O&M of Crew Transfer Vessels Against Floating Wind Turbines – Modelling the Water Run-up Effect During Personnel Transfer in Waves with Short Periods.

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O&M of Crew Transfer Vessels against Floating Wind Turbines – Modelling the water run-up effect during personnel transfer in waves with short periods.

Laurent BARTHÉLEMY

Ecole Nationale Superieure Maritime, Nantes 44103, FRANCE
laurent.barthelemy@supmaritime.fr

Abstract. For floating wind farms in areas like in Mediterranean Sea where waves with short periods occur, it is important to make sure that the Crew Transfer Vessel main deck does not get flooded.

Method description

Water elevation at boarding point:
• Calculate the water elevation downstream of the floating wind turbine boarding point, which is by accounting for the wave masking by its floater.

Vessel heave at boarding point:
• Calculate the Crew Transfer Vessel heave at the floating wind turbine boarding point.

Relative range between ship heave and wave elevation at berthing point:
• Calculate the wave height and periods where that relative range gets lower than zero, which is when the vessel deck becomes flooded by the waves.

Main results and findings

The benchmark is another reference which calculated the flooding risk while berthing the vessel against a fixed wind turbine monopile: it compares satisfactorily with the present calculation.

Keywords: Wind Turbines, Operation and maintenance, Weather stand-by, Crew transfer.

1 Introduction

Developing offshore floating wind farms involves considering the safety of O&M workers. One of the critical steps is when it comes to berthing a CTV against the floater boat landing. On that matter, reference [1] already proposed berthing criteria, based on kinetic friction. However, reference [2] author suggests that “in most cases the airgap of the catamaran is the limiting factor, causing the vessel to be subjected to high wave induced forces when the waves hit the horizontal wet deck between the hulls. That means that we also should include the relative motion between the bow of the catamaran and the wave elevation” [3]. The present paper addresses that issue.
2 Method Description

2.1 Assumptions

CTV motions are only surge, heave, pitch. We account for the 3D-coupling between those 3 motions, which is caused by the propeller thrust. We assume the friction coefficient between boat fender and floater boat landing to be the ratio of the hull wave-induced vertical forces by the sum of the hull wave-induced horizontal forces and propeller thrust [4]. The CAT CTV used is a twin Wigley hull, based on HSVA model tank test [5]. Please try to avoid rasterized images for line-art diagrams and schemas. Fig. 1 shows CAT CTV at full scale (27m long).

![Fig. 1. Wigley CAT CTV Hull [5].](image)

Table 1 lists CTV d.o.f., due to wave excitation:

<table>
<thead>
<tr>
<th>Motion</th>
<th>No. of d.o.f.</th>
<th>d.o.f.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation around floatation centre</td>
<td>1</td>
<td>Pitch ( \theta )</td>
</tr>
<tr>
<td>Translation from original position O</td>
<td>2</td>
<td>surge ( \tau_x ), heave ( \tau_z )</td>
</tr>
</tbody>
</table>

2.2 Main Deck Water Ingress Calculation

For a regular wave, those d.o.f. are:

\[
\tau_z = z_m \cos[\omega(t - t_T)] + \varphi_z \]  
\[
\theta = \theta_m \cos[\omega(t - t_N)] + \varphi_\theta
\]

Where \( t_T \) and \( t_N \) are the time phase corrections required to get the calculated wave vertical and horizontal forces \( T(t) \) and \( N(t) \) on Wigley hull in phase with the HSVA real hull test results [4] [5].

Fig. 2 shows the CTV motion at berthing point A-.
On one hand, CTV heave at berthing point A is:

\[ z_A^h = Z_A^h + \Delta z_A \equiv Z_A^h + \tau_x - X_A^h \theta \Rightarrow z_A^h = Z_A^h + C \cos \omega t + D \sin \omega t \]

with \( A \equiv z_m, B \equiv X_A^h \theta_m, F \equiv \tan \omega t / 2 \)

\[ C \equiv A \cos(-\omega t + \varphi_2) - B \cos(-\omega t + \varphi_0) \]

\[ D \equiv -A \sin(-\omega t + \varphi_2) + B \sin(-\omega t + \varphi_0) \]

On the other hand, sea surface elevation at A is:

\[ \eta = \eta_D \cos(\omega t + \varphi_D) - a \sin(\omega t - kX_A^h) \]

with \( \eta_D \) and \( \varphi_D \) being respectively diffracted wave elevation and phase angle at A. Both \( \eta_D \) and \( \varphi_D \) are calculated with NEMOH [11].

If a floater masks the CTV from the waves, then:

\[ \eta = \eta_z \cos(\omega t + \varphi_2) - a_z \sin(\omega t - kX_A^h) \]

\[ a_z \equiv a \sinh(k(z_0 + h))/\sinh(kh), z_0 \equiv \text{floater draft}, h \equiv \text{water depth} \]

Therefore, equations (3) & (6) give the relative range between ship heave and wave elevation at A:

\[ z_A^h - \eta = Z_A^h + \left[ (-E \mathcal{F}^2 + 2F \mathcal{F} + \mathcal{E}) / (1 + \mathcal{F}^2) \right] \]

\[ \mathcal{E} \equiv A \cos(\varphi_2 - \omega t) - B \cos(\varphi_2 - \omega t_N) - \eta_D \cos \varphi_D - a_z \sin(\omega t + \varphi_D) \]

\[ \mathcal{F} \equiv -A \sin(\varphi_2 - \omega t) + B \sin(\varphi_2 - \omega t_N) + \eta_D \sin \varphi_D + a_z \cos(\omega t + \varphi_D) \]

A variation study gives its minimum value:

\[ [z_A^h - \eta]_{min} = Z_A^h + \left[ (-E \mathcal{F}^2 + 2F \mathcal{F} + \mathcal{E}) / (1 + \mathcal{F}^2) \right] \]

where \( \mathcal{F} \equiv -\left( \mathcal{E} + \sqrt{\mathcal{E}^2 + \mathcal{F}^2} \right) / \mathcal{F} \)
The CTV deck gets flooded if wave elevation at point A- is greater than CTV heave at point A-. Therefore, water ingress is if \([z_A - \eta]_{\text{min}} \leq 0\).

3 Results

3.1 Berthing CTV against Monopile

The water depth is 29m. The studied monopile has 5m diameter [5] (fig.3 and 4).

Fig. 3. CTV berthing against monopile (3D view).

Since CTV is wider than the monopile, the CTV is not masked from the incidental waves: \(a_c = a\) (fig. 4).

Fig. 4. CTV berthing against monopile (plane view)
Figure 5 shows the relative range between ship heave & wave elevation at A- vs λ/B @ 2.5m Hs.

![Figure 5. (zA- η) min vs λ/B @ 2.5m Hs](image)

### 3.2 Berthing CTV against Cylindrical Floater

Water depth is h=70m [6]. The studied cylinder has [6] 13m diameter, z0=14m draft. This time, the floater masks the CTV from incidental waves: only waves passing below the keel affect the CTV heave and sea surface elevation [1]. Therefore, in eq. (2) and (3), the residual wave amplitude is \(a_c = a \sinh[k(z_0+h)] / \sinh(kh)\) (figures 6 and 7).

![Fig. 6. CTV berthing against cylindric floater (plane view)](image)
Figure 7. CTV berthing against cylindrical floater (3D view)

Figure 8 shows the relative range between ship heave & wave elevation at $A_{e}$ vs $\lambda/B$ @ 3m Hs.

![Figure 8](image)

Fig. 8. $[z_{A_{e}} - \eta_{\text{max}}]$ vs $\lambda/B$ @ 3m Hs

### 3.3 Berthing CTV against Monopile

Water depth is $h=23m$ [7]. The studied square has [7] [8]: 36m side, $z_0=7m$ draft. Once again, the floater masks the CTV from incidental waves: only waves passing below the keel affect the CTV heave and sea surface elevation [1]. Therefore, in eq. (2) & (3), the residual wave amplitude is $a_c = a \sinh[k(z_0+h)] / \sinh(kh)$ (fig 9 and 10).

Fig 11 shows the relative range between ship heave & wave elevation at $A_{e}$ vs $\lambda/B$ @ 3m Hs.
Fig. 9. CTV berthing against FLOATGEN (plane view)

Fig. 10. CTV berthing against FLOATGEN (3D view)

Fig. 11. $[z_A - \eta]_{\text{min}}$ vs $\lambda/B$ @ 3m Hs
3.4 Results Summary and Interpretations

Tables 2 and 3 sum up respectively the Hs found for deck flooding to occur whatever the wavelength may be, and the λ/B range for deck flooding to occur.

Table 2. Hs causing water ingress vs various floaters.

<table>
<thead>
<tr>
<th>Case</th>
<th>Floater Geometry</th>
<th>Depth</th>
<th>Max Hs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Triton Knoll monopile [2]</td>
<td>15m</td>
<td>2m</td>
</tr>
<tr>
<td>1</td>
<td>5m Ø monopile</td>
<td>15m</td>
<td>2m</td>
</tr>
<tr>
<td>2</td>
<td>5m Ø monopile</td>
<td>29m</td>
<td>2.5m</td>
</tr>
<tr>
<td>3</td>
<td>13m Ø cylindrical floater</td>
<td>70m</td>
<td>&gt;3m</td>
</tr>
<tr>
<td>4</td>
<td>36m side FLOATGEN</td>
<td>23m</td>
<td>2.5m</td>
</tr>
<tr>
<td>5</td>
<td>36m side FLOATGEN</td>
<td>70m</td>
<td>3.0m</td>
</tr>
</tbody>
</table>

Table 3. λ/B causing water ingress vs various floaters.

<table>
<thead>
<tr>
<th>Case</th>
<th>Floater Geometry</th>
<th>Depth</th>
<th>λ/B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Triton Knoll monopile [2]</td>
<td>15m</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>1</td>
<td>5m Ø monopile</td>
<td>15m</td>
<td>&lt;1.1</td>
</tr>
<tr>
<td>2</td>
<td>5m Ø monopile</td>
<td>29m</td>
<td>&lt;1.2</td>
</tr>
<tr>
<td>3</td>
<td>13m Ø cylindrical floater</td>
<td>70m</td>
<td>&lt;0.6</td>
</tr>
<tr>
<td>4</td>
<td>36m side FLOATGEN</td>
<td>23m</td>
<td>&lt;1.3</td>
</tr>
<tr>
<td>5</td>
<td>36m side FLOATGEN</td>
<td>70m</td>
<td>&lt;0.8</td>
</tr>
</tbody>
</table>

Note (1) Cases 3 & 4: same displacement & draft.
Note (2) “none” means for no realistic λ/B ratio.

“Realistic λ/B” means wave lengths which do occur offshore. For instance, cases 3 and 7 refer to projects located in Gulf of Lion, France, around point Leucate Nord [9]. At that location, wavelengths lower than 4.8m never occur, according to hindcast [9]. Therefore, since CTV length is 27m, ratios λ/B < 0.2 never happen.

In tables 2 and 3, case 0 is a benchmark, which is Triton Knoll offshore wind farm [2] [10]. Case 1 results for Hs and λ/B meet case 0 results with resp. 0% and 10% accuracy: that is satisfactory, given the absence of CAT CTV real hull shape data [5].

Cases 1-2 show water depth influence on Hs & λ/B: resp. 25% & 9% increases.
Cases 4-5 show water depth influence on Hs & λ/B: resp. 20% & -38% increases.
Cases 3 and 5 show that floater shape does not really matter, at same water depth, on Hs and λ/B: respectively 0% and 33% increase.

Otherwise, the other driving parameter, as regards CTV deck water ingress, appears to be the wave diffraction from the floater against the CTV, with reference to equation (2).
4 Conclusions and Recommendations

Ref. [2] author comment [3] reveals applicable to water depths of fixed offshore wind farms, which are lower than 30m. However, for future French floating wind farm water depths, which are greater than 50m, catamaran airgap should not be the limiting factor, but rather the friction of the CTV fender against the floater boat landing [1].

Apart from the water depth influence, the main limiting factor appears to be the sea surface diffraction from the floater against the CAT CTV. That phenomenon should occur at low wavelengths, which is for a wavelength over boat length ratio lower than 1, which is in accordance with [2].

The low significant wave heights limits for berthing a 27m CAT CTV against a monopile [1] show that there is still margin for improving berthing performance. Reference [2] solution is to use Surface Effect Ships, especially to dampen the CTV heave due to the waves. Reference [2] also notes that: “Compared to catamaran CTVs the SES has a potential of reducing CTV fuel consumption by 30-50% per nautical mile at 25-50% higher speed”. Another cost improvement would be to regulate the CTV bollard push in accordance with the incoming waves, rather than apply full propeller thrust for berthing all the time.

Eventually, the present study offers another axis of development: rather than using a pseudo-kinetic friction coefficient, assume a static or kinetic friction coefficient, whether the CTV fender grips or not against the boat landing. Then, make sure that it remains below the grip factor, for rubber against steel. Indeed, regulations specify that “95% waves pass with no slip above 300mm (or one ladder rung)” [13].

5 Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAT CTV</td>
<td>Catamaran Crew Transfer Vessel</td>
<td>O&amp;M</td>
<td>Operation &amp; Maintenance</td>
</tr>
<tr>
<td>dof</td>
<td>Degree of freedom</td>
<td>RAO’s</td>
<td>Response Amplitude Operators</td>
</tr>
<tr>
<td>Hs</td>
<td>Significant Wave Height</td>
<td>3D</td>
<td>Three Dimensional</td>
</tr>
<tr>
<td>HSVA</td>
<td>Hamburgische Schiffbau-Versuchsanstalt GmbH (Hamburg Ship Model Tank Test Facilities)</td>
<td>WT</td>
<td>Wind Turbine</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Terminology</th>
<th>Designation</th>
<th>Terminology</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>h</td>
<td>Water depth</td>
<td>T, N</td>
<td>Wave vertical, horizontal forces</td>
</tr>
<tr>
<td>B</td>
<td>Ship length</td>
<td>tr, ts</td>
<td>Time phase corrections to get calculated Wigley hull loads T, N in phase with HSVA hull test results</td>
</tr>
<tr>
<td>(\lambda)</td>
<td>Wavelength</td>
<td>k</td>
<td>Wave number</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>---</td>
<td>-------------</td>
</tr>
<tr>
<td>(X_A, Z_A)</td>
<td>horizontal, vertical coordinates</td>
<td>a</td>
<td>Wave amplitude (half crest to through)</td>
</tr>
<tr>
<td>(z_A)</td>
<td>Boarding point heave</td>
<td>(z_0)</td>
<td>Floater keel elevation</td>
</tr>
<tr>
<td>(\eta_D, \varphi_D)</td>
<td>Boarding pt diffracted wave elevation, phase angle</td>
<td>(\omega)</td>
<td>Wave pulsation</td>
</tr>
<tr>
<td>(x_{nl}/a, z_{nl}/a, \theta_{nl})</td>
<td>Max. non dimensional ship surge, heave, pitch</td>
<td>(\varphi_x, \varphi_z, \varphi_\theta)</td>
<td>Max. surge, heave, pitch phase angles</td>
</tr>
</tbody>
</table>

References