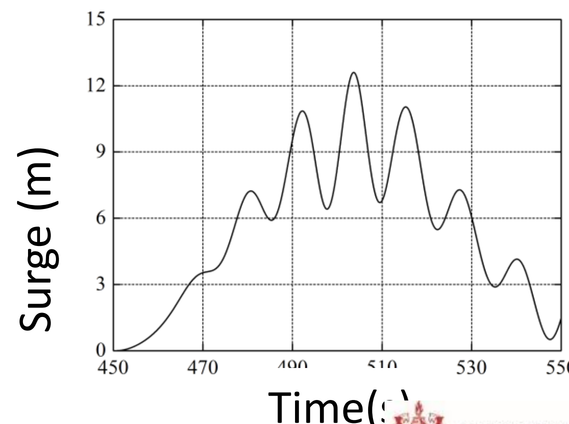

CITY UNIVERSITY LONDON

DEM: Discrete Element Modelling

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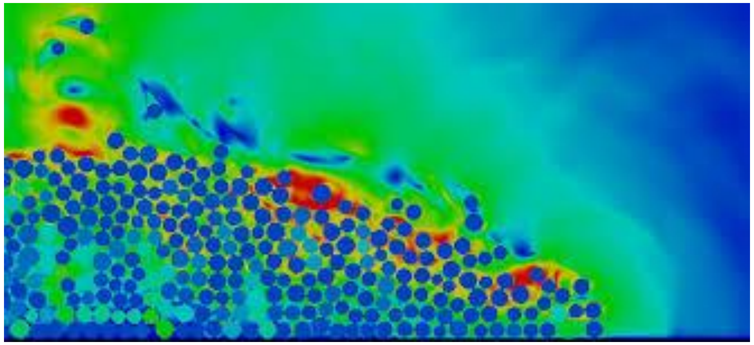
- Models collection of individual rigid grains / particles
- Consider particles from 100μm to km scale
- Allows micro-scale mechanisms to be observed
- Widely coupled with CFD:
  - Industrial processes (fludised beds, pharmaceticals, material processing)
  - Geotechnics (erosion, liquefaction)
  - Avalanches (e.g. submarine)

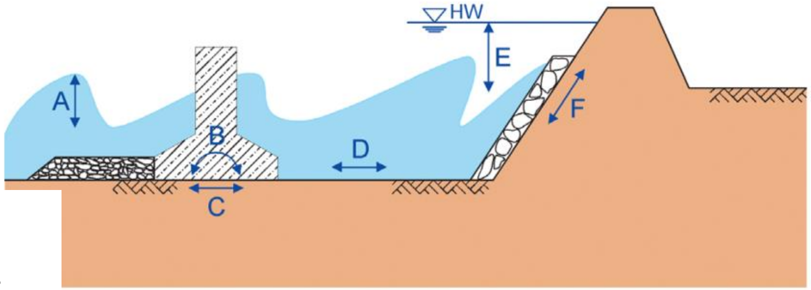
https://twiki.auscope.org/wiki/pub/EarthSim/ExistingInfrastructure/CollapsingBlock3.png



Kumar et al. 2017

University of Glasgow

Wave-structure interaction in DEM



Breakwaters / coastal defences

Debris flows

Mills

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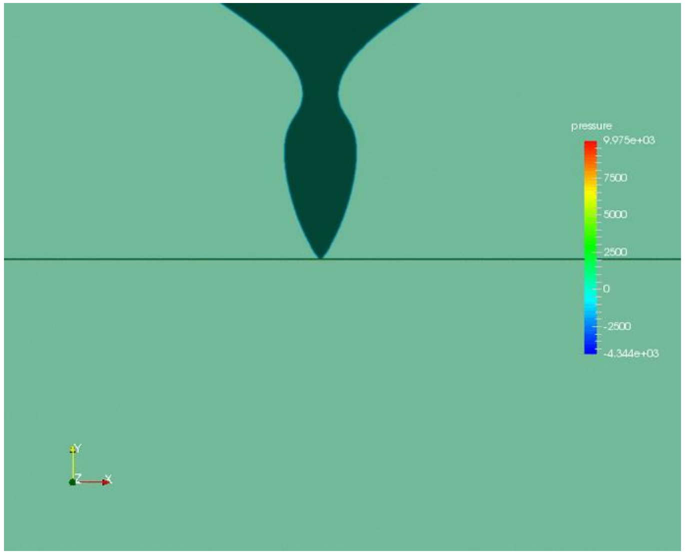
Coupling

Develop code coupling methodologies and libraries to support the range of CFD codes used within the CCP-WSI+ community, which can be released as a tool-kit, alongside recommendations and best practice to enable community members to develop specific couplings. This entails:

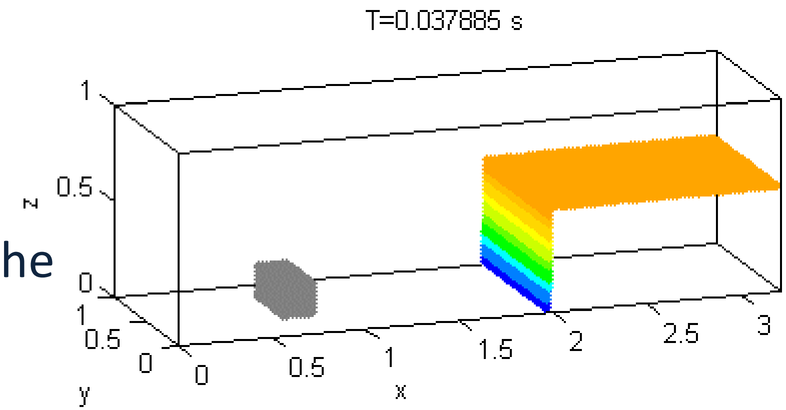
1. Support for community interface code development
2. Coupling CFD with computational structural dynamics
3. FCWSI in two fluid flows
4. Coupling between different CFD codes
5. Coupling between different solid mechanics codes



Parallelisation and optimization

Parallelisation of single and coupled codes on HPC architectures will be investigated using:

1. WSI+ software framework HPC optimizations, including performance and algorithm optimization for domain decomposition, dynamic load balancing and linear system solvers
2. Profiling with various tools and identifying the other performance bottlenecks and further optimization to deal with I/O and MPI communications
3. Case studies of WSI, single and coupled simulations with documentation
4. Improving scalability for mesh adaptivity and moving mesh applications



eCSE: Developing a dynamic load balancing library for wsiFoam

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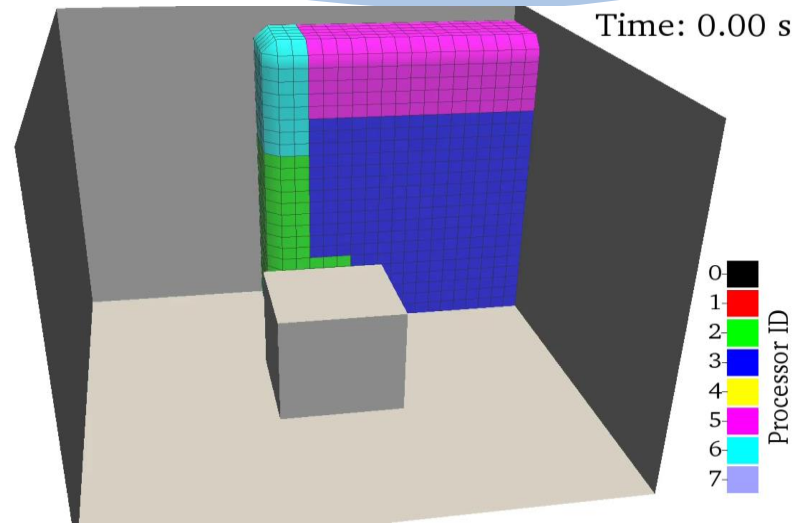
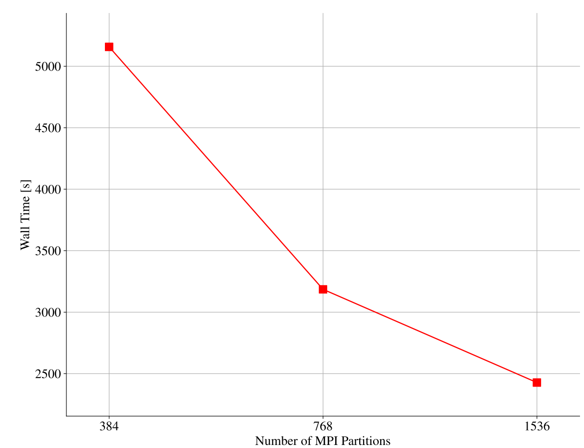
PI: Prof. Deborah Greaves

* A new dynamic load balancing library has been developed for OpenFOAM adaptive mesh
* A test case using this adaptive mesh functionality was used to benchmark the new library and shows a substantial increase in both the wall time (4-5 times speed up) and the scalability (greater than one thousand cores with more than 50% efficiency) of the OpenFOAM multi phase dynamic mesh solver.
* Current work is to push the scaling to more than 10K cores





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