FROTHER: Fundamentals and Reliability of Offshore Structure Hydrodynamics

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Flume Tests: experiments and CFD

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Objectives

• To improve understanding of wave impact on offshore structures such as FPSO hulls.
  - Experimental & numerical study of wave impact on a truncated vertical wall (rigid & elastic) representing the hull surface in pure & aerated water.
  - Impact types: broken wave; high aeration; flip-through.
Model Setup: Elasticity

Instrumentation:
- 7 XPM10 pressure sensors: range of 1 bar
- Low profile load cell: range of 200 kN
- Photron SA4 high speed camera: 3600 fps at resolution 1024x1024

Water depth = 0.7 m
Focussed waves
Tp = 1.6s
Hs = 0.163m

Sampling rate: 35 kHz
Model Setup: Aerated Water

- Aeration levels: 0% & 0.57%.
- Void fraction calculated from hydrostatic pressure measurement.
Impact Type: Broken Wave

- Wave breaks immediately before the wall.
- Produces aerated water mass impacting the wall.
- Occurrence of impact pressures varies temporally and spatially due to chaotic nature of interaction.
Impact Type: High Aeration

- Combined cloud of bubbles and air pocket.
- Time of maximum impact pressures now simultaneous.
- Distinct post-impact pressure/force oscillations:
  - Low frequency coincides with test rig natural frequency.
  - High frequency may be due to:
    - Sound wave reflecting from the flume bed (f=230Hz ⇒ T=4.35ms ⇒ c=322m/s ⇒ β=0.09%, Wood’s law) and/or
    - Entrained bubble oscillation (corresponds to bubble radius of 14mm, Minnaert, 1933).
Up-rush on the wall causes a jet just before the crest hits the wall.

Largest impact pressure recorded.

- Low frequency oscillation (~40Hz)
- High frequency oscillation (~550Hz)
Impact Pressure on Rigid or Elastic Wall

Broken

High Aeration

Flip-Through

- Rigid (18 tests)
- Elastic (17 tests)
- Rigid (10 tests)
- Elastic (16 tests)
- Rigid (15 tests)
- Elastic (20 tests)
Aerated Water: Impact Pressure on Rigid Wall

**Broken**

**High Aeration**

**Flip-Through**

- Pure Water (10 tests)
- Aerated Water (5 tests)

- Pure Water (7 tests)
- Aerated Water (6 tests)

- Pure Water (8 tests)
- Aerated Water (6 tests)
Impact Force and Impulse $\int F dt$

Impact force: elasticity

Impact force: aerated water

Impulse: elasticity

Impulse: aerated water
Numerical Simulation

- Based on open-source CFD tool – **OpenFOAM**
- Incompressible two-phase flow solver `interFoam`
- Wave generation tool - `waveFoam`
- Governing Equations - the **Reynolds averaged Navier-Stokes (RANS) equations**
- Laminar and turbulent flow solvers were used in our computations
Wave impact on a truncated vertical wall

Focussed wave with Jonswap spectrum:

\[ H_s = 0.163 \text{ m}; \quad T_p = 1.601 \text{ s} \]
Wave impact on a truncated vertical wall

(a) Broken wave impact
(b) Aerated impact
(c) Flip-through impact

Free surface profiles in front of the rigid wall
Flip-through impact

Time histories of free surface elevations

<table>
<thead>
<tr>
<th>Wave gauge</th>
<th>wg6</th>
<th>wg7</th>
<th>wg8</th>
<th>wg9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from vertical wall (m)</td>
<td>0.24</td>
<td>0.15</td>
<td>0.065</td>
<td>0.015</td>
</tr>
</tbody>
</table>
Flip-through impact

Time histories of impact pressures at different locations on the vertical wall

<table>
<thead>
<tr>
<th>Probe</th>
<th>P6</th>
<th>P7</th>
<th>P8</th>
<th>P9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance above still water level (m)</td>
<td>0.050</td>
<td>0.200</td>
<td>0.100</td>
<td>0.175</td>
</tr>
</tbody>
</table>

Time histories of force
Flip-through impact on rigid wall
Comparison for rigid wall case in 2D and 3D

- Free surface elevations in front of the wall agree well in both 2D and 3D.
- Pressure on the wall is overestimated in 2D because the wall is not the full width of the flume in experiment.
The wall oscillates in response to wave interaction and the high frequency oscillation corresponds with the natural frequency of the tested model. The maximum horizontal force on the elastic wall is lower than that on the rigid wall.
Comparison of surface elevations in front of rigid and elastic walls
Comparison of impact pressure on rigid and elastic walls

2D OpenFOAM
Pressure at level z of P6=0.05m above still water

3D Experiment
Pressure at level z of P6=0.05m above still water
Conclusions

✓ Different wave impact on rigid and elastic wall were investigated by both experiments and numerical simulations
  - Broken wave, high aeration and flip-through impact
  - Rigid and Elastic wall
  - Pure water and aerated water
  - Laminar flow and turbulent flow solvers
  - Impressible and compressible flow solvers

✓ Oscillations observed in p-t and F-t due to undesirable test rig vibration, pressure wave reflections and entrained bubbles.

✓ Elasticity did not reduce peak wave loads (lower spring stiffness should be tested).
Conclusions

✓ Aeration **did** reduce peak wave loads - both pressure and force - but importantly impulse **was not** reduced.

✓ Flip-through impact causes the largest impact pressure on the wall.

✓ Very good agreement between physical and CFD results were achieved.

✓ Implications for design are that maximum instantaneous loads may be conservative in the presence of aerated water.