DIMPACT
Numerical simulation of FOWT in breaking sea states

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FOWT - Time domain simulations

Objective :

Characterize the columns orientation/velocity during breaking events

Plan of the presentation

- **Site conditions**
- **10MW floater solutions and behavior in waves**
- **Breaking wave identification**
- **Outputs of interest for DIMPACT : focus on the columns velocity**
- **Conclusions**

Site conditions

FOWT - Time domain simulations

Sea states considered in the analysis

- 3 sites 50-y contours defined by FEM
- Selection of « steep » couples [Hs ; Tp] conditions on the 50-y contour
- Most probable wind speed associated to the wave heights
- 2 wind headings are considered for each Hs/Tp : 0° and 90° wind/waves misalignement

Med. Sea : 100m WD

Hs	Tp	Steepness	γ	WS
1.02	1.5	0.290	3	5
1.17	1.64	0.279	3	5
1.33	1.79	0.266	3	5
1.52	1.97	0.251	3	5
1.72	2.18	0.232	3	5
1.94	2.4	0.216	3	6
2.17	2.64	0.199	3	7
2.41	2.9	0.184	3	8
2.66	3.19	0.167	3	9
2.93	3.5	0.153	3	10
3.21	3.83	0.140	3	11
3.49	4.18	0.128	3	12
3.79	4.56	0.117	3	13
4.09	4.95	0.107	2.5	14
4.4	5.36	0.098	2.5	15
4.71	5.79	0.090	2.5	16
5.03	6.24	0.083	2.5	17
5.35	6.69	0.077	2.5	18
5.68	7.15	0.071	2.5	19
6	7.63	0.066	2	20
6.32	8.1	0.062	2	21
6.64	8.58	0.058	2	22
6.96	9.05	0.054	1.5	23
7.26	9.53	0.051	1.5	24
7.57	9.99	0.049	1.5	25

Metcenter : 200m WD

Hs	Tp	Steepness	γ	WS
2.15	3.46	0.115	3	5
2.33	3.68	0.110	3	6
2.54	3.92	0.106	3	7
2.76	4.19	0.101	3	8
3	4.49	0.095	3	9
3.26	4.81	0.090	3	10
3.54	5.16	0.085	3	11
3.84	5.53	0.080	2.5	12
4.17	5.93	0.076	2.5	13
4.52	6.34	0.072	2.5	14
4.89	6.78	0.068	2.5	15
5.29	7.24	0.065	2	16
5.71	7.7	0.062	2	17
6.14	8.15	0.059	2	18
6.57	8.6	0.057	2	19
7.01	9.03	0.056	1.5	20
7.45	9.45	0.053	1.5	21
7.9	9.87	0.052	1.5	22
8.35	10.27	0.051	1.5	23
8.8	10.65	0.050	1	24
9.25	11.03	0.049	1	25
9.7	11.39	0.048	1	50
10.14	11.75	0.047	1	50
10.58	12.09	0.046	1	50
11.01	12.42	0.046	1	50
11.43	12.75	0.045	1	50

10 x 6h =60h sea state,
x 2 wind directions

Britany : 100m WD

Hs (m)	Tp (s)	Steepness	Υ	WS
2,13	4,06	0,083	3	6
2,34	4,25	0,083	3	7
2,57	4,46	0,083	3	8
2,82	4,68	0,083	3	9
3,08	4,93	0,081	3	10
3,38	5,2	0,080	3	11
3,69	5,5	0,078	2,5	12
4,03	5,82	0,076	2,5	13
4,4	6,16	0,074	2,5	14
4,79	6,52	0,072	2,5	15
5,19	6,9	0,070	2	16
5,6	7,28	0,068	2	17
6,02	7,68	0,065	2	18
6,44	8,08	0,063	2	19
6,87	8,48	0,061	1,5	20
7,31	8,89	0,059	1,5	21
7,75	9,3	0,057	1,5	22
8,18	9,71	0,056	1,5	23
8,62	10,11	0,054	1	24
9,05	10,52	0,052	1	25
9,48	10,91	0,051	1	50
9,91	11,3	0,050	1	50
10,33	11,69	0,048	1	50
10,73	12,06	0,047	1	50
11,13	12,43	0,046	1	50

(note : Steepness= 2π Hs / ($g*Tp^2$))

FOWT - Time domain simulations

Floaters and floater response to waves

FOWT - Time domain simulations

Systems studied, associated with the DTU 10 MW

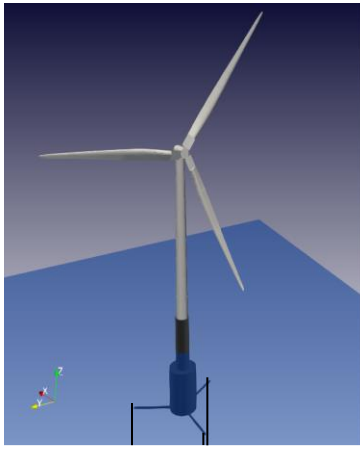
- **Simulations of 4 floater solutions**
  - **TLP with inclined legs (EDF design)**
  - **TLP with vertical legs (DTU design)**
  - **Semi-Sub (Nautilus design)**
  - **SPAR (EDF design)**

EDF TLP

Water depth : 100m
Surge/Pitch period : 37s

Source :
***Milano et Al* (OMAE2020-18174)**

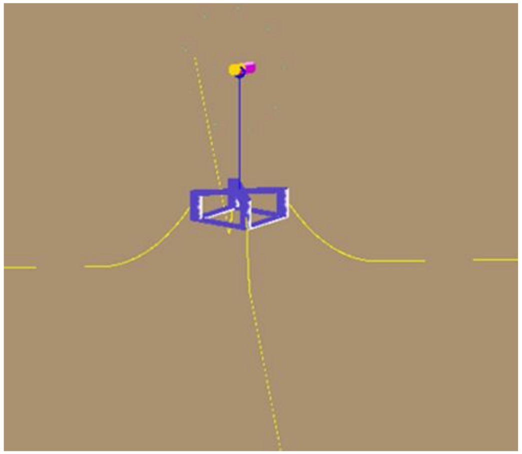
DTU TLP



Water depth : 180m
Surge period : 38s

Source :
***Laugesen&Hansen* (Msc Thesis – 2015, DTU)**

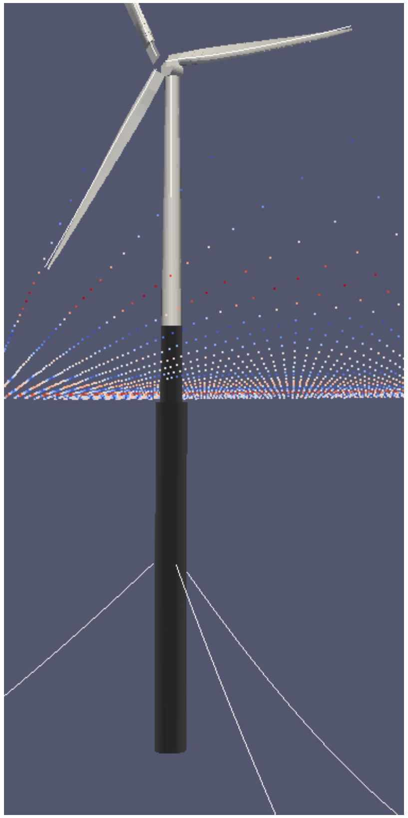
Life50+ Semisub (Nautilus)



Water depth : 130m
Surge period : 30s

Source :
Pegalajar-Jurado et Al
(Lifes50+ D4.5)
Note : Active-ballast disabled

SPAR



Water depth : 320m
Surge period : 165s
Pitch period : 30s

Source :
***Dupin* (Msc Thesis – 2018, ENSTA)**

FOWT - Time domain simulations

Numerical models hypothesis

Turbulent Wind
Kaimal spectrum

Flexible Turbine :
Blades : Aeroelastic BEMT
+
Tower : Drag loads

Rigid Floater

Bracings: Strip Theory

Columns : Diffraction

Irregular Waves
Airy Theory + Stretching

Lines :
Finite Elements
or
Quasi-Static

~ 7200 x 6h sea states ran for each floater

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3 sites
x 120 sea states
x 20 Hs/Tp

Cases run on the EDF R&D supercomputer in parallel.

Allow to get enough breaking events to draw statistics

Note : For the semi-sub, a drag disc is used in order to capture the thrust effects w/o increasing the CPU time too much.

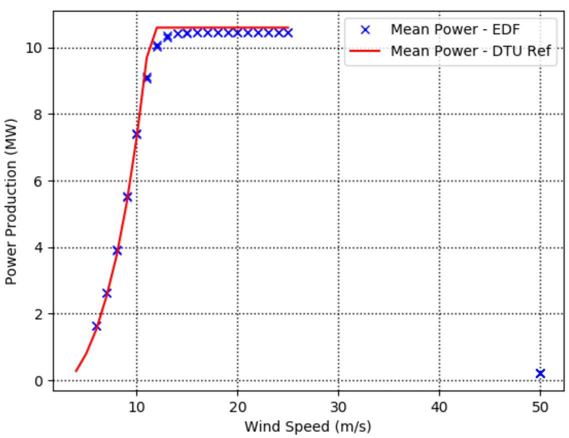
FOWT - Time domain simulations

Production conditions

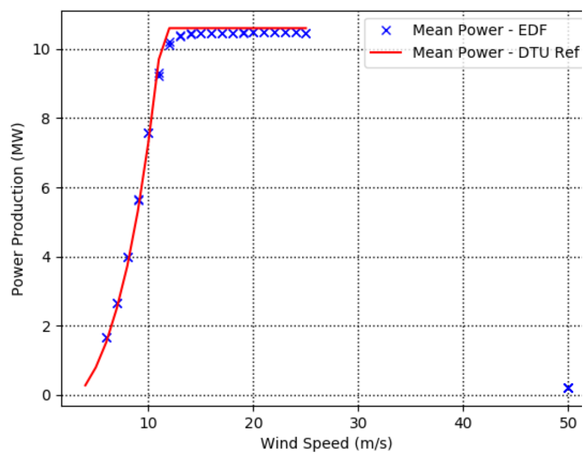
Most of the sea states considered are production sea states.
⇒ Hs small enough to get Hs/Wind speed couples in the typicall range of operation

A preliminary step is to check the power production to see if the turbine behavior is OK or not.

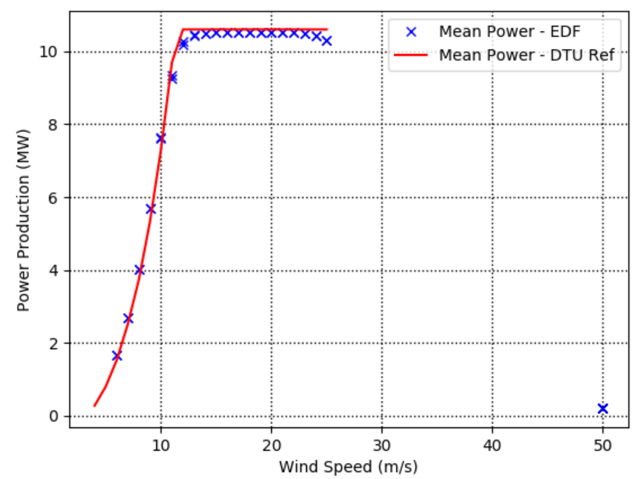
SPAR



DTU TLP



EDF TLP



The DTU 10 MW reference turbine power curve is well fitted
⇒ Turbine thrust accounted for
⇒ Turbulent wind and wind induced motions

Note : Use of a controler adapted to floating conditions (in particular for the SPAR and the DTU TLP)

FOWT - Time domain simulations

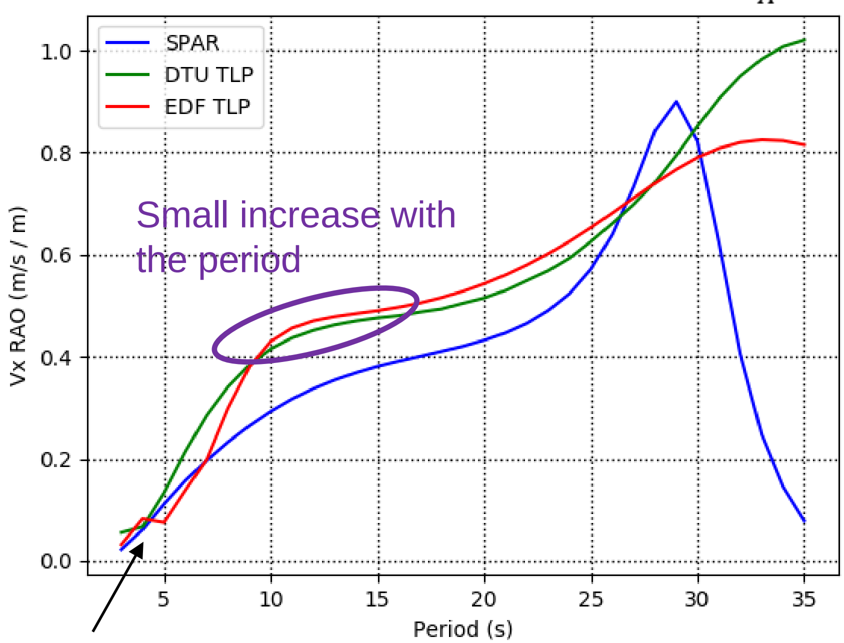
Floaters horizontal velocity RAOs

- **Horizontal velocity at MSL [0;0;0] : Amplitude and phasing with the crests**

$$\eta(t) = \mathrm{A}\cos\omega t \Rightarrow \mathrm{V}(t) = R\cos\omega t + I\sin\omega t$$

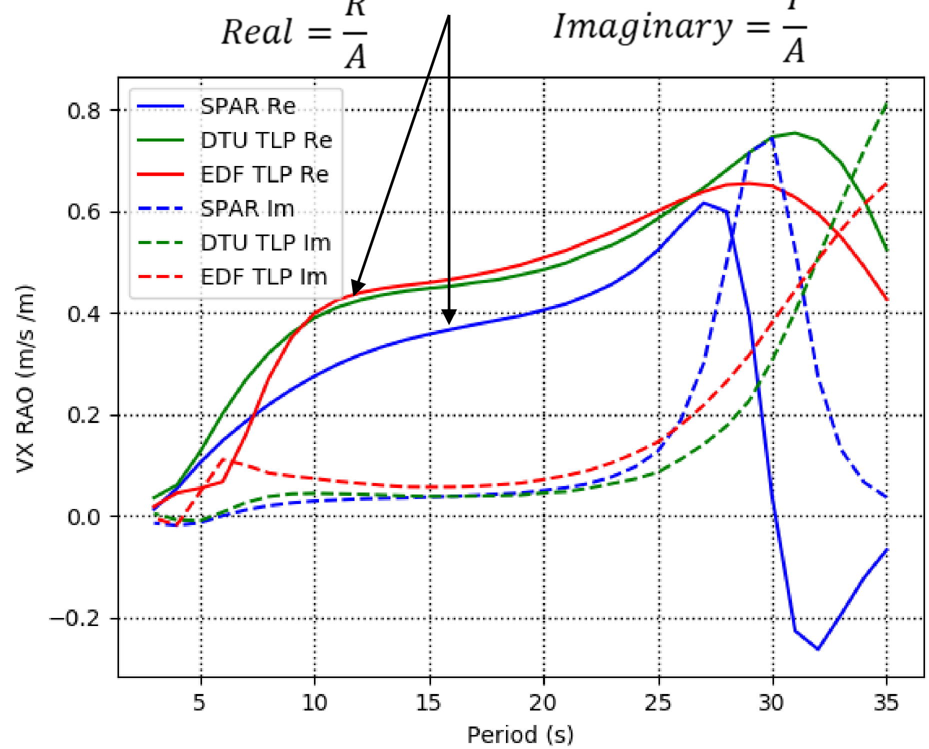
Real part dominant and >0 ⇔ in phase with the crest
=> in phase with the crest velocities

RAOs of horizontal velocities $\mathrm{RAO} = \frac{\sqrt{R^2+I^2}}{A}$



Small periods ⇔ no induced velocities

$$Real = \frac{R}{A} \qquad Imaginary = \frac{I}{A}$$



Large periods ⇔ velocities following the waves

FOWT - Time domain simulations

Breaking wave identification

FOWT - Time domain simulations

Methodology steps for breaking event detection :

- **Step 1 : Phase velocity, using a formula used at the early phase of DIMPACT**

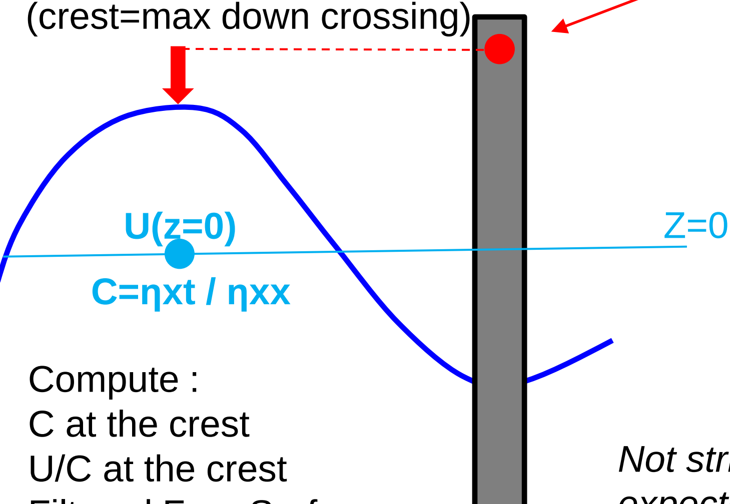
1,3fp

$$C_p\left(x_{peak},t\right) = -\frac{\frac{d^2Z}{dx\,dt}(x,t)}{\frac{d^2Z}{dx^2}(x,t)} = -\frac{\sum_{f_{c,min}}^{f_{c,max}} a_{f_i} * \omega_{f_i} * k_{f_i} * \sin(k_{f_i}x_{peak} - \omega_{f_i}t + \varphi_{f_i})}{\sum_{f_{c,min}}^{f_{c,max}} -1 * a_{f_i} * k_{f_i}^2 * \sin(k_{f_i}x_{peak} - \omega_{f_i}t + \varphi_{f_i})}$$

0,7fp

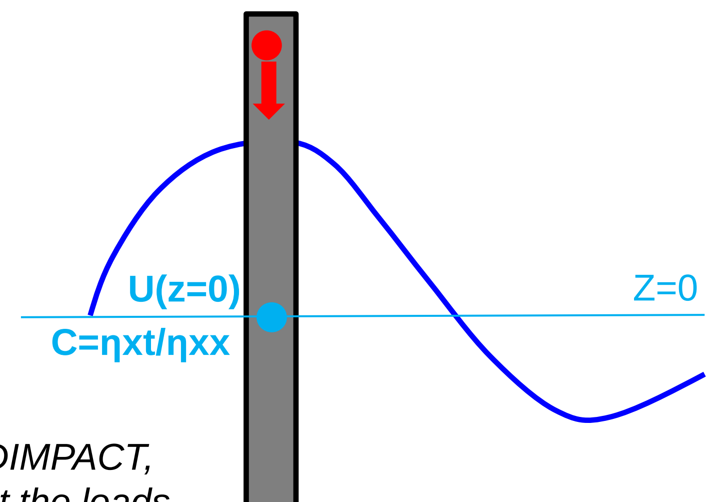
- **Step 2 : Time domain, use of probes located at the structure center for TLPs & SPAR, at 2 columns of the semi sub**

Detect the crest coming on the column, compute its phase velocity at any time (crest=max down crossing)



Compute :
C at the crest
U/C at the crest
Filtered Free Surface

Breaking occurrence :
only when : U/C>0.24 @ the column location



Not strictly needed at this stage of DIMPACT, expected to be necessary to comput the loads

FOWT - Time domain simulations

Outputs of interest

FOWT - Time domain simulations

Breaking loads are expected to have the following form :

$$F_I \equiv \pi \rho R \lambda \eta_b c_b^2$$

Set to 1

Will be an indicator of the breaking severity

Curling factor

$T_b \, d(u/c)/dt$

Crest height

$\eta(t)$

Phase velocity,
=> Hypothesis :
relative wave/body velocity in our case?

$$C_b = C - V_b$$

Thus the following quantities are to be extracted

- **U/C and its time derivative**
- **Tb**
- **The filtered free surface**
- **Body velocity**
- **Phase velocity**

In addition, as the fluid/structure angle of incidence can have an influence

- **Pitch of the floater**

All these quantities have been analysed,

In this presentation we only discuss the relative velocity

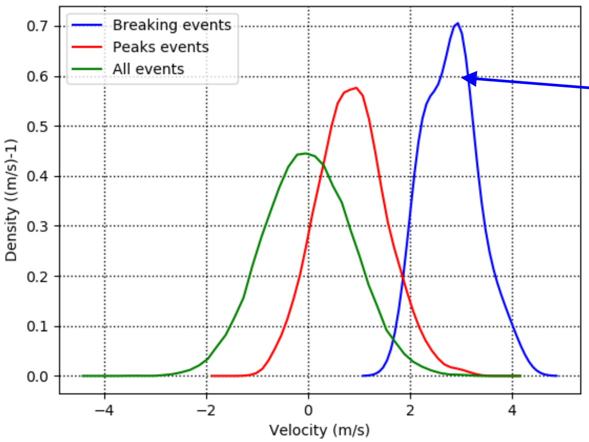
FOWT - Time domain simulations

South Britany : Body velocity

$$F_I \equiv \pi \rho R \lambda \eta_b c_b^2$$

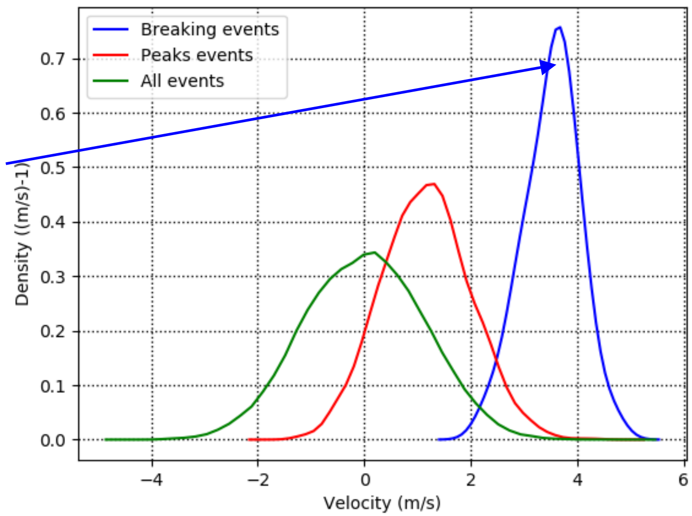
- **Horizontal Velocity distribution :**
  ex : High sea state Hs=11.13m Tp=12.43 (Wind // Wave)

SPAR

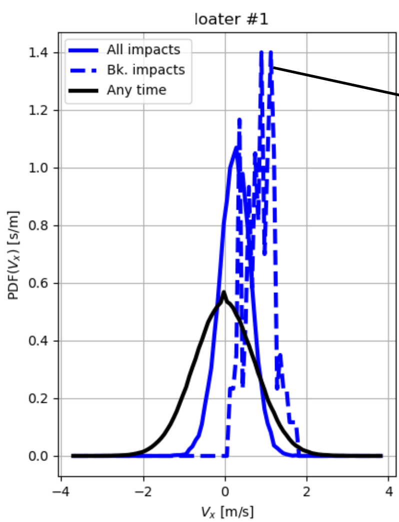


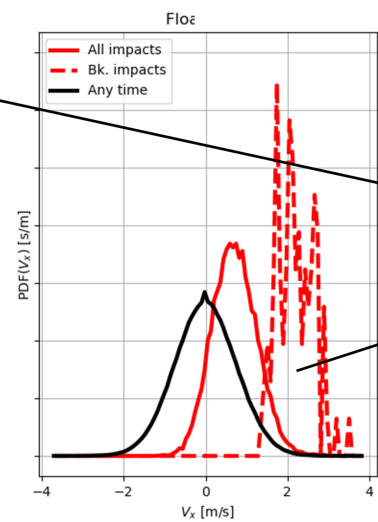
Distribution of the column velocity during a breaking event

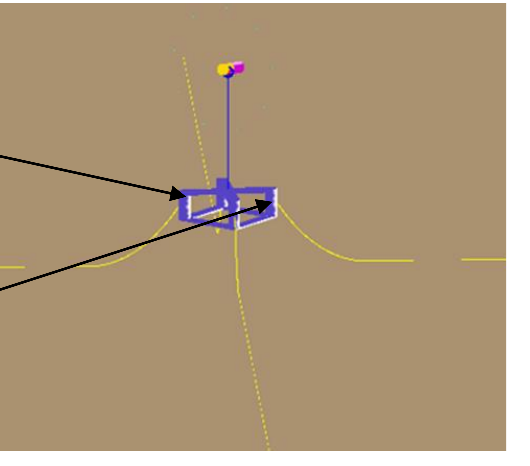
EDF TLP



Nautilus







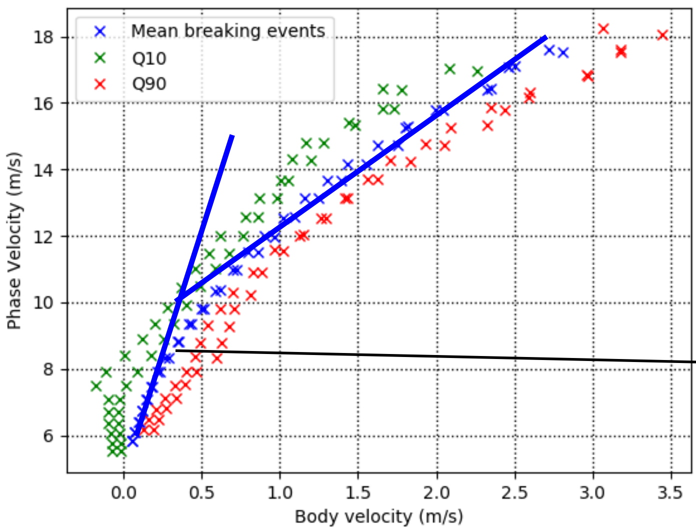
FOWT - Time domain simulations

South Britany : Velocities

$$F_I \equiv \pi \rho R \lambda \eta_b c_b^2$$

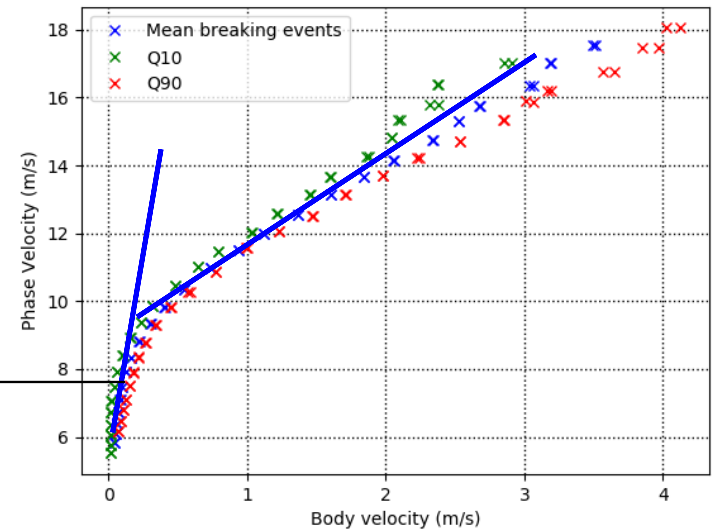
- **Horizontal Velocity distribution against phase velocity**

SPAR

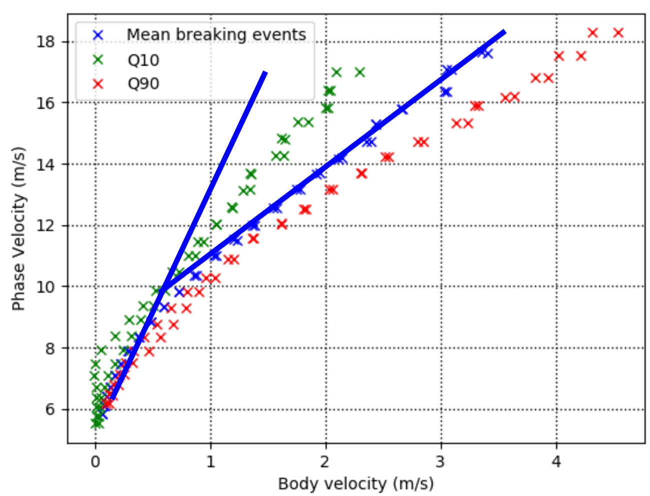


No response

EDF TLP



DTU TLP



2 clear regimes, as the floaters have little response to waves at low wave periods

At high wave periods, a simple relation is found between phase velocity and body velocity

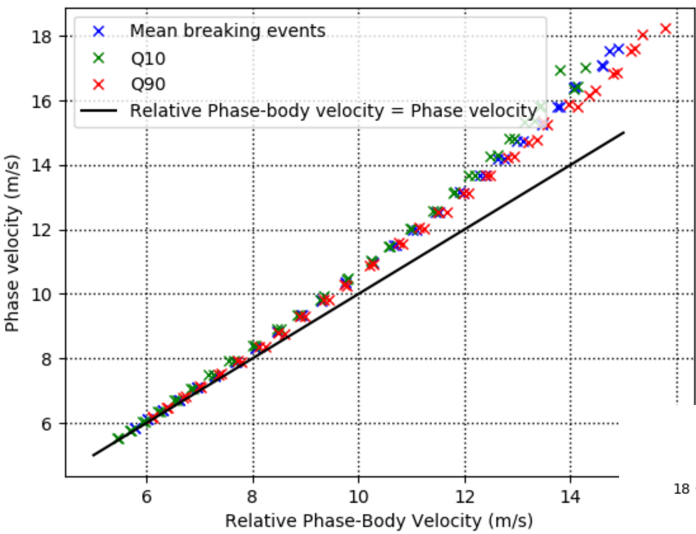
FOWT - Time domain simulations

South Britany : Breaking Severity

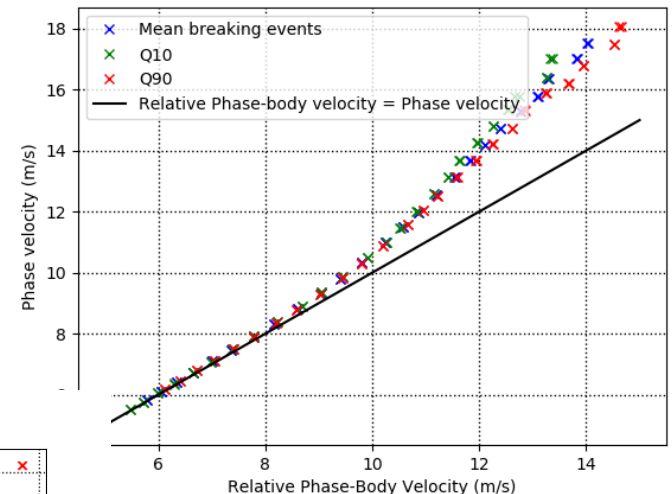
$$F_I = \pi \rho R \lambda \eta_b c_b^2$$

- **Relative Phase-Body velocity ⇔ influence of motions**

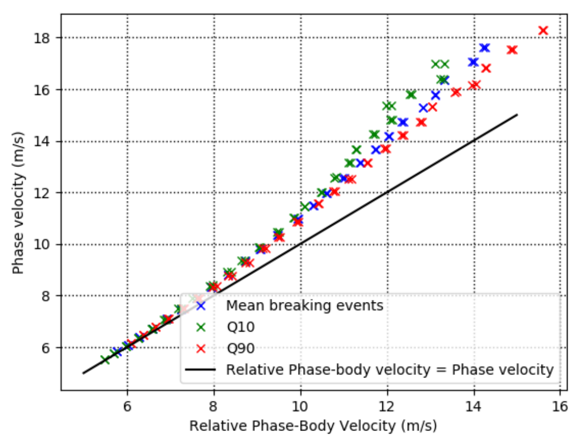
SPAR



EDF TLP



DTU TLP



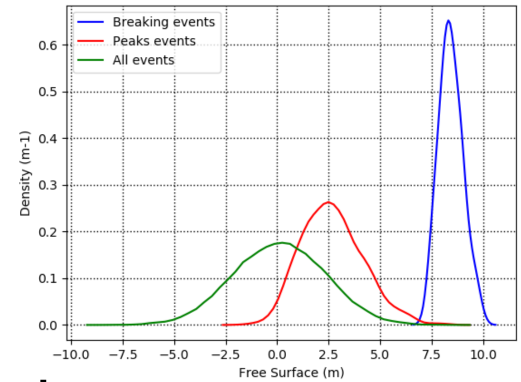
The floater motions reduce the relative wave-body velocity

FOWT - Time domain simulations

Conclusion

FOWT - Time domain simulations

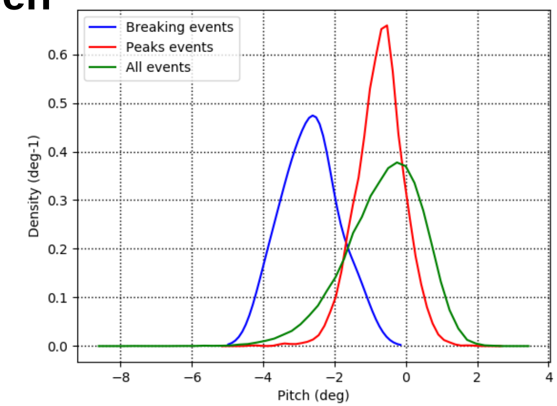
Conclusion



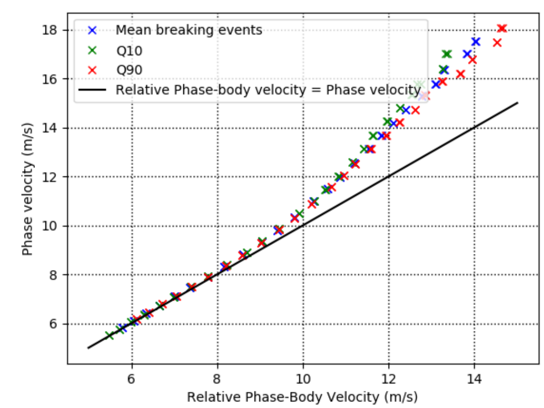
- **Various type of floaters investigated in breaking wave sea state conditions**

⇒ **Breaking crest are specific as compared to the other crest, in general higher, generating higher floater response.**

- **All the parameters expected to play a role in the breaking loads severity have been investigated, their distribution have been quantified.**
    - **Body velocity**
        - ⇒ **Strongly influenced by the wave conditions**
        - ⇒ **Tendency : relative velocity lower than phase velocity**
    - **Pitch**
        - ⇒ **Strongly influenced by the wave conditions**
        - ⇒ **Tendency : larger pitch than for typical crests**



- **Use of these results for the basin tests campaign definition**
    - ⇒ **Determined looking to all floater technologies and all site conditions**
    - ⇒ **Pitch : Chosen in the range [0° - 10°]**
    - ⇒ **Horizontal velocity chosen in the range [0 m/s-4 m/s] in the direction of the wave celerity**



FOWT - Time domain simulations

Thank you !