Challenges in the hydrodynamics modelling of wave energy converters

Vincenzo Nava

Image from the website of OPERA H2020 project, courtesy of EVE
Outline

Motivation

Top Five Challenges in Modelling the Hydrodynamics of WECs

Four Lessons Learnt
Why Harnessing Energy From Oceans?

Credits
the data originate from the ECMWF WAM model archive and are calibrated and corrected by Fugro OCEANOR against a global buoy and Topex satellite altimeter database).
How can we get Energy From Oceans?

Oscillating Water Column (OWC)

Overtopping Devices

Oscillating Bodies (Point Absorbers & Surge Devices)

Source(s)

Figure inspired from
doi: 10.3390/en9070506
Why numerical models are needed to simulate the FSI?

A more precise modelling of the hydrodynamics will improve:

- Economic assessments
- Impacts on the environment
- Survivability
- Overtopping
- Optimisation of shapes, losses, etc...
- Wave propagation
- Environmental impacts
- Forces, displacements, stresses and deformations
- Power production
Top FIVE Challenges

1. 

2. 

3. 

4. 

5. WAVE PROPAGATION
Reduction of Energy – Using TMA spectra

Table 2. Extracted wave power for different water depths.

<table>
<thead>
<tr>
<th>Water depth (m)</th>
<th>Power absorbed (kW)</th>
<th>% Power lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>79</td>
<td>33.57</td>
<td>0.0</td>
</tr>
<tr>
<td>58</td>
<td>31.11</td>
<td>7.33</td>
</tr>
<tr>
<td>20</td>
<td>16.83</td>
<td>49.86</td>
</tr>
</tbody>
</table>

Source
Modeling devices with Mike 21

“Boussinesq models are not capable of modelling the hydrodynamics of a moving device.

They may be used to model device characteristics, such as wave transmission reflection and absorption.

If radiation characteristics are known, these may be included by use of an internal generation line, although this may become cumbersome when more than 1 WEC is considered and, for this reason, their use warrants caution.”

Source
Top FIVE Challenges

1.

2.

3.

4. VALIDATION OF MODELS

5. WAVE PROPAGATION
How validate and verify models?

- **Code-to-code verification**
  
  EXAMPLE: Task 10 – OES – Methodology
  
  ✓ **Modeling case studies**, as for example a heaving sphere (decay tests, regular waves tests, irregular wave tests)
  
  ✓ **Review the models**
  
  o Model a WEC
  
  o Compare with existing test data

---

**Heave RAO, low steepness, no PTO**

General agreement among participants. Largest differences around resonant period, larger spread than with PTO.
How validate and verify models?

- Experimental Data

Source
Importance of scale – Scaling Law

Performance of WECs will normally be scaled using Froude similitude.

Tests with large scales are recommended when scale effects are envisaged.

Important factors in energy conversion that are not addressed by standard scaling procedures include, but are not limited to, the effects listed below:

• The power output of devices utilising a pneumatic power take off is related to the compressibility of the air, which is dictated by atmospheric pressure and the absolute temperature of atmosphere. Therefore, the stiffness of the air “spring” will not be scaled correctly using Froude similarity if geometric similarity is maintained.

• In small-scale model tests, viscous damping and in particular damping associated with vortex shedding from sharp edges cannot be scaled appropriately with Froude similarity and may be overestimated.

Source
ITTC – Recommended Guidelines, Wave Energy Converter Model Test Experiments, 2014
Importance of scale – Instrumentation and Indirect Measurements

Measurements of:
• Displacements / Velocities / Accelerations
• Line Tensions
• Wave Characteristics
• Overtopping

Use of indirect measurements, especially with data in sea.

Development of algorithms for indirect measurements, also from other sectors. For example, FDD for modal characteristics (from the Structural health monitoring Sector).

Source
Top FIVE Challenges

1.

2.

3. MODELING ARRAY EFFECTS

4. VALIDATION OF MODELS

5. WAVE PROPAGATION
Why arrays?

Deploying arrays of ocean energy devices would increase the profitability of the investment.
### How to model array effects?

<table>
<thead>
<tr>
<th>Method</th>
<th>Point-absorber method</th>
<th>Plane-wave method</th>
<th>Multiple Scattering Method</th>
<th>Direct Matrix Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Diameters smaller than wavelengths and interdistances - diffraction of radiated and diffracted waves from each device by others in the array is neglected</td>
<td>Spacing between axisymmetric absorbers is large compared to the incident wavelength – diffraction is taken into account</td>
<td>Radiation and diffraction taken into account as succession of distinct scattering events</td>
<td>The amplitudes of all scattered waves simultaneously without the need for iteration, using a single body solution</td>
</tr>
</tbody>
</table>

**Source**


Some results

Table 1: Geometrical characteristics of the devices

<table>
<thead>
<tr>
<th>Device</th>
<th>Radius [m]</th>
<th>Draft [m]</th>
<th>Mass [kg]</th>
<th>$T_o$ [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>10</td>
<td>20</td>
<td>6.45 $10^6$</td>
<td>10.2</td>
</tr>
<tr>
<td>II</td>
<td>12.6</td>
<td>12.6</td>
<td>6.45 $10^6$</td>
<td>8.83</td>
</tr>
<tr>
<td>III</td>
<td>15.9</td>
<td>7.9</td>
<td>6.45 $10^6$</td>
<td>7.03</td>
</tr>
</tbody>
</table>

Personal Note: when fully designing an array of heaving point absorbers, most probably the layout would depend on other subsystems rather than on the hydrodynamic impacts.

Source
Some results

Source
Development of Tools

DTOcean is the acronym for an European FP7 project and it stands for Optimal Design Tools for Ocean Energy Arrays.

Hydrodynamics modeled using semi-analytical methods

BEM NEMOH + DMM
Top FIVE Challenges

1.

2. VISCOUS EFFECTS AND EXTREME LOADS

3. MODELING ARRAY EFFECTS

4. VALIDATION OF MODELS

5. WAVE PROPAGATION
Sloshing

It is difficult to extract energy from sloshing frequency, so they should be avoided.

Source
Vortex Formation

The formation of the vortex in front of and behind the front wall of the air chamber and evolution of the air vortex can be seen clearly which is a good indicator of energy loss.

Source
Vortex Induced Vibration / Motions

If the structure is flexible or flexibly mounted, these vortices may cause vibrations, leading to stresses and fatigue damage. This motion of the body influences, in turn, the vortex formation process, establishing a feedback mechanism that may lead to stable or unstable dynamic equilibria.

On the hull:
- They increase the global loads
- They may increase the offset (drag effect)

On the mooring lines:
- They may affect fatigue life of the line

The disagreement between numerical and experimental observations attributes much to the underestimation of multimodal vibration state by numerical method.

Source
Vortex Induced Vibration / Motions

On the hull:
- They increase the global loads
- They may increase the offset (drag effect)

On the mooring lines:
- They may affect fatigue life of the line

Higher harmonic components of strain and acceleration are significant. Fatigue damage calculations, by taking into account the higher harmonic components, give fatigue damage values of up to one order of magnitude larger than those calculated based on only first-harmonic signals.

Source
Extreme Wave Loads

Source
Top FIVE Challenges

1. NONLINEARITIES AND COUPLING
2. VISCIOUS EFFECTS AND EXTREME LOADS
3. MODELING ARRAY EFFECTS
4. VALIDATION OF MODELS
5. WAVE PROPAGATION
Mooring Lines Effects

Definition of physical characteristics of the WEC system

Build up the numerical model

Definition of numerical setting, e.g. simulation time, time step size, etc.

De-coupled \( \Rightarrow \) Coupled / de-coupled analysis?

Linear frequency-domain hydrodynamic analysis of the WEC unit

Motion response at fairleads of the mooring lines

Nonlinear time-domain hydrodynamic and structural analysis of the entire WEC system, including the WEC unit and the mooring system

Force response of the mooring lines

Stress response analysis of the mooring lines

Fatigue damage analysis of the mooring lines

Source
Parametric Roll – Mathieu/Hill Instability

Source
Parametric Roll – Mathieu/Hill Instability

The phenomenon happens in real seas: which are numerical tools to learn more about its occurrence?

Source
Lessons Learnt

1) Describing the problem properly and identifying the outcomes

What problem are we trying to solve?

Problem statement stage is important, in order to focus on the right physics to study.
Lessons Learnt

2) Importance of using the appropriate numerical model for solving the problem

Risks:

a. Unneeded computational burden
b. Not answering to the questions
Lessons Learnt

3) Interpreting the results of the experimental / numerical study in order to “bark at the right tree”

The results of a good experimental campaign or numerical test can be jeopardised by a wrong understanding of what’s going on.
Lessons Learnt

4) All the problems are important, but some problems are more important than others

Developers have identified different priorities for the problems to be solved through their experience.

Moreover, sometimes we look at a problem from a wrong perspective.
THANKS FOR YOUR ATTENTION

Vincenzo Nava
vincenzo.nava@tecnalia.com

vnava@bcamath.org