SHORT PRESENTATION OF SIMBAD(*) NUMERICAL MODEL

(*)SIMULATION DE BATEAUX AMARRÉS SUR DÉFENSES

A MOORING SYSTEM WHICH RESISTED…

ANOTHER ONE NOT…

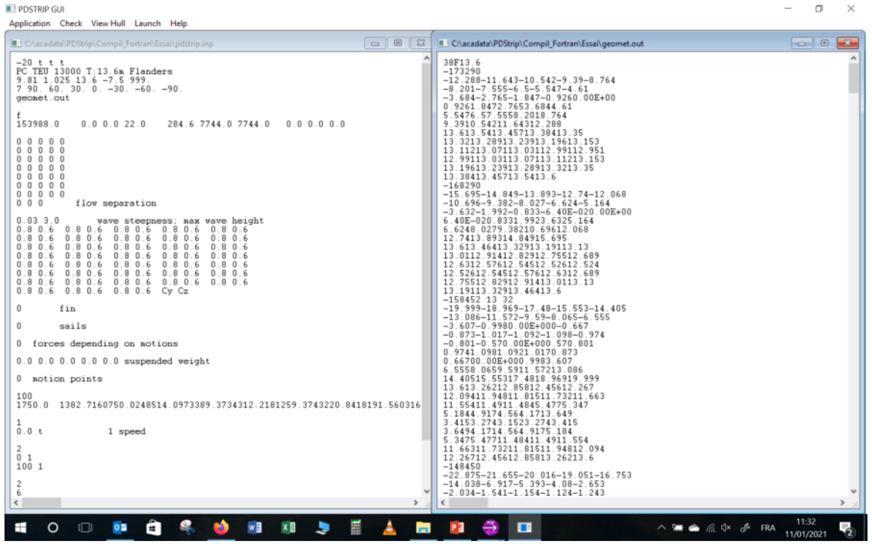
Foreword

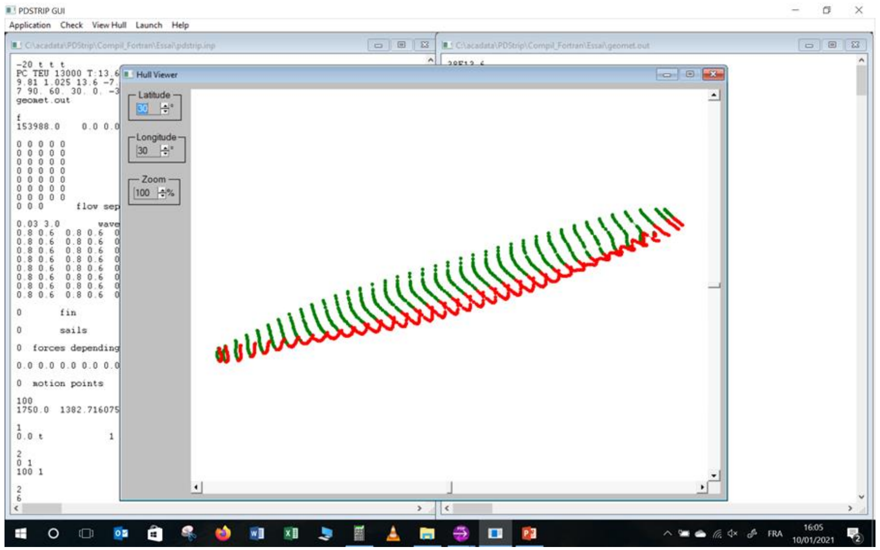
The SIMBAD program allows the calculation of the mooring forces for a given type of vessel. The hydrodynamic parameters necessary to solve the linear hydrodynamic model in time domain (Cummins equation) are provided by the PDSTRIP (Public Domain Strip Method) program developed by H. Söding and V. Bertram, that was simply adapted to obtain the characteristics of the desired parameters.

This chain of programs is not intended to replace more elaborate models (3D models for example) but because of its quite fast operation, can provide useful information at the time of a pre-feasibility or feasibility study. The comparison with a certain number of results published in the literature (physical or mathematical models) shows that it can provide good orders of magnitude.

NOTICE

Program PDSTRIP (Public Domain Strip Method*)





PDSTRIP computes from the ship's characteristics (cross-sectional strips of the wetted hull, displacement, position of centre of gravity, radii of gyration…) the following responses:

- **Hydrostatic values**
- **Added masses**
- **Radiation damping values**
- **First order wave forces**
- **Drift forces**

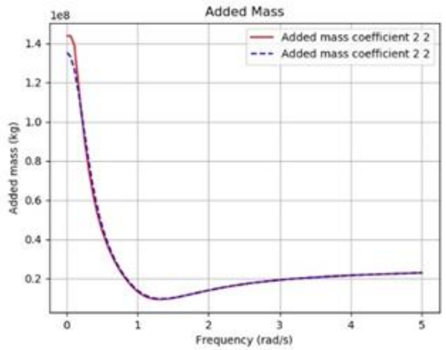
Added masses, damping values, wave loads have to be computed on a large frequency range (about 0.05 to 5 rad/s).

(*) For more information, see: Söding H. and Bertram V., "Program PDSTRIP: Public Domain Strip Method", April 2009

SIMBAD: Data pre-processing

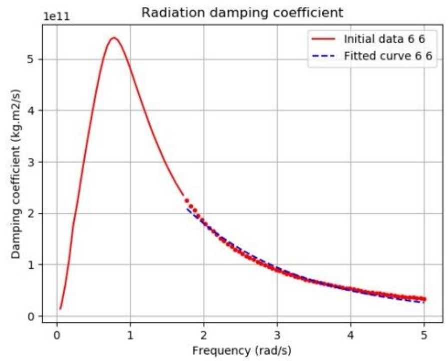
The above data are pre-processed so as to obtain:

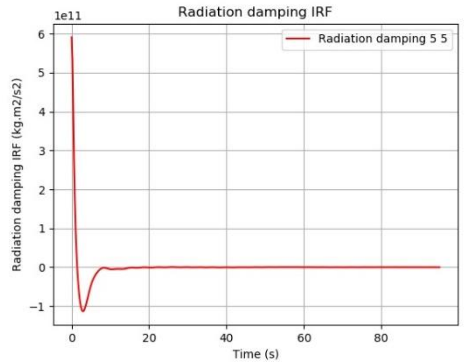
- **The “infinity” added masses**
- **The impulse response functions (“IRF”) of radiation damping values**
- **The impulse response functions (“IRF”) of wave excitation and drift forces**



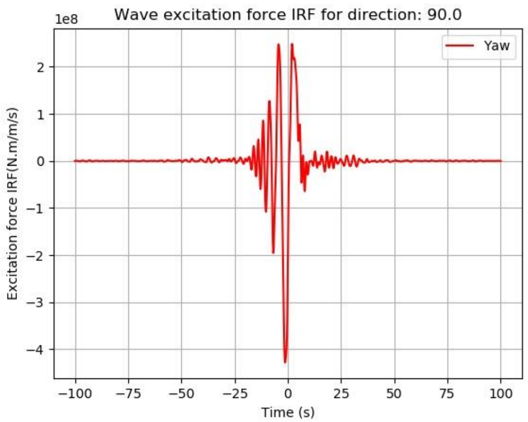
Added masses

Damping coefficients

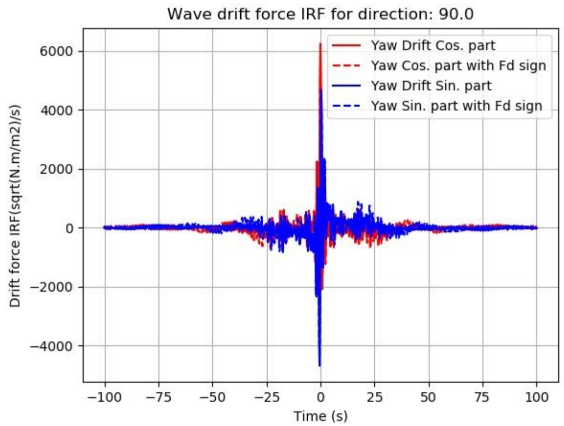




Wave excitation forces IRF



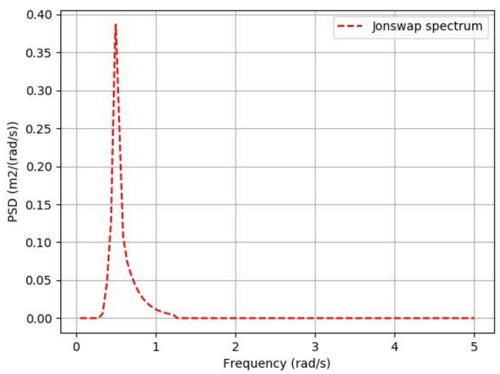
Drift forces IRF

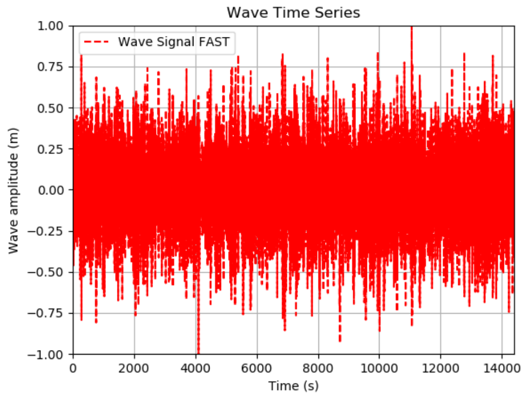


SIMBAD: Data pre-processing

From the previous elements, calculation of:

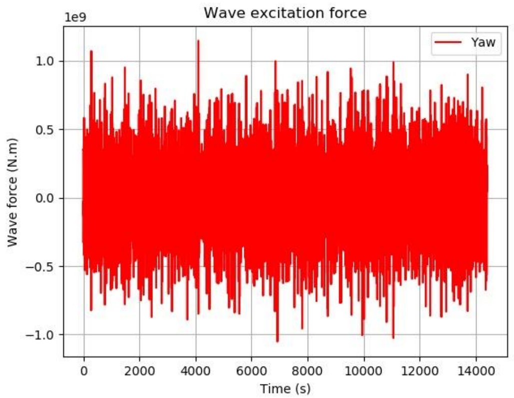
- **Random wave time series (different options):**
  - With random phase, on the basis of Hs, Tp and different spectrum density models (Jonswap, Bretschneider, Torsethaugen, McCormick, OchiHubble, Wallop)
  - With the Fast method, on the basis of Hs, Tp and different spectrum density models (Jonswap, Bretschneider, Torsethaugen, McCormick, OchiHubble, Wallop)
  - With random phase, on the basis of Hs, Tp and a specific density spectrum
  - Other options for wave time series: input as a specific file, regular waves
- **Time series of wave excitation forces**
- **Time series of drift forces (3 options: no drift forces, mean forces, “Molin” variant)**



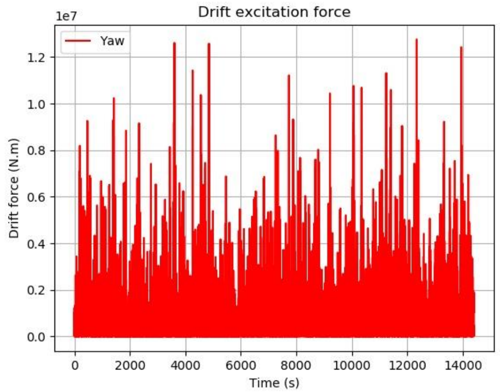


Wave time series

Wave excitation forces



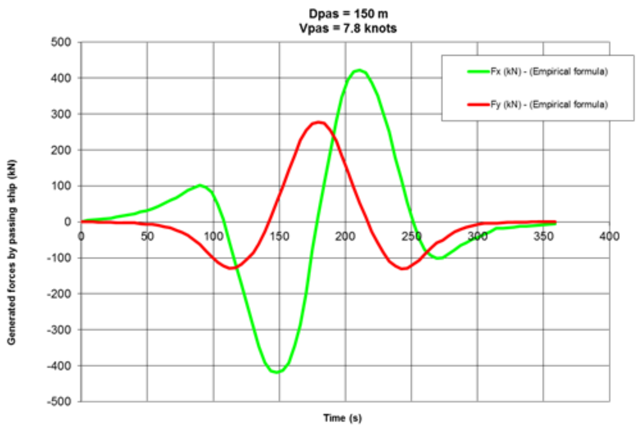
Drift forces



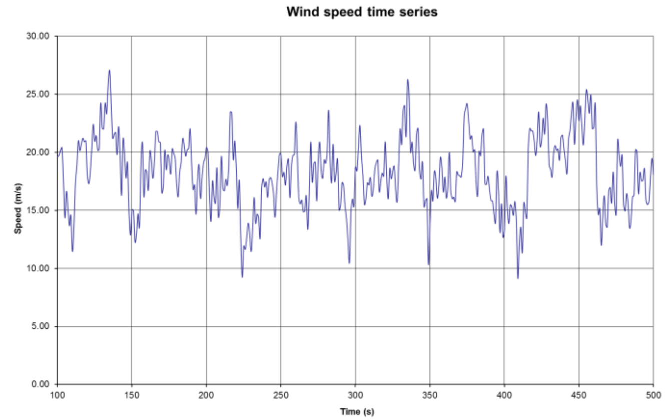
SIMBAD NUMERICAL MODEL

THE SIMBAD PROGRAM CAN BE USED TO SIMULATE THE BEHAVIOR OF A MOORED SHIP, USING THE CUMMINS EQUATION (TIME SIMULATION) AND TAKING INTO ACCOUNT THE FOLLOWING ELEMENTS:

- RANDOM WAVE FORCES (EXCITATION AND DRIFT, SEE ABOVE)
- GUSTY WIND FORCES (GENERATION OF WIND SPEEDS ACCORDING TO A WIND SPECTRUM)
- FORCES INDUCED BY A PASSING SHIP
- LINEAR OR NON-LINEAR MOORING CHARACTERISTICS FOR MOORING LINES AND FENDERS, AS WELL AS RIGID CONNECTION TYPE MOORING SYSTEM



FORCES INDUCED BY A PASSING SHIP



WIND SPEED TIME SERIES

SIMBAD: Data post-processing

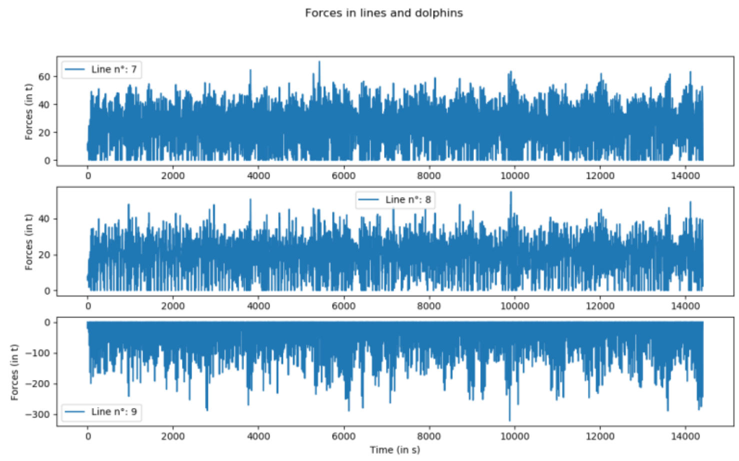
The results of SIMBAD model include:

- Mooring line and fender loads
- Motions, speeds and accelerations at the center of gravity and at other possible points of the ship

They can be post-processed, in order to obtain:

- Time series,
- Tables of results (min, max, 1/3, 1/10 values)

Time series of motions and loads



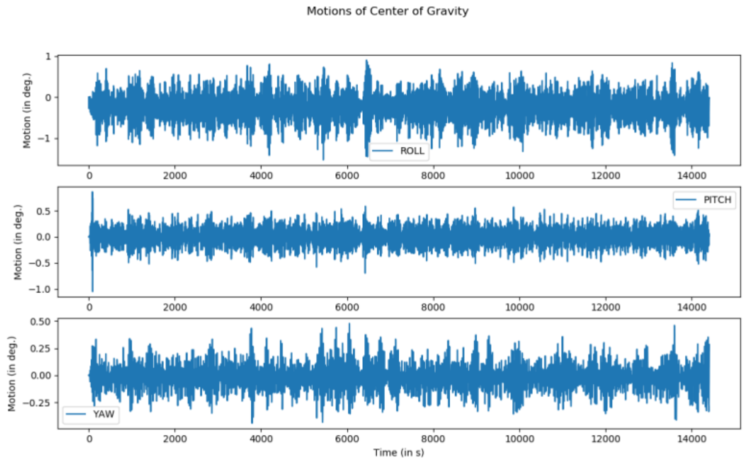


Table of results for motions

MotionCG.txt

Type:	Motion Min	Max	Minst.	Maxst.	F1/3	F1/10
SURGE	-1.819	1.121	-1.975	1.3813	-1.024	-1.304
SWAY	-1.051	0.2476	-0.671	0.4536	-0.355	-0.503
HEAVE	-0.438	0.4062	-0.450	0.4431	-0.237	-0.294
ROLL	-1.529	0.9028	-1.468	0.9614	-0.886	-1.076
PITCH	-0.696	0.5842	-0.598	0.5971	-0.312	0.3968
YAW	-0.443	0.4789	-0.467	0.4275	-0.233	-0.304

Table of results for loads

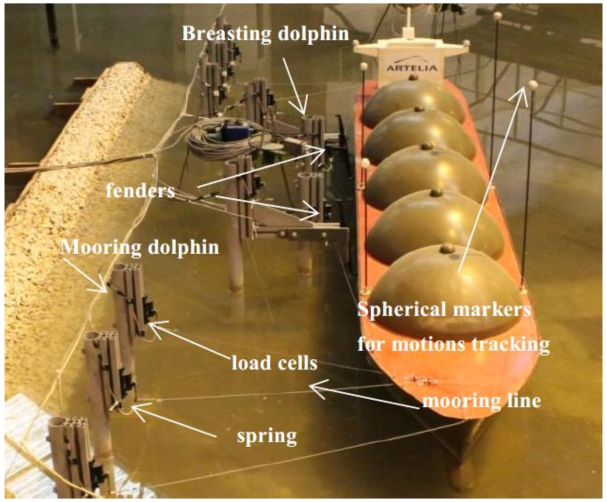
Max_Min.txt

Line n°:	Forces Min	Max	F1/3	F1/1
1	0.00	42.65	29.47	33.48
2	0.00	63.51	45.12	50.87
3	0.00	60.96	38.18	43.32
4	0.00	67.24	44.45	50.87
5	0.00	34.73	24.05	27.87
6	0.00	44.88	28.37	31.90
7	0.00	70.58	47.87	53.69
8	0.00	54.78	35.85	40.75
9	-321.80	0.00	-180.27	-230.50
10	-241.40	0.00	-122.25	-161.02
11	-134.80	0.00	-88.42	-110.16
12	-280.20	0.00	-132.53	-170.59
13	0.00	11.42	6.02	7.52

Comparison with published model tests

Note: The comparison is always a challenge insofar as when going into the details of things, we realize that some parameters may be missing or are known with a certain approximation. This comparison, even imperfect, however makes it possible to ensure that the SIMBAD numerical model gives results with good orders of magnitude.

ARTELIA (2018)



130,000 m3 LNG model vessel at ARTELIA laboratory (from ref.[1])

Test case (see details in references):

- Loaded 130,000 m3 LNG ship moored on a jetty supported by piles
- Water depth of 1.67 times the vessel draught
- Mooring arrangement (see hereafter): eight "model lines" (ML1 to ML8), each representative of two wire lines with nylon tails and two "model fenders" (FD1 to FD2), each representative of two fenders
- 26t pre-tension applied in each "model line" (13t per wire line)
- Linear stiffness for lines and fenders
- Uni-Directional (long-crested) sea used for moored ship model tests

References:

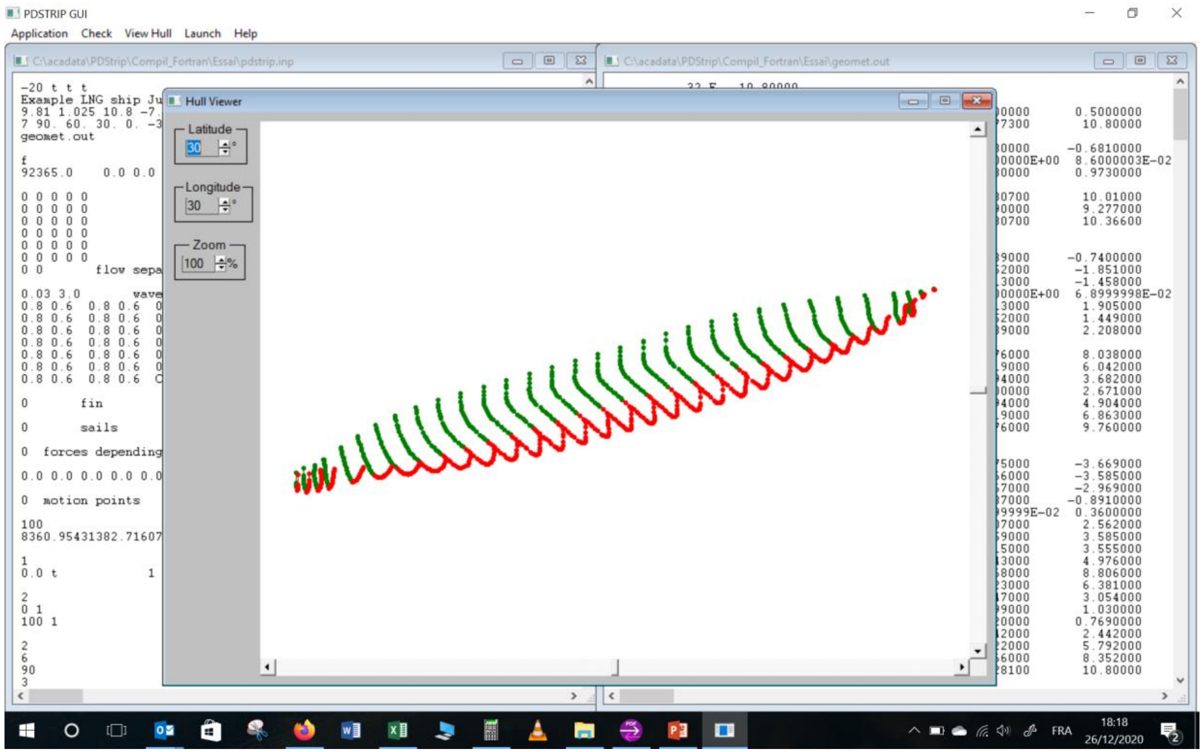
- [1]: Guisier L., Marcol C., Ouaked R., "Study of dynamic behaviour of ships moored in harbour by physical and numerical modelling", COASTLAB18, 2018
- [2]: Demenet P.F., Marcol C., Guisier L., "Physical and numerical modelling of ships moored in ports", PIANC Panama, 2018

ARTELIA (2018)

Particulars of the LNG carrier:

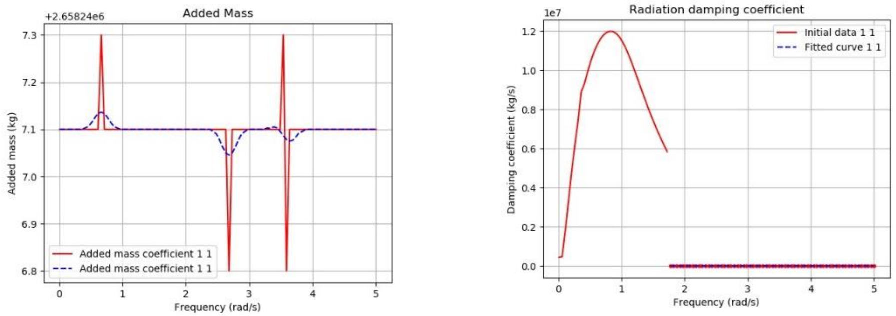
- Table hereafter gives original data and data from PDSTRIP schematisation.
- Frequency range for added mass and damping values, first order wave loads, drift forces: 0.01 – 5.0 rad/s

Dimensions of ship		
Ship	Model test	PDSTRIP
Length overall (m)	287	287
Length between perpendiculars (m)	274	274
Beam (m)	43.4	43.4
Draught (m)	10.8	10.8
Displacement (m3)	90112	90112
Block coefficient	0.702	0.702
Height of Centre of Gravity KG (m)	14.39	14.2
Longitudinal Centre of Gravity (m)	0.00	0.00
Transverse Metacentric Height GM (m)	5.02	5.05
Roll Radius of Gyration (m)	17.54	17.54
Pitch Radius of Gyration (m)	70.95	70.95
Yaw Radius of Gyration (m)	69.4	69.4
Water depth (m)	18	18

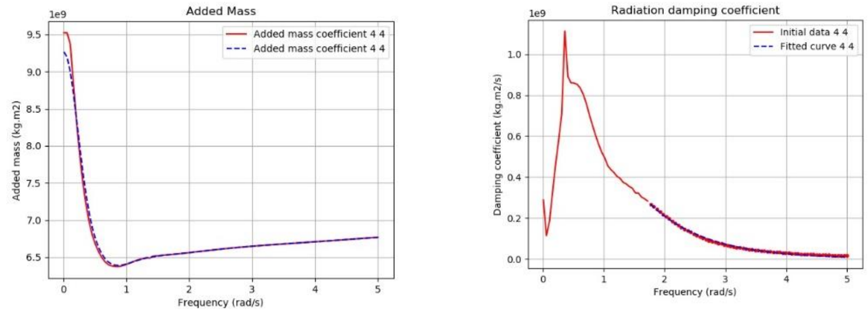


ARTELIA (2018)

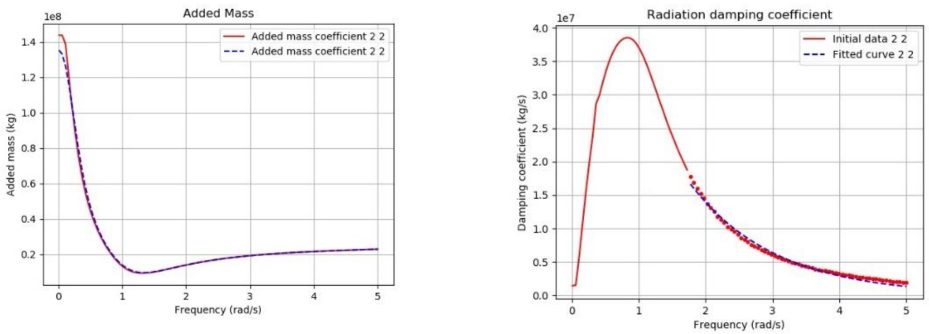
PDSTRIP ADDED MASS AND DAMPING:



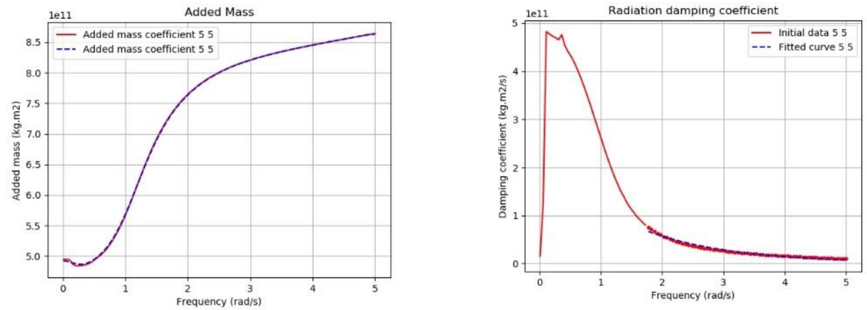
SURGE ADDED MASS AND DAMPING



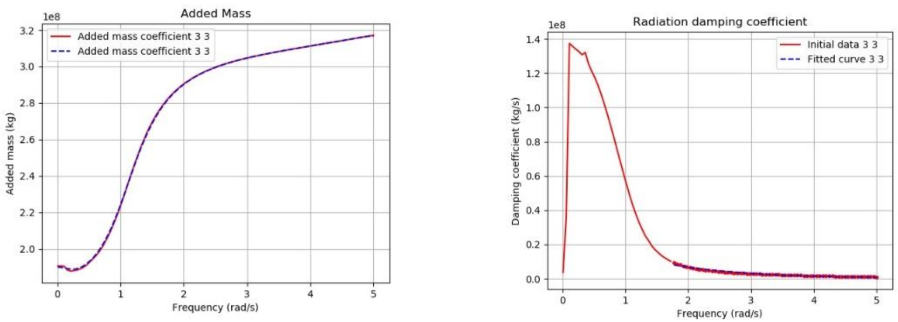
ROLL ADDED MASS AND DAMPING



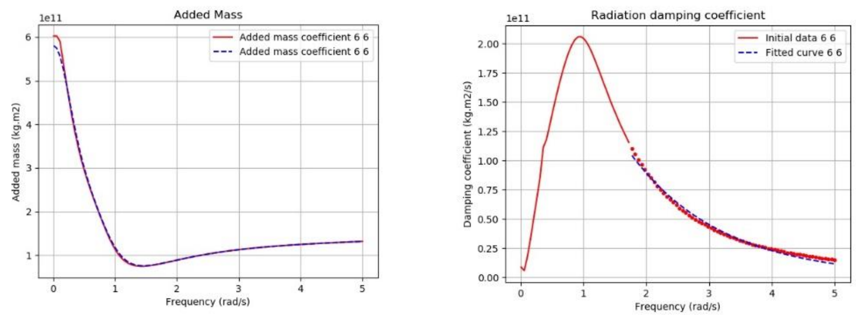
SWAY ADDED MASS AND DAMPING



PITCH ADDED MASS AND DAMPING



HEAVE ADDED MASS AND DAMPING



YAW ADDED MASS AND DAMPING

ARTELIA (2018)

Mooring arrangement:

- **Three bow lines, one fore spring line, one aft spring line, three stern lines (ML1 to ML8)**
- **Two fenders (FD1 to FD2)**

Mooring arrangement (from ref.[1])

ARTELIA (2018)

Uncertain inputs and differences:

- No indication of length of mooring line on-board. It was then assumed no length on-board.
- No details are also given for the friction between ship model and fender. It was considered no friction of the fenders.
- Wave time series generated in the physical model tests were not fully available for the 135° wave angle and could not be fully compared with that of the mathematical model.

ARTELIA (2018)

SIMBAD calculations:

- Ref. [1] gives results of tests using long crested waves. The tests used a JONSWAP wave spectrum with different significant wave heights and peak periods. The tests were about 3-4h long but no indication of a wave ramp-up time was given. The angles of wave attack were 90° (beam waves) and 135° (bow quartering waves).

- The SIMBAD numerical model tests were simulated by doing a series of ten tests all using the same JONSWAP spectra but with different time series. The wave ramp-up time was 400s for a total length of 14400s (4h).

- Time series of first-order wave loads were calculated from the PDSTRIP wave loads on the ship together with the JONSWAP spectral wave amplitude at each frequency, according to the FAST random method. Second-order wave loads considered here are the slow-drift loads (MOLIN variant).

- Calculations using SIMBAD are compared with model test results for the moored ship setup described here above. An exact comparison is not possible, due to the uncertain inputs and also because of difference of sea waves reproduced in physical and numerical models.

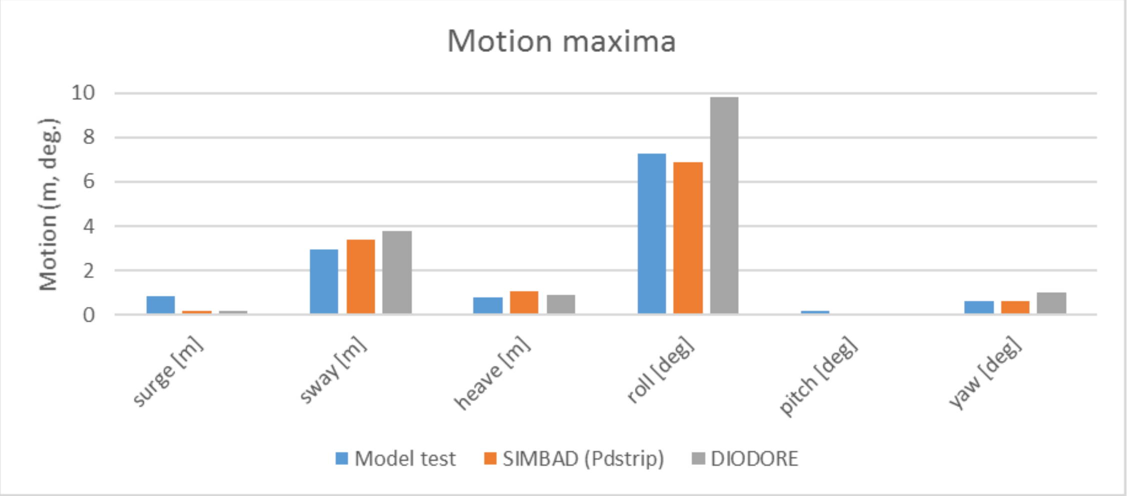
ARTELIA (2018)

Moored ship with wave heading: 90° (beam waves); Hs=0.85m; Tp=16s

PEAK HORIZONTAL MOTIONS AND MOORING LOADS ARE SHOWN IN THE FOLLOWING TABLE AND FIGURES. THE TABLE GIVES THE MINIMUM, MAXIMUM AND MEAN VALUES OBTAINED OVER TEN RUNS WITH DIFFERENT INPUT WAVE PHASING. IN THE FIGURES, ARE SHOWN THE SIMBAD MEAN VALUES COMPARED WITH RESULTS GIVEN IN REF. [1].

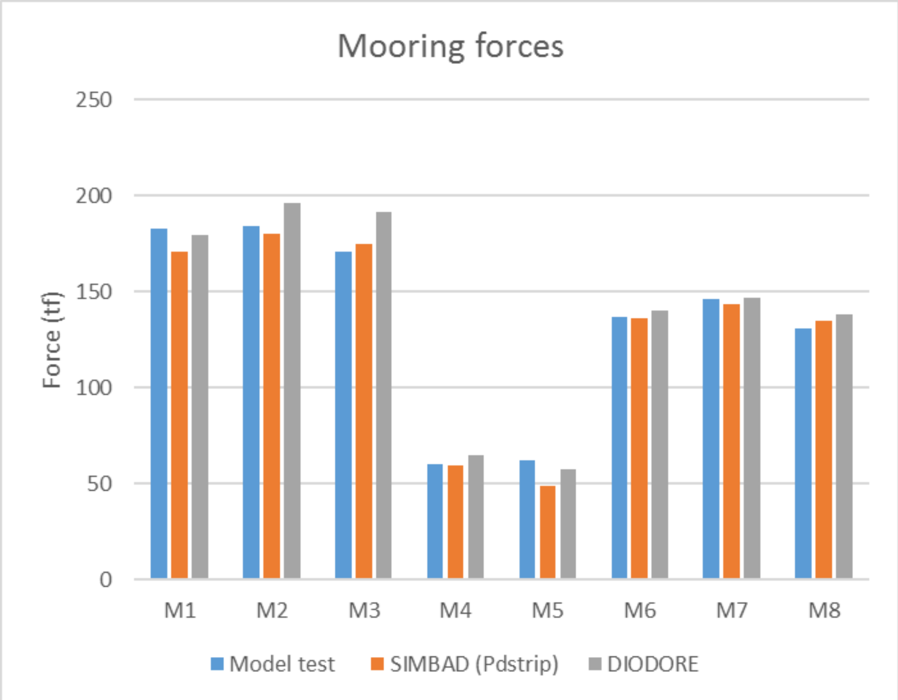
REF. [1] PROVIDES ALSO RESULTS OF CALCULATION WITH DIODORE® WHICH ARE ALSO GIVEN IN THE TABLE AND FIGURES

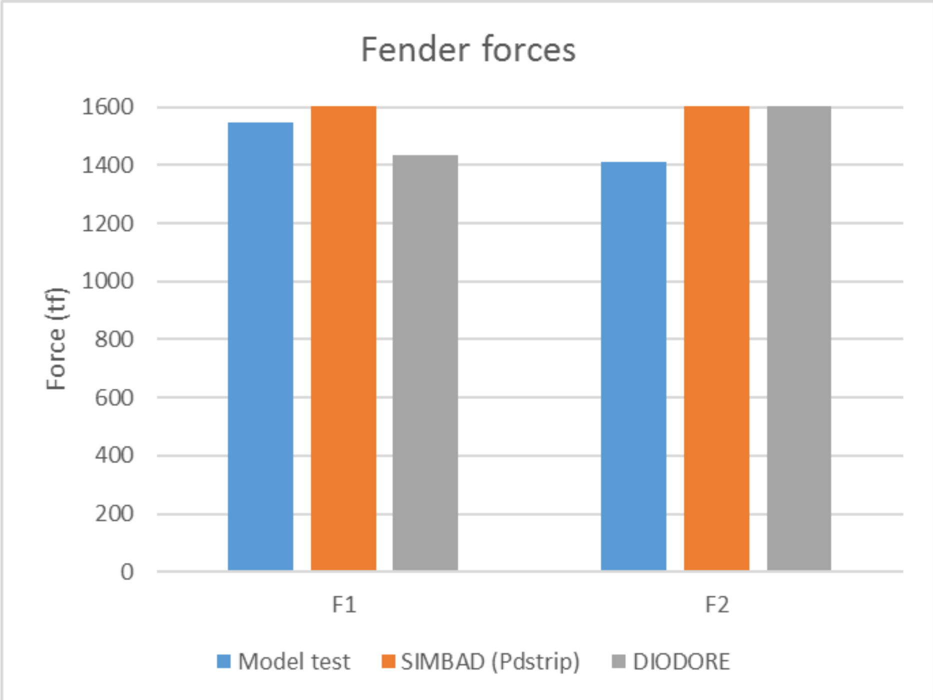
Moored ship with wave heading 90° (beam seas): comparison between calculations and model test results from Artelia (2018)					
	Model test Hs = 0.85 m - Tp=16s	DIODORE	SIMBAD (2020) With 2nd-order loads (Molin formulation)	SIMBAD (2020) With 2nd-order loads (Molin formulation)	SIMBAD (2020) With 2nd-order loads (Molin formulation)
Solver	Model test	Calculation	Min. values	Mean values	Max. values
Ship motions					
surge [m]	0.862	0.16	0.12	0.16	0.19
sway [m]	2.94	3.76	3.07	3.37	3.83
heave [m]	0.77	0.92	0.91	1.05	1.20
roll [deg]	7.27	9.83	6.10	6.89	7.90
pitch [deg]	0.191	0.09	0.02	0.02	0.02
yaw [deg]	0.642	0.99	0.53	0.61	0.75
Mooring line max (tf)					
M1	183	180	143	171	207
M2	184	196	149	180	220
M3	171	191	145	175	215
M4	60	65	53	60	72
M5	62	58	46	49	52
M6	137	140	124	136	162
M7	146	147	131	144	172
M8	131	138	121	135	161
Fender max (tf)					
F1	1545	1436	1370	1618	1854
F2	1411	1665	1486	1660	1996



ARTELIA (2018)

Moored ship with wave heading: 90° (beam waves); Hs=0.85m; Tp=16s





NOTE:

- ***PEAK MOTIONS ARE QUITE WELL PREDICTED WITH SIMBAD, INCLUDING THE PEAK ROLL MOTION***
- ***PEAK MOORING LINE AND FENDER LOADS ARE IN GOOD AGREEMENT WITH MEASURED VALUES***

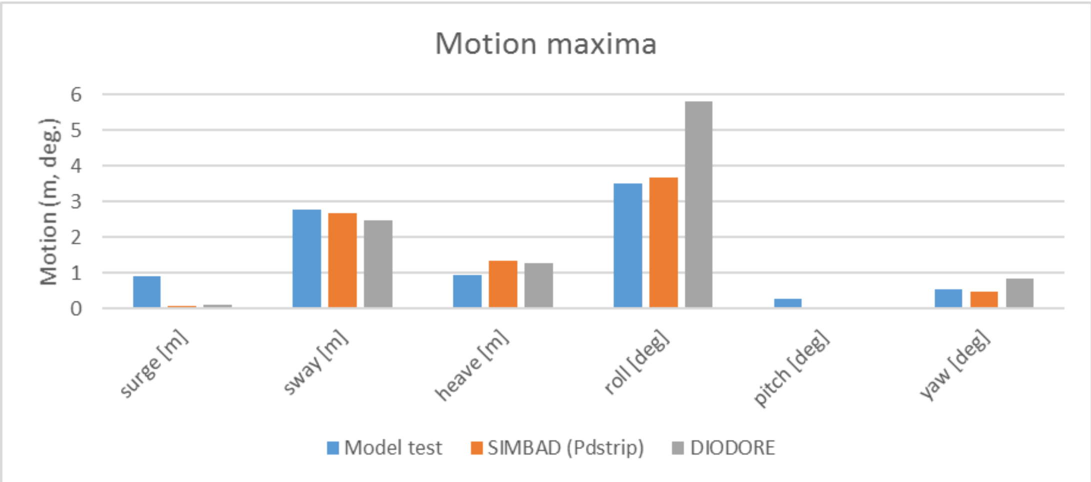
ARTELIA (2018)

Moored ship with wave heading: 90° (beam waves); Hs=1.25m; Tp=12s

Peak horizontal motions and mooring loads are shown in the following table and figures. The table gives the minimum, maximum and mean values obtained over ten runs with different input wave phasing. In the figures, are shown the SIMBAD mean values compared with results given in ref. [1].
Ref. [1] provides also results of calculation with DIODORE® which are also given in the table and figures

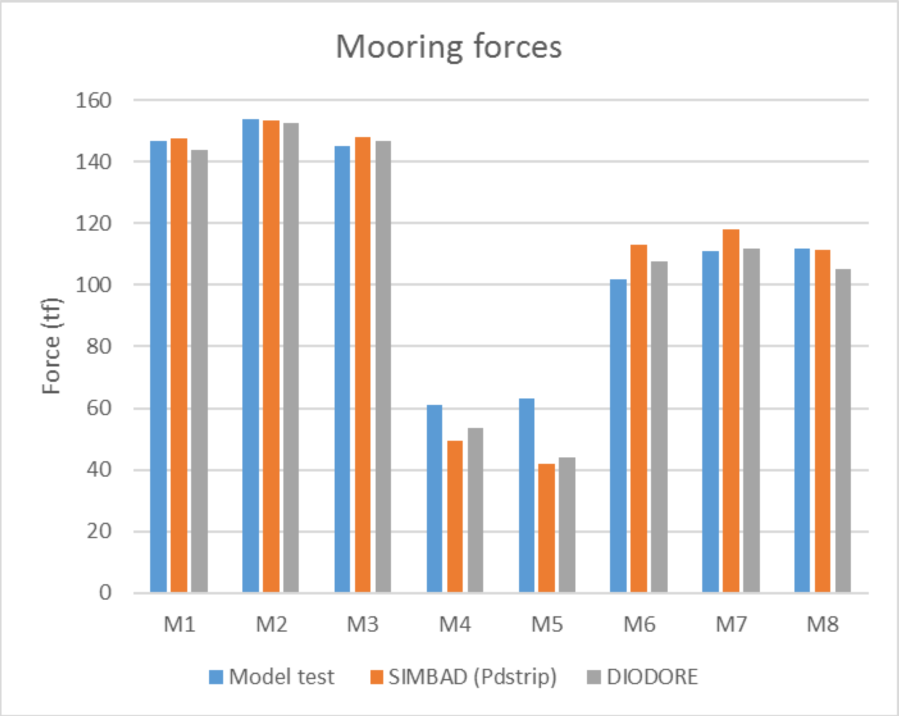
Moored ship with wave heading 90° (beam seas): comparison between calculations and model test results from Artelia (2018)

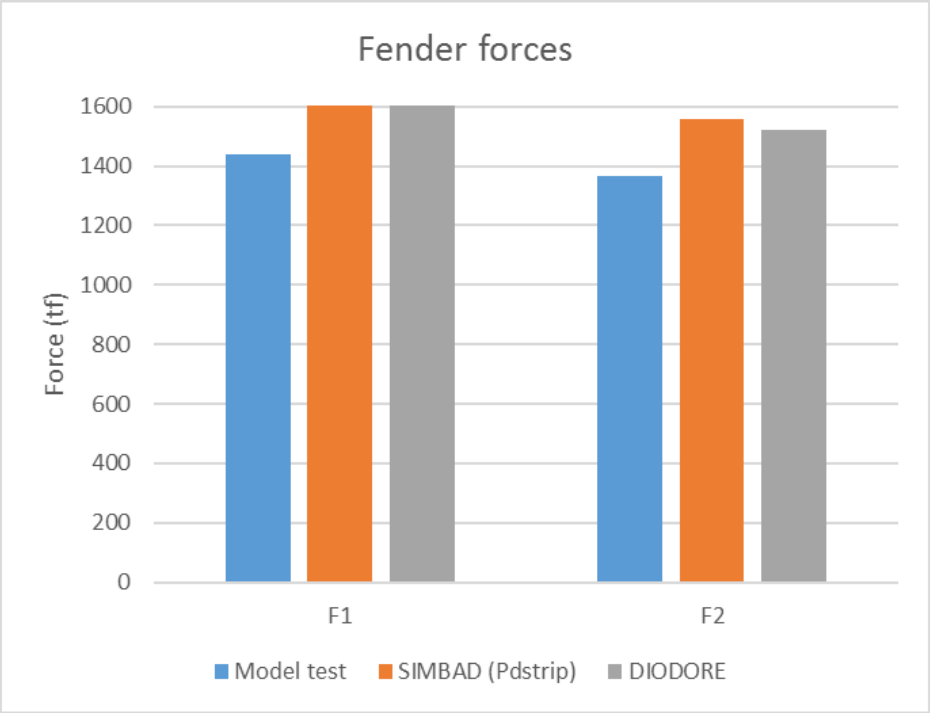
	Model test Hs = 1.25 m - Tp=12s	DIODORE	SIMBAD (2020) With 2nd-order loads (Molin formulation)	SIMBAD (2020) With 2nd-order loads (Molin formulation)	SIMBAD (2020) With 2nd-order loads (Molin formulation)
Solver	Model test	Calculation	Min. values	Mean values	Max. values
Ship motions					
surge [m]	0.92	0.125	0.07	0.08	0.10
sway [m]	2.76	2.49	2.36	2.68	3.00
heave [m]	0.95	1.27	1.21	1.35	1.53
roll [deg]	3.5	5.81	3.35	3.68	4.00
pitch [deg]	0.27	0.059	0.04	0.04	0.06
yaw [deg]	0.53	0.835	0.43	0.49	0.68
Mooring line max (tf)					
M1	147	144	129	148	162
M2	154	152	134	154	169
M3	145	147	130	148	164
M4	61	54	45	50	53
M5	63	44	38	42	46
M6	102	108	102	113	131
M7	111	112	107	118	137
M8	112	105	101	112	130
Fender max (tf)					
F1	1440	1757	1438	1669	1902
F2	1367	1519	1411	1558	2121



ARTELIA (2018)

Moored ship with wave heading: 90° (beam waves); Hs=1.25m; Tp=12s





NOTE:

- ***PEAK MOTIONS ARE QUITE WELL PREDICTED WITH SIMBAD, EXCEPT FOR SURGE BUT THIS MOTION IS DIFFICULT TO PREDICT WITH LONG CRESTED BEAM WAVES***
- ***PEAK MOORING LINE AND FENDER LOADS ARE IN GOOD AGREEMENT WITH MEASURED VALUES***

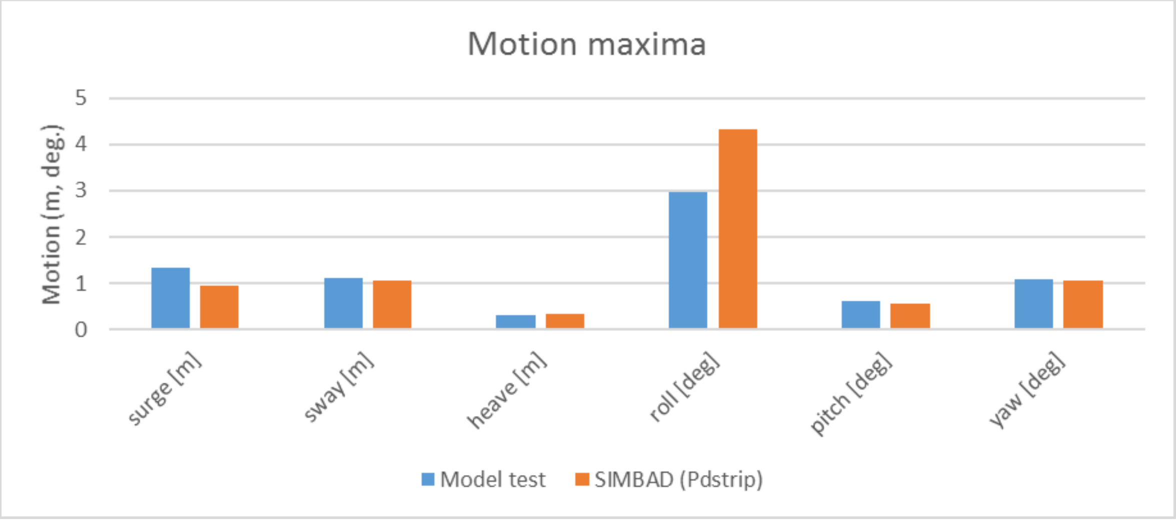
ARTELIA (2018)

Moored ship with wave heading: 135° (bow quartering waves); Hs=1.04m; Tp=16s

PEAK HORIZONTAL MOTIONS AND MOORING LOADS ARE SHOWN IN THE FOLLOWING TABLE AND FIGURES. THE TABLE GIVES THE MINIMUM, MAXIMUM AND MEAN VALUES OBTAINED OVER TEN RUNS WITH DIFFERENT INPUT WAVE PHASING. IN THE FIGURES, ARE SHOWN THE SIMBAD MEAN VALUES COMPARED WITH RESULTS GIVEN IN REF. [1].

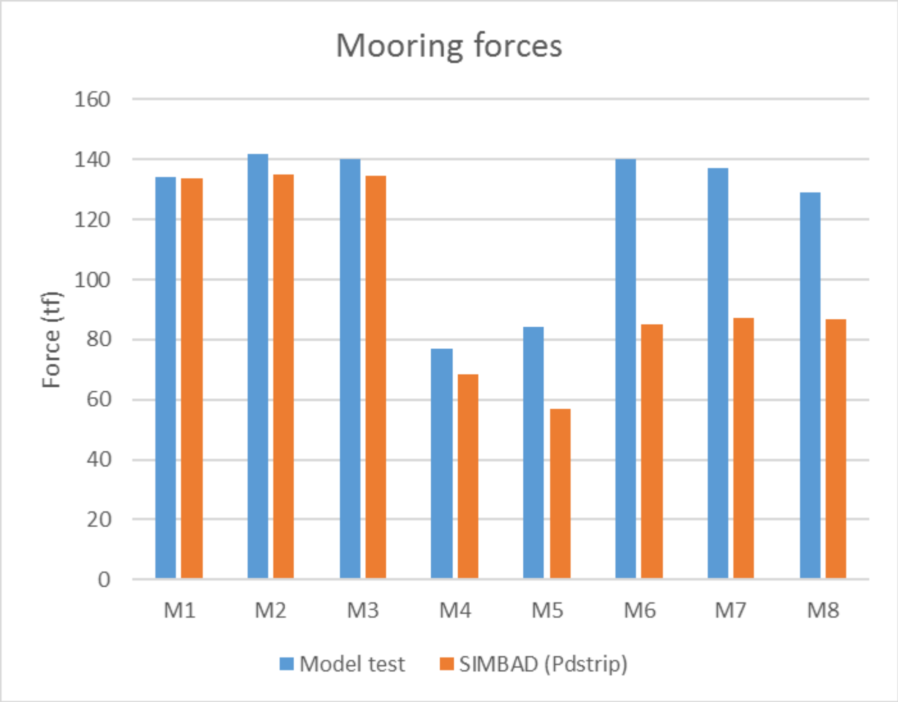
Moored ship with wave heading 135˚ (bow quartering seas): comparison between calculations and model test results from Artelia (2018)

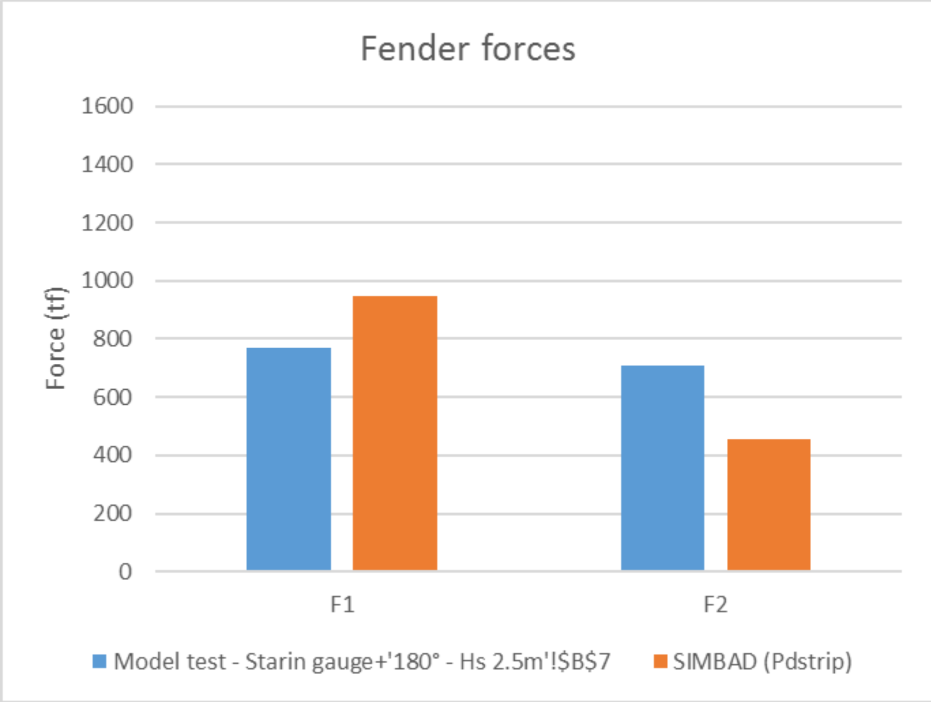
	Model test Hs = 1.04 m - Tp=16s	SIMBAD (2020) With 2nd-order loads (Molin formulation)	SIMBAD (2020) With 2nd-order loads (Molin formulation)	SIMBAD (2020) With 2nd-order loads (Molin formulation)
Solver	Model test	Min. values	Mean values	Max. values
Ship motions				
surge [m]	1.34	0.85	0.96	1.14
sway [m]	1.11	0.91	1.07	1.29
heave [m]	0.31	0.28	0.34	0.44
roll [deg]	2.96	3.95	4.34	4.84
pitch [deg]	0.615	0.49	0.56	0.67
yaw [deg]	1.09	0.92	1.07	1.18
Mooring line max (tf)				
M1	134	123	134	147
M2	142	125	135	149
M3	140	125	135	151
M4	77	62	68	75
M5	84	54	57	61
M6	140	80	85	94
M7	137	80	87	95
M8	129	79	87	96
Fender max (tf)				
F1	768	867	949	1127
F2	708	399	455	532



ARTELIA (2018)

Moored ship with wave heading: 135° (bow quartering waves); Hs=1.04m; Tp=16s

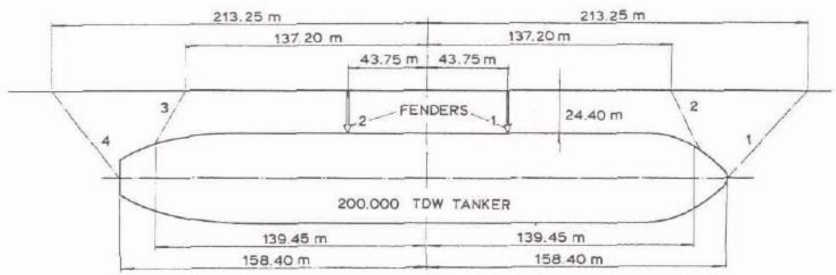


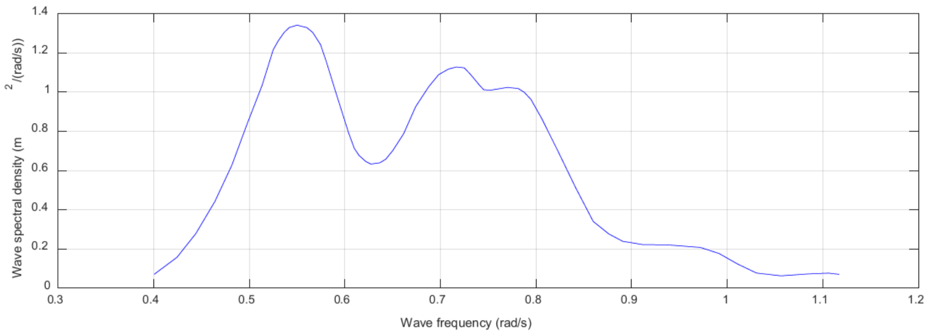


NOTE:

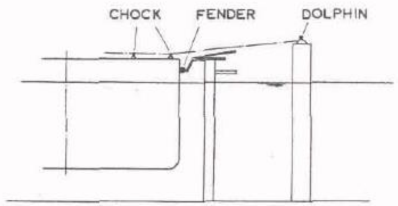
- ***PEAK MOTIONS ARE QUITE WELL PREDICTED WITH SIMBAD, EXCEPT FOR ROLL MOTION FOR WHICH THE VALUES ARE OVER-PREDICTED IN THE NUMERICAL MODEL WITH THIS WAVE DIRECTION***
- ***PEAK MOORING LINE LOADS ARE IN GOOD AGREEMENT WITH MEASURED VALUES FOR BOW AND FORE SPRING LINES BUT UNDER-PREDICTED FOR STERN LINES***
- ***PEAK FENDER LOADS ARE QUITE IN GOOD AGREEMENT FOR THE FORE FENDER AND UNDER-PREDICTED FOR THE AFT FENDER***

NSMB (1976) – Perth Hydro (2019)





Mooring arrangement and wave spectrum (Hs = 2.6 m) (from ref.[1] and [3])



Test case (see details in references):

- Loaded 200000DWT tanker moored at an open berth
- Water depth of 1.2 times the vessel draught
- Mooring arrangement shown in here above figures: Four lines representative of two or three wire lines with nylon tails and two fenders
- 20T pre-tension applied in each line
- Linear stiffness for lines and fenders (see remark hereafter)
- Uni-directional (long-crested) sea used for moored ship model tests with measured wave spectrum shown here above

References:

- [1]: Van Oortmerssen G., "The motions of a moored ship in waves", NSMB report n°510, 1976
- [2]: Spencer JM., "Mathematical simulations of a ship moored in waves and of the effects of a passing vessel on a moored ship", Hydraulics research Wallingford, Report n°SR 145, 1988
- [3]: Gourlay T., "Comparison of Wamit and Moormotions with model tests for a tanker moored at an open berth", Perth hydro research report R2019-09

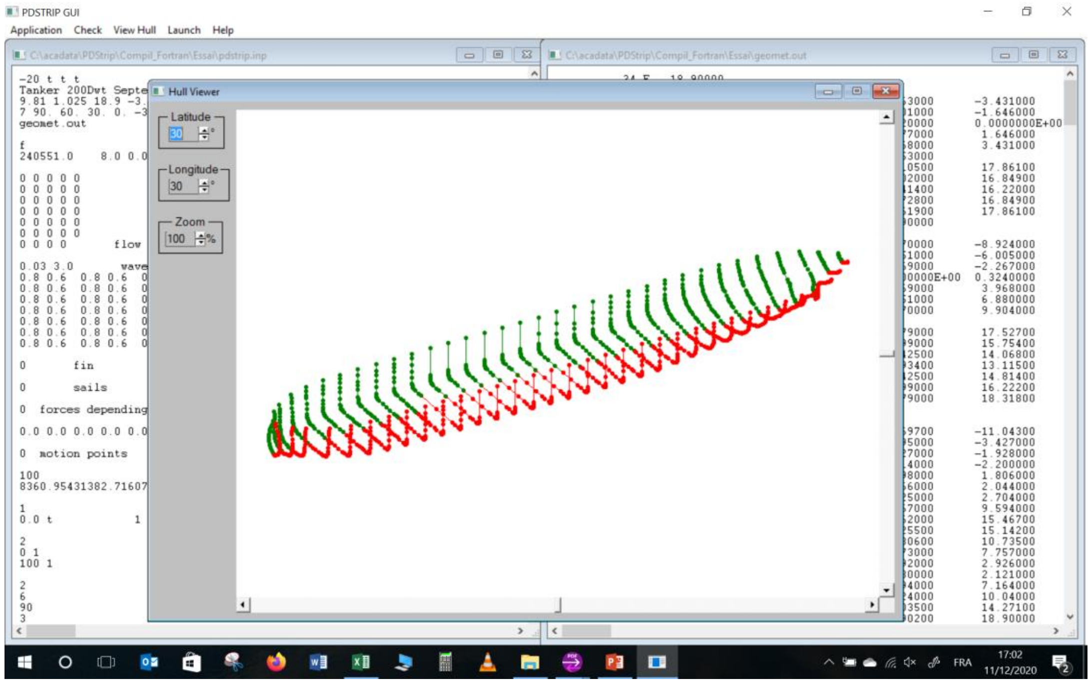
NSMB (1976) – Perth Hydro (2019)

Particulars of the tanker:

- Table hereafter gives original data and data from PDSTRIP schematisation. Small differences are present resulting from uncertainties in the available information and from body plan used for 200,000 DWT tanker, taken from an existing one and not from original data
- Frequency range for added mass and damping values, first order wave loads, drift forces: 0.011 – 5.0 rad/s

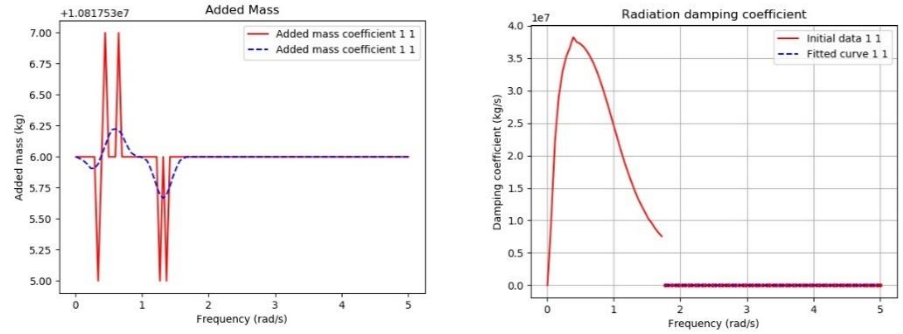
Dimensions of ship		
Ship	Model test	PDSTRIP
Length overall (m)	316.8	317.8
Length between perpendiculars (m)	310	310
Beam (m)	47.2	47.2
Draught (m)	18.9	18.9
Displacement (m3)	235,000	234,684
Block coefficient	0.85	0.848
Height of Centre of Gravity KG (m)	13.32	13.32
Longitudinal Centre of Gravity (m)	6.61	8(*)
Transverse Metacentric Height GM (m)	5.78	6.58(*)
Roll Radius of Gyration (m)	17	17
Pitch Radius of Gyration (m)	77.5	77.5
Yaw Radius of Gyration (m)	77.5	77.5
Water depth (m)	22.68	22.68

(*) Slightly different values according to used body plan

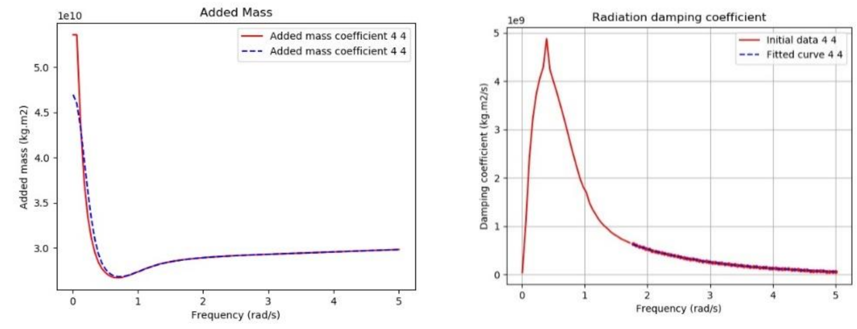


NSMB (1976) – Perth Hydro (2019)

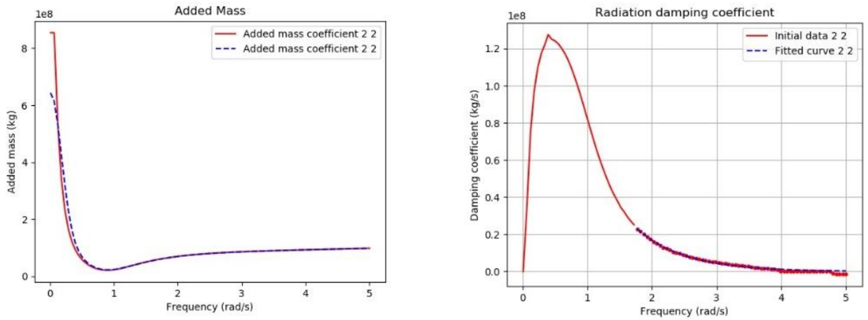
PDSTRIP added mass and damping:



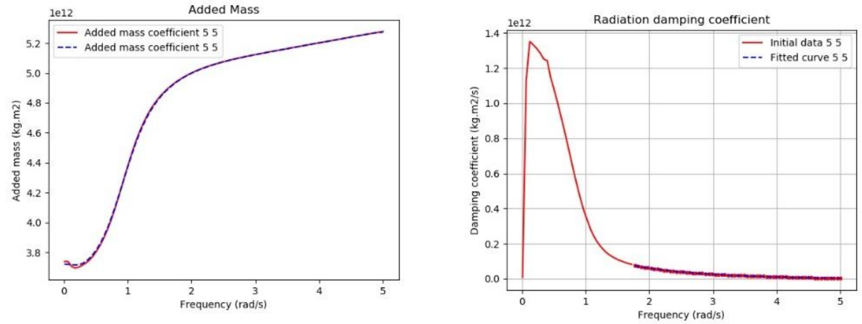
Surge added mass and damping



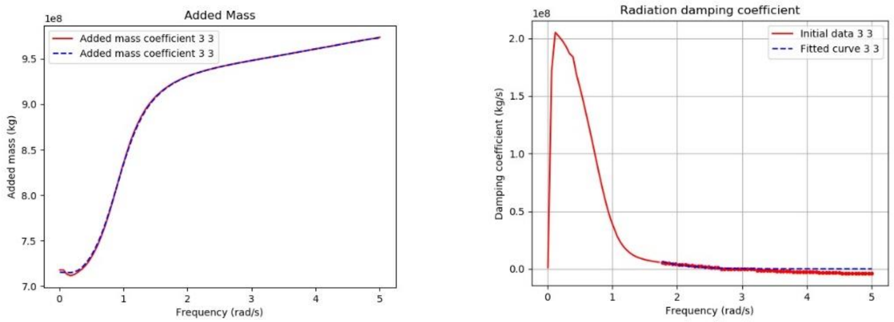
Roll added mass and damping



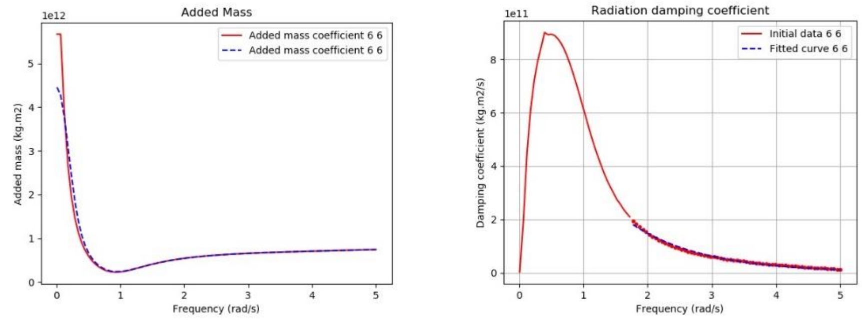
Sway added mass and damping



Pitch added mass and damping



Heave added mass and damping



Yaw added mass and damping

NSMB (1976) – Perth Hydro (2019)

Uncertain inputs and differences:

- **Undefined:**
  - Vertical co-ordinates of the fairleads on the ship: 8m above Water Level (WL) used for all lines
  - Vertical co-ordinates of the bollards on the dolphin: 4.7m above WL used for all lines
  - Lateral co-ordinates of the fairleads for lines 2 and 3 on the ship: 17m off the ship's center line used
  - Vertical co-ordinates of the fenders: 2.7 m above water level used
  - Length of mooring line on-board: no length on-board was applied

- In ref. [1], load-extension curves were given for the lines in terms of percentage extension but no indication of a reference length. Furthermore, it is said that each line was pre-tensioned with a force of 20 t. However it is not absolutely clear that 20 t for each "model" line is meant or 20 t for each "real“ line (as each line corresponds to two or three lines in reality). No details are also given for the friction between ship model and fender. In ref. [2], it was assumed that the extension would apply only to the lines' tails and that it was found necessary to add friction for horizontal motions in order to obtain sensible results. Due to these uncertainties, it was considered linear stiffnesses for all lines (based on the load-extension curves), no friction of the fenders and 20 t pretension per "model" line. Results obtained using these assumptions turned out to be consistent with original ones.

NSMB (1976) – Perth Hydro (2019)

SIMBAD calculations:

- Ref. [1] gives results of tests using long crested waves. The tests all used the same wave spectrum (see here above) with a significant wave height of 2.6m and a mean period of 8.9s. Each was 2200s long with a wave ramp-up time of 100s. They differed in that the angle of wave attack was different for each test : 90° (beam sea), 135° (bow quartering sea) and 180° (bow sea).

- The 3 tests were simulated with SIMBAD by doing, for each one, a series of ten tests all using the same force spectra but with different time series. The wave ramp-up time was nevertheless increased to 400s for a total length of 2500s.

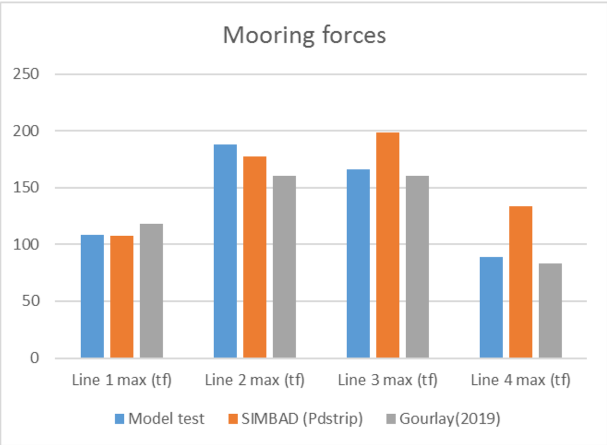
- Time series of first-order wave loads were calculated from the PDSTRIP wave loads on the ship together with the spectral wave amplitude at each frequency, according to the random phasing method. Second-order wave loads considered here are the "mean-drift" wave loads and not the slow-drift loads (MOLIN variant).

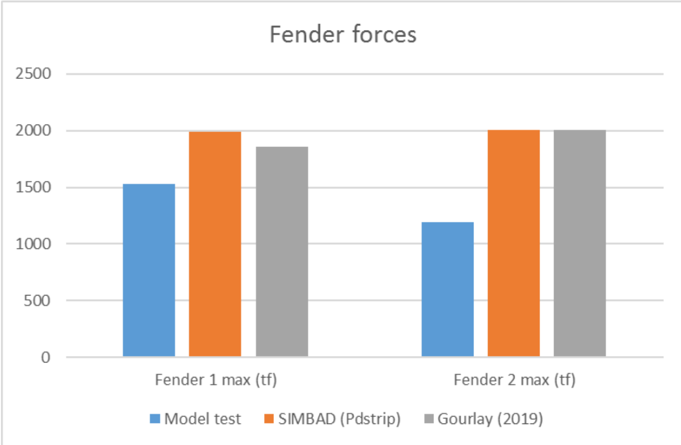
- Calculations using SIMBAD are compared with model test results for the moored ship setup described here above. An exact comparison is not possible, due to the uncertain inputs and also because the mooring layout is characterised by the lack of longitudinal restraint. This means that the ship will be susceptible to long periodic surge motions. These will be affected by any wanted or unwanted long wave energy present in the physical or numerical models. As it is impossible to fully control the occurrence of this long wave energy, the resulting ship response may well be influenced by small inaccuracies in this respect.

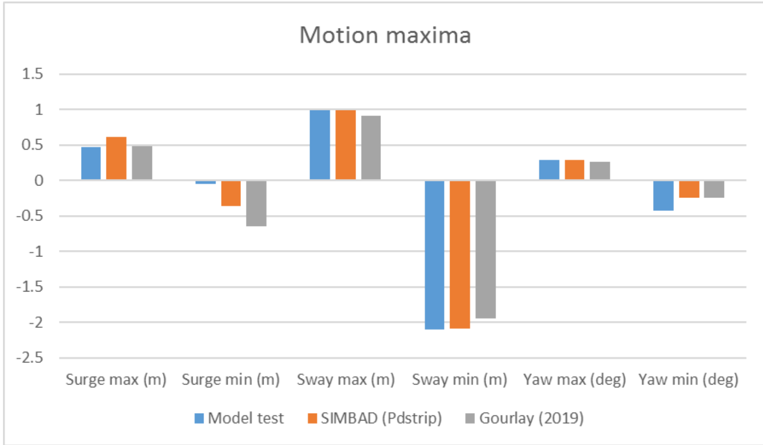
NSMB (1973) – PERTH HYDRO (2019)

Moored ship with wave heading: 90° (beam sea); Hs=2.6m

PEAK HORIZONTAL MOTIONS AND MOORING LOADS ARE SHOWN IN THE FOLLOWING TABLE AND FIGURES. THEY GIVE THE MINIMUM, MAXIMUM AND MEAN VALUES OBTAINED OVER TEN RUNS WITH DIFFERENT INPUT WAVE PHASING. IN THE FIGURES, ARE SHOWN THE SIMBAD MEAN VALUES COMPARED TO MODEL TEST AND RESULTS OF REF. [3] (MEAN VALUES OF MOORMOTIONS® CALCULATIONS WITH 2ND-ORDER LOADS)







Moored ship with wave heading 90˚ (beam seas): comparison between calculations and model test results from van Oortmerssen (1976, Table 5.2)

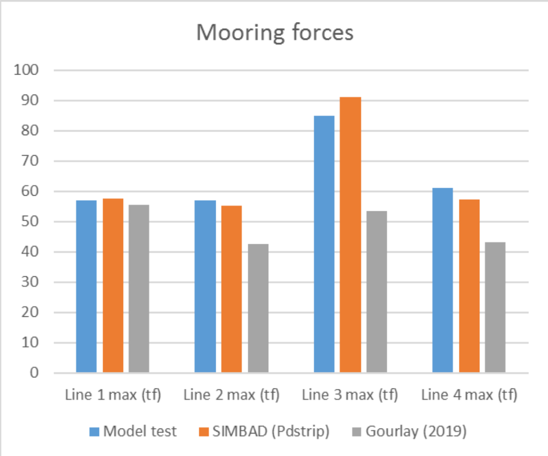
	Model test	SIMBAD (2020) With 2nd-order loads	SIMBAD (2020) With 2nd-order loads	SIMBAD (2020) With 2nd-order loads	MoorMotions calculations Gourlay (2019) Without 2nd-order loads	MoorMotions calculations Gourlay (2019) With 2nd-order loads
Solver	–	Min. values	Mean values	Max. values	Wamit	Wamit
Surge max (m)	0.47	0.45	0.61	0.79	0.08 – 0.54	0.06 – 0.91
Surge min (m)	-0.05	-0.48	-0.37	-0.24	(-0.66) – (-0.11)	(-1.16) – (-0.14)
Sway max (m)	0.99	0.84	0.99	1.20	0.58 – 1.21	0.63 – 1.18
Sway min (m)	-2.1	-2.60	-2.10	-1.91	(-3.33) – (-1.70)	(-2.26) – (-1.64)
Yaw max (deg)	0.28	0.25	0.29	0.32	0.06 – 0.46	0.05 – 0.48
Yaw min (deg)	-0.43	-0.30	-0.25	-0.20	(-0.38) – (-0.03)	(-0.45) – (-0.05)
Line 1 max (tf)	108	104	108	119	88 – 138	88 – 148
Line 2 max (tf)	188	160	177	202	126 – 219	116 – 205
Line 3 max (tf)	166	179	198	221	132 – 248	129 – 191
Line 4 max (tf)	89	115	134	158	73 – 118	70 – 96
Fender 1 max (tf)	1530	1626	1989	2276	1129 – 2306	1413 – 2296
Fender 2 max (tf)	1196	1608	2001	2427	1214 – 2287	1503 – 2504

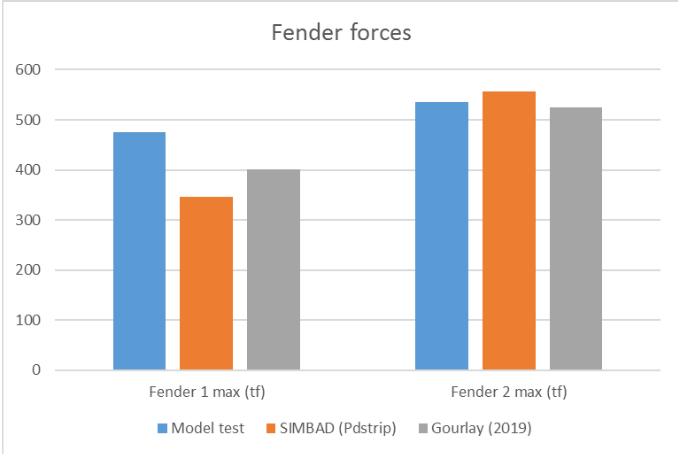
- ***PEAK MOTIONS AND MOORING LINE LOADS ARE QUITE WELL PREDICTED***
- ***FENDER LOADS ARE SLIGHTLY OVER-PREDICTED, AS WELL AS FOR MOORMOTIONS RESULTS***

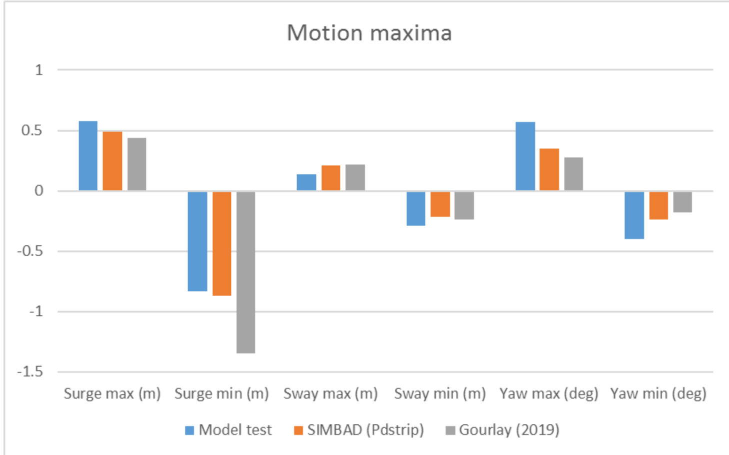
NSMB (1973) – Perth Hydro (2019)

Moored ship with wave heading: 135° (bow quartering sea); Hs=2.6m

Peak horizontal motions and mooring loads are shown in the following table and figures. They give the minimum, maximum and mean values obtained over ten runs with different input wave phasing. In the figures, are shown the SIMBAD mean values compared to model test and results of ref. [3] (mean values of MoorMotions calculations with 2nd-order loads)







Moored ship with wave heading 135˚ (bow quartering seas): comparison between calculations and model test results from van Oortmerssen (1976, Table 5.3)

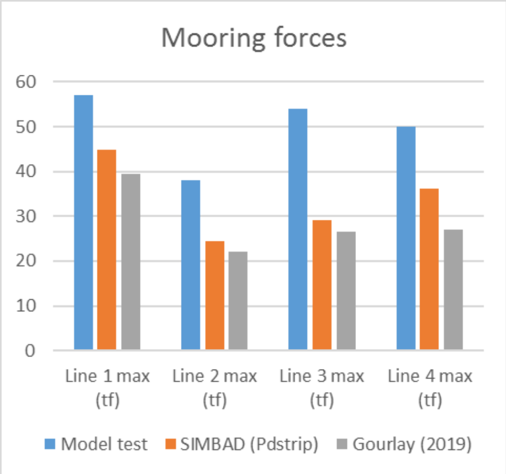
	Model test	SIMBAD (2020) With 2nd-order loads	SIMBAD (2020) With 2nd-order loads	SIMBAD (2020) With 2nd-order loads	MoorMotions calculations Gourlay (2019) Without 2nd-order loads	MoorMotions calculations Gourlay (2019) With 2nd-order loads
Solver	–	Min Pdstrip	Mean Pdstrip	Max Pdstrip	Wamit	Wamit
Surge max (m)	0.58	0.20	0.49	0.83	0.05 – 0.24	0.06 – 0.82
Surge min (m)	-0.83	-1.33	-0.87	-0.77	(-0.38) – (-0.23)	(-1.77) – (-0.93)
Sway max (m)	0.14	0.17	0.21	0.30	0.08 – 0.15	0.15 – 0.28
Sway min (m)	-0.29	-0.24	-0.22	-0.17	(-0.30) – (-0.16)	(-0.29) – (-0.18)
Yaw max (deg)	0.57	0.31	0.35	0.42	0.18 – 0.32	0.24 – 0.31
Yaw min (deg)	-0.4	-0.29	-0.24	-0.20	(-0.21) – (-0.16)	(-0.22) – (-0.14)
Line 1 max (tf)	57	51	58	82	33 – 42	46 – 65
Line 2 max (tf)	57	49	55	60	35 – 43	35 – 50
Line 3 max (tf)	85	79	91	105	42 – 59	45 – 62
Line 4 max (tf)	61	51	57	64	36 – 47	34 – 52
Fender 1 max (tf)	476	268	346	449	227 – 317	321 – 482
Fender 2 max (tf)	536	511	557	614	265 – 364	364 – 685

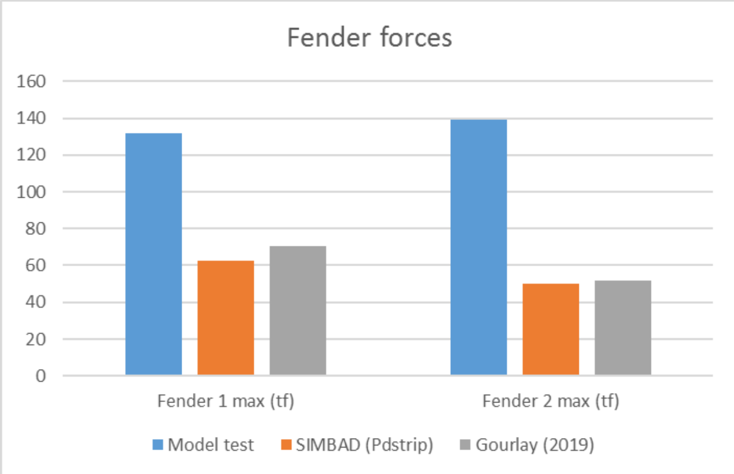
- ***Fender loads and mooring line loads are in close agreement with experimental values***
- ***Surge and sway are close to the measured values, while yaw is slightly under-predicted***

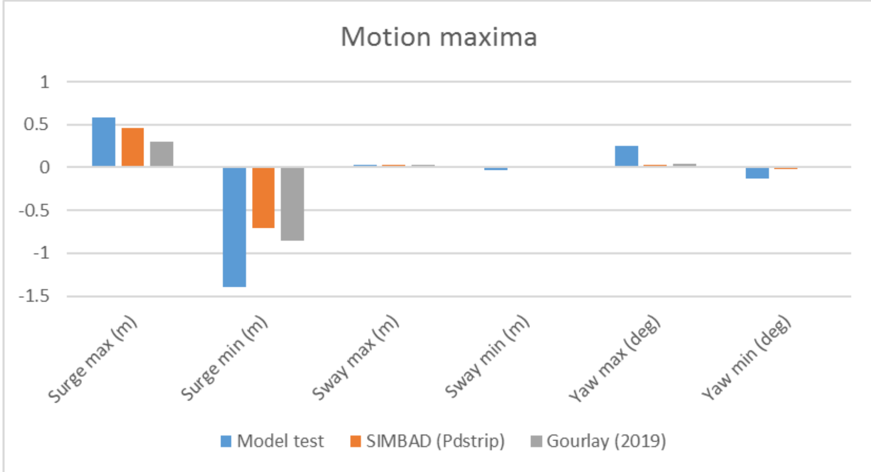
NSMB (1973) – Perth Hydro (2019)

Moored ship with wave heading: 180° (bow sea); Hs=2.6m

Peak horizontal motions and mooring loads are shown in the following table and figures. They give the minimum, maximum and mean values obtained over ten runs with different input wave phasing. In the figures, are shown the SIMBAD mean values compared to model test and results of ref. [3] (mean values of MoorMotions calculations with 2nd-order loads)





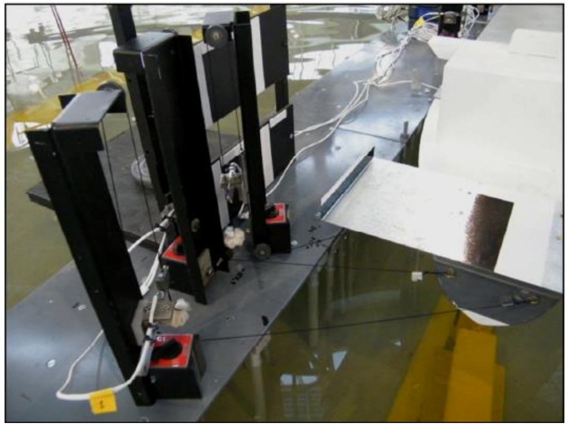


Moored ship with wave heading 180˚ (head seas): comparison between calculations and model test results from van Oortmerssen (1976, Table 5.4)

	Model test	SIMBAD (2020) With 2nd-order loads	SIMBAD (2020) With 2nd-order loads	SIMBAD (2020) With 2nd-order loads	MoorMotions calculations Gourlay (2019) Without 2nd-order loads	MoorMotions calculations Gourlay (2019) With 2nd-order loads
Solver	–	Min Pdstrip	Mean Pdstrip	Max Pdstrip	Wamit	Wamit
Surge max (m)	0.58	0.27	0.46	1.20	0.12 – 0.19	0.04 – 0.57
Surge min (m)	-1.39	-1.20	-0.71	-0.50	(-0.28) – (-0.20)	(-1.14) – (-0.58)
Sway max (m)	0.03	0.03	0.03	0.03	0.03	0.03
Sway min (m)	-0.03	-0.01	0.01	0.02	0	0
Yaw max (deg)	0.25	0.02	0.03	0.04	0.01	0.02 – 0.06
Yaw min (deg)	-0.13	-0.05	-0.02	-0.01	0	(-0.02) – 0.00
Line 1 max (tf)	57	37	45	63	24 – 26	33 – 46
Line 2 max (tf)	38	22	24	35	20 – 21	20 – 24
Line 3 max (tf)	54	26	29	33	21 – 22	24 – 29
Line 4 max (tf)	50	30	36	63	23 – 25	21 – 33
Fender 1 max (tf)	132	53	62	79	52	61 – 80
Fender 2 max (tf)	139	42	50	76	43 – 47	43 – 61

- ***Numerical values (SIMBAD and MoorMotions) are in close agreement together***
- ***In comparison with the measured values, surge motions are slightly under-predicted in head seas. Yaw motions, and hence line and fender loads, are noticeably under-predicted in head seas. The numerical method assumes long-crested, pure head seas; any variation in wave direction either side of head seas in the experiments may contribute to this difference.***

Stellenbosch University (2015)

300 kDwt model vessel at the CSIR (from ref.[1] and [2])

Test case (see details in reference):

- Loaded 300000Dwt bulk carrier moored on a jetty supported by piles
- Water depth of 1.47 times the vessel draught
- Mooring arrangement (see hereafter): eight lines (B1 to B8), each representative of two wire lines with nylon tails and five fenders (F3 to F7)
- 10t pre-tension applied in each "model line" (5t per wire line)
- Non-linear stiffness for lines and linear stiffness for fenders
- Directional spreading (short-crested) sea used for moored ship model tests

References:

- [1]: Eigelaar L.S., "Scale model validation of QUAYSIM and WAVESCAT numerical models of ship motions", Stellenbosch University, 2015
- [2]: Kievet J., "A non intrusive video tracking method to measure movement of a moored vessel", Stellenbosch University, 2015

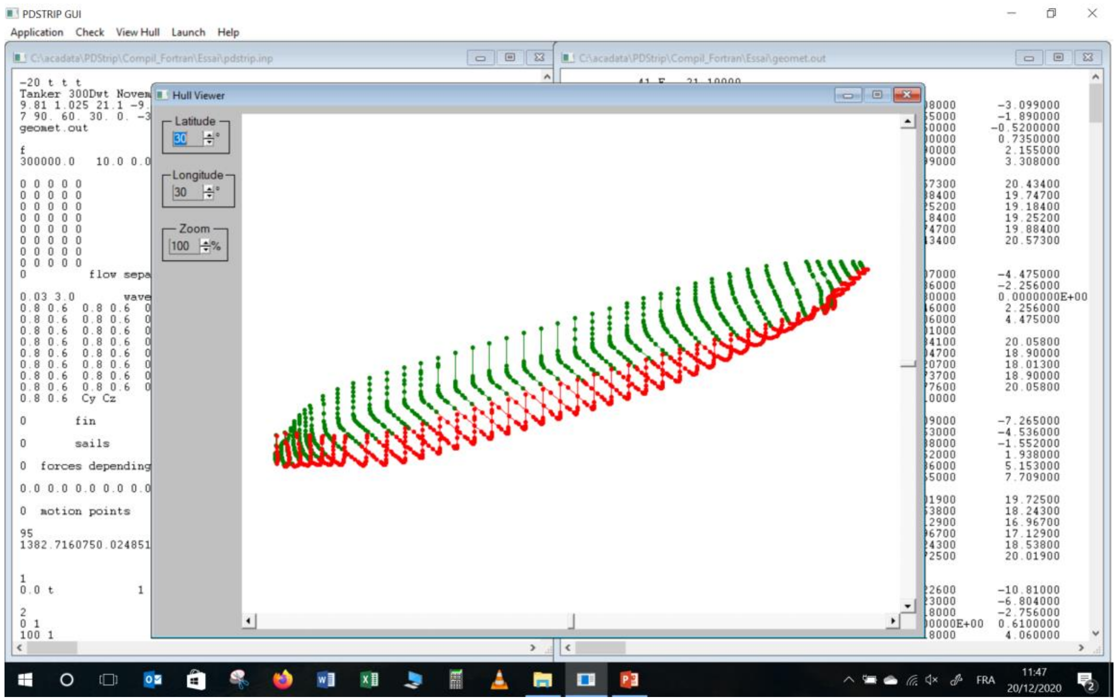
STELLENBOSCH UNIVERSITY (2015)

PARTICULARS OF THE BULK CARRIER:

- TABLE HEREAFTER GIVES ORIGINAL DATA AND DATA FROM PDSTRIP SCHEMATISATION. SMALL DIFFERENCES ARE PRESENT RESULTING FROM UNCERTAINTIES IN THE AVAILABLE INFORMATION AND FROM BODY PLAN USED FOR 300,000 DWT BULK CARRIER, TAKEN FROM AN EXISTING ONE AND NOT FROM ORIGINAL DATA
- FREQUENCY RANGE FOR ADDED MASS AND DAMPING VALUES, FIRST ORDER WAVE LOADS, DRIFT FORCES: 0.08 – 4.8 RAD/S

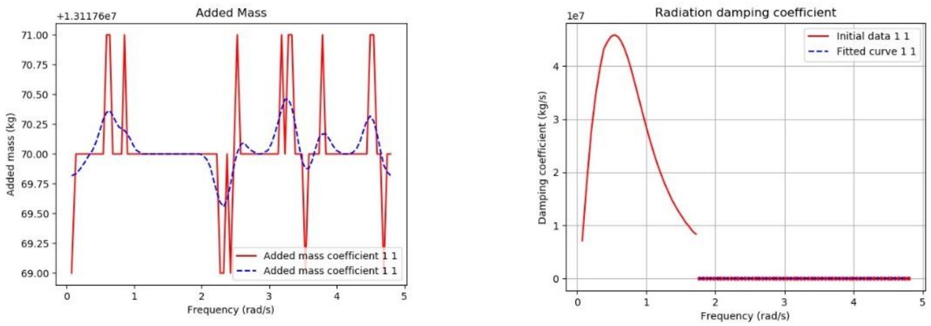
Dimensions of ship		
Ship	Model test	PDSTRIP
Length overall (m)	337	344
Length between perpendiculars (m)	326	326
Beam (m)	54	54
Draught (m)	21.1	21.1
Displacement (m3)	292666	292683
Block coefficient	0.788	0.788
Height of Centre of Gravity KG (m)	14.0	15.7(*)
Longitudinal Centre of Gravity (m)	10.0	10.0
Transverse Metacentric Height GM (m)	?	8.04
Roll Radius of Gyration (m)	19.8	19.8
Pitch Radius of Gyration (m)	88.98	88.98
Yaw Radius of Gyration (m)	88.98	88.98
Water depth (m)	31	31

(*) KG slightly changed to obtain a more appropriate GM value (less than 0.4 x draught)

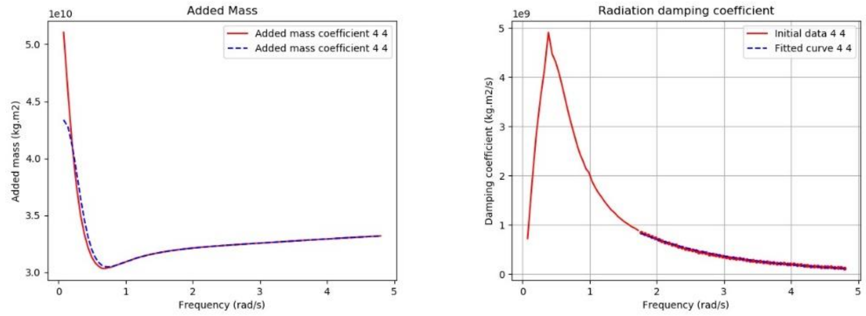


STELLENBOSCH UNIVERSITY (2015)

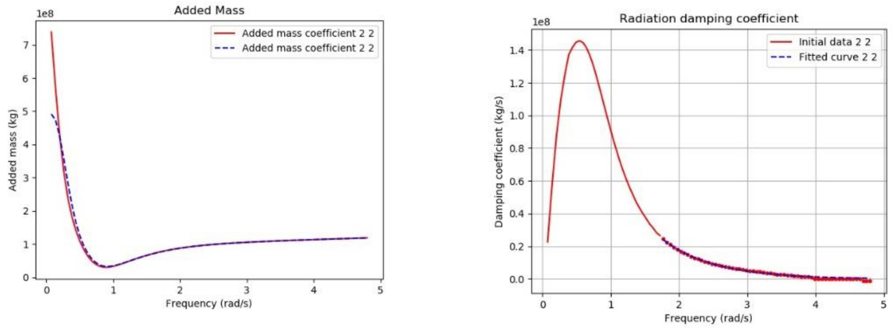
PDSTRIP ADDED MASS AND DAMPING:



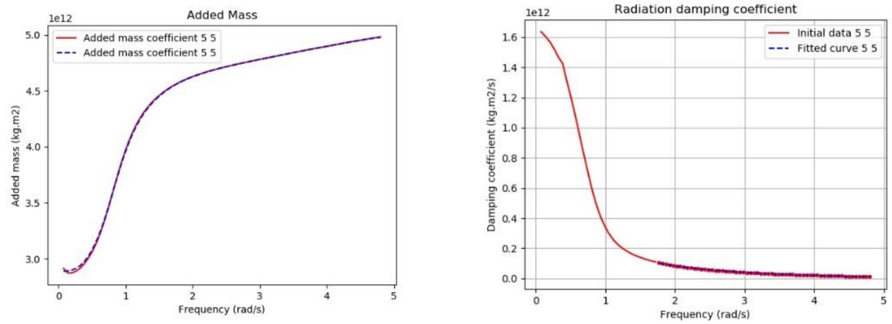
SURGE ADDED MASS AND DAMPING



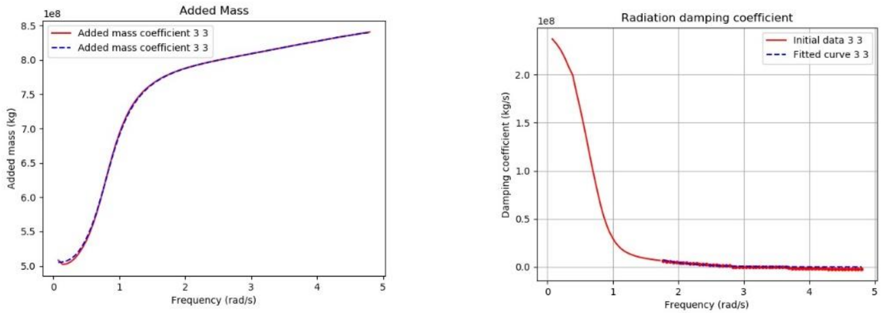
ROLL ADDED MASS AND DAMPING



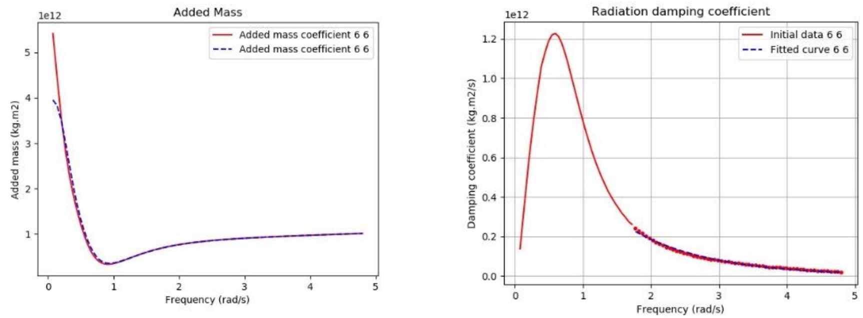
SWAY ADDED MASS AND DAMPING



PITCH ADDED MASS AND DAMPING



HEAVE ADDED MASS AND DAMPING

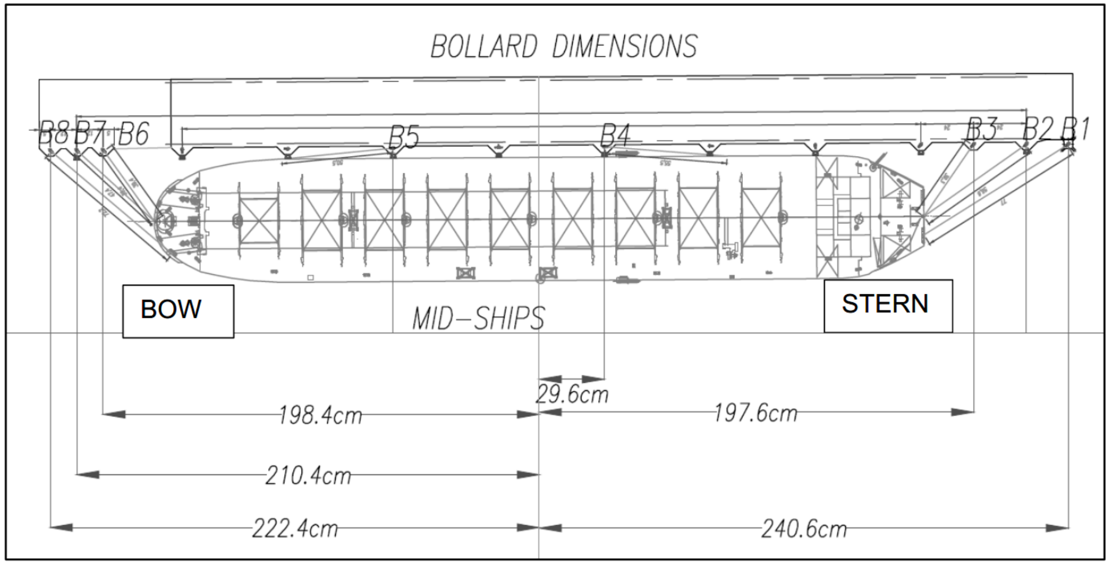


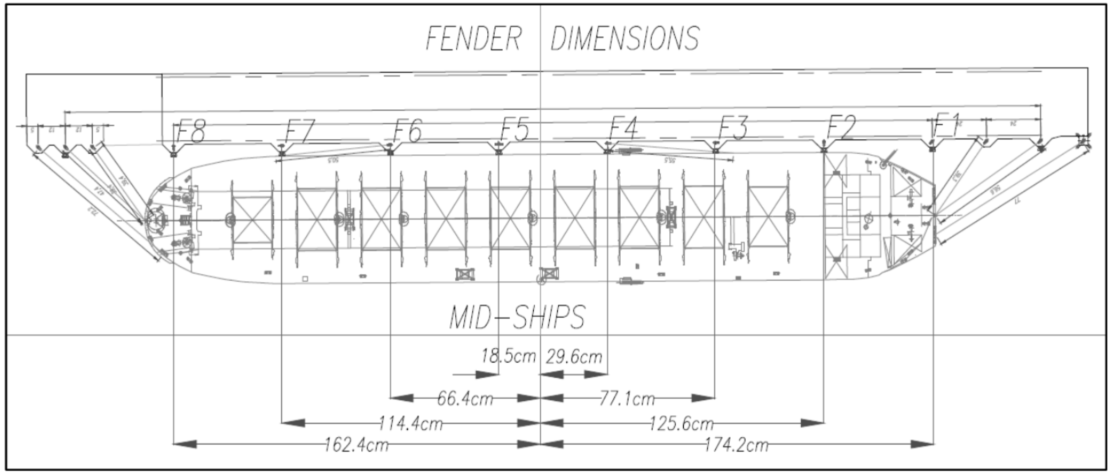
YAW ADDED MASS AND DAMPING

STELLENBOSCH UNIVERSITY (2015)

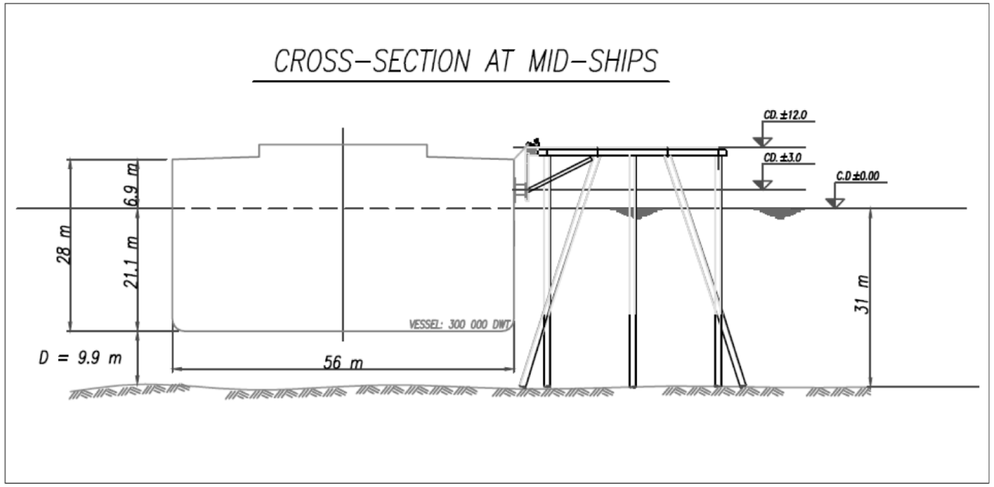
MOORING ARRANGEMENT:

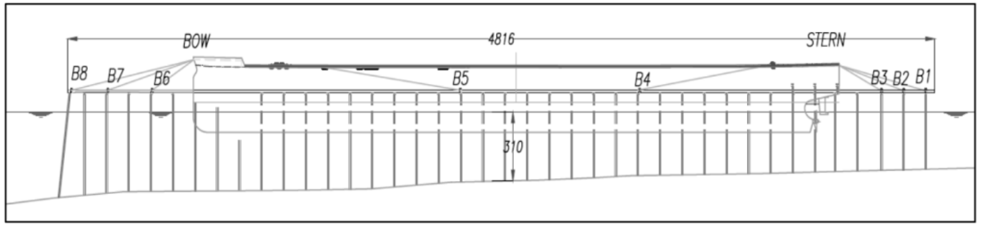
- THREE STERN LINES, ONE AFT SPRING LINE, ONE FORE SPRING LINE, THREE BOW LINES (B1 TO B8)
- FIVE FENDERS (F3 TO F7) – FENDERS F1, F2 AND F8 DO NOT TOUCH THE VESSEL





MOORING ARRANGEMENT (FROM REF.[1])





CROSS-SECTIONS OF VESSEL (FROM REF.[1])

Stellenbosch University (2015)

Uncertain inputs and differences:

- No indication of reference lengths for mooring lines as well as lengths of mooring lines on-board. Furthermore, there was no load-extension curves given for the lines. It was then assumed no length on-board and each "model" line was supposed representative of two wire lines with nylon tails (11m), as per the real life. According to this, stiffness of each mooring line was non-linear in the SIMBAD numerical model.

- No value is given for the pre-tension of each mooring line. It was considered a 10t pre-tension per "model" line.

- No details are also given for the friction between ship model and fender. It was considered no friction of the fenders.

Stellenbosch University (2015)

SIMBAD calculations:

- Ref. [1] gives results of a test using short crested waves. The test used a JONSWAP wave spectrum with a significant wave height of 2.5m, a mean period of 12s and a 20° spreading . The test was about 5h long but no indication of a wave ramp-up time was given. The angle of wave attack was 180° (head on waves).

- The SIMBAD numerical model test was simulated by doing a series of ten tests all using the same force spectra but with different time series. The wave ramp-up time was 400s for a total length of 14400s (4h). Only, long crested head-on waves (no directional spreading) were reproduced with SIMBAD.

- Time series of first-order wave loads were calculated from the PDSTRIP wave loads on the ship together with the JONSWAP spectral wave amplitude at each frequency, according to the FAST random method. Second-order wave loads considered here are the slow-drift loads (MOLIN variant).

- Calculations using SIMBAD are compared with model test results for the moored ship setup described here above. An exact comparison is not possible, due to the uncertain inputs and also because of difference of sea waves reproduced in physical and numerical models.

STELLENBOSCH UNIVERSITY (2015)

Moored ship with wave heading: 180° (head on waves); Hs=2.5m; Tp=12s

PEAK HORIZONTAL MOTIONS AND MOORING LOADS ARE SHOWN IN THE FOLLOWING TABLE AND FIGURES. THE TABLE GIVES THE MINIMUM, MAXIMUM AND MEAN VALUES OBTAINED OVER TEN RUNS WITH DIFFERENT INPUT WAVE PHASING. IN THE FIGURES, ARE SHOWN THE SIMBAD MEAN VALUES COMPARED WITH RESULTS GIVEN IN REF. [1].

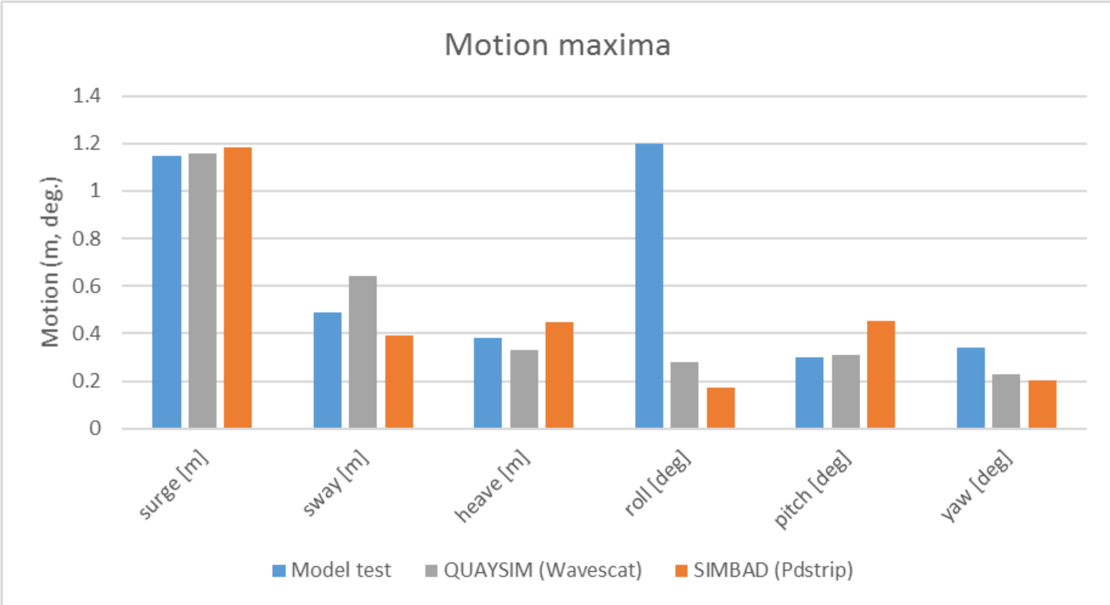
THE MODEL TEST MEASUREMENTS WERE CARRIED OUT WITH TWO TYPES OF MEASUREMENT SYSTEMS:

- THE KEOGRAM MEASUREMENT SYSTEM WAS USED TO RECORD MOORING LINE FORCES, FENDER FORCES AND SHIP MOTIONS
- THE STRAIN GAUGE MEASURING SYSTEM MEASURED PHYSICALLY THE MOORING LINE AND FENDER FORCES

REF. [1] PROVIDES ALSO RESULTS OF CALCULATION WITH QUAYSIM (WAVESCAT)® WHICH ARE ALSO GIVEN IN THE TABLE AND FIGURES

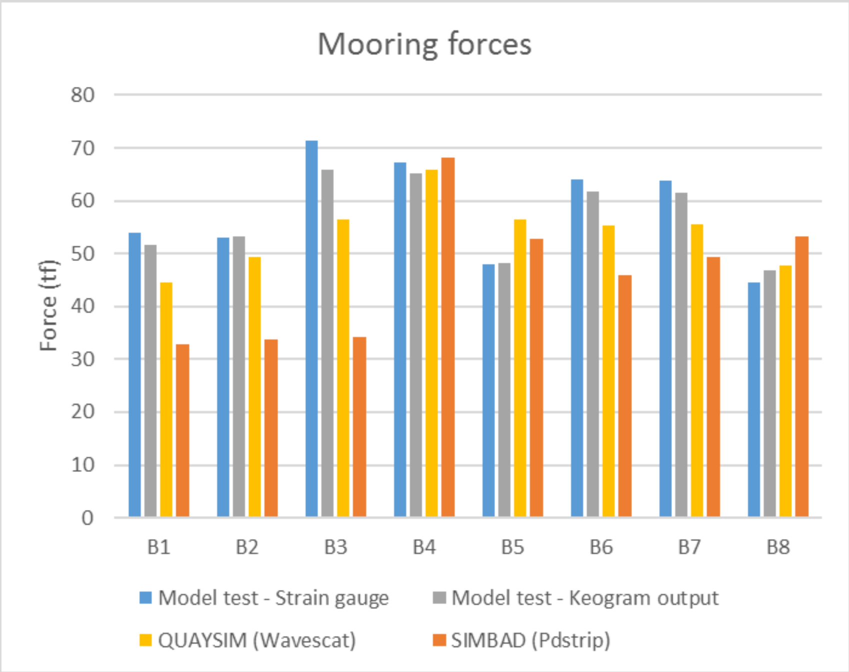
Moored ship with wave heading 180˚ (head on seas): comparison between calculations and model test results from Lerika Susan Eigelaar, Stellenbosch University (2015) (Ref.[1])

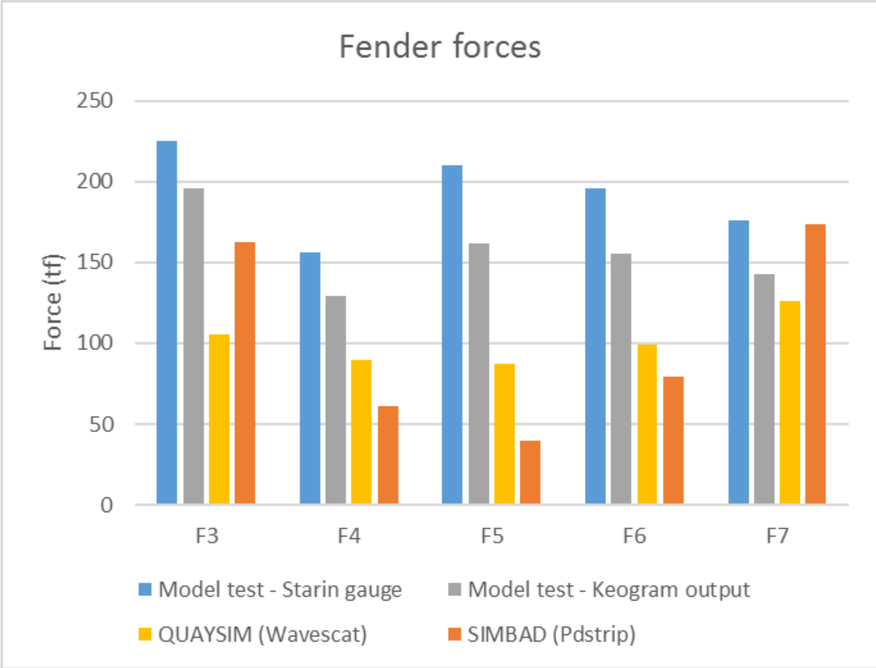
	Model test Hs = 2.5 m - Tp=12s		Numerical model	SIMBAD (2020) With 2nd-order loads (Molin formulation)	SIMBAD (2020) With 2nd-order loads (Molin formulation)	SIMBAD (2020) With 2nd-order loads (Molin formulation)
Solver	Strain Gauge Output	Keogram Output	QUAYSIM (Wavescat)	Min. values	Mean values	Max. values
Ship motions						
surge [m]	-	1.15	1.16	0.92	1.18	1.56
sway [m]	-	0.49	0.64	0.24	0.39	0.56
heave [m]	-	0.38	0.33	0.40	0.45	0.54
roll [deg]	-	1.2	0.28	0.12	0.17	0.22
pitch [deg]	-	0.3	0.31	0.39	0.45	0.58
yaw [deg]	-	0.34	0.23	0.16	0.20	0.33
Mooring line max (tf)						
B1	54	52	44	30	33	38
B2	53	53	49	31	34	39
B3	71	66	56	30	34	39
B4	67	65	66	52	68	96
B5	48	48	56	44	53	73
B6	64	62	55	40	46	58
B7	64	62	56	40	49	67
B8	45	47	48	42	53	74
Fender max (tf)						
F3	225	196	105	131	162	211
F4	156	129	90	49	61	75
F5	210	162	87	33	40	56
F6	196	156	99	69	80	96
F7	176	143	126	134	174	242



Stellenbosch University (2015)

Moored ship with wave heading: 180° (head on waves); Hs=2.5m; Tp=12s

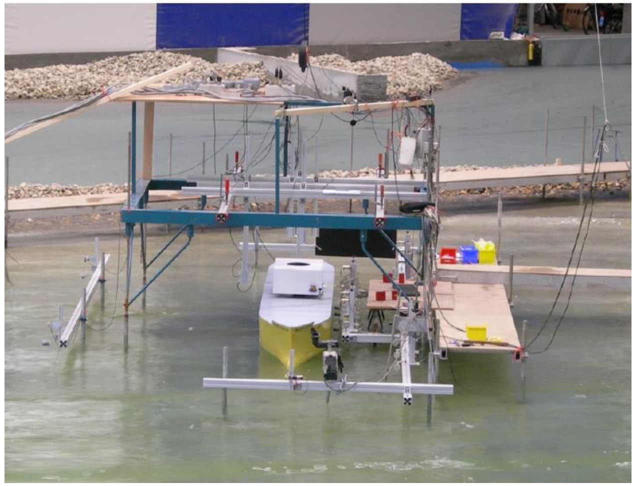


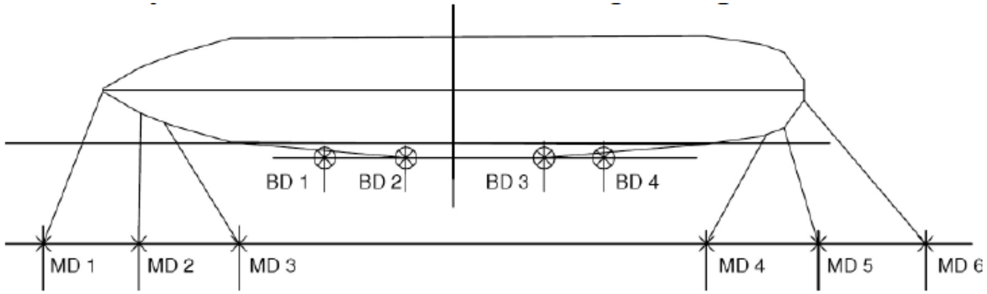


Note:

- ***Peak motions are quite well predicted with SIMBAD, except for the roll motion that seems to be underestimated (also with QUAYSIM)***
- ***Peak mooring line loads are in accordance with measured values for the bow and spring lines. The stern line loads are under-estimated. Use of directionally spreaded waves would have improved the reproduction of stern mooring line loads***
- ***Measured fender loads are within the predicted range for the both outer fenders and under-predicted for the inner fenders***

Deltares - Yemen LNG (2009)





165,000 m3 LNG carrier model at DELTARES laboratory (from ref.[1])

Test case (see details in reference):

- Ballasted 165,000 m3 LNG ship moored on a jetty supported by piles
- Complex bathymetry with water depth of 2.2 to 4.4 times the vessel draught (20-40 m)
- Mooring arrangement (see here above): eight "model lines" (MD1 to MD6; BD2-BD3), each representative of a group of 2 or 3 wire lines with nylon tails and four "model fenders" (BD1 to BD4)
- 10 to 15t pre-tension applied in each "model line" (5t per single line)
- Non-linear stiffness for lines and linear stiffness for fenders
- Directional spreading (short-crested) sea used for moored ship model tests
- Wind included in scale model as constant forces and gusting wind investigated through numerical modelling (TERMSIM® model from MARIN). Dynamic Amplification Factor (DAF) applied, after each test, to all motions and loads

Reference:

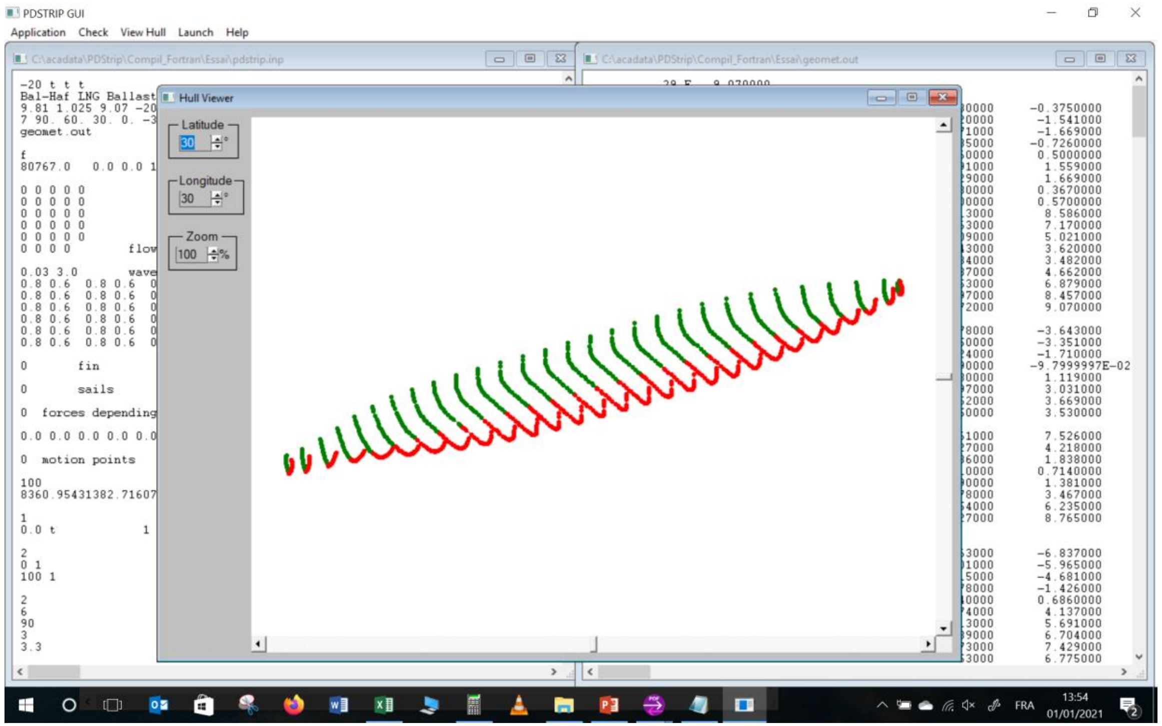
- [1]: Weiler O., Cozijn H., Wijdeven B., Le Guennec S., Capt. Fontaliran F., "Motion and mooring loads on an LNG-carrier moored at a jetty in a complex bathymetry", OMAE2009-79420, 2009

Deltares - Yemen LNG (2009)

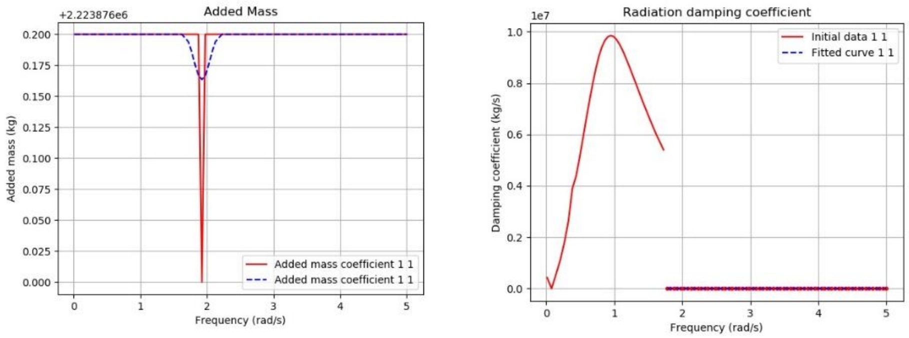
Particulars of the LNG carrier:

- Table hereafter gives original data and data from PDSTRIP schematisation. Small differences are present resulting from uncertainties in the available information and from body plan used for the LNG carrier, taken from an existing one and not from original data
- Frequency range for added mass and damping values, first order wave loads, drift forces: 0.013 – 5.0 rad/s

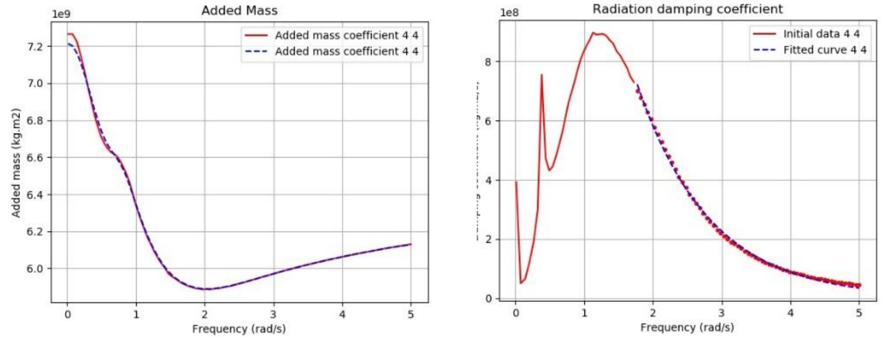
Dimensions of ship		
Ship	Model test	PDSTRIP
Length overall (m)	290	291
Length between perpendiculars (m)	281	281
Beam (m)	46	46
Draught (m)	9.07	9.07
Displacement (m3)	78797	78797
Block coefficient	0.672	0.672
Height of Centre of Gravity KG (m)	18.99	17.63
Longitudinal Centre of Gravity (m)	1.20	1.20
Transverse Metacentric Height GM (m)	4.99	4.99
Roll Radius of Gyration (m)	15.86	15.86
Pitch Radius of Gyration (m)	71.54	71.54
Yaw Radius of Gyration (m)	71.54	71.54
Water depth (m)	40-20	30



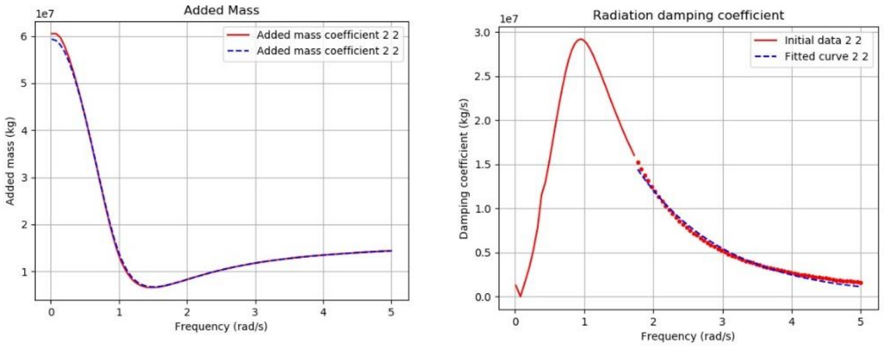
PDSTRIP ADDED MASS AND DAMPING:



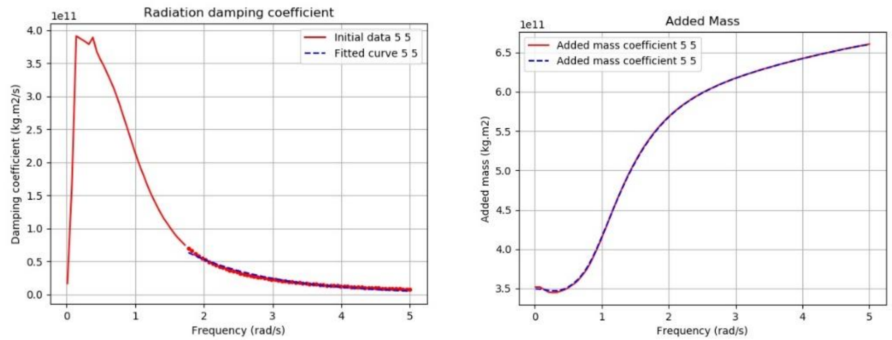
SURGE ADDED MASS AND DAMPING



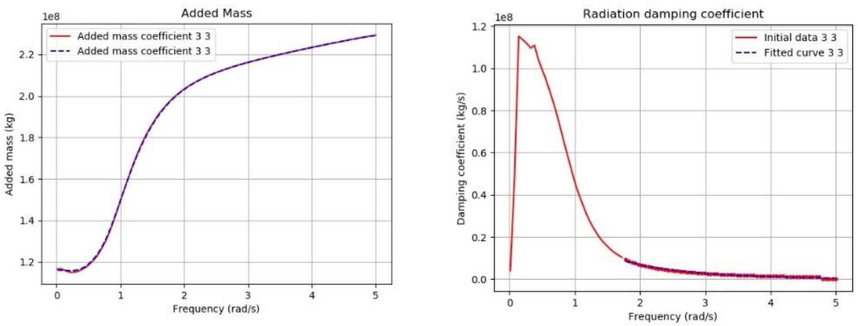
ROLL ADDED MASS AND DAMPING



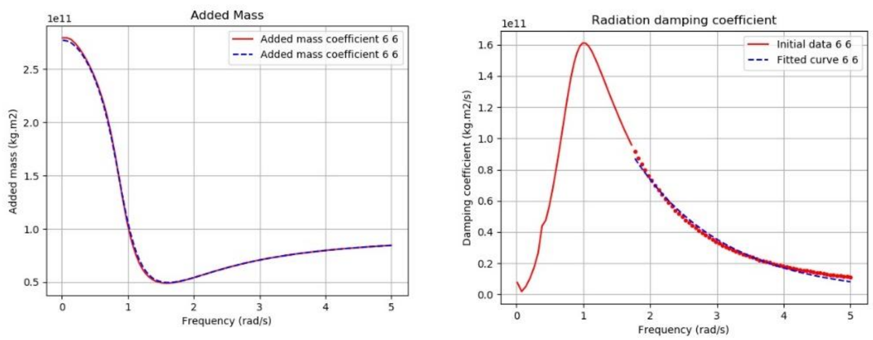
SWAY ADDED MASS AND DAMPING



PITCH ADDED MASS AND DAMPING



HEAVE ADDED MASS AND DAMPING



YAW ADDED MASS AND DAMPING

Deltares - Yemen LNG (2009)

Uncertain inputs and differences:

- All the longitudinal and lateral coordinates of the fairleads and bollards on jetty were not given. They were taken out from the schematic drawing of the mooring arrangement, according to the main particulars given for the LNG carrier.
- Also were undefined the vertical co-ordinates of the bollards on the jetty and dolphins (7.5m above WL used for all lines) and the vertical coordinates of the fenders (5.0 m above water level used).
- No indication of reference lengths for mooring lines as well as lengths of mooring lines on-board. Furthermore, the load-extension curves were given separately for the nylon tails (22m) and the wire lines. It was then assumed no length on-board and a non-linear stiffness was considered for each "model" line, according to the estimated reference length.
- No details are also given for the friction between ship model and fender. It was considered no friction of the fenders.
- Motions are given for the manifold but there were no indication of lateral and vertical coordinates. Typical values for such type of LNG carrier were then considered in SIMBAD numerical model.

Deltares - Yemen LNG (2009)

SIMBAD calculations:

- The scale model test used short crested waves, a JONSWAP wave spectrum with a significant wave height of 3.4m and a peak period of 11s. No indication was given about the duration of test and the wave ramp-up time. The angle of wave attack from the ship was 195° (N210°).
- In the scale model, constant wind loads were also applied during the test. The wind forces were supposed to correspond to 30s gust values applied by a 17m/s wind speed with a 210° angle of attack (N195°).
- The SIMBAD numerical model test was simulated by doing a series of ten tests all using the same wave force spectra but with different time series. The wave ramp-up time was 400s for a total length of 14400s (4h). Only, long crested waves (no directional spreading) were reproduced with SIMBAD.
- Time series of first-order wave loads were calculated from the PDSTRIP wave loads on the ship together with the JONSWAP spectral wave amplitude at each frequency, according to the FAST random method. Second-order wave loads considered here are the “mean-drift” wave loads and not the slow-drift loads (MOLIN variant).
- Time series of wind loads were calculated with a wind speed time-series according to a DAVENPORT spectrum.
- Calculations using SIMBAD are compared with model test results for the moored ship setup described here above. An exact comparison is not possible, due to the uncertain inputs and also because of difference of sea waves and wind loads reproduced in physical and numerical models.

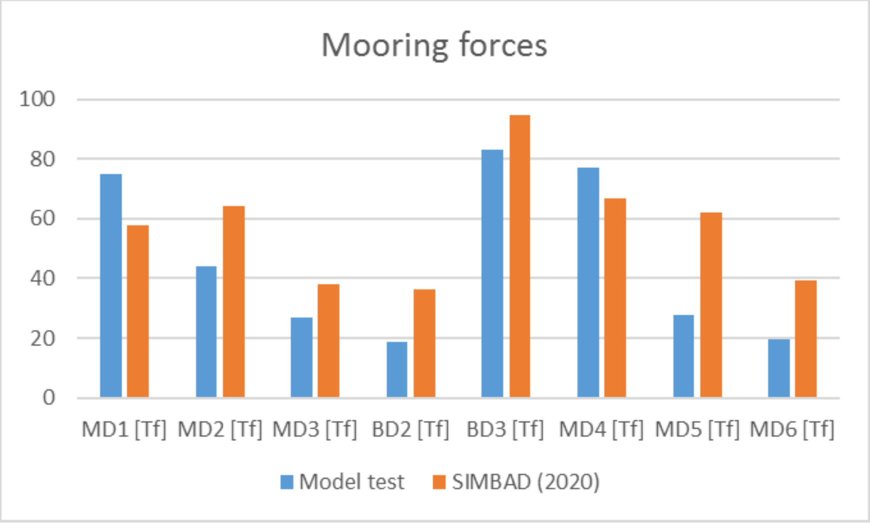
DELTARES - YEMEN LNG (2009)

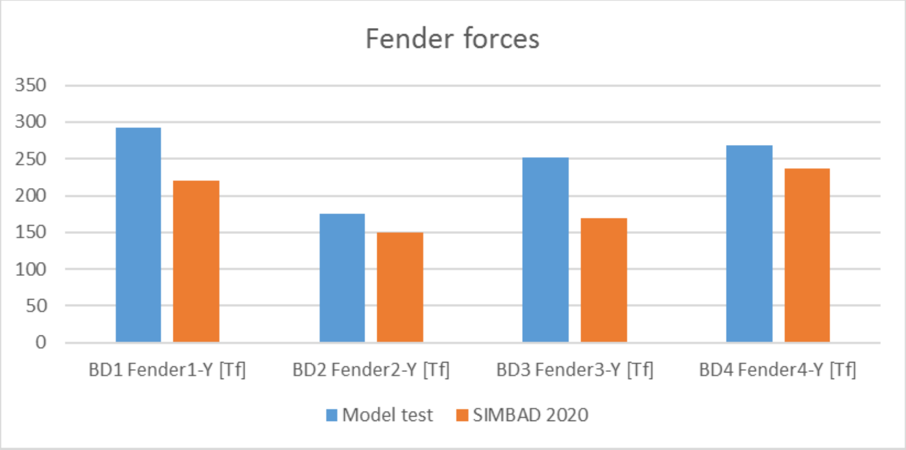
Ballast condition. Moored ship with wave heading wave heading 195˚, Hs 3.4m, Tp 11s. Wind gusts N210° 17m/s

PEAK HORIZONTAL MOTIONS AND MOORING LOADS ARE SHOWN IN THE FOLLOWING TABLE AND FIGURES. THE TABLES GIVE THE MINIMUM, MAXIMUM AND MEAN VALUES OBTAINED OVER TEN RUNS WITH DIFFERENT INPUT WAVE PHASING. IN THE FIGURES, ARE SHOWN THE SIMBAD MEAN VALUES COMPARED WITH SCALE MODEL RESULTS, CORRECTED WITH DAF'S OBTAINED WITH A TERMSIM NUMERICAL SIMULATION

Moored ship with wave heading 195˚ Hs 3.4m Tp 11s, wind gusts N210° 17m/s av.: comparison between calculations and model test results from Deltares (2009)

	Model test	SIMBAD (2020) With "Mean drift" loads Min values	SIMBAD (2020) With "Mean drift" loads Mean values	SIMBAD (2020) With "Mean drift" loads Max values
BD1 Fender1-Y [Tf]	293	203	220	252
BD2 Fender2-Y [Tf]	175	135	149	173
BD3 Fender3-Y [Tf]	252	155	169	186
BD4 Fender4-Y [Tf]	269	209	237	264
MD1 [Tf]	75	50	58	73
MD2 [Tf]	44	57	64	71
MD3 [Tf]	27	35	38	42
BD2 [Tf]	19	29	37	53
BD3 [Tf]	83	75	95	126
MD4 [Tf]	77	54	67	94
MD5 [Tf]	28	54	62	76
MD6 [Tf]	20	33	39	50





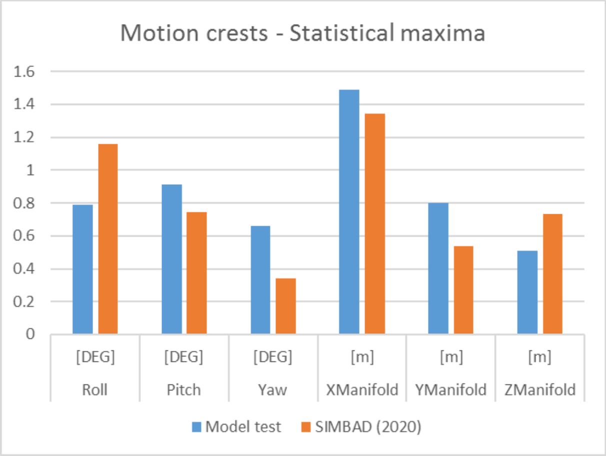
Deltares - Yemen LNG (2009)

Ballast condition. Moored ship with wave heading wave heading 195˚, Hs 3.4m, Tp 11s. Wind gusts N210° 17m/s

PEAK HORIZONTAL MOTIONS AND MOORING LOADS ARE SHOWN IN THE FOLLOWING TABLE AND FIGURES. THE TABLE GIVES THE MINIMUM, MAXIMUM AND MEAN VALUES OBTAINED OVER TEN RUNS WITH DIFFERENT INPUT WAVE PHASING. IN THE FIGURES, ARE SHOWN THE SIMBAD MEAN VALUES COMPARED WITH SCALE MODEL RESULTS, CORRECTED WITH DAF'S OBTAINED WITH A TERMSIM NUMERICAL SIMULATION

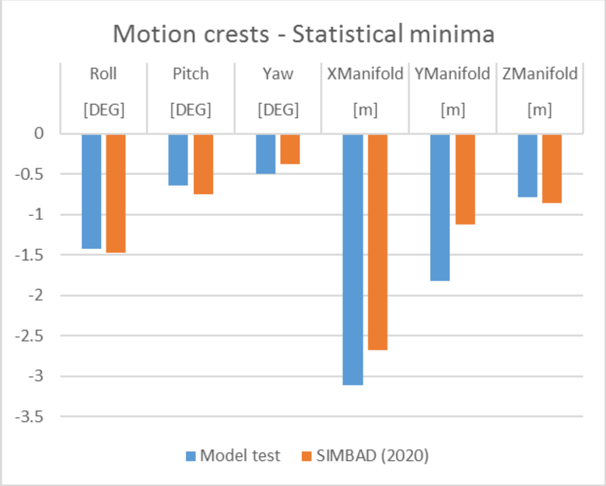
Moored ship with wave heading 210˚ Hs 3.4m Tp 11s, wind gusts N195° 17m/s av.: comparison between calculations and model test results from Deltares

Motion crests Statistical maxima		Model test	SIMBAD (2020) With "Mean drift" loads Min values	SIMBAD (2020) With "Mean drift" loads Mean values	SIMBAD (2020) With "Mean drift" loads Max values
Roll	[DEG]	0.79	1.06	1.16	1.25
Pitch	[DEG]	0.91	0.66	0.74	0.80
Yaw	[DEG]	0.66	0.30	0.34	0.40
XManifold	[m]	1.49	0.92	1.34	1.95
YManifold	[m]	0.8	0.45	0.54	0.65
ZManifold	[m]	0.51	0.66	0.73	0.80



Moored ship with wave heading 210˚ Hs 3.4m Tp 11s, wind gusts N195° 17m/s av.: comparison between calculations and model test results from Deltares

Motion throughs Statistical minima		Model test	SIMBAD (2020) With "Mean drift" loads Min values	SIMBAD (2020) With "Mean drift" loads Mean values	SIMBAD (2020) With "Mean drift" loads Max values
Roll	[DEG]	-1.43	-1.64	-1.48	-1.36
Pitch	[DEG]	-0.64	-0.81	-0.75	-0.70
Yaw	[DEG]	-0.5	-0.42	-0.38	-0.34
XManifold	[m]	-3.11	-3.33	-2.67	-2.27
YManifold	[m]	-1.82	-1.33	-1.12	-0.96
ZManifold	[m]	-0.79	-0.98	-0.87	-0.79

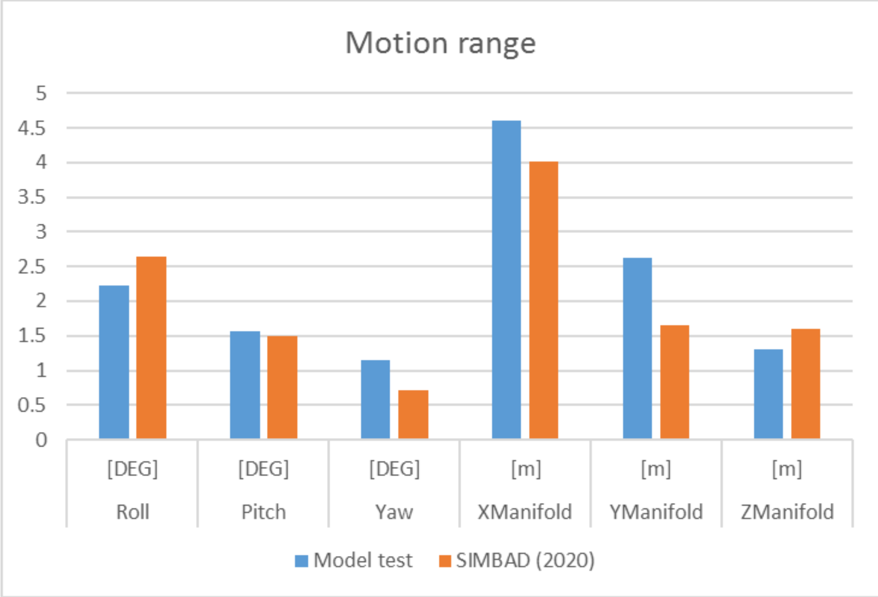


DELTARES - YEMEN LNG (2009)

Ballast condition. Moored ship with wave heading wave heading 195˚, Hs 3.4m, Tp 11s. Wind gusts N210° 17m/s

PEAK HORIZONTAL MOTIONS AND MOORING LOADS ARE SHOWN IN THE FOLLOWING TABLE AND FIGURES. THE TABLE GIVES THE MINIMUM, MAXIMUM AND MEAN VALUES OBTAINED OVER TEN RUNS WITH DIFFERENT INPUT WAVE PHASING. IN THE FIGURES, ARE SHOWN THE SIMBAD MEAN VALUES COMPARED WITH SCALE MODEL RESULTS, CORRECTED WITH DAF'S OBTAINED WITH A TERMSIM NUMERICAL SIMULATION

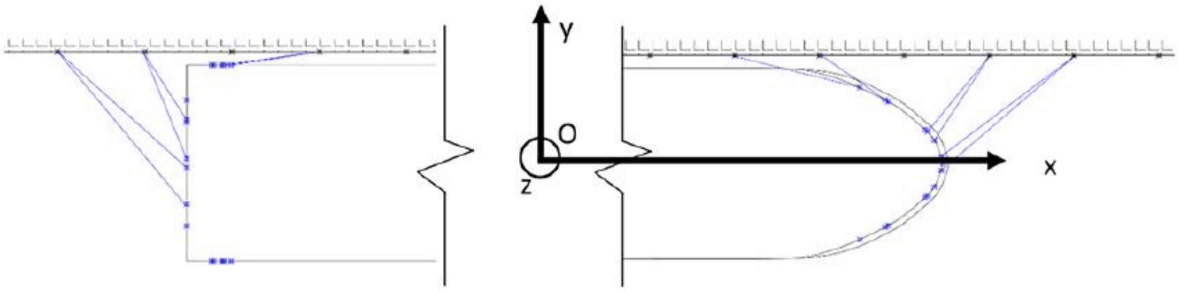
Moored ship with wave heading 210˚ Hs 3.4m Tp 11s, wind gusts N195° 17m/s av.: comparison between calculations and model test results from Deltares					
Motion range		Model test	SIMBAD (2020) With "Mean drift" loads Min values	SIMBAD (2020) With "Mean drift" loads Mean values	SIMBAD (2020) With "Mean drift" loads Max values
Roll	[DEG]	2.22	2.45	2.64	2.89
Pitch	[DEG]	1.56	1.36	1.50	1.59
Yaw	[DEG]	1.15	0.64	0.72	0.79
XManifold	[m]	4.6	3.21	4.01	5.28
YManifold	[m]	2.62	1.45	1.66	1.94
ZManifold	[m]	1.3	1.49	1.60	1.76

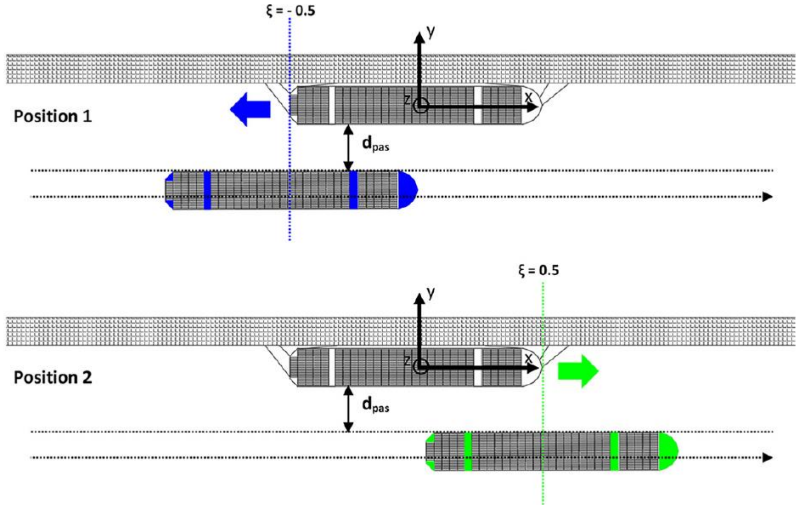


NOTE:

- ***PEAK MOTIONS ARE QUITE WELL PREDICTED WITH SIMBAD, EXCEPT FOR THE LATERAL MOTION THAT SEEMS TO BE UNDERESTIMATED***
- ***PEAK MOORING LINE LOADS ARE IN ACCORDANCE WITH MEASURED VALUES***
- ***MEASURED FENDER LOADS ARE SLIGHTLY UNDER-PREDICTED WITH THE NUMERICAL MODEL***

Ghent University (2019)





13000 TEU container vessel moored at quay (from ref.[1])

Test case (see details in references):

- **Partly loaded 13000 TEU container vessel moored at quay**
- **Water depth of 1.55 times the vessel draught**
- **Mooring arrangement (see here above): twelve lines (2 fore lines, 2 fore breasts, 2 fore and 2 aft springs, 2 aft breasts and 2 aft lines), each representative of a synthetic mooring line and 11 fenders**
- **16t pre-tension applied in each line**
- **Linear stiffness for lines and fenders**
- **No wave, wind and current**
- **Same ship as passing vessel, with different speeds and passing distances**

References:

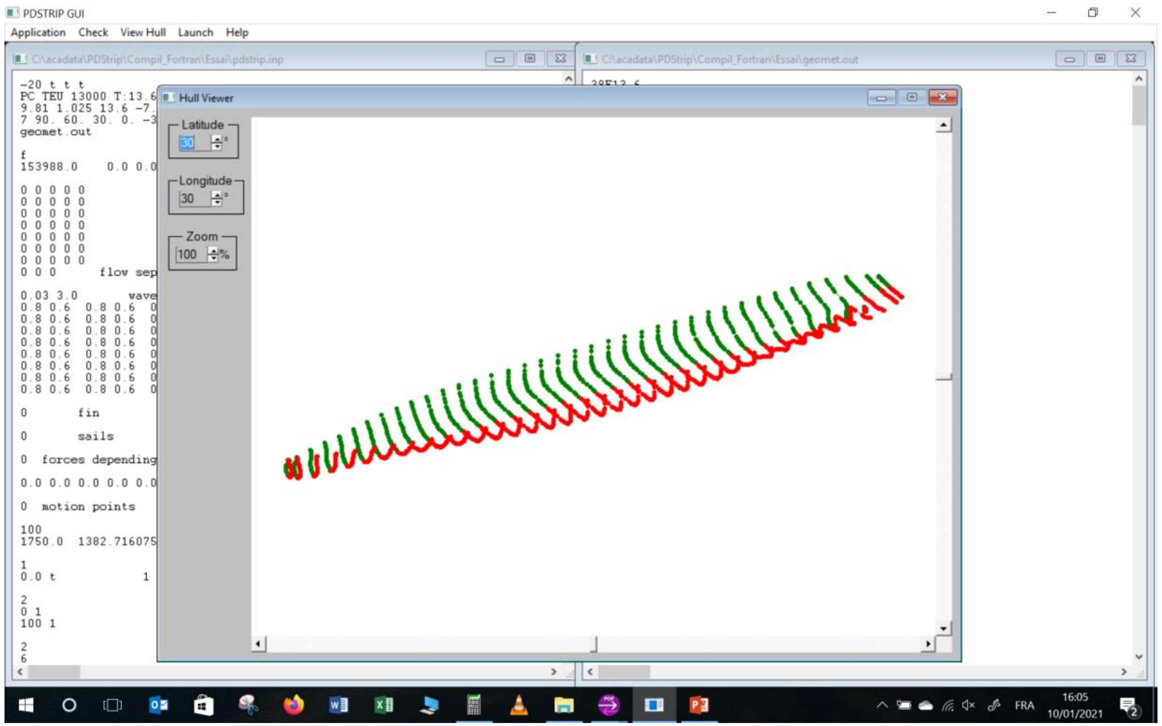
- **[1]: Van Zwijnsvoorde Th., Vantorre M., Eloot K., Ides S., "Safety of container ship (un)loading operations in the Port of Antwerp: Impact of passing shipping traffic", Maritime Business Review Vol.4 N°1, 2019 – DOI: http://dx.doi.org/10.1108/MABR-09-2018-0033**
- **[2]: Van Zwijnsvoorde Th., Vantorre M., Ides S., "Container ships moored at the port of Antwerp: Modelling response to passing vessels", PIANC World Congress Panama City, 2018**
- **[3]: Swiegers P.B., "Calculation of the forces on amoored ship due to a passing container ship", dissertation, Stellenbosch University, 2011**

Ghent University (2019)

Particulars of the container vessel:

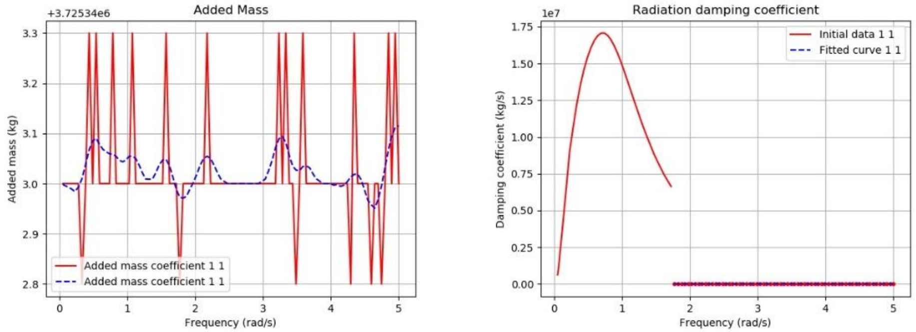
- Table hereafter gives original data and data from PDSTRIP schematisation. The available information about ship's characteristics was scarce and these characteristics were obtained from knowledge about this type of ship, including the used body plan
- Frequency range for added mass and damping values: 0.052 – 5.0 rad/s

Dimensions of ship		
Ship	VLUGMOOR	PDSTRIP
Length overall (m)	366	366
Length between perpendiculars (m)	352	352
Beam (m)	48.2	48.2
Draught (m)	13.6	13.6
Displacement (m3)	?	150232
Block coefficient	?	0.651
Height of Centre of Gravity KG (m)	?	22
Longitudinal Centre of Gravity (m)	?	0.0
Transverse Metacentric Height GM (m)	?	2.04
Roll Radius of Gyration (m)	?	16.9
Pitch Radius of Gyration (m)	?	88
Yaw Radius of Gyration (m)	?	88
Water depth (m)	21.1	21.1

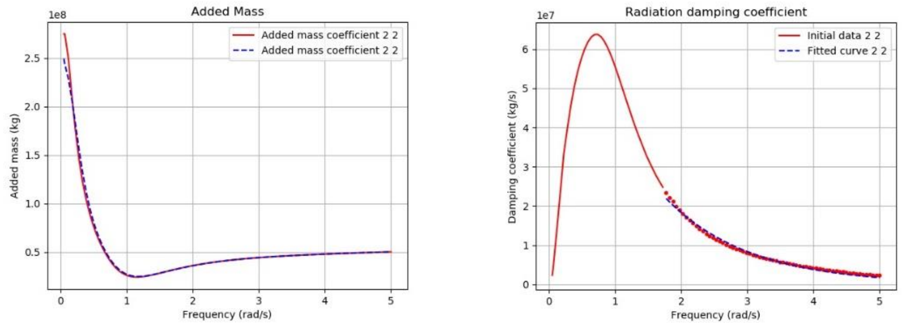


GHENT UNIVERSITY (2019)

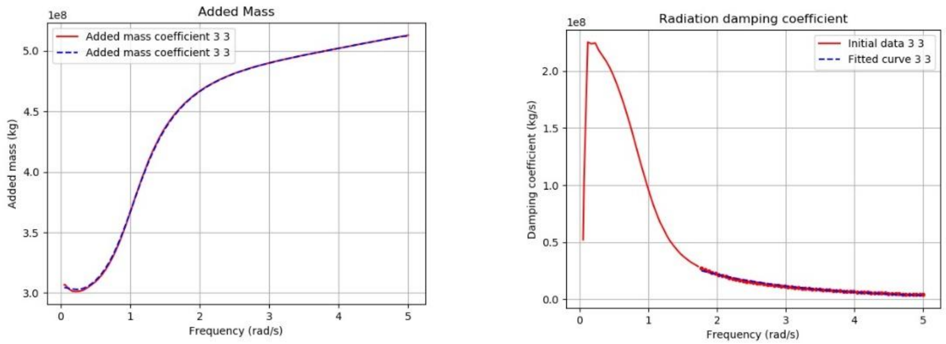
PDSTRIP ADDED MASS AND DAMPING:



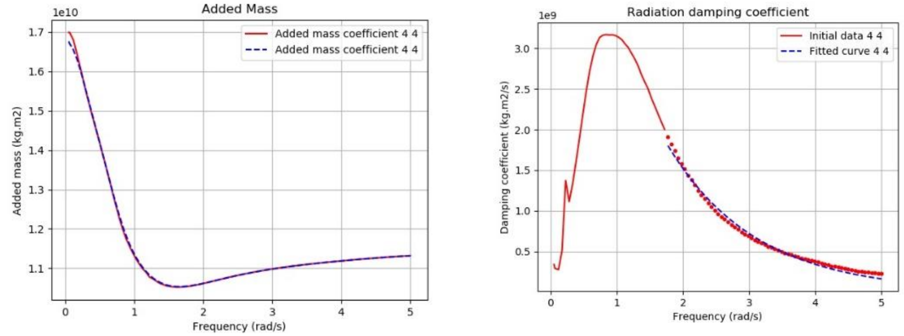
SURGE ADDED MASS AND DAMPING



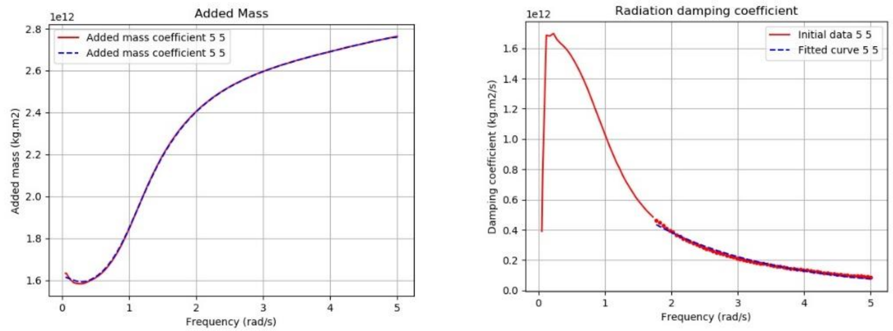
SWAY ADDED MASS AND DAMPING



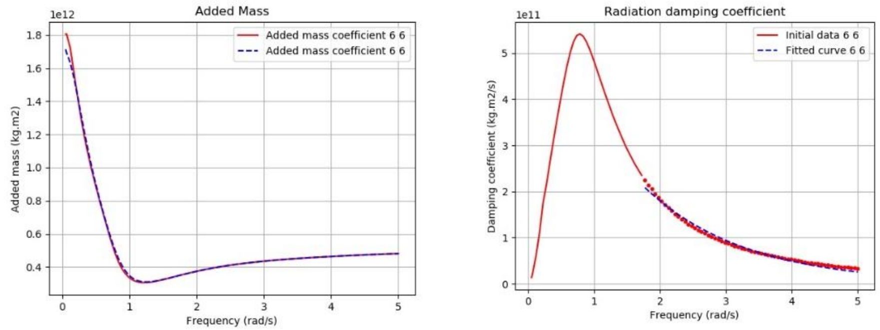
HEAVE ADDED MASS AND DAMPING



ROLL ADDED MASS AND DAMPING



PITCH ADDED MASS AND DAMPING



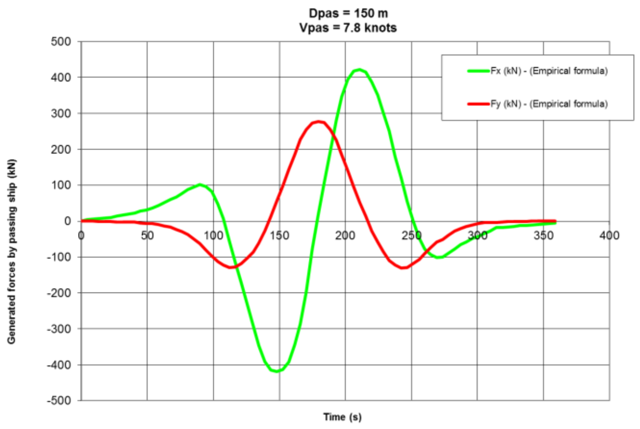
YAW ADDED MASS AND DAMPING

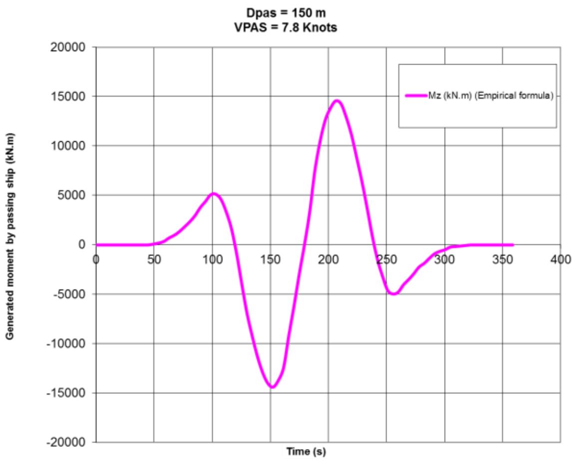
GHENT UNIVERSITY (2019)

UNCERTAIN INPUTS AND DIFFERENCES:

- ALL THE LONGITUDINAL AND LATERAL COORDINATES OF THE FAIRLEADS ON-BOARD AND BOLLARDS AT THE QUAY WERE NOT GIVEN. THEY WERE TAKEN OUT FROM THE SCHEMATIC DRAWING OF THE MOORING ARRANGEMENT, ACCORDING TO THE MAIN PARTICULARS GIVEN FOR THE CONTAINER VESSEL.
- ALSO WERE UNDEFINED THE LEVELS OF THE BOLLARDS AT THE QUAY AND FAIRLEADS ON-BOARD AS WELL AS THE VERTICAL COORDINATES OF THE FENDERS. THE VERTICAL COORDINATES WERE TAKEN FROM REF. [2], AS PER THE CASE C1-C3. DUE TO THE PRESENCE OF A HIGHER FORECASTLE DECK, THE FORE LINES ARE STEEPER THAN THE AFT LINES.
- NO INDICATION OF REFERENCE LENGTHS FOR MOORING LINES AS WELL AS LENGTHS OF MOORING LINES ON-BOARD. IT WAS THEN ASSUMED NO LENGTH ON-BOARD.
- THE FORCES GENERATED ON THE MOORED VESSEL IN SIMBAD NUMERICAL MODEL WERE ASSESSED BY USING EMPIRICAL FORMULA (SEE REF. [3]), AS IN REF. [1], THE NUMERICAL PACKAGE ROPES (RESULT OF THE ROPES JIP PROJECT) WAS USED TO MODEL THESE FORCES.

EXAMPLE OF GENERATED FORCES INDUCED BY PASSING SHIP, USED WITH SIMBAD NUMERICAL MODEL

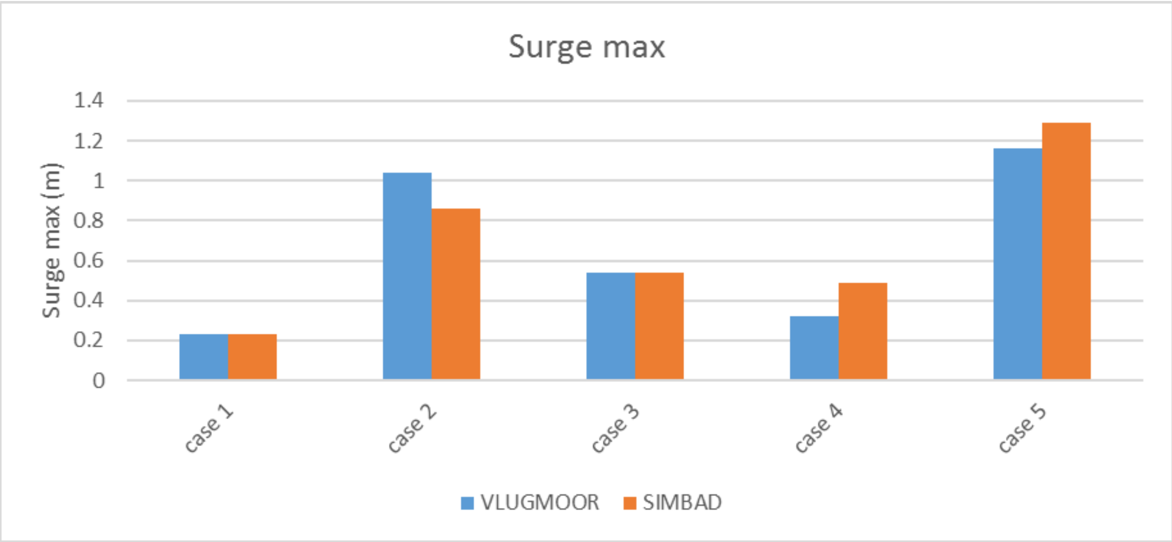




GHENT UNIVERSITY (2019)

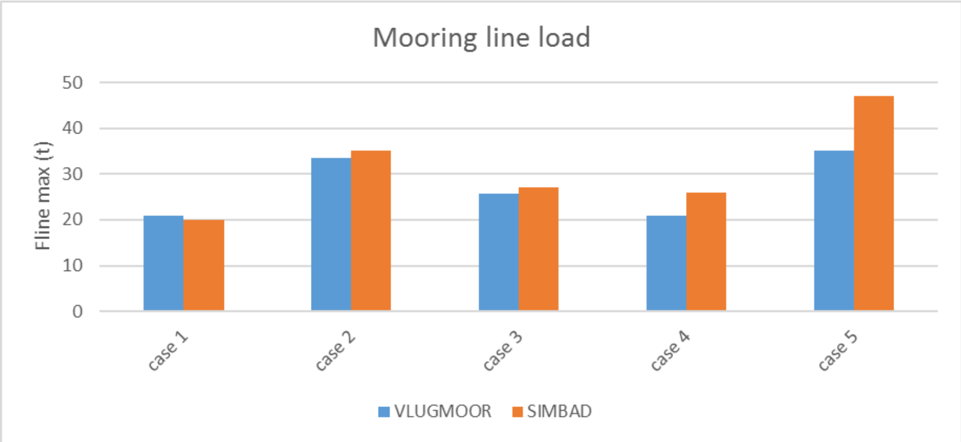
PEAK HORIZONTAL MOTIONS, MOORING AND FENDER LOADS ARE SHOWN IN THE FOLLOWING TABLE AND FIGURES. IN THE TABLE AND FIGURES, ARE SHOWN THE SIMBAD PEAK VALUES COMPARED WITH VLUGMOOR® NUMERICAL MODEL RESULTS (CF. REF. [1]).

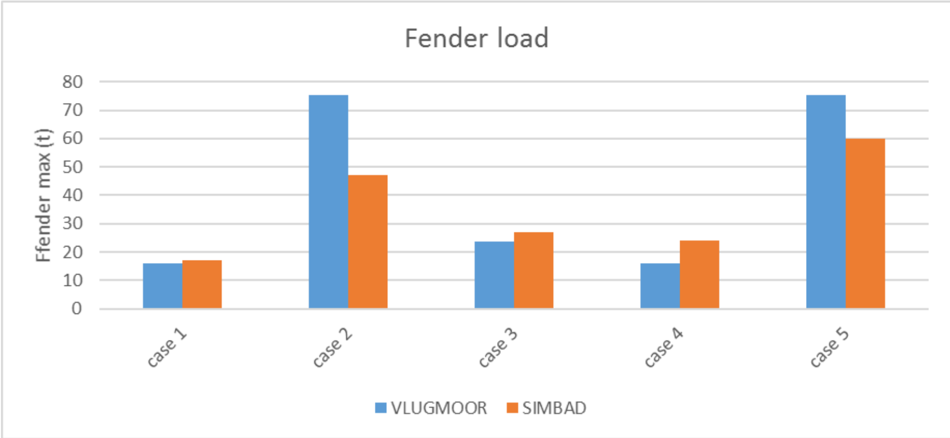
Modelling response to passing vessels - Comparison with Ghent's University modelling results										
	VLUGMOOR (2019)	SIMBAD (2020)	VLUGMOOR (2019)	SIMBAD (2020)	VLUGMOOR (2019)	SIMBAD (2020)	VLUGMOOR (2019)	SIMBAD (2020)	VLUGMOOR (2019)	SIMBAD (2020)
Vpas (knots)	5.8	5.8	7.8	7.8	7.8	7.8	7.8	7.8	9.7	9.7
Dpas (m)	150	150	100	100	150	150	200	200	150	150
Ship motions										
surge [m]	0.23	0.23	1.04	0.86	0.54	0.54	0.32	0.49	1.16	1.29
sway [m]	0	0.04	0.07	0.04	0	0.04	0	0.04	0.06	0.05
Mooring line max (t)										
Fline (t)	21	20	34	35	26	27	21	26	35	47
Fender max (t)										
Ffender(t)	16	17	75	47	24	27	16	24	75	60



GHENT UNIVERSITY (2019)

PEAK HORIZONTAL MOTIONS, MOORING AND FENDER LOADS ARE SHOWN IN THE FOLLOWING TABLE AND FIGURES. IN THE TABLE AND FIGURES, ARE SHOWN THE SIMBAD PEAK VALUES COMPARED WITH VLUGMOOR NUMERICAL MODEL RESULTS (CF. REF. [1]).

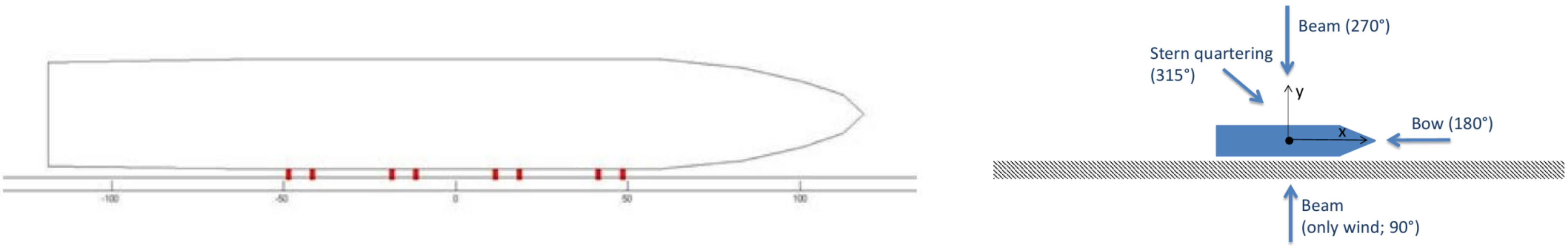




NOTE: IN COMPARISON WITH VLUGMOOR NUMERICAL MODEL RESULTS:

- ***PEAK MOTIONS ARE QUITE WELL PREDICTED WITH SIMBAD***
- ***PEAK MOORING LINE LOADS ARE ALSO IN AGREEMENT WITH VLUGMOOR RESULTS***
- ***PEAK FENDER LOADS ARE SLIGHTLY UNDER-PREDICTED WITH SIMBAD NUMERICAL MODEL***
- ***EVEN IF THE SIMBAD RESULTS WOULD HAVE BEEN IMPROVED BY USING INPUT (FORCES GENERATED BY PASSING SHIP) FROM A NUMERICAL PACKAGE AS PER VLUGMOOR, INSTEAD OF USING EMPIRICAL FORMULA, THE RESULTS OBTAINED FOR THE TWO MODELS ARE QUITE IN GOOD AGREEMENT***

Royal Haskoning DHV (2014)



3000 TEU container vessel moored at quay with specific connections (Moormaster®) (from ref.[1])

Test case (see details in references):

- **Partly loaded 3000 TEU container vessel moored at quay**
- **Water depth not known (assumed 2 times the vessel draught)**
- **Mooring arrangement (see hereafter): specific connection units (four pairs of Moormaster® 200) and ten Supercone® fenders**
- **No pre-tension**
- **Non-linear stiffness for fenders**
- **Wave conditions simulated as short wind generated waves, together with gusty winds**

References:

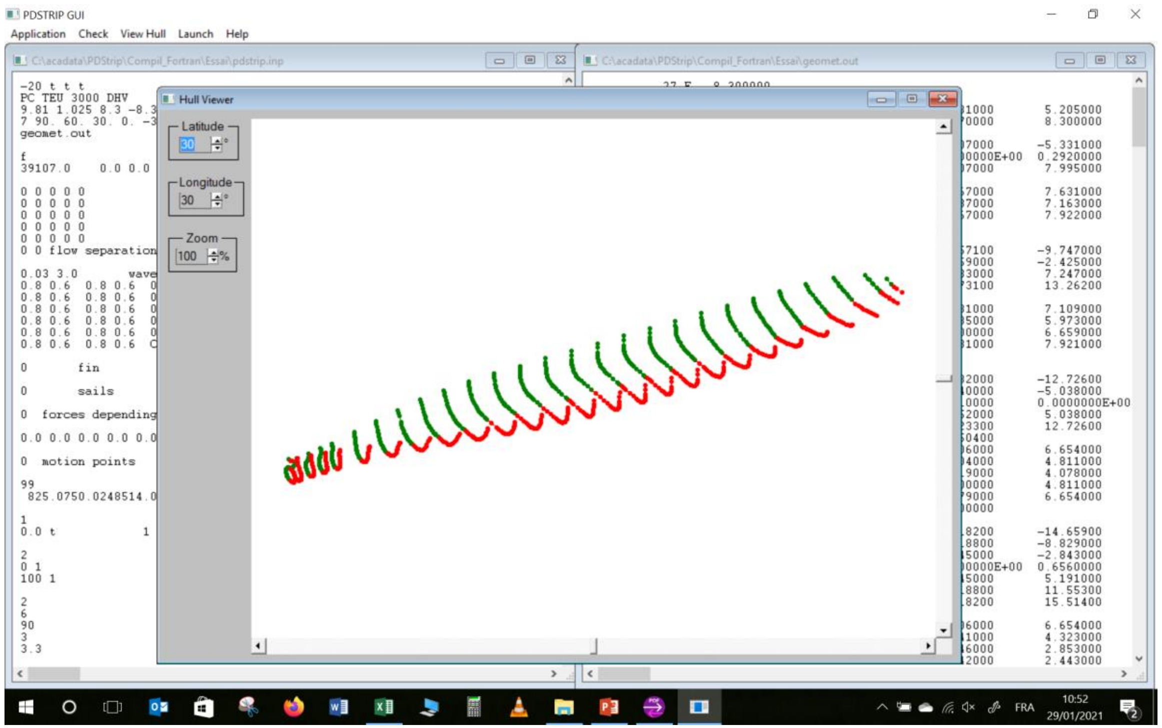
- **[1]: Van Deyzen A.F.J., Van Der Lem J.C., Beimers P.B., De Bont J.A.M., "The effect of active motion dampening systems on the behaviour of moored ship", PIANC World Congress San Francisco, 2014**
- **[2]: Penders M.J.J., "The suitability of the Moormaster® system for inland shipping – considering quay side mooring in the Amsterdam Rijnkanaal under the influence of passing ships", TUDELFT, 2016**

ROYAL HASKONING DHV (2014)

PARTICULARS OF THE CONTAINER VESSEL:

- TABLE HEREAFTER GIVES ORIGINAL DATA AND DATA FROM PDSTRIP SCHEMATISATION. THE AVAILABLE INFORMATION ABOUT SHIP'S CHARACTERISTICS WAS SCARCE AND THESE CHARACTERISTICS WERE OBTAINED FROM KNOWLEDGE ABOUT THIS TYPE OF SHIP, INCLUDING THE USED BODY PLAN
- FREQUENCY RANGE FOR ADDED MASS AND DAMPING VALUES: 0.097 – 5.0 RAD/S

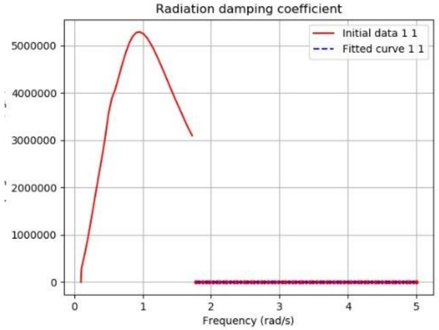
Dimensions of ship		
Ship	Model test	PDSTRIP
Length overall (m)	237	236.5
Length between perpendiculars (m)	225.8	225.8
Beam (m)	31.9	31.9
Draught (m)	8.3	8.3
Displacement (m3)	34015	38153
Block coefficient	0.569	0.638
Height of Centre of Gravity KG (m)	?	12.0
Longitudinal Centre of Gravity (m)	?	0.00
Transverse Metacentric Height GM (m)	?	4.54
Roll Radius of Gyration (m)	?	11.16
Pitch Radius of Gyration (m)	?	56.45
Yaw Radius of Gyration (m)	?	56.45
Water depth (m)	?	16.6



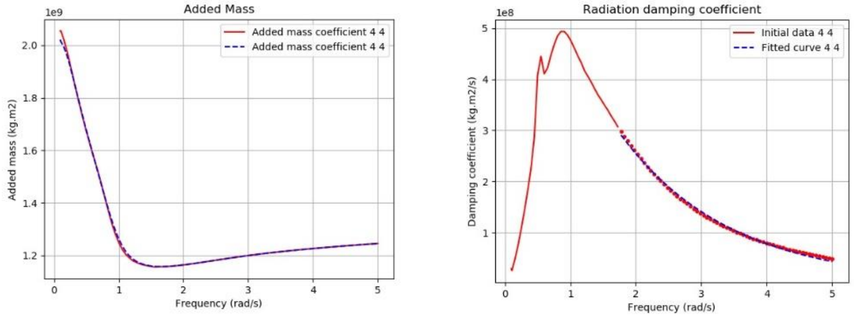
Royal Haskoning DHV (2014)

PDSTRIP added mass and damping:

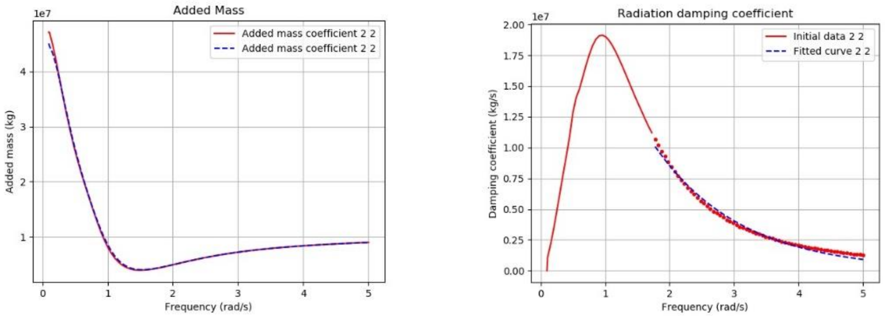
Surge added mass small; not representative



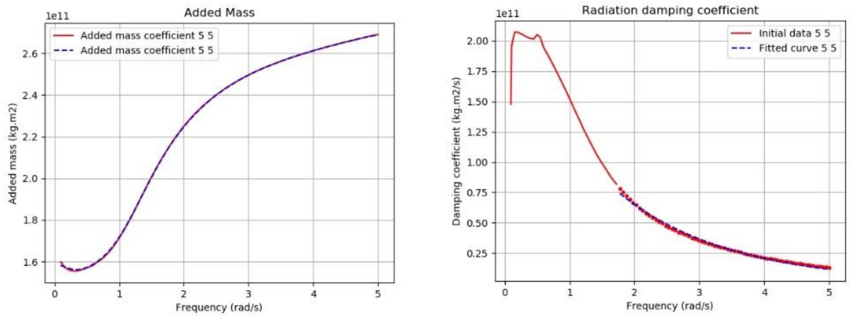
Surge added mass and damping



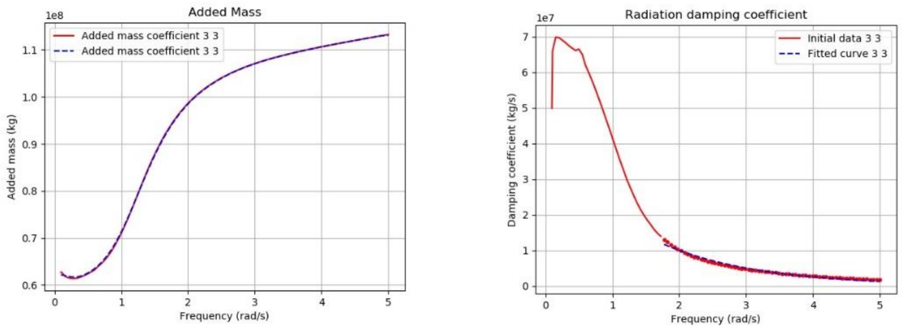
Roll added mass and damping



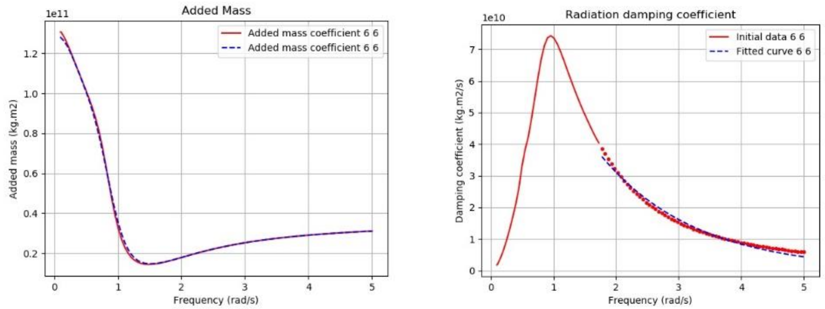
Sway added mass and damping



Pitch added mass and damping



Heave added mass and damping



Yaw added mass and damping

Royal Haskoning DHV (2014)

Uncertain inputs and differences:

- All the longitudinal, lateral and vertical coordinates of the connection units and fenders at the quay were not given. They were taken out from the schematic drawing of the mooring arrangement, according to the main particulars given for the container vessel.
- The model of the specific connections (Moormaster® units) to determine the applied forces is not given in Ref.[1]. Ref. [2] gives some details about the system and the applied forces acting on the ship that result in a certain offset from the neutral position of each unit. Each unit responds to the error in displacement (x and y directions) with a reaction force with the aim of getting the unit, and thus the ship, back in the neutral position. The model of the units is written to calculate the angle and magnitude of this reaction force. The error in displacement is run through a PID controller. The control value and the angle, defining the maximum force, are used to determine the maximum force.
- The PID regulator, defining the control value, depends on different parameters: a proportional part, a differentiate part and an integrate part. The coefficients define the rate and speed of change of reaction force. These coefficients are not known and mean values were taken for the present SIMBAD simulation, except for the integral control that was left out in the model. In any case, to prevent the forces larger than the maximum force, the control variable has a maximum of 1.
- In Ref.[1], 8 units were mobilized and installed in pairs, each pair being allocated to execute a force in either surge and sway force. The 2 outermost pairs were allocated to exert a sway force (2 x 230 kN per pair) and the 2 pairs around midships a surge force (2 x 100 kN per pair). It is not indicated in Ref.[1] if there is a possible switch of units from one axis to the other, in case that the units devoted to this particular axis approach their maximum load and the units controlling the other axis are below a certain level of their maximum load. In the present SIMBAD simulation, there was no allocated axis control and all units were able to control surge and sway simultaneously, according to the offset angle.

Royal Haskoning DHV (2014)

SIMBAD calculations:

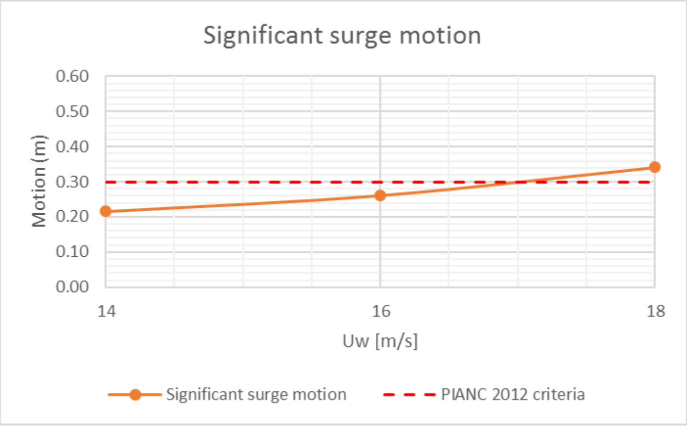
- The Ref. [1] simulated wave conditions as short wind generated waves. The wave parameters were determined by wind fetch calculations. For each combination of wind speed and direction, a significant wave height, peak period and direction were determined based on the available fetch. The wave spectrum used in the simulations was a JONSWAP wave spectrum. The wave directions were: bow waves (180° wind direction), beam waves (270° wind direction) and stern quartering waves (315° wind direction). No indication was given about the duration of test and the wave ramp-up time.
- Wind loads were also applied together with the wave conditions. It was assumed to be gusty wind but the wind spectrum was not indicated in Ref.[1].
- The SIMBAD numerical model test was simulated by doing only one test for each wind and wave condition. The wave ramp-up time was 400s for a total length of 14400s (4h). Only, long crested waves (no directional spreading) were reproduced with SIMBAD.
- Time series of first-order wave loads were calculated from the PDSTRIP wave loads on the ship together with the JONSWAP spectral wave amplitude at each frequency, according to the FAST random method. Second-order wave loads were introduced, as slow-drift loads (MOLIN variant).
- Time series of wind loads were calculated with a wind speed time-series according to a DAVENPORT spectrum.
- Calculations using SIMBAD are compared with DMA® numerical modelling results for the moored ship setup described here above. An exact comparison is not possible, due to the uncertain inputs (especially uncertainties related to control regulation) and also because of difference of sea waves and wind loads reproduced in the both numerical models.

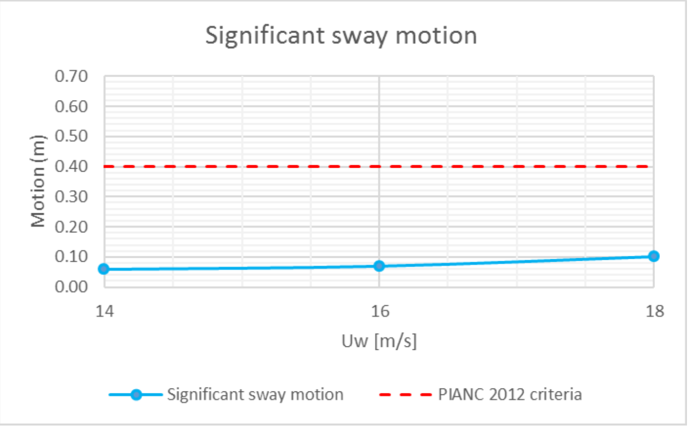
ROYAL HASKONING DHV (2014)

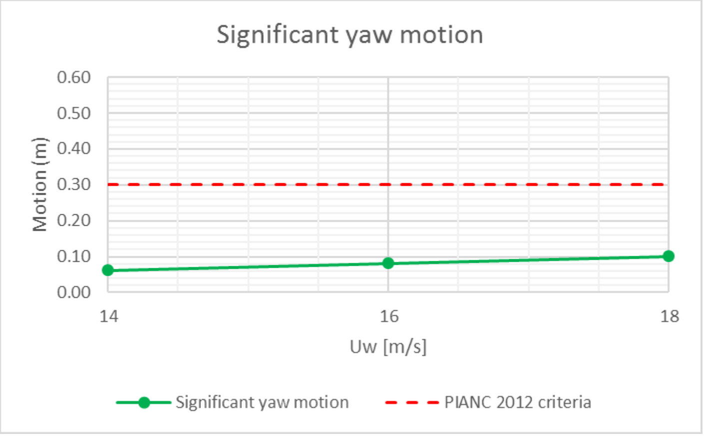
Bow wind and waves

THE FOLLOWING TABLE AND FIGURES SHOW THE SIGNIFICANT AND MAXIMUM SURGE, SWAY AND YAW MOTIONS FOR INCREASING WIND SPEEDS IN BOW WIND AND WAVES. FOR THE SIGNIFICANT AND MAXIMUM MOTIONS, THE PIANC 2012 MOTION CRITERIA AND MAXIMUM ALLOWABLE OUTREACHES FOR THE UNITS, ACCORDING TO REF.[1] (-/+ 0.40 M FOR SURGE; -/+1.1M FOR SWAY) HAVE BEEN ALSO PLOTTED.

Moored ship with bow wind and waves			
	SIMBAD (2020) With 2nd-order loads (Molin formulation)	SIMBAD (2020) With 2nd-order loads (Molin formulation)	SIMBAD (2020) With 2nd-order loads (Molin formulation)
Solver	Pdstrip	Pdstrip	Pdstrip
Wave	Hs:1.5m; Tp:5.8s	Hs:1.8m; Tp:6s	Hs:2.1m; Tp:6.5s
Uw [m/s]	14	16	18
Significant ship motions			
surge [m]	0.21	0.26	0.34
sway [m]	0.06	0.07	0.10
heave [m]	0.03	0.04	0.06
roll [deg]	0.09	0.15	0.26
pitch [deg]	0.05	0.07	0.11
yaw [deg]	0.06	0.08	0.10
Maximum ship motions			
surge [m]	0.29	0.37	0.47
sway [m]	0.11	0.14	0.18
heave [m]	0.04	0.07	0.13
roll [deg]	0.21	0.31	0.49
pitch [deg]	0.10	0.15	0.21
yaw [deg]	0.13	0.17	0.23
Mooring line max (tf)			
M1	16.2	20	20
M2	15.9	19	20
M3	16.0	19	22
M4	22.5	23	29
Fender max (tf)			
F1	36	42	63
F10	40	45	60



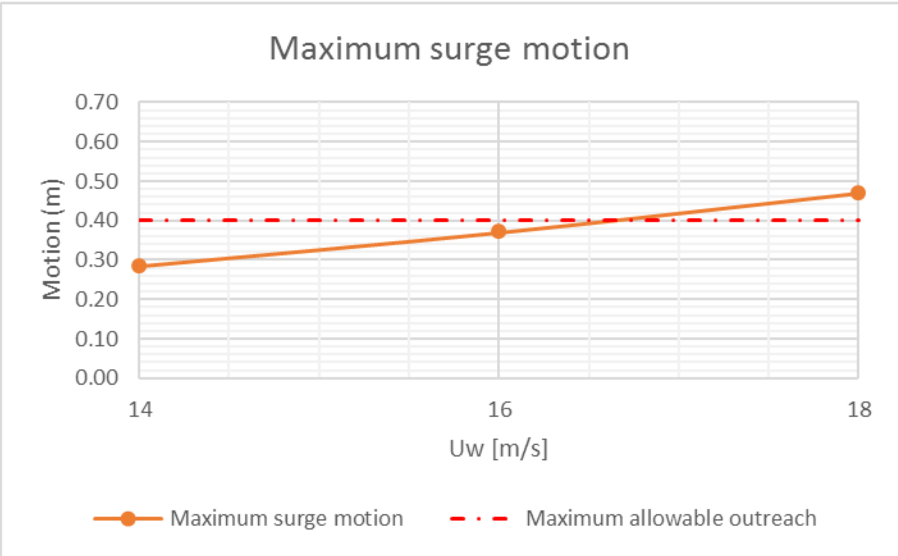


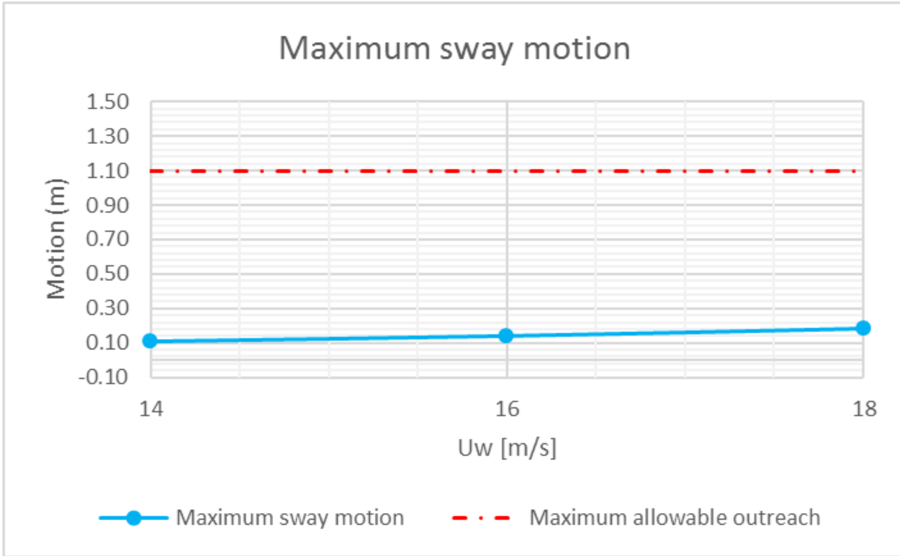


Royal Haskoning DHV (2014)

Bow wind and waves

The following table and figures show the significant and maximum surge, sway and yaw motions for increasing wind speeds in bow wind and waves. For the significant and maximum motions, the PIANC 2012 motion criteria and maximum allowable outreaches for the units, according to Ref.[1] (-/+ 0.40 m for surge; -/+1.1m for sway) have been also plotted.





Note:

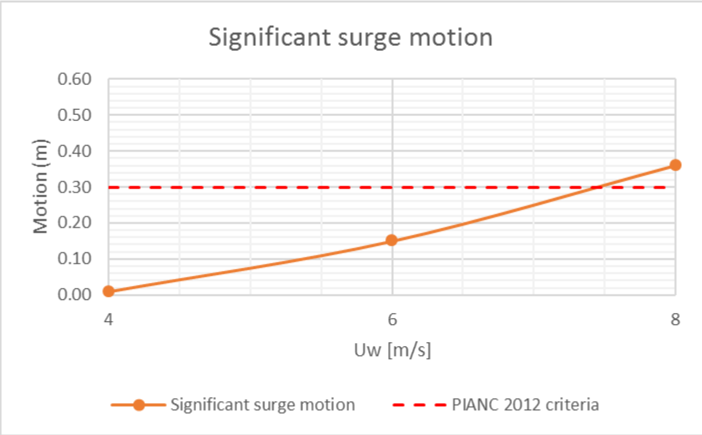
- ***In Ref.[1], for this moored ship configuration, the mooring was safe up to 14 m/s wind speed and wave conditions. With the present SIMBAD simulation, this configuration of specific connections could be applied up to 16m/s wind speed and wave conditions. This difference could be attributed to the uncertainties and differences in the modelling of parameters and more precisely in control regulation modelling.***

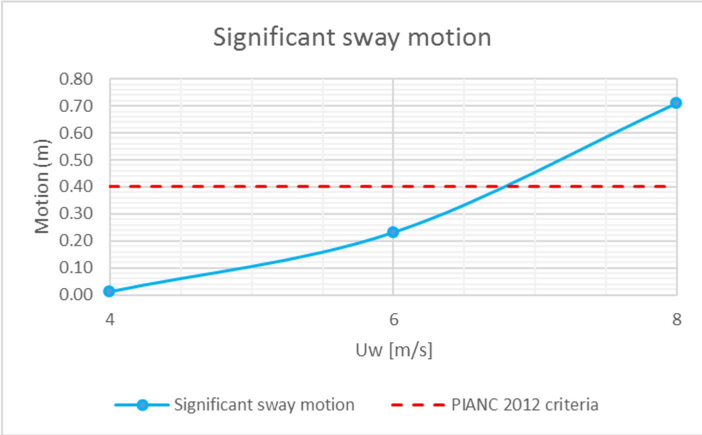
ROYAL HASKONING DHV (2014)

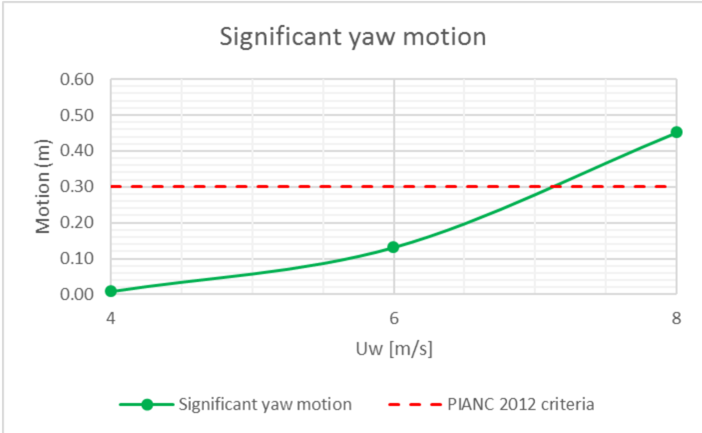
Beam wind and waves

THE FOLLOWING TABLE AND FIGURES SHOW THE SIGNIFICANT AND MAXIMUM SURGE, SWAY AND YAW MOTIONS FOR INCREASING WIND SPEEDS IN BEAM WIND AND WAVES. FOR THE SIGNIFICANT AND MAXIMUM MOTIONS, THE PIANC 2012 MOTION CRITERIA AND MAXIMUM ALLOWABLE OUTREACHES FOR THE UNITS, ACCORDING TO REF.[1] (-/+ 0.40 M FOR SURGE; -/+1.1M FOR SWAY) HAVE BEEN ALSO PLOTTED.

Moored ship with beam wind and waves			
	SIMBAD (2020) With 2nd-order loads (Molin formulation)	SIMBAD (2020) With 2nd-order loads (Molin formulation)	SIMBAD (2020) With 2nd-order loads (Molin formulation)
Solver	Pdstrip	Pdstrip	Pdstrip
Wave	Hs:0.35m; Tp:3.2s	Hs:0.85m; Tp:5s	Hs:1.3m; Tp:5.85s
Uw [m/s]	4	6	8
Significant ship motions			
surge [m]	0.01	0.15	0.36
sway [m]	0.01	0.23	0.71
heave [m]	0.00	0.42	0.26
roll [deg]	0.05	0.41	0.87
pitch [deg]	0.00	0.03	0.07
yaw [deg]	0.01	0.13	0.45
Maximum ship motions			
surge [m]	0.02	0.30	0.76
sway [m]	0.03	0.56	1.52
heave [m]	0.01	0.18	0.55
roll [deg]	0.09	0.89	1.93
pitch [deg]	0.00	0.06	0.12
yaw [deg]	0.02	0.37	1.10
Mooring line max (tf)			
M1	5.6	47	47
M2	4.5	47	47
M3	3.8	47	47
M4	3.1	47	47
Fender max (tf)			
F1	20	188	303
F10	11	178	305



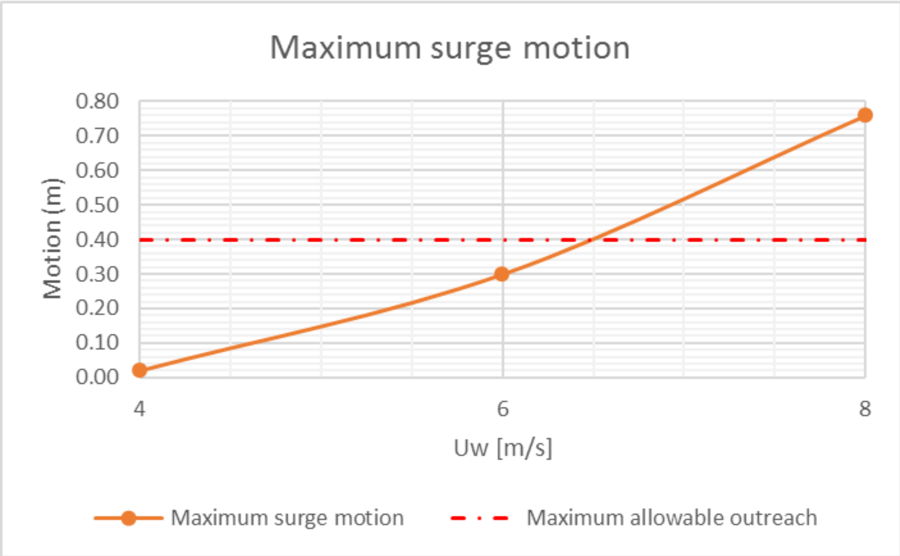


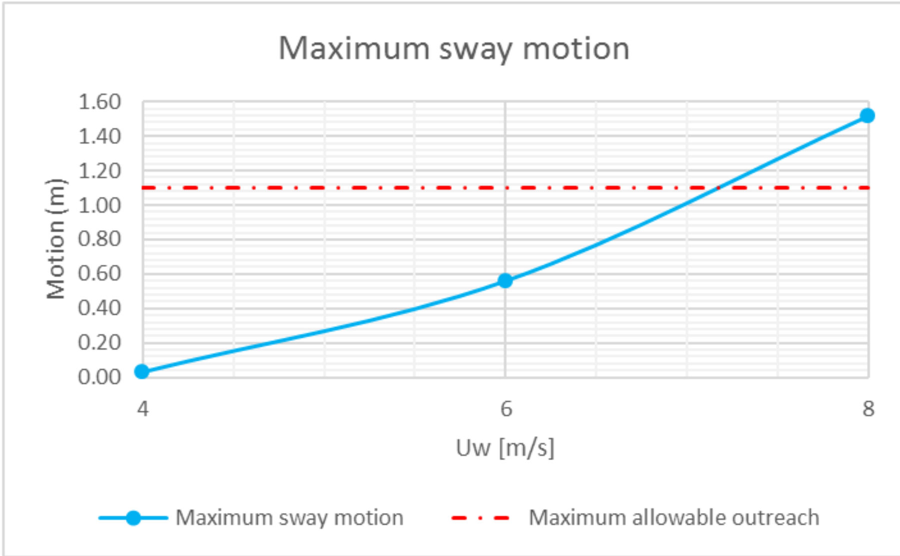


Royal Haskoning DHV (2014)

Beam wind and waves

THE FOLLOWING TABLE AND FIGURES SHOW THE SIGNIFICANT AND MAXIMUM SURGE, SWAY AND YAW MOTIONS FOR INCREASING WIND SPEEDS IN BOW WIND AND WAVES. FOR THE SIGNIFICANT AND MAXIMUM MOTIONS, THE PIANC 2012 MOTION CRITERIA AND MAXIMUM ALLOWABLE OUTREACHES FOR THE UNITS, ACCORDING TO REF.[1] (-/+ 0.40 M FOR SURGE; -/+1.1M FOR SWAY) HAVE BEEN ALSO PLOTTED.





NOTE:

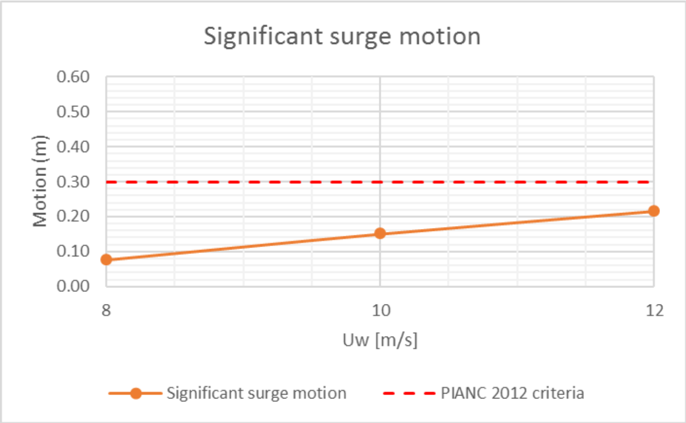
- ***AS IN REF.[1], FOR THIS MOORED SHIP CONFIGURATION, THE MOORING WAS SAFE UP TO 6 M/S WIND SPEED AND WAVE CONDITIONS.***

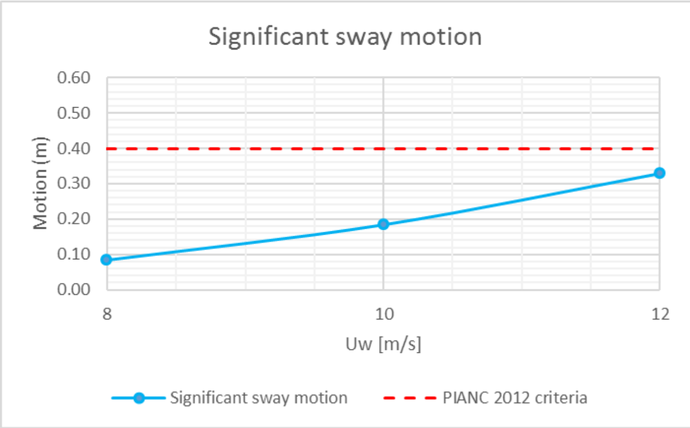
ROYAL HASKONING DHV (2014)

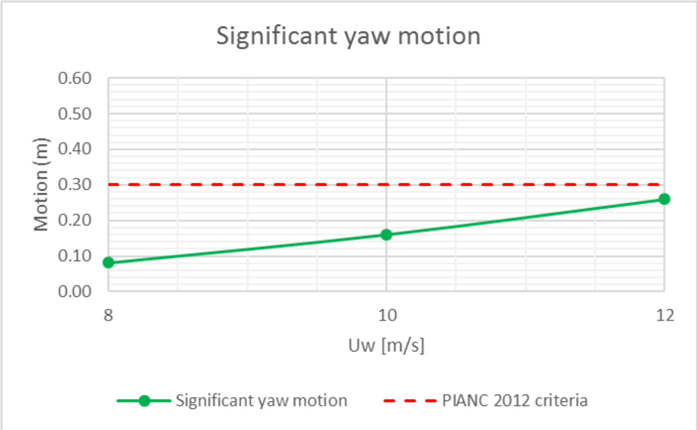
Stern quartering wind and waves

THE FOLLOWING TABLE AND FIGURES SHOW THE SIGNIFICANT AND MAXIMUM SURGE, SWAY AND YAW MOTIONS FOR INCREASING WIND SPEEDS IN BOW WIND AND WAVES. FOR THE SIGNIFICANT AND MAXIMUM MOTIONS, THE PIANC 2012 MOTION CRITERIA AND MAXIMUM ALLOWABLE OUTREACHES FOR THE UNITS, ACCORDING TO REF.[1] (-/+ 0.40 M FOR SURGE; -/+1.1M FOR SWAY) HAVE BEEN ALSO PLOTTED.

Moored ship with stern quartering wind and waves			
	SIMBAD (2020) With 2nd-order loads (Molin formulation)	SIMBAD (2020) With 2nd-order loads (Molin formulation)	SIMBAD (2020) With 2nd-order loads (Molin formulation)
Solver	Pdstrip	Pdstrip	Pdstrip
Wave	Hs:1m; Tp:5.4s	Hs:1.35m; Tp:6s	Hs:1m; Tp:5.4s
Uw [m/s]	8	10	12
Significant ship motions			
surge [m]	0.08	0.15	0.22
sway [m]	0.09	0.19	0.33
heave [m]	0.02	0.04	0.06
roll [deg]	0.27	0.58	0.98
pitch [deg]	0.05	0.10	0.16
yaw [deg]	0.08	0.16	0.26
Maximum ship motions			
surge [m]	0.15	0.34	0.40
sway [m]	0.21	0.47	0.68
heave [m]	0.05	0.07	0.11
roll [deg]	0.62	1.10	1.78
pitch [deg]	0.11	0.20	0.30
yaw [deg]	0.23	0.44	0.57
Mooring line max (tf)			
M1	32	47	47
M2	24	47	47
M3	34	47	47
M4	47	47	47
Fender max (tf)			
F1	110	199	272
F10	109	155	228



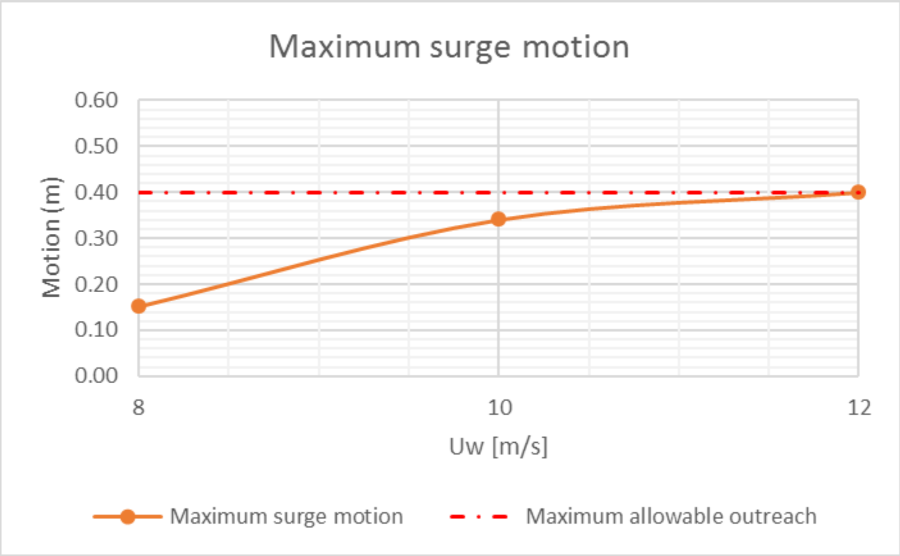


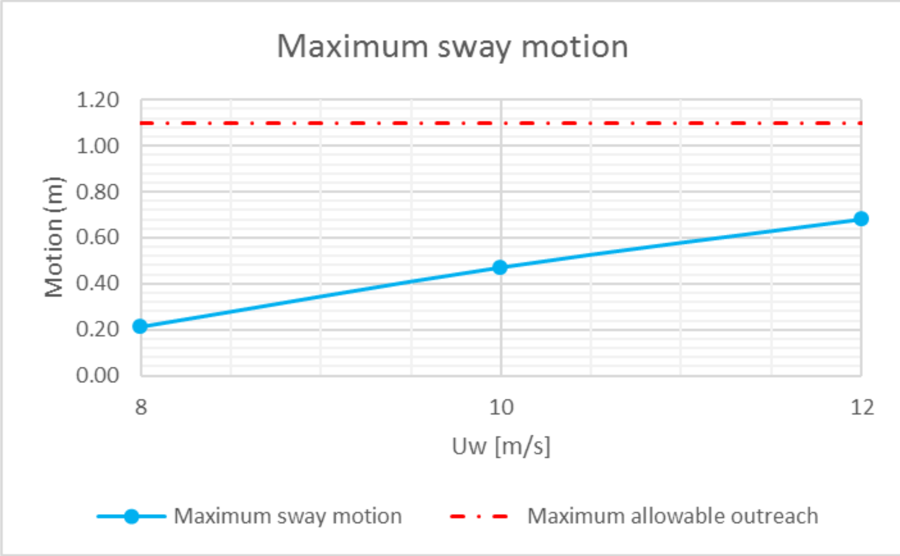


Royal Haskoning DHV (2014)

Stern quartering wind and waves

The following table and figures show the significant and maximum surge, sway and yaw motions for increasing wind speeds in bow wind and waves. For the significant and maximum motions, the PIANC 2012 motion criteria and maximum allowable outreaches for the units, according to Ref.[1] (-/+ 0.40 m for surge; -/+1.1m for sway) have been also plotted.





Note:

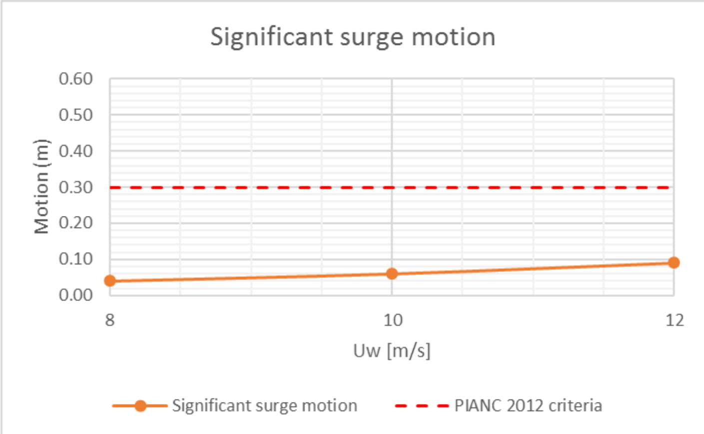
- ***In Ref.[1], for wind speeds higher than 8m/s, the configuration and placement of the connection units was not suitable and could no longer be applied. With the present SIMBAD simulation, this configuration of connection units could be applied up to 10m/s wind speed and wave conditions. This difference could be attributed to the uncertainties and differences in the modelling of parameters and more precisely in control regulation modelling.***

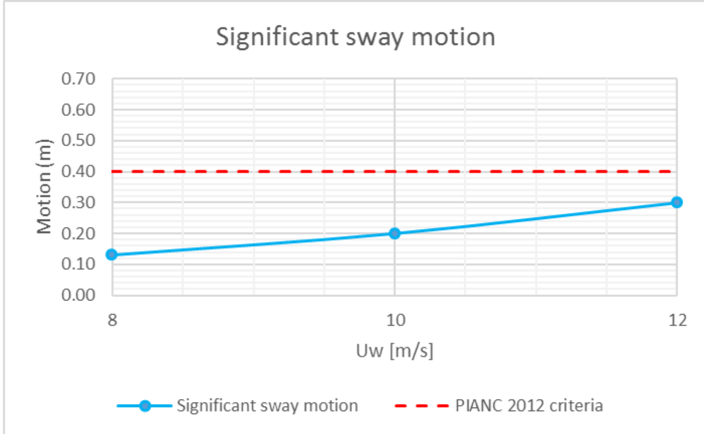
Royal Haskoning DHV (2014)

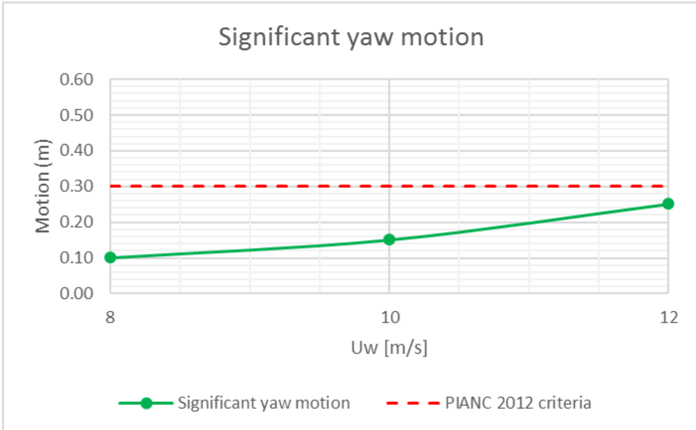
Beam wind (no waves)

The following table and figures show the significant and maximum surge, sway and yaw motions for increasing wind speeds in beam wind and waves. For the significant and maximum motions, the PIANC 2012 motion criteria and maximum allowable outreaches for the units, according to Ref.[1] (-/+ 0.40 m for surge; -/+1.1m for sway) have been also plotted.

Moored ship with beam wind (no waves)			
	SIMBAD (2020)	SIMBAD (2020)	SIMBAD (2020)
Solver	Pdstrip	Pdstrip	Pdstrip
Wave	nil	nil	nil
Uw [m/s]	8	10	12
Significant ship motions			
surge [m]	0.04	0.06	0.09
sway [m]	0.13	0.20	0.30
heave [m]	0.00	0.00	0.00
roll [deg]	0.08	0.12	0.21
pitch [deg]	0.00	0.00	0.00
yaw [deg]	0.10	0.15	0.25
Maximum ship motions			
surge [m]	0.05	0.08	0.13
sway [m]	0.15	0.27	0.39
heave [m]	0.00	0.00	0.00
roll [deg]	0.10	0.16	0.29
pitch [deg]	0.00	0.00	0.00
yaw [deg]	0.11	0.19	0.33
Mooring line max (tf)			
M1	28.0	47	47
M2	22.0	40	47
M3	17.0	31	47
M4	13.0	24	34
Fender max (tf)			
F1	13	19	41
F10	23	42	66



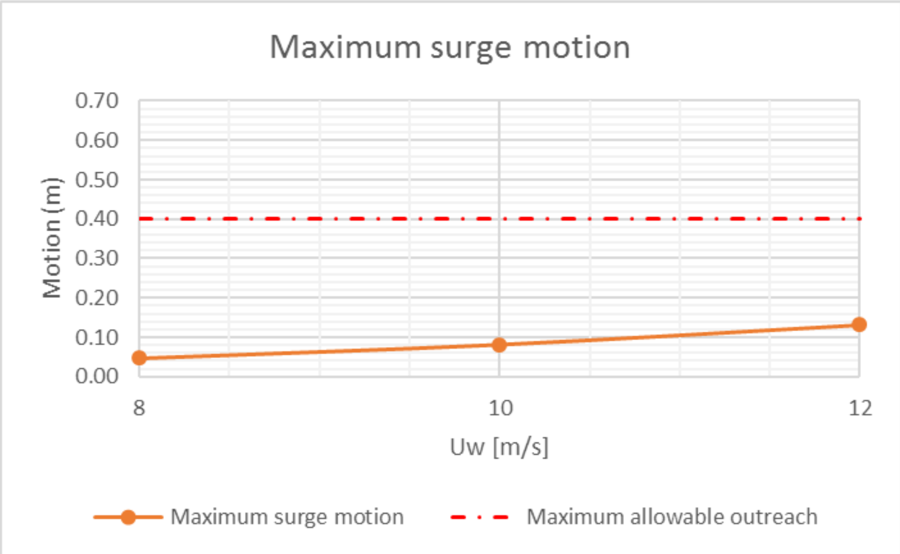


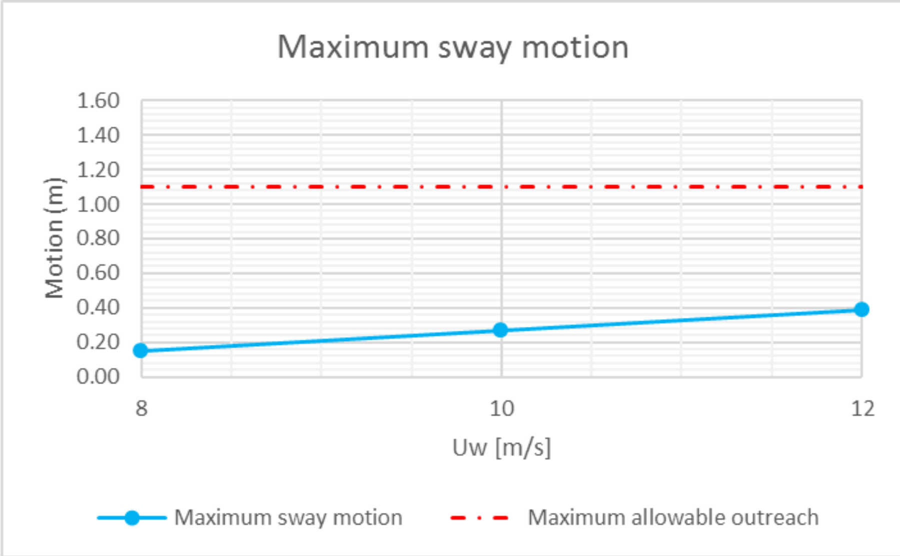


Royal Haskoning DHV (2014)

Beam wind (no waves)

The following table and figures show the significant and maximum surge, sway and yaw motions for increasing wind speeds in bow wind and waves. For the significant and maximum motions, the PIANC 2012 motion criteria and maximum allowable outreaches for the units, according to Ref.[1] (-/+ 0.40 m for surge; -/+1.1m for sway) have been also plotted.





Note:

- ***In Ref.[1], the wind forces become too large for the mooring configuration chosen to withstand for wind speeds greater than 8 m/s. With the present SIMBAD simulation, this configuration of connection units could be applied up to 12m/s wind speeds. This difference could be attributed to the uncertainties and differences in the modelling of parameters and more precisely in control regulation modelling.***