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 Barthelemy

August 21, 2023

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 BARTHELEMY [1][0000-0002-6178-7586]

[1] 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).

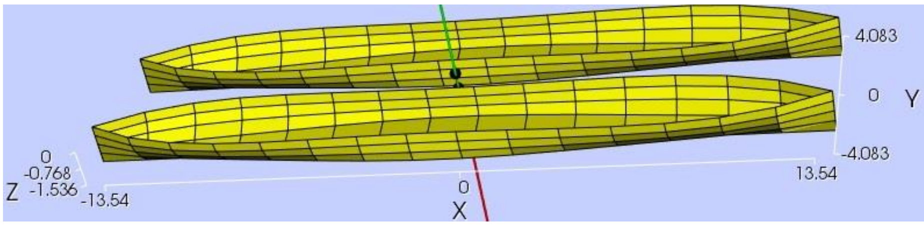

Fig. 1. Wigley CAT CTV Hull [5].

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

Table 1. Table captions should be placed above the tables.

Motion	No. of d.o.f.	d.o.f.
Rotation around floatation centre	1	Pitch θ
Translation from original position O	2	surge τx, heave τz

2.2 Main Deck Water Ingress Calculation

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

$$\tau_z = z_m \cos[\omega(t - t_T) + \varphi_z] \quad (1)$$

$$\theta = \theta_m \cos[\omega(t - t_N) + \varphi_\theta] \quad (2)$$

Where tT and tN 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-.

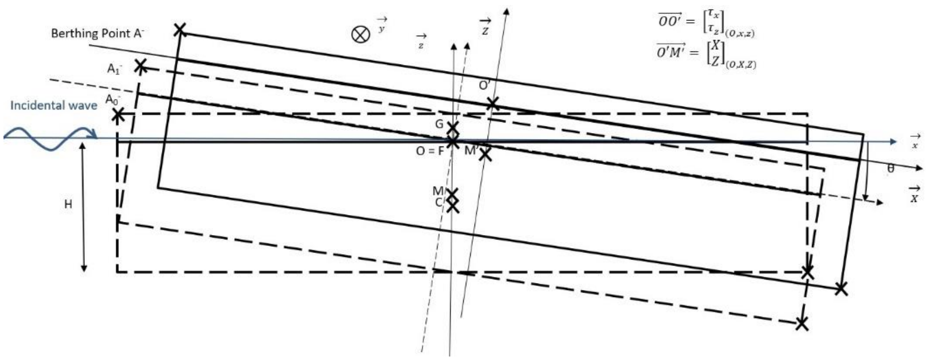

Fig. 2. CTV motion at berthing point A- due to waves

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

$$z_A^- = Z_A^- + \Delta z_A \cong Z_A^- + \tau_z - X_A^- \theta \Longrightarrow z_A^- = Z_A^- + \mathcal{C}\cos\omega t + \mathcal{D}\sin\omega t \tag{3}$$

$$\text{with } \mathcal{A} \stackrel{\text{def}}{=} z_m,\ \mathcal{B} \stackrel{\text{def}}{=} X_A^- \theta_{\mathrm{m}},\ \mathcal{T} \stackrel{\text{def}}{=} \tan\omega t/2, \tag{4}$$

$$\mathcal{C} \stackrel{\text{def}}{=} \mathcal{A}\cos(-\omega t_T + \varphi_z) - \mathcal{B}\cos(-\omega t_N + \varphi_\theta) \tag{5}$$

$$\mathcal{D} \stackrel{\text{def}}{=} -\mathcal{A}\sin(-\omega t_T + \varphi_z) + \mathcal{B}\sin(-\omega t_N + \varphi_\theta) \tag{6}$$

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

$$\eta = \eta_D\cos(\omega t + \varphi_D) - a\sin(\omega t - kX_A^-) \tag{7}$$

with η_D and φ_D being respectively diffracted wave elevation and 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:

$$\eta = \eta_D\cos(\omega t + \varphi_D) - a_c\sin(\omega t - kX_A^-) \tag{8}$$

$$a_c \stackrel{\text{def}}{=} a\sinh[k(z_0 + h)]/\sinh(kh),\ \mathrm{z}_0 \stackrel{\text{def}}{=} \text{floater draft},\ h \stackrel{\text{def}}{=} water\ depth \tag{9}$$

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

$$z_A^- - \eta = Z_A^- + [(-\mathcal{E}\mathcal{T}^2 + 2\mathcal{F}\mathcal{T} + \mathcal{E})/(1 + \mathcal{T}^2)] \tag{10}$$

$$\mathcal{E} \stackrel{\text{def}}{=} \mathcal{A}\cos(\varphi_z - \omega t_T) - \mathcal{B}\cos(\varphi_\theta - \omega t_N) - \eta_D\cos\varphi_D - a_c\sin(kX_A^-) \tag{11}$$

$$\mathcal{F} \stackrel{\text{def}}{=} -\mathcal{A}\sin(\varphi_z - \omega t_T) + \mathcal{B}\sin(\varphi_\theta - \omega t_N) + \eta_D\sin\varphi_D + a_c\cos(kX_A^-) \tag{12}$$

A variation study gives its minimum value:

$$[z_A^- - \eta]_{min} = Z_A^- + [\,(-\mathcal{E}\mathcal{T}_+^2 + 2\mathcal{F}\mathcal{T}_+ + \mathcal{E})/(1 + \mathcal{T}_+^2)] \tag{13}$$

$$\text{where } \mathcal{T}_+ \stackrel{\text{def}}{=} -\left(\mathcal{E} + \sqrt{\mathcal{E}^2 + \mathcal{F}^2}\right)/\mathcal{F} \tag{14}$$

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] (fig.3 and 4).

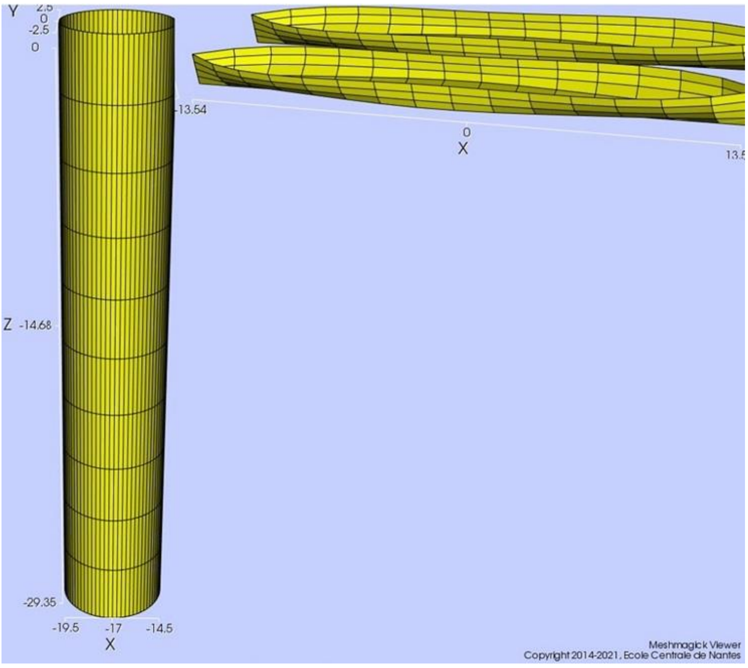

Fig. 3. CTV berthing against monopile (3D view).

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

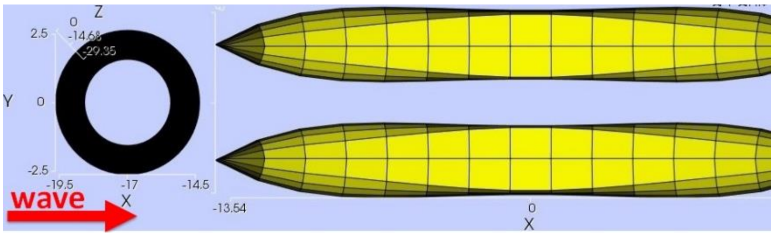

Fig. 4. CTV berthing against monopile (plane view)

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

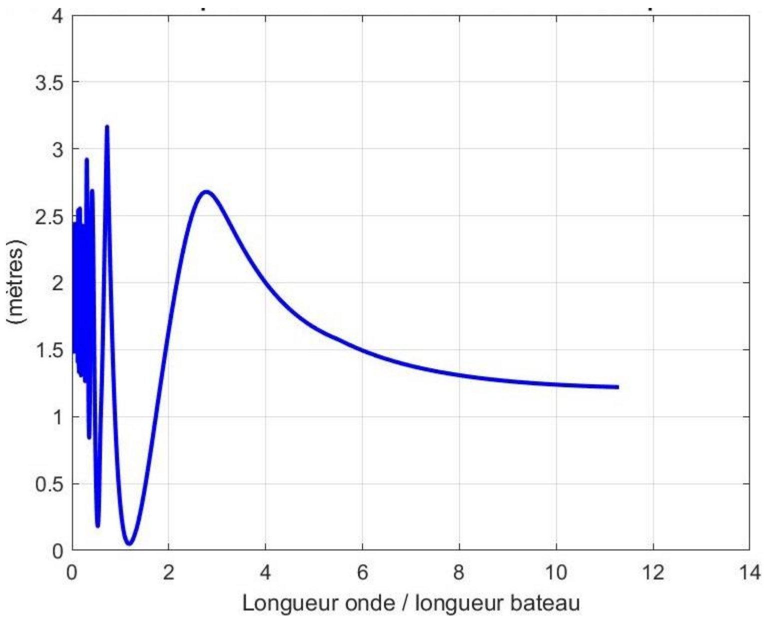

Fig. 5. $[z_A^- - \eta]_{min}$ vs λ/B @ 2.5m Hs

3.2 Berthing CTV against Cylindrical Floater

Water depth is h=70m [6]. The studied cylinder has [6] 13m diameter, 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 ac =a sinh[k(z0+h)] / sinh(kh) (figures 6 and 7).

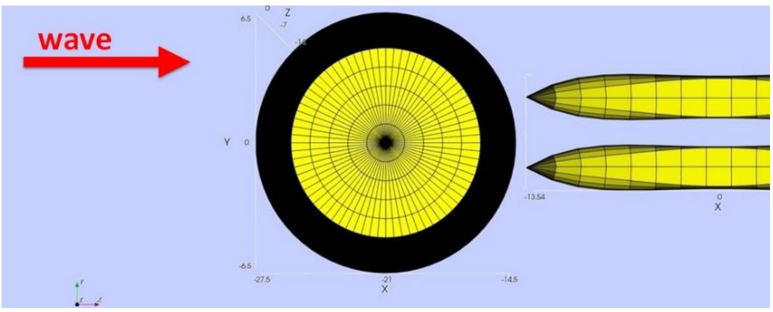

Fig. 6. CTV berthing against cylindric floater (plane view)

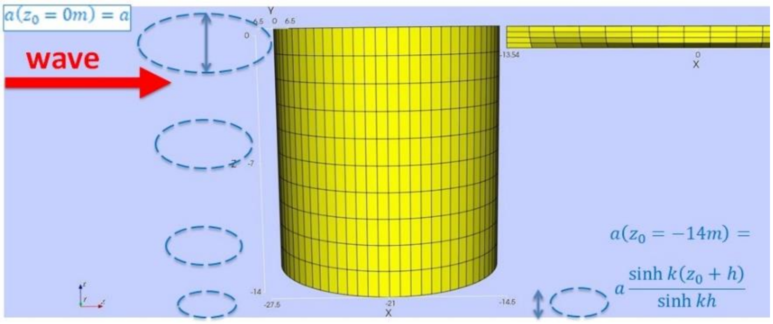

Fig. 7. CTV berthing against cylindrical floater (3D view)

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

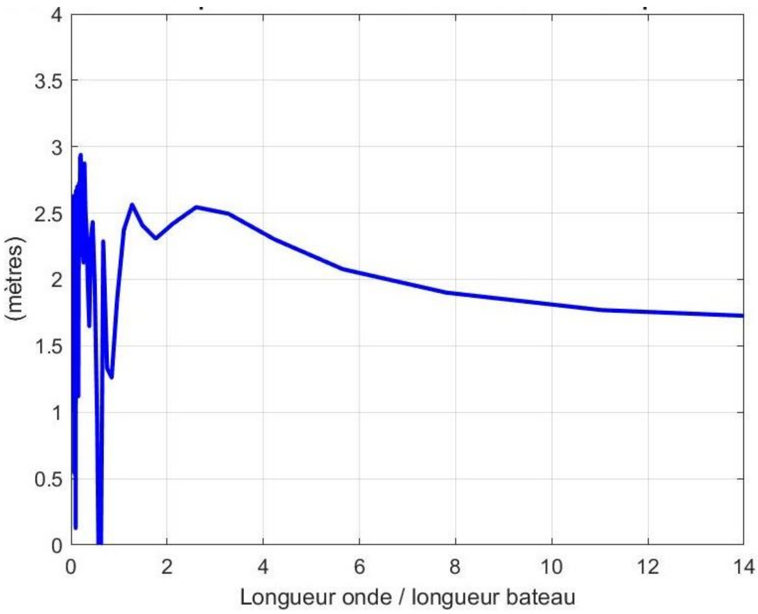

Fig. 8. $[z_A^- - \eta]_{min}$ vs λ/B @ 3m Hs

3.3 Berthing CTV against Monopile

Water depth is h=23m [7]. The studied square has [7] [8]: 36m side, z0=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 ac =a sinh[k(z0+h)] / sinh(kh) (fig 9 and 10).

Fig 11 shows the relative range between ship heave & wave elevation at A- vs λ/B @ 3m Hs.

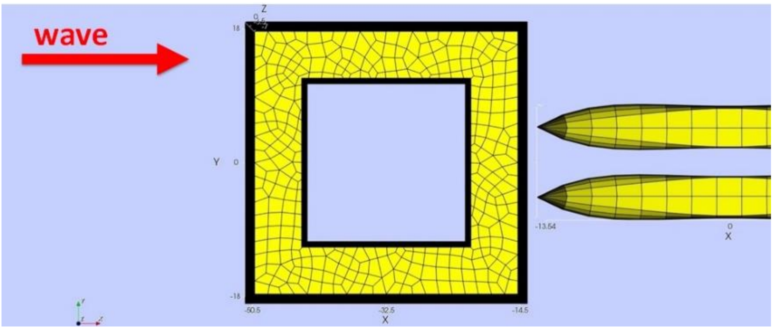

Fig. 9. CTV berthing against FLOATGEN (plane view)

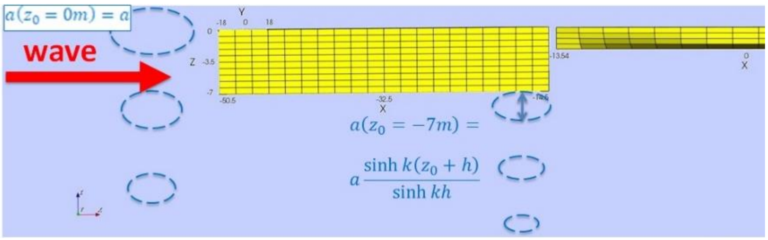

Fig. 10. CTV berthing against FLOATGEN (3D view)

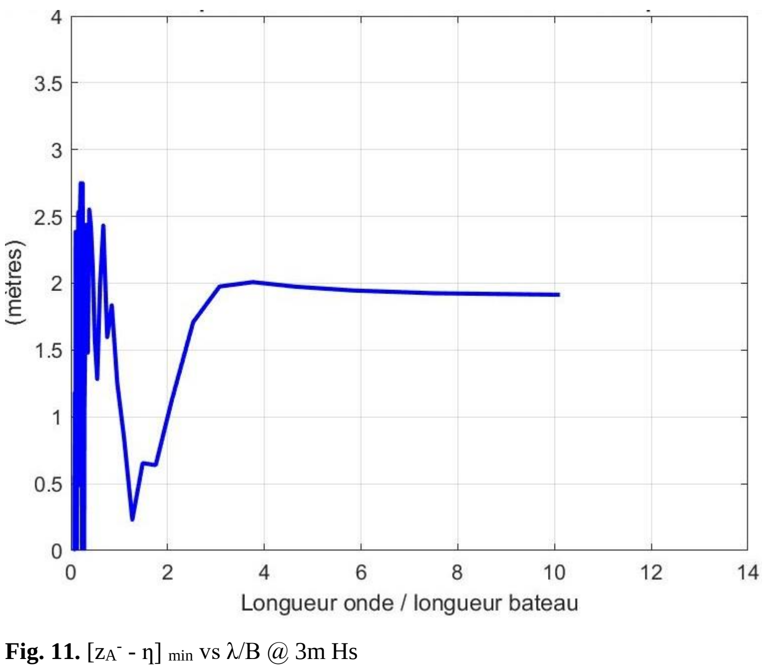

Fig. 11. $[z_A^- - \eta]_{min}$ vs λ/B @ 3m Hs

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 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	36m side FLOATGEN	23m	2.5m
5	36m side FLOATGEN	70m	3.0m

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	36m side FLOATGEN	23m	<1.3
5	36m side FLOATGEN	70m	<0.8

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

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

Terminology	Designation	Terminology	Designation
h	Water depth	T, N	Wave vertical, horizontal forces
B	Ship length	t_T , t_N	Time phase corrections to get calculated Wigley hull loads T , N in phase with HSVA hull test results

λ	Wavelength	k	Wave number
X_A^- , Z_A^-	horizontal, vertical coordinates	a	Wave amplitude (half crest to through)
z_A^-	Boarding point heave	z_0	Floater keel elevation
η_D , φ_D	Boarding pt diffracted wave elevation, phase angle	ω	Wave pulsation
x_m/a , z_m/a , θ_m	Max. non dimensional ship surge, heave, pitch	φ_x , φ_z , φ_θ	Max. surge, heave, pitch phase angles

References

1. Barthélemy L. (2022), “Optimizing Berthing of Crew Transfer Vessels against Floating Wind Turbines – A Comparative Study of Various Floater Geometries”, ENSM, ICICT 2022 conference, London, UK.
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, 5th World S4 2021 conference, London, UK
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]