16èmes Journées de l'Hydrodynamique

27-29 novembre 2018 - Marseille

CENTRALE MARSEILLE irphé Institut de Recherche sur les Phénomènes Hors Equilibre

COMPARAISON DE TROIS APPROCHES COUPLEES HYDRO-STRUCTURE POUR LE DESIGN DE PLATEFORMES FLOTTANTES

COMPARISON OF THREE HYDRO-STRUCTURE COUPLING APPROACHES FOR THE DESIGN OF FLOATING PLATFORMS

A.L. DEFOY(1), J.M. HEURTIER(1), C.LE CUNFF(1), R.ANTONUTTI(2), P.WEYNE(2)

a-laure.defoy@principia.fr, j-michel.heurtier@principia.fr.fr, cedric.lecunff@principia.fr, rantonutti@naval-energies.com, pweyne@naval-energies.com

(1) PRINCIPIA, Floating Unit Department, La Ciotat
(2) NAVAL ENERGIES, Naval Architecture Department, Brest

Résumé

Avec le développement des turbines éoliennes flottantes, il est intéressant de pouvoir vérifier le design du flotteur à partir de simulations dynamiques du système complet. En effet, l'ensemble ancrage, flotteur, turbine est un système fortement couplé soumis à des efforts hydrodynamiques et aérodynamiques. Il n'est donc pas possible d'obtenir le mouvement du flotteur sans modéliser toutes les composantes dans un même modèle. Les approches classiques en théorie potentielle considèrent le plus souvent le flotteur comme rigide et les efforts internes ne peuvent donc pas être directement extraits des calculs. C'est pourquoi une approche avec un flotteur modélisé par des éléments poutres est souvent utilisée pour capturer la flexibilité du flotteur. Les efforts hydrodynamiques sont fournis par des approches de type Morison applicable pour de larges périodes de houle. Une méthode alternative dite de sous-structures a alors été développée afin de combiner les avantages de l'une et de l'autre: le flotteur est toujours modélisé par des éléments poutres mais ceux-ci sont individuellement chargés par des efforts potentiels avec une correction de traînée visqueuse de type Morison. Cette approche ainsi que des modélisations plus conventionnelles sont comparées à des essais en bassin. La méthode hybride donne de très bons résultats pour les mouvements de premier ordre. Les résultats sur les mouvements de second ordre sont grandement améliorés par la prise en compte de la non-linéarité géométrique dans les efforts de houle incidente ; cela permet de conjuguer les atouts des modèles classiques « tout Morison » et potentiel. Finalement, les comparaisons sur les efforts internes au flotteur avec l'approche Morison sur des cas à grande période de houle montre que l'approche sous-structure peut être utilisée avec confiance pour le design d'un flotteur. Un intérêt supplémentaire de la méthode par sous-structures réside dans l'accès à la pression dynamique totale qui s'exerce sur les parois du flotteur ; ceci a été validé par les mesures de pression.

Summary

With the development of Floating Offshore Wind Turbines (FOWT), the design of a floater needs to be revisited. Indeed, the global system involves aerodynamic and hydrodynamic loadings together with a strongly coupled system. Therefore, in order to have the proper motions, the whole system has to be modelled at once. It is then interesting to directly obtain the internal loads in the floater to check its design. Most potential flow approaches considers the floaters as a rigid body and do not allow direct extraction of these loads. Due to the size of the floater, it can also be modelled with beam elements, the hydrodynamic loadings being provided by a Morison type formulation. Nonetheless, the validity of this formulation is restricted to larger wave periods, whereas at lower periods its limitations appear. In the present paper, an alternative solution is presented, the so called sub-structures approach, which aims at combining the advantages of both previous approaches. The floater is defined through beam elements but those elements are loaded with potential flow theory forces together with a drag correction. The sub-structure modelling as well as the more conventional approaches are compared to basin test in terms of motion. The new approach provides very good results for first order wave motion. Second order wave motion is greatly improved by taking into account the geometric non-linearity in the incident wave loads, ultimately uniting the best features of conventional Morison and HDB approaches. The comparison of the internal loads with the Morison formulation on cases with similar motions shows that sub-structure modelling can be used confidently for floater design. Finally, the substructure approach can also be used confidently to derive wave pressure at any point on the hull, since very good agreement with instantaneous pressure measurements was found.

I - Introduction

Floating Offshore Wind Turbines (FOWT) are complex systems with couplings between their different components subjected to hydrodynamic and aerodynamic loads and their design remains challenging.

From a hydrodynamic viewpoint, the actual FOWT dimensions are at the edge between small and large body assumptions depending on the incident wave and the hydrodynamic loads acting on the floater. They may be represented either by a Morison-type or a potential-flow type model or a combination of the two.

On one hand, the potential theory is currently the most advanced engineering solution to compute the hydrodynamic loads on a floater represented by a rigid body. Of course, more advanced approaches resorting to CFD can be envisaged but they are not mature yet to be used during a design loop.
The potential approach allows accounting for incident, diffracted and radiated flows; viscous damping on the hull shall be derived by CFD or basin tests and are often added through damping matrices.
On the other hand, the conventional full Morison approach is fit for detailed floater design (as opposed to a floater represented by a whole rigid body) since it directly provides distributed loads along the structural elements, but is expected to become less accurate since the Morison formulation ignores the diffracted flow and may over estimate hydrodynamic loads at lower wave periods. Therefore, a new potential-flow approach (so-called sub-structure model) was developed by NAVAL ENERGIES (NE) and PRINCIPIA (PRI) in order to combine the advantages of both approaches by the generation of local hydrodynamic loads from a diffraction/radiation data base that are loaded on a flexible model.

This paper presents the intercomparison and experimental validation of the three different hydrodynamic approaches, including the new sub-structured option introduced above. It borrows from the results of a recent project carried out by NE with the support of PRI, comparing DeepLines Wind (DLW) numerical outputs to basin tests previously performed by NE at MARIN in the Netherlands. The hydrodynamic models used are:

- **The Full Morison** ("MOR"): the floater structure is modelled by flexible beam elements. All hydrodynamic forces including drag, added mass, and inertial wave loads are calculated with a Morison formulation applied in both axial and transverse directions;
- **The Integral HDB model** with difference-frequency QTFs applied on the horizontal DOFs under the Newman approximation. ("HDB"). The potential model is also referred to as the HDB for Hydrodynamic DataBase model. The floater structure is a rigid body. Global diffraction/radiation loads are extrapolated from a classic integral HDB file. Distributed drag coefficients are identical to full Morison.
- **The Sub-structure HDB model** ("SUB_HDB"). The floater structure is modelled by flexible beam elements loaded with distributed hydrodynamic forces derived from potential theory results (sub-HDB files). Distributed drag coefficients are identical to the full Morison model.

First, the three models are theoretically described, as well as their implementation in DeepLines. Then, the MARIN test campaign carried out by NE is introduced; some of its outputs are then compared with the three numerical models. Based on the promising results of the SUB_HDB modelling, some further hydrodynamic modelling investigations are also presented. The results are then discussed, and summarized in order to assess the performance of each model.

II - The three modelling approaches

II - 1 General

This section aims at presenting the three modelling approaches. It should be kept in mind that the substructure model (SUB_HDB) is a combination of a Morison and a potential model, as detailed below:
The flexible structure is composed of beam elements. It is then the equivalent of the full Morison model from a structutal of viewpoint, i.e. the beam elements directly provide the following efforts:

- Internal forces and moments due to beam strains and curvatures;
- Mass and inertia loads excluding added masses;
- Drag loads.

The substructure hydrodynamic database (Sub-HDB), computed by the potential-flow software DIODORE™, is used to calculate the hydrodynamic loads. From a global hydrodynamic point of view, this is equivalent to a full HDB model except that the floater's hull mesh has been divided into sub-meshes and pressures loads are integrated on every sub-strucutre. Finally:

- The potential loads transfer reponse amplitudes are stored in a Sub-HDB file for each structural element that composes the floater's hull (Wave excitation forces, radiation damping and added mass);
- the hydrostatic loads are directly computed during the time domain calculations from the panel mesh.

II - 2 Implementation in DeepLines Wind

The three models are built, considering MARIN model's mechanical properties. The methodology used to define the three models is illustrated in Figure 1. The goal is to have similar models, differences being only linked to the calculation approach.

- Build the beam model and the associated panel's mesh with Isymost software.
- Define each substructure: a substructure is defined by a set of beam finite elments associated with the correponding panel mesh.
- Run the potential flow analysis with Diodore. This generates the potential flow loads for each substructure (HDB).

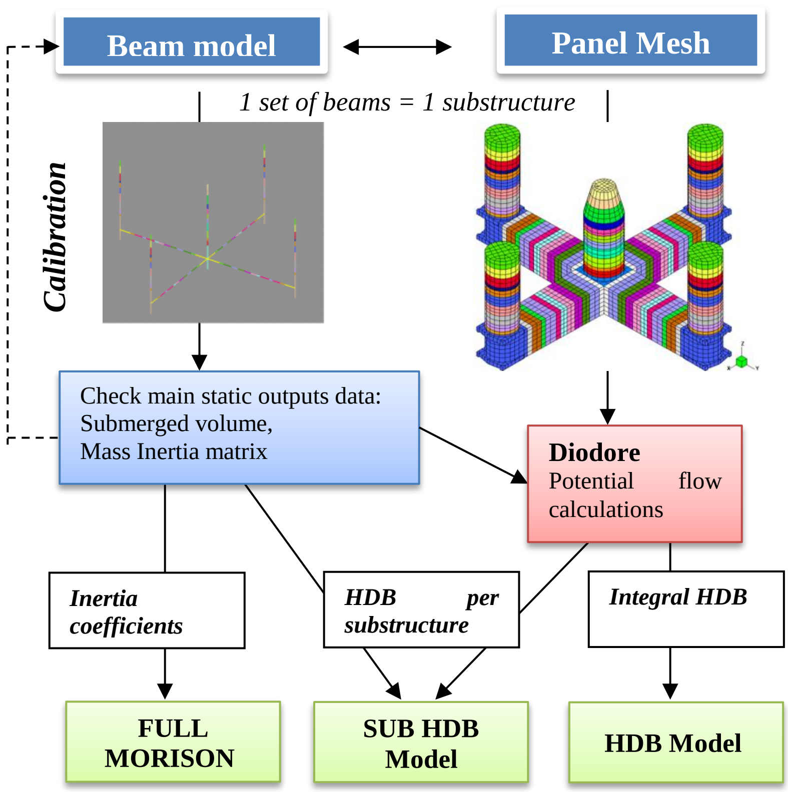
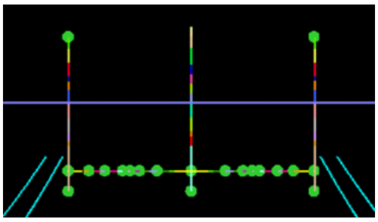
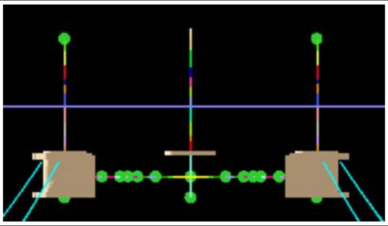
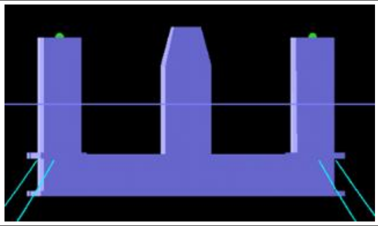


Figure 1 : Definition of the three models

Once the beam model is built in Isymost, it is automatically imported in DeepLines Wind, taking into account all mechanical mass and inertia, and the Hydrodynamic database properly defined with Diodore. The three models can easily be defined at once in DeepLines Wind, ensuring that they will be equivalent.

Figure 2 provides a summary of the three models and their input data.

<table>
<tr><th></th><th>FULL MORISON MODEL</th><th>SUB_HDB MODEL</th><th>HDB MODEL</th></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Mechanical properties</td><td colspan="2">From Beam model
(used to derive the global mass and Inertia matrix)</td><td>Global Mass and inertia matrix</td></tr>
<tr><td>Buoyancy</td><td>From beams
+ additional buoyancy for connections</td><td colspan="2">From Panel's Mesh
Calculation options: Nonlinear hydrostatic stiffness
+ additional buoyancy due to panel's mesh</td></tr>
<tr><td rowspan="2">Wave loads</td><td rowspan="2">Inertia and added mass coefficients (Cm, Ca)
applied on each beam

(may be derived from the Sub HDB file)</td><td colspan="2">Radiation/ Diffraction Calculation
1st order wave loads, added masses matrix and radiation damping, computed on the whole structure</td></tr>
<tr><td>HDB per Sub structure</td><td>Integral HDB</td></tr>
<tr><td>Additional damping</td><td colspan="3">Drag Coefficients Cd applied on each beam</td></tr>
<tr><td>Additional 2nd order loads</td><td colspan="2">-</td><td>Mean and slow-varying drift forces using Newman's approximation</td></tr>
</table>

Figure 2 : Summary of input Morison, SUB_HDB and HDB model

The floater may now be defined on the three different ways but the rest of the FOWT remains identical:

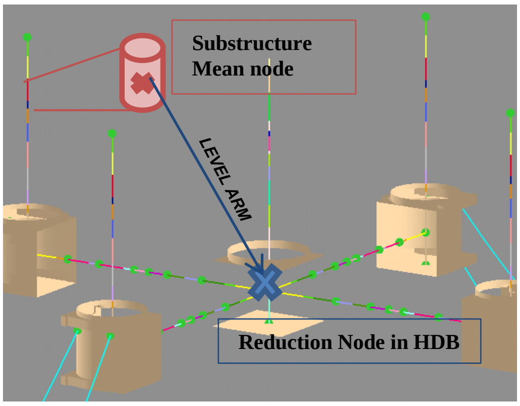
- The mooring system modelled by finite elements and Morsion formulation for the fluid loads;
- The tower and rotor nacelle assembly mass and inertia matrix.

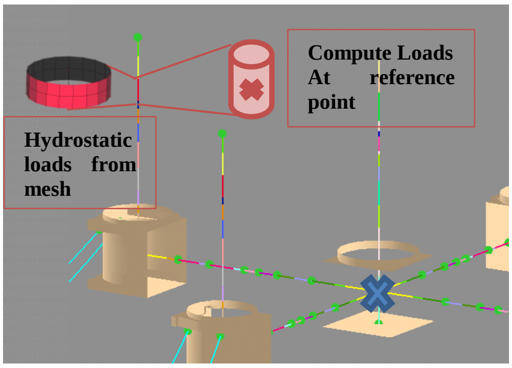
II - 3 Sub-structure model

The excitation loads, added mass and radiation damping terms of each substructure in the Sub-HDB file are expressed in the floater's global frame at the reduction point and not in the beam local frame. More details can be found in reference [4] and [6] . Therefore, a first step is to change the application point of the input in the Sub-HDB file, the application point being the center (or reference node) of the beam elements defining the substructure. Note that this process assumed that the floater's deformation remains small.
The calculations of the hydrodynamic loads is then performed for each sub-structure as detailed in Figure 3.

- Transfer the input file from the reduction point to the sub-structure reference node;
- Identify all nodes of the sub-structure and calculate the sub-structure reference node positions, velocities and accelerations;
- Calculate the hydrodynamic loads at substructure node in the seakeeping frame (main direction of the floater):
    - The first order wave loads with the wave components;
    - The added mass and radiation damping terms with the node velocities and accelerations
- Calculate the hydrostatic with the sub-structure mesh at the reference node in the global reference frame.
- The total load is then:

$$F_{tot} = F_{added\_mass} + F_{damping\_rad} + F_{Wave\ 1st\ order} + F_{hydrostatic}$$





- Dispatch F_{tot} on the sub-structure nodes as such:
    - Let L_{tot} be the sub-structure total length;
    - The linear hydrodynamic loads is approximated by: $f = \frac{F_{tot}}{L_{tot}}$
    - For every beam element of length l, every end node gets: $F_{node} = \frac{f.l}{2}$

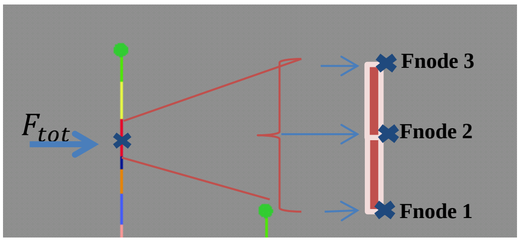


Figure 3 : Sub-structure definition

Note that the drag force accounting for the viscous effects is direcly added on the nodes through the beam element. Also the first order wave force can be further defined as an incident wave term and a diffracted term. In that case, the incident wave term can alternatively be computed at each step from pressure intergration on the sub-structure mesh.

II - 4 Morison model (inertial part)

In the Full-Morison model, inertia loads on the structure members are imposed using the Morison equations [2], [3]. The inertia loads are made of an added mass term due to the floater acceleration and an excitation term proportional to the wave acceleration.

In this study, it has been chosen to separately define these coefficients (C_m and C_a) and calibrate them according to each Sub-HDB file. The coefficient C_m is then derived from the wave excitation forces of the Sub-HDB file by the following formulae depending on the period, under the assumption that forces are in phase with the wave kinematic acceleration:

$$C_m(\omega) = \frac{|F_{ext}(w)|}{\rho.Vol.a_{wave}(w)}$$

Where $F_{ext}(w)$ is the wave excitation force RAO of the substructure, ρ the seawater density, Vol the Morison cylinder volume, and $a_{wave}(w)$, the wave acceleration for 1m amplitude wave at the center of the Morison cylinder.

Ca is then derived from the translational added mass matrix of the Sub-HDB by the following formulae depending on the period:

$$C_a(\omega) = \frac{Ma(w)}{\rho.Vol}$$

Where $Ma(w)$ is the substructure added mass, ρ the seawater density, and Vol the Morison cylinder volume.

II - 5 HDB model

Compared to the two others models, the difference-frequency forces using the Newman approach are included in the model. The floater is considered rigid.

III - Results and comparison with basin tests

III - 1 NE MARIN campaign presentation

In 2017, NE carried out a FOWT hydrodynamic testing campaign in the Marin Offshore Basin (ref[1]). The 1:35 model of the NE floating system (Figure 4) included a semi-submersible floater, a wind turbine superstructure, and a downscaled 8-line catenary mooring system allowing direct measurement of fairlead tensions. The basin water depth was set to 60 m full-scale. About 80 load cases were treated, many of which representing 3-hour long sea states. Multiple wave headings were tested, as well as aligned and misaligned wind-wave conditions.

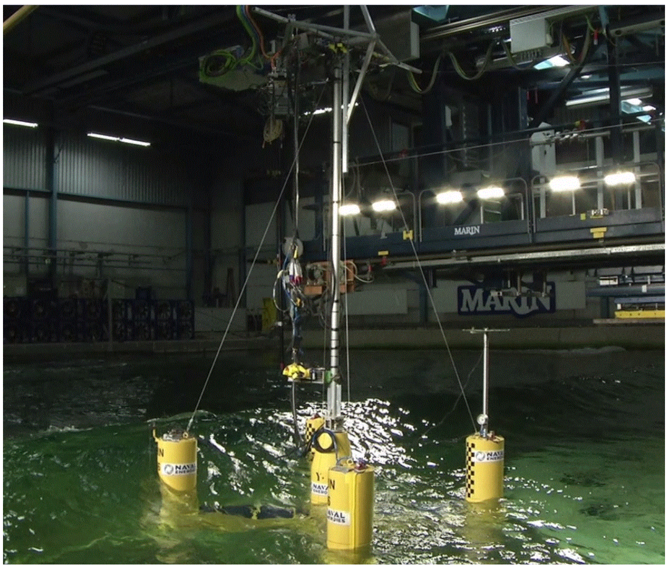


Figure 4 : Naval Energies FOWT model test.

Although the present paper focuses on pure hydrodynamic tests, the campaign also included a large set of coupled aero-hydrodynamic cases. Since wind turbine aerodynamics are governed by the Reynolds number, they cannot be easily scaled down under the Froude similitude, which is a requirement of water wave scaling. Thus, wind turbine forces were applied through servo-controlled winches using novel software-in-the-loop technology: turbine aerodynamics and control were resolved in real time by a BEM software bespokely developed by NE, taking into account the motions of the system; the resulting loads were fed through the winch system, ultimately letting model physics close the loop.

III - 2 Presentation of numerical work

NE contracted PRI for validation of DeepLines-based numerical models against some of the 2017 campaign hydrodynamic tests; part of the outputs of this task are used for the present article.

All numerical models are built and simulated at full scale. The mooring lines (identical in the three models) are modelled dynamically by finite elements. The related numerical model was first calibrated with regards to the experimental mooring static load curves. Inertia and drag coefficients of mooring lines are implemented by means of Morison formulation.

The comparisons were performed on:

- Free-floating and moored decay tests, in order to validate the hydrostatic stiffness implementation, as well as added mass. From these tests, drag coefficients were calibrated. The same set of coefficients is used in the three models.
- Regular wave and pink noise cases. In the latter, incident waves are defined by a mostly flat spectrum with energy in the period range [5s;20s].
- A set of long-crested JONSWAP irregular wave cases from the campaign. A subset of these cases will be used below for illustration purposes. The overall set features:
    - Different wave heights from H_s equal 3.0m to 12.0m in order to assess low and high dynamics and their effect on response non-linearity.
    - Different wave peak periods to assess the influence of each modelling approach with respect to the period of excitation forces. Note that the low-Tp case with (Hs, Tp) = (3.0m, 7.0s) expressly uses high-steepness waves to bring out some of the numerical models' limitations.
    - Two different wave headings.
    - Two cases with added current.

For the full Morison model, a C_m and C_a database depending on wave period is derived from the Sub HDB files. For decay test, the natural period is chosen in the simulations, whereas the spectral peak period is chosen for regular and irregular waves. In the particular case of pink noise, the C_m and C_a corresponds to a wave period of 10s.

For irregular waves and pink noise tests, the measured wave elevation time series is directly applied ensuring the same input as in the basin.

The following sections deal with a small subset of these irregular wave cases (presented in Table 1). Square-root power spectral densities are plotted and for each of the three cases presented some conclusions are derived. These cases have been selected such as to represent the wave heigt and period range.

Wave name	Hs (m)	Tp (s)	Gamma	Dir (°)
W5a	3.0	7.0	1.0	180.0
W7b	7.5	12.0	1.0	180.0
W7e	12.0	16.0	1.3	180.0

Table 1 : 3 selected irregular sea states

III - 3 Specific cases spectral analysis

From a general point of view, the surge, heave and pitch responses are well reproduced for the three modelling at wave frequency range for wave period higher than 10s. The HDB and the SUB_ HDB models are even superposed which validates the sub-structure approach.

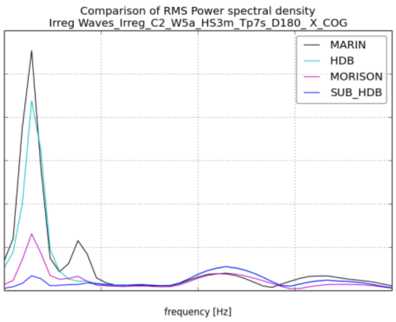
For low period (Tp<10s), the Morison model with the present calibration produces less accurate WF vertical motions than the other models. However, due to its inherent non-linearities, this kind of model tendentially outperforms the others on mid-low frequency vertical motions, whose corresponding nonlinear loads are not incorporated in the potential-flow models.

The HDB model with QTF is best at capturing low-frequency surge responses thanks to the modelling of the low-frequency loads through Newman's approximation.

Note that in the shown comparisons experimental surge response tends to be higher due to low-frequency wave energy content in the experiments not accounted for in the numerical models.

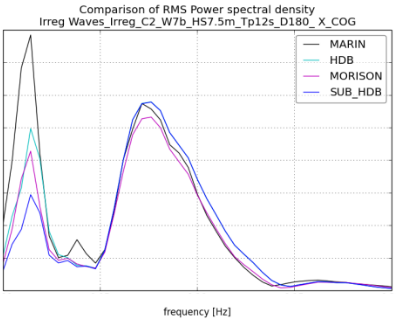
PSD OF SURGE RESPONSE

Hs=3.0m Tp 7s



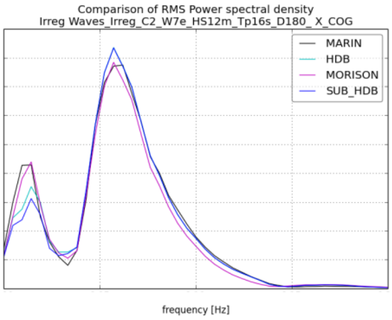
In case of low Tp, surge motions are dominated by low frequency motions. This phenomenon is well captured by the HDB model, which takes into account drift forces by Newman approximation. The SUB_HDB model is superposed to the HDB except at the LF range since no drift force is included in this model. The Morison model neither catches the LF response.

Hs=7.5m Tp 12s



For intermediate wave period, the wave frequency surge motions are very well captured by the three modelling approaches. The amplitude of low-frequency response is however under predicted by the numerical models.
It should be highlighted that some energy on wave signals was recorded in the basin at low frequency, which has not been initially modelled. This could be responsible at least partly for the differences in surge low frequency motions.

Hs=12.0m Tp 16s

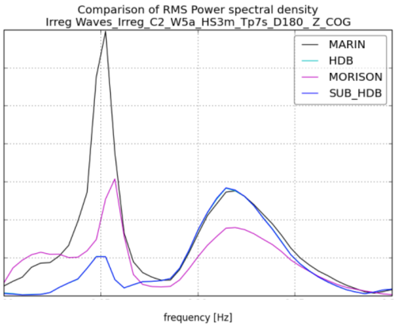


For large wave periods, surge motions are dominated by the wave frequency response, which is very well captured by the three numerical models.

Figure 5 : Surge response spectrum for 3 sea states

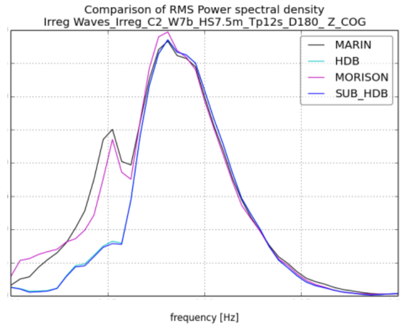
PSD OF HEAVE RESPONSE

Hs=3.0m Tp 7s



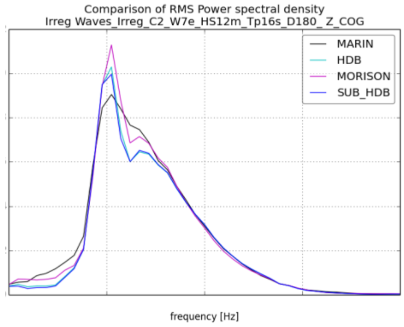
The SUB_HDB and HDB models are perfectly superposed, and also superposed to MARIN heave motions in the wave frequency range.
In MARIN results a resonant response is observed at heave natural period which is under estimated by the two potential models. This effect is better captured by the Morison model.

Hs=7.5m Tp 12s



For intermediate wave period, the Morison model best captures all components of the MARIN heave signals.
As for the above test, the HDB model does not match the energy at the heave natural period.

Hs=12.0m Tp 16s

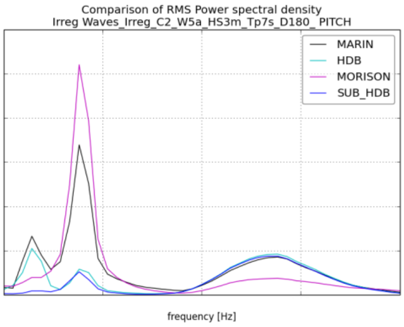


In case of large period waves, wave energy is close enough to the heave natural period so that the three models simulate very well the heave motions over all the period range.

Figure 6 : Heave response spectrum for 3 sea states

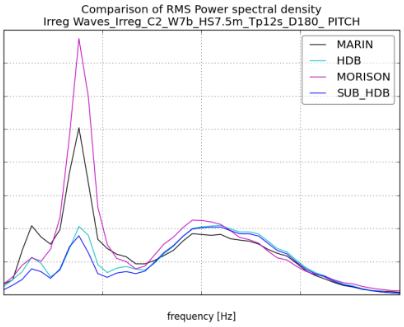
PSD OF PITCH RESPONSE

Hs=3.0m Tp 7s



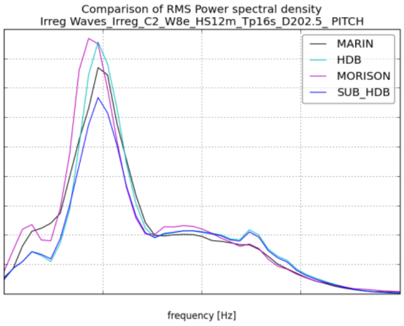
As for heave motions, the SUB_HDB and HDB model perfectly reproduce the wave frequency pitch motions.
The Morison model is not as good on the first order response bur is able to get a response at pitch natural period, even it is overestimated.

Hs=7.5m Tp 12s



For higher period, the Morison model well reproduces the response at wave frequency range as do the two potential models.
Pitch response of the Morison model at pitch natural period is still overestimated while underestimated by the potential approach.

Hs=12.0m Tp 16s



For higher periods, the three models are relatively close to the MARIN results. It should however be highlighted that the sub-structure and HDB model responses are slightly different contrary to other degrees of freedom and pitch responses on lower wave periods. Further investigation is underway to explain this observation.

Figure 7 : Pitch response spectrum for 3 sea states

IV - <u>Discussions & investigations</u>

As seen during the comparison campaign, the Morison model is a good approach, in particular to capture the low frequency pitch and heave motions, though overestimated with the present calibration. This is not as well captured by the two potential models due to the linearity of the loading approach. However, it is possible to add some non linearity by means of geometrically non-linear Froude-Krylov wave loads for the two potential flow models. Investigations on this topic are presented in §IV - 1.

Then, the SUB_HDB model fulfils its objective to derive internal loads as does the Morison model, as presented in § IV - 2. Finally, one of the advantages of the SUB_HDB model is the ability to derive the wave pressure at any point of the model, as presented in §IV - 3, where output pressure is compared to MARIN wave probe signal.

IV - 1 Non-linear Froude-Krylov investigation

As a base case, only the hydrostatic term was computed intantaneously on the surface mesh for the HDB and SUB_HDB model. At each time step of the simulation, the buoyancy force (hydrostatic) is recomputed taking into account the tilt and draft of the floater. However another calculation option is to compute the hydrostatic forces and incident wave forces (Froude-Krylov) on the instantaneous wetted surface. Sensitivity results are presented for two sea states below.

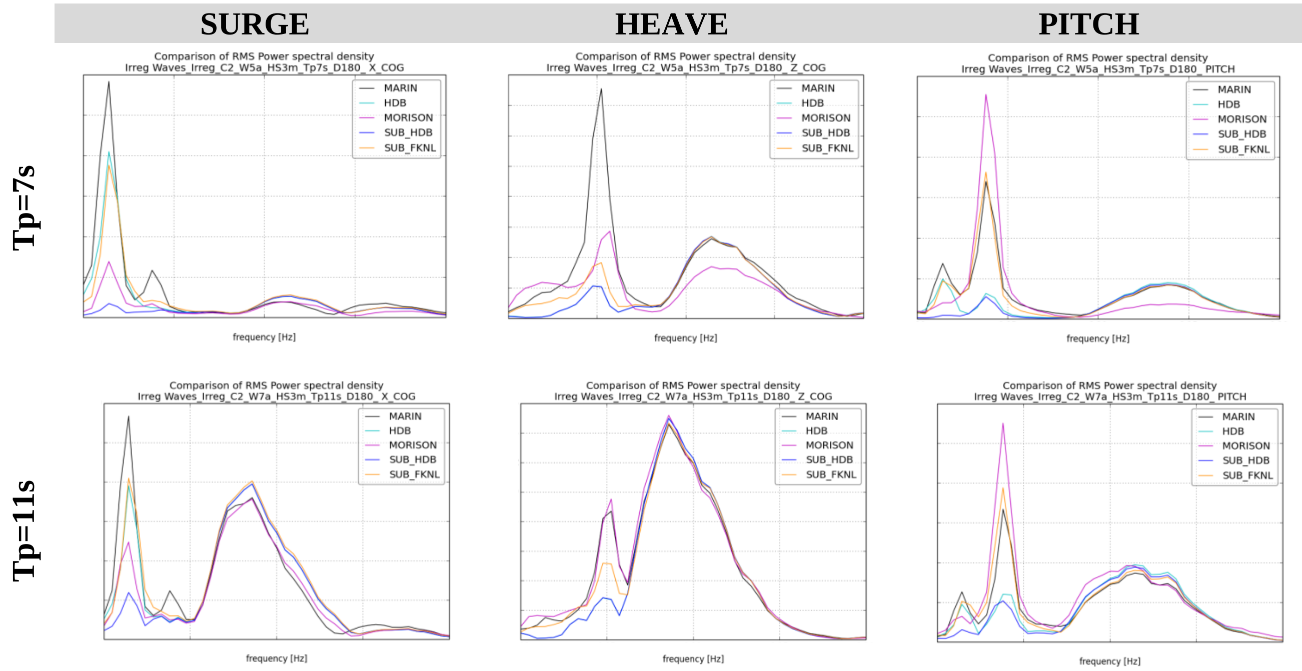


Figure 8 : Response spectrum on two sea states with FKNL forces on the SUB_HDB model

As seen in Figure 8, pitch motion is very well reproduced by the non linear Froude-Krylov approach (orange curve). It is also interesting to note that the FKNL method is very similar to taking into account the drift forces in surge through QTFs. Regarding heave motions, the FKNL model is more sensitive to excitation at natural heave period than without FKNL, but may be reduced.

IV - 2 Internal loads comparison

One important aspect of the SUB_HDB model validation is to check the internal loads of the model compared to a classical Morison approach. Therefore, the internal axial loads (referred to as "True tension"), and local moment M1 (vertical plane) are compared at different locations i.e. at the central and external columns connections, and at three points along one pontoon.

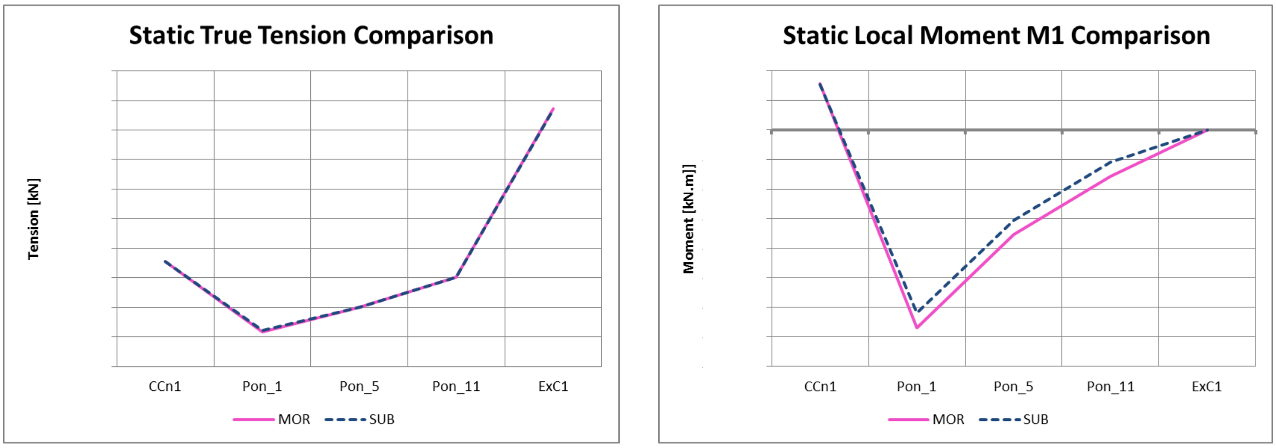


Figure 9 : Static axial tension and local moment

As seen in Figure 9, except for the local moment M1 along the pontoon, the two models are identical in terms of static loads. Note that one of the differences between the models is the application of buoyancy forces, which are imposed by panel mesh in the SUB_HDB model. This explains the slight difference on pontoons local moment M1 (in the vertical plane).

Regarding dynamic loadings the behaviour is much the same. Figure 10 presents the plots of maximum / minimum loads at each location post-treated for 3 sea states. Differences can easily be explained by slightly different motions, even if the selected sea states used for comparison are chosen to be as similar as possible in terms of responses.

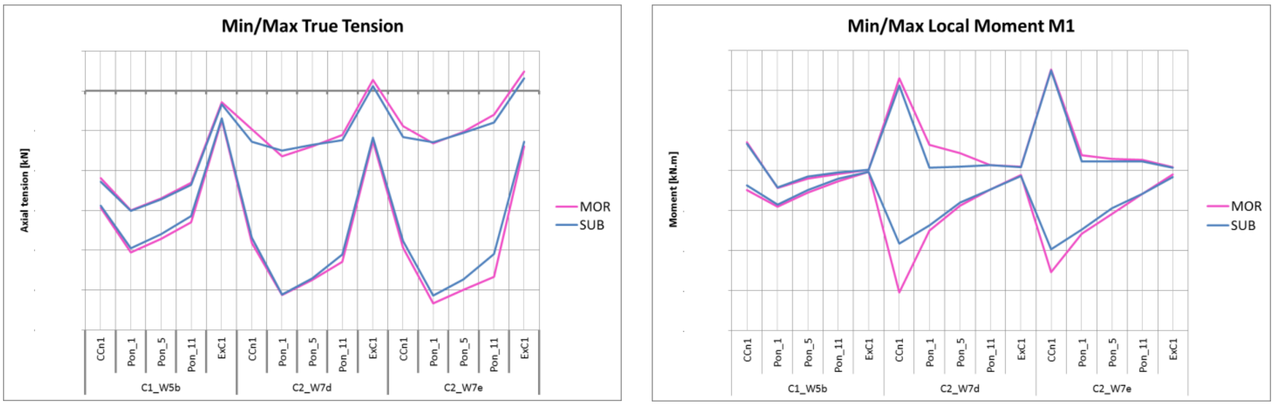


Figure 10 : Min/Max loads on dynamic simulations

The internal forces in the floater are very comparable between the Morison and SUB_HDB model. This point required some verification as the Morison formulation used in the present calculations is based on the concept of "effective tension" (the reference system is floater and external water therefore the obtained tension, i.e. internal axial load, contains pressure effects) while the sub-structure model is based on the "true tension" (the reference system is the floater only submitted to external pressure therefore the tension obtained is directly the tension in the structure).

IV - 3 Wave Pressure comparison

The physical model's wave probe is located at keel level under one of the pontoons as illustrated in Figure 11. From a time-domain simulation, motion of the substructure of interest, as well as velocity and acceleration are derived. They are combined to the wave spectrum and results of hydrodynamic processor from Diodore (see ref [5]).

The total external pressure is then derived. It is composed of:

- The hydrostatic pressure,
- The Froude-Krylov incident wave pressure,
- A diffraction term,
- A radiation term.

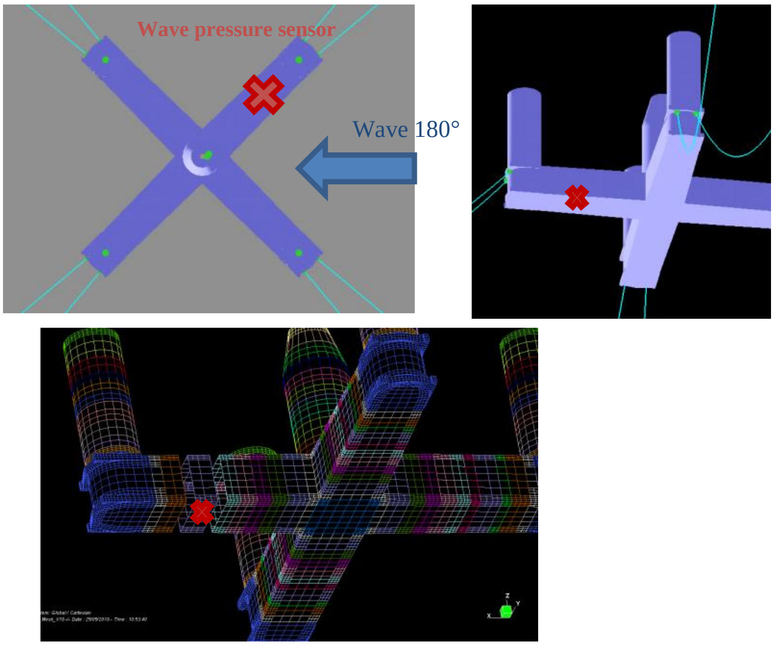


Figure 11 : Wave pressure sensor location

In order to validate the wave pressure calculation, a first comparison is performed on a regular wave: *H*=2m (double amplitude), *T*=15s. From theory, and leaving out dependence from the horizontal position of the calculation point, the Froude-Krylov pressure for a regular wave is derived from the following formulae:

$$\text{Pfkr}(t) = \frac{1}{2}\rho g H \frac{cosh[k(z+d)]}{cosh[kd]} \cos[-\omega t]$$

Where, ρ is the water density, *g* the acceleration gravity, *H* the wave double amplitude, *d* the water depth, *k* the wave number, and *w* the wave circular frequency.

Figure 12 shows the hydrostatic and Froude-Krylov pressure comparison between the theory and the output from SUB_HDB simulation. It is added to get the total pressure in red, which is compared to the experimental output (in black).

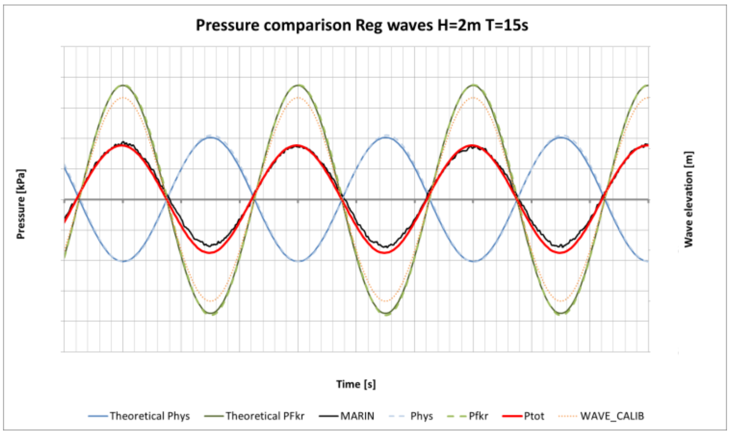


Figure 12 : Pressure comparison on regular waves H=2m T=15s

As seen in Figure 12, the MARIN and DeepLines outputs are similar, and correspond to the theory.

Figure 13 plots the comparison between the SUB_HDB wave pressure output and the wave pressure signal from MARIN basin test. Calculations are validated by the experimental results, since discrepancies can easily be explained by the small differences in motions.

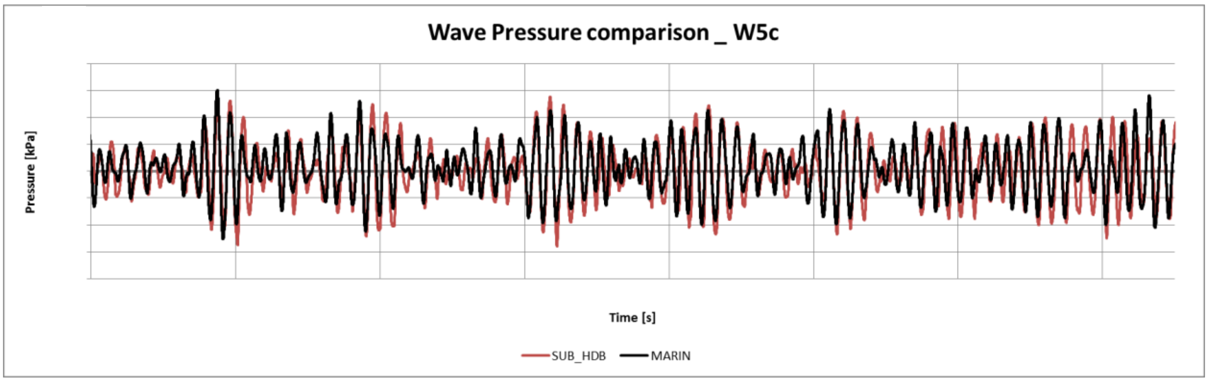


Figure 13 : Wave pressure on irregular waves – Hs=7.5m, Tp=16s

V - Conclusions

The present article shows that, upon appropriate calibration, both Morison and potential-flow hydrodynamic approaches are viable for coupled simulation of a typical Naval Energies FOWT. With the given numerical tool, DeepLines Wind, both approaches can be declined to resolve the loads locally for application on a beam type structure, which facilitates robust and cost-effective platform design. In general, a good agreement with the experimental validation data is found; the relative performances of three hydrodynamic methodologies of choice are summarized below.

Firstly, the first-order wave response of the floater is very well captured by the potential-flow approach with or without sub-structures. As for the Morison formulation, it provides its best results at wave frequency for larger peak periods. The Morison model is shown to be naturally capable of generating nonlinear vertical (heave, roll, pitch) loads which are missed by linear potential-flow modelling.

Secondly, the sub-structure modelling approach developed for Naval Energies provides floater motions in line with the classic integral potential-flow model. One of its advantages is to take into account the drift forces either by Newman approximation or Full QTF. Note that this can potentially be implemented within a sub-structured model as well, at least as a global load at reduction point.

Moreover, sensitivity on the sub-structure model is performed by introducing the geometric non-linearity in the incident wave forces. This is shown to remove most observed limitations of linear HDB models; in particular, it improves vertical resonant responses leading to very accurate prediction of pitch motion. At the same time, it provides a good approximation of horizontal drift forces, potentially removing the need for explicit QTF computation.

Furthermore, the internal forces in the floater are very comparable between the Morison and sub-structure model.

Finally, the external fluid pressure at any point of the hull can be derived with the sub-structure model which is especially useful for pontoon design. The instantaneous pressure is indeed very well captured by the sub-structure model compared to basin test results.

References

[1] 29692-3-OB, Hydrodynamic Model Test – NE FOWT Model Tank Tests, MARIN, Rev3.0, January 2018

[2] Morison, J. R.; O'Brien, M. P.; Johnson, J. W.; Schaaf, S. A. (1950), "The force exerted by surface waves on piles", Petroleum Transactions, American Institute of Mining Engineers

[3] Sarpkaya, T. (2010), Wave Forces on Offshore Structures, Cambridge University Press

[4] DCP.174.054.02 – Validation of Multi Structures Floater in DeepLines, PRINCIPIA, June 2017

[5] NET.174.437.01, Validation of Pressure calculation for Substructure model in DeepLines, PRINCIPIA, 12/2017

[6] DIODORE V5R5 – Theoretical Manual – PARTA- CH3 – Modelling of Marine Structures