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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.

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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 Operation & Maintenance (O&M) workers. One of the critical steps is when it comes to berthing a Crew Transfer Vessel (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 Three Dimensional (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 Catamaran (CAT) CTV used is a twin Wigley hull, based on Hamburg Facility (HSVA) model tank test [5].

Fig. 1 shows CAT CTV at full scale (27m long).

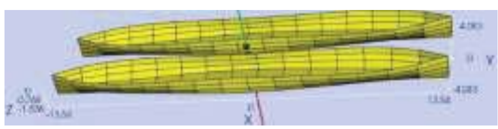

Fig. 1. CAT CTV Wigley hull mathematical approx. [5]

Table 1 lists CTV degrees of freedom (d.o.f.,) due to wave excitation:

Rotation around floatation centre	1 dof	Pitch θ
Translation from original position O	2 dof	surge τ_x, heave τ_z

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-

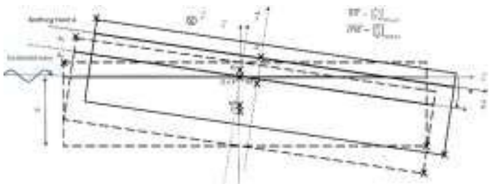

Fig. 2. CTV motion at berthing point A- due to waves

On one hand, CTV heave at berthing point A- is:

$$z_A^- = Z_A^- + \Delta z_A \cong Z_A^- + \tau_z - X_A^- \theta$$

$$\Longrightarrow z_A^- = Z_A^- + \mathcal{C}\cos\omega t + \mathcal{D}\sin\omega t \qquad (1)$$

with $\mathcal{A} \stackrel{\text{def}}{=} z_m$, $\mathcal{B} \stackrel{\text{def}}{=} X_A^- \theta_{\text{m}}$, $\mathcal{T} \stackrel{\text{def}}{=} \tan \omega t/2$,
$\mathcal{C} \stackrel{\text{def}}{=} \mathcal{A}\cos(-\omega t_T + \varphi_z) - \mathcal{B}\cos(-\omega t_N + \varphi_\theta)$,
$\mathcal{D} \stackrel{\text{def}}{=} -\mathcal{A}\sin(-\omega t_T + \varphi_z) + \mathcal{B}\sin(-\omega t_N + \varphi_\theta)$

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

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

with $\eta_D \stackrel{\text{def}}{=}$ diffracted wave elevation at $A-$

and $\varphi_D \stackrel{\text{def}}{=}$ diffracted wave phase angle at A –

Both η_D and φ_D are calculated with NEMOH [11].

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

$$\eta = \eta_D \cos(\omega t + \varphi_D) - a_c \sin(\omega t - kX_A^-) \quad (2)$$

$$a_c \stackrel{\text{def}}{=} a\frac{\sinh[k(z_0 + h)]}{\sinh(kh)},$$

$z_0 \stackrel{\text{def}}{=}$ floater draft, $h \stackrel{\text{def}}{=}$ *water depth*

Therefore, eq. (1) & (2) give the relative range between ship heave and wave elevation at A-:

$$z_A^- - \eta = Z_A^- + \frac{-\mathcal{E}\mathcal{T}^2 + 2\mathcal{F}\mathcal{T} + \mathcal{E}}{1 + \mathcal{T}^2}$$

$$\mathcal{E} \stackrel{\text{def}}{=} \mathcal{A}\cos(\varphi_z - \omega t_T) - \mathcal{B}\cos(\varphi_\theta - \omega t_N) - \eta_D \cos\varphi_D - a_c \sin(kX_A^-)$$

$$\mathcal{F} \stackrel{\text{def}}{=} -\mathcal{A}\sin(\varphi_z - \omega t_T) + \mathcal{B}\sin(\varphi_\theta - \omega t_N) + \eta_D \sin\varphi_D + a_c \cos(kX_A^-)$$

A variation study gives its minimum value:

$$[z_A^- - \eta]_{min} = Z_A^- + \frac{-\mathcal{E}\mathcal{T}_+^2 + 2\mathcal{F}\mathcal{T}_+ + \mathcal{E}}{1 + \mathcal{T}_+^2} \quad (3)$$

$$\text{where } \mathcal{T}_+ \stackrel{\text{def}}{=} -\left(\mathcal{E} + \sqrt{\mathcal{E}^2 + \mathcal{F}^2}\right)/\mathcal{F}$$

The CTV deck gets flooded if wave elevation at point A- is greater than CTV heave at point A-.

Therefore, water ingress is if $[z_A^- - \eta]_{min} \leq 0$.

3. Results

3.1. *Berthing CTV against Monopile*

The water depth is 29m. The studied monopile has 5m diameter [5] (figures3 and 4).

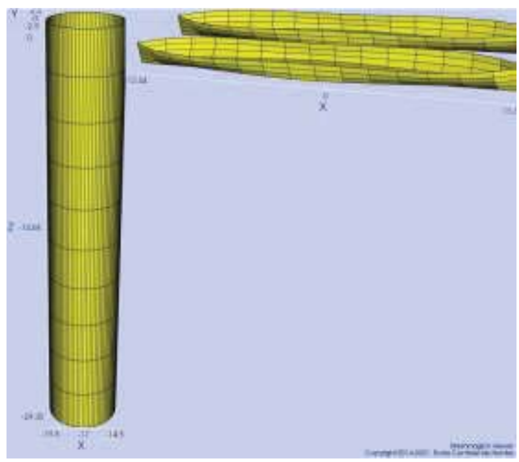

Fig. 3. CTV berthing against monopile (3D view)

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

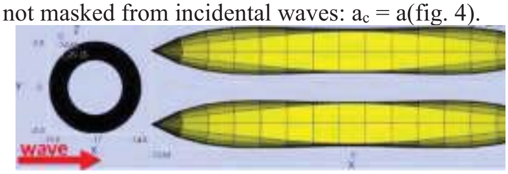

Fig. 4. CTV berthing against monopile (plane view)

Figure 5 shows the relative range between ship heave & wave elevation at A- vs λ/B @ 2.5m Significant Wave Height (Hs).

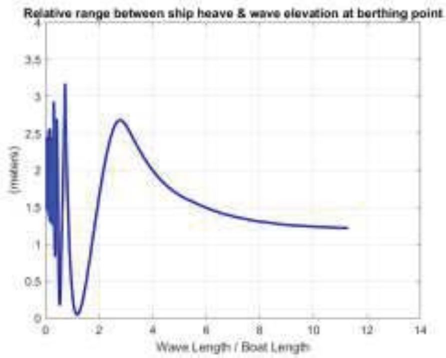

Fig. 5. $[z_A^- - \eta]_{min}$ vs λ/B @ 2.5m Hs

3.2. *Berthing CTV against Cylindrical Floater*

Water depth is h=70m [6]. The studied cylinder has [6] 13m diameter, z_0=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).

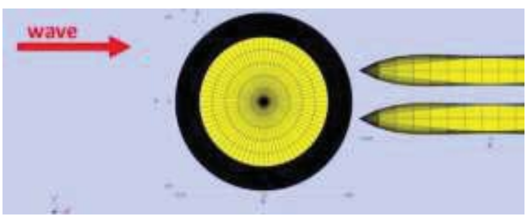

Fig. 6. CTV berthing against cylindric floater (plane view)

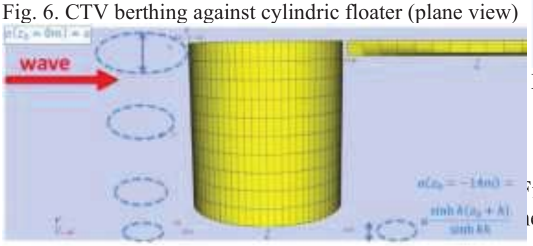

Fig. 7. CTV berthing against cylindrical floater (3D view)

Figure 8 shows the relative range between ship heave & wave elevation at A- vs λ/B @ 3m Hs.

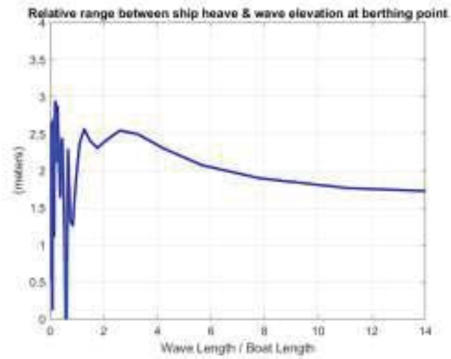

Fig. 8. $[z_A^- - \eta]_{min}$ vs λ/B @ 3m Hs

3.3. *Berthing CTV against Cuboïd Floater*

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) and (3), the residual wave amplitude is a_c =a sinh[k(z_0+h)] / sinh(kh) (figures 9 and 10).

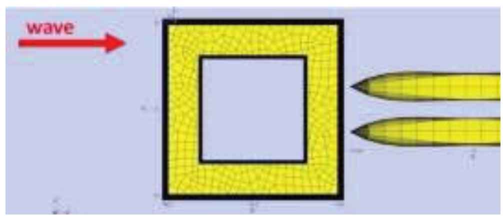

Fig. 9. CTV berthing against FLOATGEN (plane view)

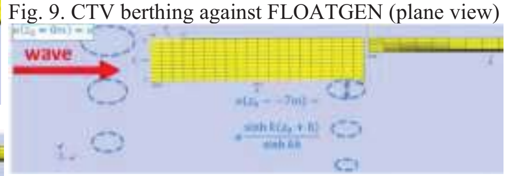

Fig. 10. CTV berthing against FLOATGEN (3D view)

Figure 11 shows the relative range between ship heave & wave elevation at A- vs λ/B @ 2.5m Hs.

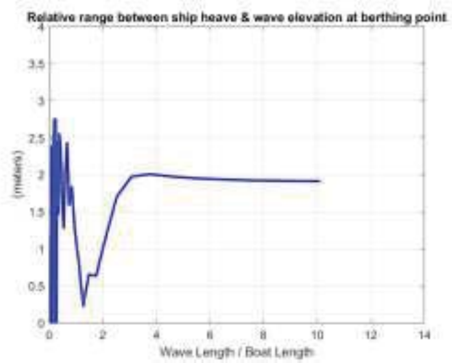

Fig. 11. $[z_A^- - \eta]_{min}$ vs λ/B @ 3m Hs

3.4. *Results Summary and Interpretations*

Table 2 sums up the Hs found for deck flooding to occur whatever the wavelength may be.

Table 2. Hs causing water ingress vs various floaters.

Case	Floater Geometry	Depth	Max Hs
0	Triton Knoll monopile[2]	15m	2m
1	5m Ø monopile	15m	2m
2	5m Ø monopile	29m	2.5m
3	13m Ø cylindrical floater	70m	>3m
4	41m Ø cylindrical floater	23m	>3m
5	36m side square floater (1)	23m	>3m
6	36m side FLOATGEN	23m	2.5m
7	36m side FLOATGEN	70m	3.0m

Note (1) Cases 3 & 4: same displacement & draft.

Table 3 gives λ/B range for deck flooding to occur

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

Case	Floater Geometry	Depth	λ/B
0	Triton Knoll monopile[2]	15m	<1.0
1	5m Ø monopile	15m	<1.1
2	5m Ø monopile	29m	<1.2
3	13m Ø cylindrical floater	70m	<0.6
4	41m Ø cylindrical floater	23m	None
5	36m side square floater (1)	23m	None
6	36m side FLOATGEN	23m	<1.3
7	36m side FLOATGEN	70m	<0.8

Note (1) Cases 3 & 4 : same displacement & draft.

Note (2) "none" means for no realistic λ/B ratio.

By "realistic" wavelength over boat length ratio, we mean 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 (3°16'39"E, 42°52'58"N) [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 used as a benchmark, which is Triton Knoll offshore wind farm [2] [10]. In comparison, case 1 results for Hs and λ/B meet case 0 results with respectively 0% and 10% accuracy: that is satisfactory, bearing in mind the absence of CAT CTV real hull shape data [5].

Comparison of cases 1 and 2 shows that the influence of water depth on Hs and λ/B in significant: respectively 25% and 9% increase.

Comparing case 2 on one hand and cases 4-5 on the other hand show a significant influence of floater wave masking on both Hs and λ/B: respectively more than 20% increase and no more λ/B causing water ingress, provided it stays realistic (λ/B < 0.2).

Comparing cases 2 and 6 show that FLOATGEN wave masking does not improve water ingress, both as regards Hs and λ/B.

Comparing cases 6 and 7 shows one more time a significant influence of water depth on Hs and λ/B: respectively 20% increase and 38% decrease.

Eventually, comparing cases 3 and 7 shows 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

Reference [2] author comment [3] reveals applicable to the 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, the airgap of the catamaran 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 (SES), 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].

The ground behind the above regulations is a research programme [13] : it resulted in identifying the implication of fender slip during the transfer mode, as "a parameter clearly at the heart of transfer safety".

Acknowledgement
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Appendix A. Abbreviations and Acronyms

Abbreviation	Definition
CAT	Catamaran
CTV	Crew Transfer Vessel
d.o.f.	Degree Of Freedom
H_s	Significant Wave Height (Hs = 2a)
HSVA	Hamburgische Schiffbau-Versuchsanstalt GmbH (Hamburg Ship Model Tank Test Facilities)
O&M	Operation & Maintenance
SES	Surface Effect Ship
3D	Three Dimensional

Terminology	Designation
h	Water depth
B	Ship length
λ	Wavelength
X_{A^-}	Horiz. coordinate of boarding point
Z_{A^-}	Vertical coordinate of boarding point
z_{A^-}	Vertical heave of boarding point
η_D	Diffracted wave elevation at berthing point
φ_D	Diffracted wave phase angle at berthing point
x_m/a	Maximum non dimensional ship surge
z_m/a	Maximum non dimensional ship heave
θ_m	Maximum non dimensional ship pitch angle
T	Wave vertical force
N	Wave horizontal force
t_T and t_N	Time phase corrections required to get the calculated Wigley hull loads T(t) and N(t) in phase with the HSVA real hull test results
k	Wave number
a	Wave amplitude (half crest to through)
z_0	Floater keel
ω	Wave pulsation
φ_x	Maximum ship surge phase angle
φ_z	Maximum ship heave phase angle
φ_θ	Maximum ship pitch phase angle

References

1. Barthélemy L. (2022), "Optimizing *Berthing of Crew Transfer Vessels against Floating Wind Turbines – A Comparative Study of Various Floater Geometries"*, ENSM, ESREL 2022 conference, Dublin, Ireland.
2. Skomedal N. G. and Espeland T. H. (2017): "*Cost-effective Surface Effect Ships for Offshore Wind*", ESNA AS, KRISTIANSAND S, NORWAY, FAST 2017 conference, Nantes, France.
3. Skomedal N. G (2022), "RE error in yr paper?", e-mail.
4. Barthélemy L. (2021), "*Berthing Criteria for Wind Turbine Crew Transfer Vessel with Low or High Friction Fender*", ENSM, ESREL 2021 conference, Angers, France.
5. König M., Ferreira González D., Abdel-Maksoud M. & Düster A. (2017). "*Numerical investigation of the landing manoeuvre of a crew transfer vessel to an offshore wind turbine*", *Ships and Offshore Structures*,12:sup1,S115-S133, DOI:10.1080/17445302.2016.1265883, https://doi.org/10.1080/17445302.2016.1265883
6. https://info-efgl.fr/le-projet/le-flotteur-ppi-eiffage/ [Accessed: 2021-10-29]
7. Dr Sam Weller (20119), "*Fibre rope selection for offshore renewable energy: Current status and future needs*" , Tension Technology International Ltd EUROMECH 607, Brest 29th August 2019,https://wwz.ifremer.fr/rd_technologiques/content/download/136107/file/Session%204%20Weller.pdf [Accessed: 2020-01-02]
8. https://www.energiesdelamer.eu/bin/statsnews.php?lst=2&nid=395&img=publications/4085-bouygues-travaux-publics-presente-le-flotteur-floatgen-au-concours-tekla
9. OPEN OCEAN Marine Data Intelligence (2015), "*Metocean Analytics Report Leucate_Nord*"
10. https://en.wikipedia.org/wiki/Triton_Knoll [Accessed: 2023-03-24].
11. Babarit, Delhommeau - Theoretical & numerical aspects of the open source BEM solver NEMOH - 11th European Wave & Tidal Energy Conference, https://lheea.ec-nantes.fr/logiciels-et-brevets/nemoh-presentation-192863.kjsp , 2015
12. Skomedal, Espeland (ESNA AS, KRISTIANSAND S, NORWAY), "*Low Emission Fast Vessels for Crew Transfer Operations*", FAST conference, Providence, USA – Oct., 2021
13. Carbon Thrust (2017): "*Crew Transfer Vessel (CTV) Performance Plot (P-Plot) Development*" Notice to the Offshore Wind Energy Sector. Can be downloaded from https://www.carbontrust.com/media/674745/carbon-trust-p-plot-development-researchsummary-june-2017.pdf [Accessed: 2019-05-13]