Delta Marine Consultants

Technical design note

To IMDC

From Michiel Muilwijk
Telephone +31 631672423
E-mail michiel.muilwijk@bam.com

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Subject **Pontoon motions analysis**

1. Introduction

The Wilhelmshaven FSRU requires an emergency evacuation berth, which needs to be accessible for evacuation of personnel when the FSRU is at the berth. This structure needs to be a floating pontoon type structure, which is to be accessed from MD6 with a gangway.

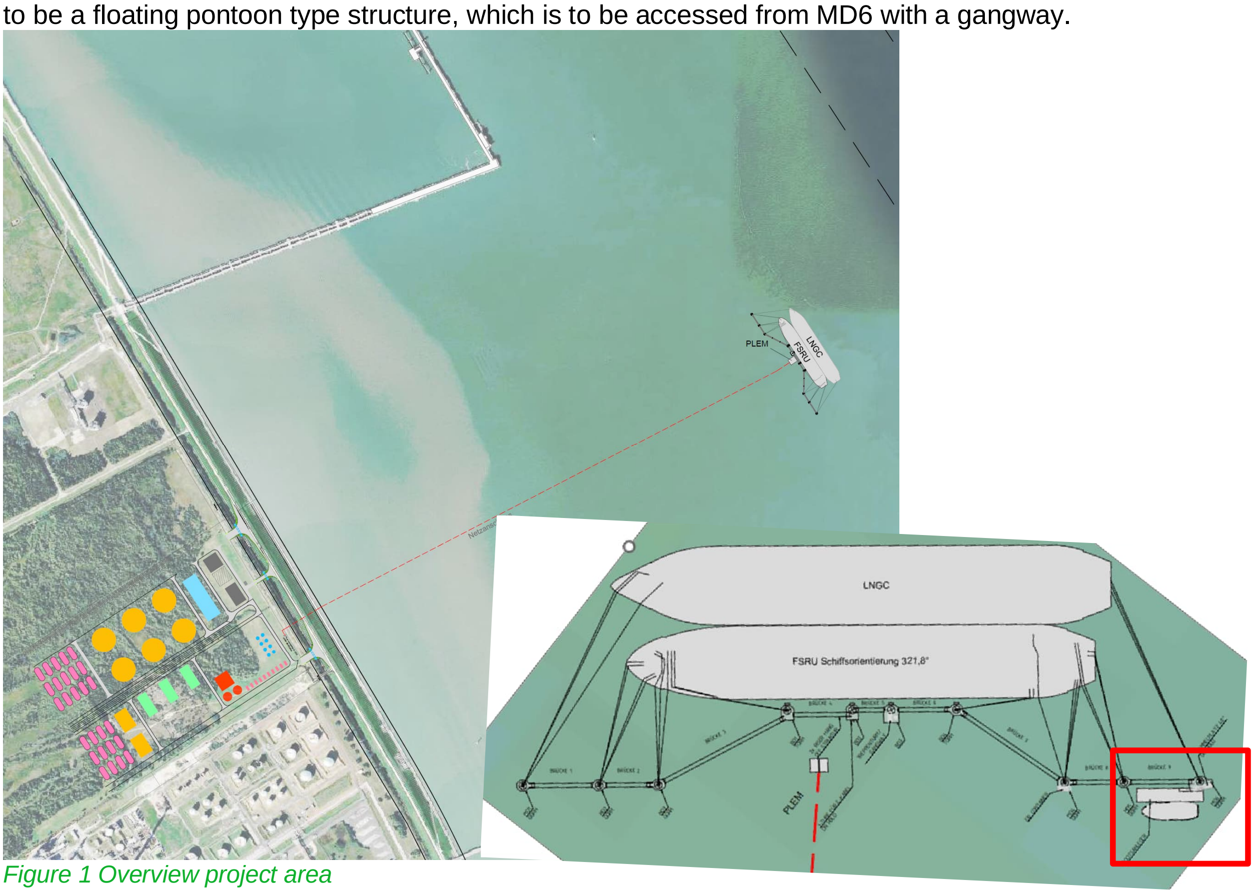

Figure 1 Overview project area

Subject Pontoon motions analysis

In the figure below a schematic layout of the Pontoon Facility is provided. The Pontoon Facility consist of a floating pontoon, which is moored against driven piles. For fixation of the pontoon pile clamps/pile guides will be used.

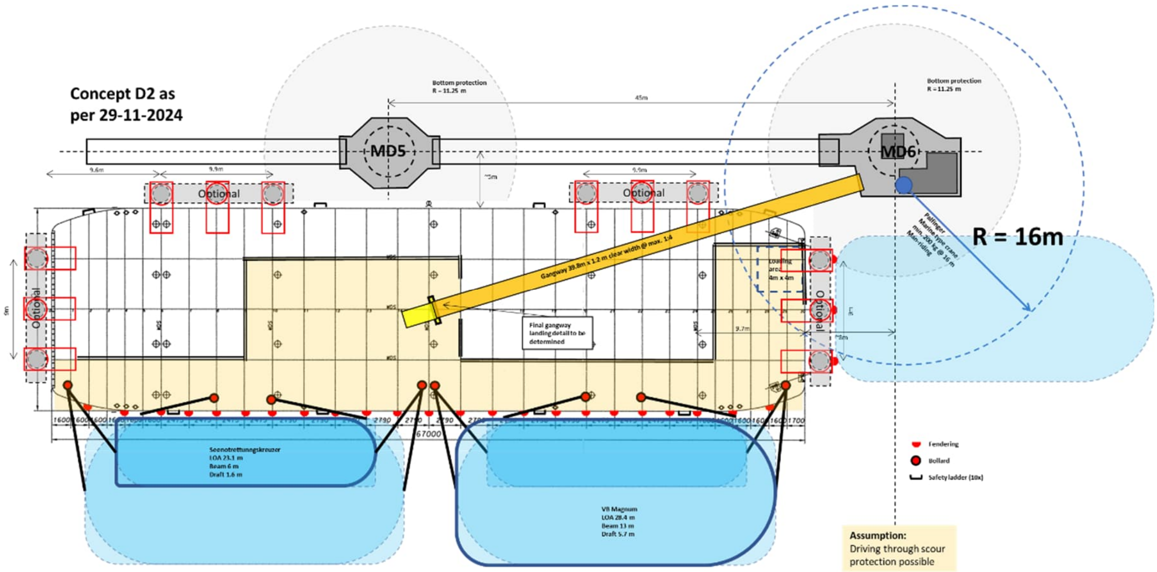

Figure 2 Layout Pontoon Facility

The objective of this technical design note is to get a feel for the motions of the barge by preparing so-called RAO's (Response Amplitude Operators). In addition a moored situation will be considered for the preferred pontoon, to understand the number of mooring piles that need to be applied as well as the loads acting on these piles.

In the previous stage various barges have been investigated:

- Damen Stan pontoon B24 (63 m), investigated for both conditions without ballast ("light") and with ballast ("heavy")
- Damen Stan pontoon 8916 (89m), investigated for condition with ballast ("heavy") only
- Baars Couple pontoon, investigated for condition without ballast ("light")
- Hebo P63 pontoon in light and heavy configuration

From these pontoons a HEBO P63 pontoon has been selected. The suitability of this pontoon is provided in chapter 4.

The modelling of the floating behaviour is performed with Ansys AQWA, a 3D diffraction program. The RAO's will give the ratio between the response of the free floating barge (roll, pitch, heave, surge, sway, yaw) in relation to the incoming wave height for the range of wave periods. This will give insight into the behaviour of the pontoon under wave load.

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2. Starting points

Barge Characteristics

The pontoon motions analysis has been performed for the HEBO P63 pontoon. Two loading conditions have been considered; a fully loaded condition with a maximum draft of 3.2m and a design loading condition with a draft of 2.3m. The relevant characteristics that have been applied in the mooring analysis are shown in the table below.

Table 1: Barge characteristics

Characteristic	unit	HEBO-P63	
		Heavy	Design
Length	[m]	67	67
Beam	[m]	18	18
Moulded depth	[m]	4.5	4.5
Draft	[m]	3.2	2.3
Displacement	[ton]	3849	2740
Cog from keel	[m]	2.25	2.5
K_{xx} (0.34 * Beam)	[m]	6.12	6.12
K_{yy} (0.25 * Length)	[m]	16.75	16.75
K_{zz} (0.26 * Length)	[m]	17.42	17.42

Seabed and Water level for modelling purposes

The water depth is assumed to be 21m; dredged level at CD -15m and water level of CD + 6.15m.

Low water scenarios have been checked at a water level of -1.0m CD and a bottom level of CD – 11m, leading to a water depth of 10m.

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Limits in movement

In the previous sections the response of the various pontoons on incoming waves is determined. In the next sections limits are defined for movements and based on the actual wave climate the suitability of the pontoon is checked.

In the figure below a cut out is shown of the recommended motion criteria as mentioned in [PIANC WG24 (1995)]. The criteria for a storm ramp are selected as limits for allowable motions for the pontoons during the 1/1year working conditions (indicated with red rectangle in the figure below).

Ship Type	Cargo Handling Equipment	Surge (m)	Sway (m)	Heave (m)	Yaw (°)	Pitch (°)	Roll (°)
Fishing vessels	Elevator crane	0.15	0.15	0.4	3	3	3
	Lift-on-lift-off	1.0	1.0				
	suction pump	2.0	1.0				
Freighters, coasters	Ship's gear	1.0	1.2	0.6	1	1	2
	Quarry cranes	1.0	1.2	0.8	2	1	3
Ferries, Ro-Ro	Side ramp[2]	0.6	0.6	0.6	1	1	2
	Dew/storm ramp	0.8	0.6	0.8	1	1	4
	Linkspan	0.4	0.6	0.8	3	2	4
	Rail ramp	0.1	0.1	0.4	-	1	1
General cargo	-	2.0	1.5	1.0	3	2	5
Container vessels	100% efficiency	1.0	0.6	0.8	1	1	3
	50% efficiency	2.0	1.2	1.2	1.5	2	6
Bulk carriers	Cranes	2.0	1.0	1.0	2	2	6
	Elevator/bucket-wheel	1.0	0.5	1.0	2	2	2
	Conveyor belt	5.0	2.5		3		
Oil tankers	Loading arms	3.0[3]	3.0				
Gas tankers	Loading arms	2.0	2.0		2	2	2

Remarks: [1]) Motions refer to peak-peak values (except for sway: zero-peak).
[2]) Ramps equipped with rollers.
[3]) For exposed locations 5.0 m (regular loading arms allow large movements)

Figure 3: Motion criteria for safe working conditions [PIANC WG24]

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3. Wave Climate

From the Metocean campaign report [TES-WHV-FSRU-ENV-DOC-2049.01] wave climate conditions have been selected conform the basis of design report [DMC-231121-R-00006-MVB]. Below is a short description of the climate.

Direction
The wave climate is predominantly NNW orientated. Other directions occur but with a much smaller likelihood and a lower significant wave height.

Wave height versus wave period
The local wave conditions show a typical sea wave component with periods ranging between 0s up to 5 or 6s (up to 2.0 m) and a swell component with larger period waves (6 to 15s) with smaller amplitude (<0.2m).

Below is a sketch indicating the direction of the coming waves in relation to the jetty

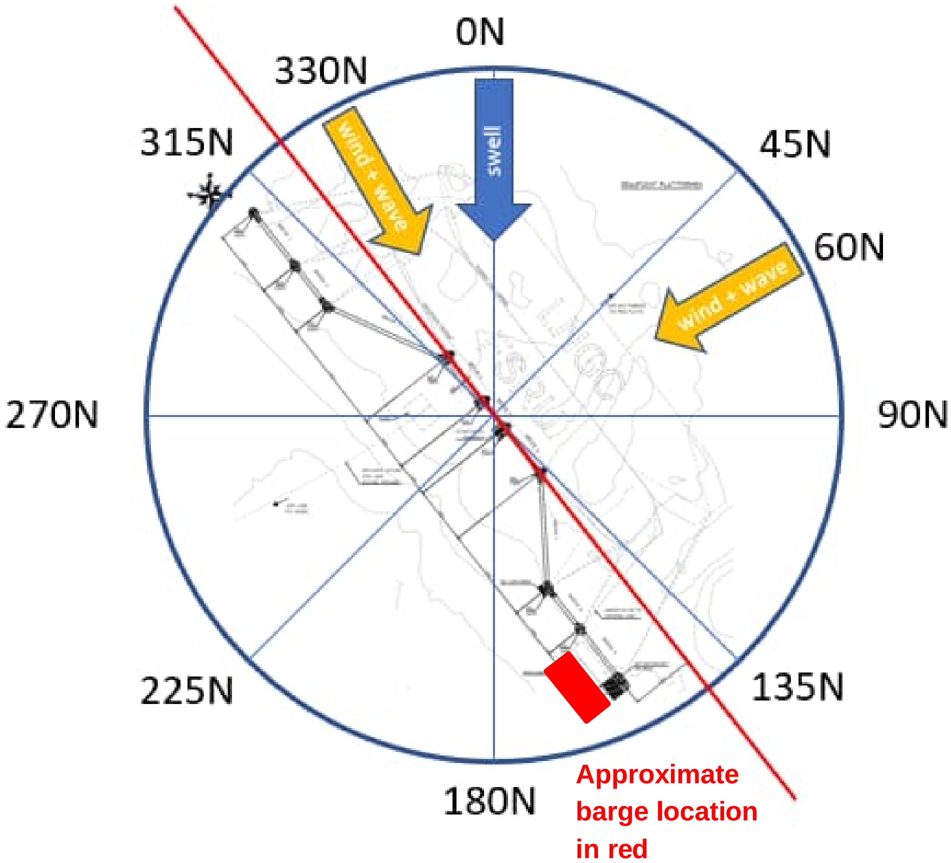

Figure 4: Barge location and main wind/wave/swell directions

From the conditions described above and in the Metocean campaign report [TES-WHV-FSRU-ENV-DOC-2049.01] the following wave scenarios have been selected:

Extreme conditions (RP = 100year)
The 1:100 year conditions have been used to determine the design loads on the mooring piles of the pontoon.

Table 2: Sea wave conditions (1/100 year), from [TES-WHV-FSRU-ENV-DOC-2049.01]

Wind		Windwellen					
Richtung aus (°N)	Geschwindigkeit (m/s)	Mdir aus (°N)	Hm0 (m)	Tp (s)	Gamma (JONSWAP)	Richtungs-- ausbreitung (s)	Richtungs-- ausbreitung (°)
0	27,2	347,2	2,1	5,1	2,3	9,6	24,7
30	22,6	9,4	1,6	4,4	2,8	5,4	32,4
60	18,0	51,1	1,2	3,8	3,3	5,5	32,1
90	21,0	94,2	1,3	3,8	3,4	5,7	31,6
120	17,9	122,8	1,1	3,7	3,5	7,5	27,7
150	16,8	138,8	1,0	3,7	2,4	10,3	24,0
180	21,6	150,7	1,3	4,1	1,7	7,9	27,0
210	24,2	171,0	1,2	3,8	1,5	4,5	35,0
240	26,4	239,5	1,0	3,0	2,9	1,9	46,5
270	26,0	314,3	1,3	4,3	1,5	4,9	33,8
300	26,8	333,5	1,8	4,9	1,9	11,5	22,8
330	27,8	339,0	2,1	5,2	2,0	13,7	21,1

Table 3: Swell wave conditions (1/100year), from [TES-WHV-FSRU-ENV-DOC-2049.01]

Swell waves						
Sector	Mdir Coming from (°N)	Hm0 (m)	Tp (s)	Gamma (Jonswap)	Directional spreading (s)	Directional spreading (°)
West	345	0.1	13.5	1.8	34.0	13.5
WNW	348	0.1	14.7	1.8	29.9	14.5
NNW	356	0.2	15.4	1.8	19.2	18.1
North	358	0.4	8.7	1.1	12.6	21.9
NNE	0	0.4	6.7	1.7	9.4	25.0
Representative swell scenario	357	0.3	12.1	1.5	15.4	20.0

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Operational conditions (RP = 10year)

The 1:10 year conditions have been used to determine the fatigue loads on the mooring piles of the pontoon.

Table 4: Sea wave conditions (1/1 year), from [TES-WHV-FSRU-ENV-DOC-2049.01]

Wind		Wind waves					
Direction Coming from (°N)	Speed (m/s)	Mdir Coming from (°N)	Hm0 (m)	Tp (s)	Gamma (Jonswap)	Directional spreading (°)	Directional spreading (s)
0	21.0	347.7	1.7	4.7	2.4	9.4	24.9
30	18.1	10.2	1.3	4.1	2.8	5.2	32.9
60	15.1	51.1	1.0	3.5	3.3	5.4	32.4
90	16.6	91.9	1.0	3.5	3.2	5.8	31.4
120	14.7	122.6	0.9	3.4	3.5	7.3	28.0
150	14.4	138.9	0.8	3.4	2.2	10.1	24.1
180	17.7	151.1	1.1	3.8	1.7	8.3	26.5
210	20.3	171.5	1.0	3.5	1.5	4.5	35.0
240	21.7	239.8	0.8	2.8	2.8	2.0	45.8
270	21.4	313.5	1.1	4.0	1.7	4.8	34.2
300	21.9	334.2	1.5	4.5	1.9	11.1	23.2
330	22.4	339.7	1.7	4.9	2.1	13.7	21.1

Operational conditions (RP = 1year)

The operational conditions have been used to determine pontoon motions in the working conditions

Table 5: Sea wave conditions (1/1 year), from [TES-WHV-FSRU-ENV-DOC-2049.01]

Wind		Wind waves					
Direction Coming from (°N)	Speed (m/s)	Mdir Coming from (°N)	Hm0 (m)	Tp (s)	Gamma (Jonswap)	Directional spreading (°)	Directional spreading (s)
0	14.8	349.1	1.2	4.1	2.4	9.1	25.4
30	13.5	12.3	1.0	3.7	2.8	5.3	32.7
60	12.1	51.7	0.7	3.5	3.3	7.2	28.3
90	12.3	90.4	0.7	3.0	3.2	5.9	31.1
120	11.4	121.9	0.7	3.1	3.5	7.2	28.2
150	12.0	138.7	0.6	3.1	2.2	10.0	24.3
180	13.8	151.7	0.9	3.6	1.7	8.3	26.5
210	16.4	172.5	0.8	3.2	1.5	4.5	35.2
240	17.0	240.3	0.6	2.5	2.8	2.1	45.3
270	16.7	312.6	0.9	3.6	1.7	4.6	34.7
300	16.9	334.6	1.2	4.2	1.9	10.6	23.6
330	17.0	339.6	1.4	4.4	2.1	13.7	21.1

Swell wave conditions (1/1 year)

No swell waves have been provided for the operational condition.

Modelling starting points

- Calculation time in the simulations is 3 hours (10800s)
- A tidal currents has been assumed to be present. In the calculations a current speed of 1.88m/s is applied with direction coinciding with wind direction (flowing either in or out, so at the bow or at the stern of the pontoon (as per BOD [DMC-231121-R-00006-MVB]

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4. Response results pontoon (RAO's)

The modelled pontoon geometry is shown in the figure below. At this stage only the floating body of the pontoon is considered. The connections are not yet included.

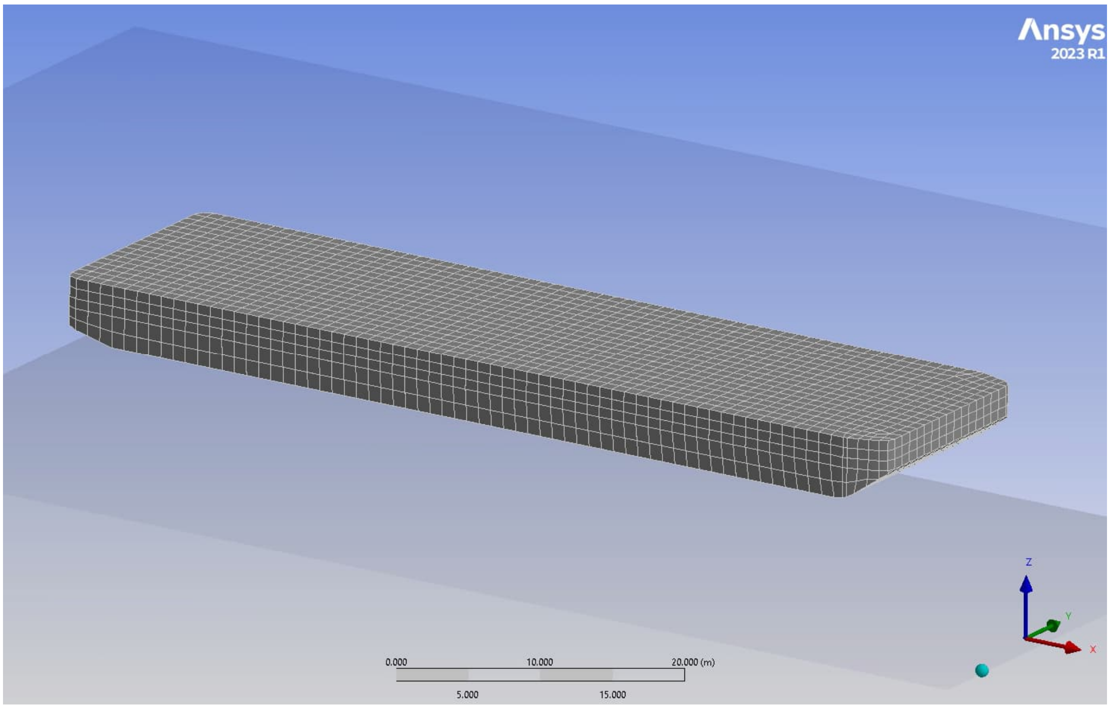

Figure 5: Ansys AQWA model: Pontoon panel model used for hydrodynamic diffraction analysis

The pontoon is modelled with panels; the panel size varies between 0.5m and 1m, which gives the possibility to simulate wave periods varying from 3 to 60 seconds.

The analysis in Ansys AQWA is done in two stages, the first stage is the hydrodynamic diffraction analysis in which the program calculates the response of the floating body to wave action over a range of wave periods and incoming wave angles. This response is presented in Response Amplitude Operators (RAO's) which are presented in this chapter for "beam on" and "bow on" directions. In the second stage the land connections of the pontoon are added and a time domain analysis is performed yielding actual motions and forces. These results are presented in chapter 5.

The Response Amplitude Operators (RAO's) are configured for the pontoon in two loading conditions; Fully laden (heavy) and design draft. These RAO's show the behavior of the pontoon for a given wave height and period and give an insight in the suitability of the pontoon for the given environmental conditions.

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For the head-on waves the RAO’s present surge (linear X), heave (linear Z) and pitch (roll around RY-axis); sway, roll and yaw are zero. For the beam-on waves the RAO’s present sway (linear Y), heave (linear Z) and roll (roll around RX-axis); surge, pitch and yaw are zero.

Head-on waves

The RAO’s of the pontoon in both loading conditions are plotted on the same scale . The pontoon shows similar behaviour between “heavy” and “design” condition for all three motions (surge, heave and pitch), indicating that the loading condition has a limited effect on the pitch of the pontoon in head-on waves.

The surge motion (Figure 6) shows decreasing response amplitude with increasing frequency. The limit for surge motion is 0.8m (peak-to-peak). With bow on wave heights of up to 1.2m, this limit will be exceed by the pontoon for wave frequencies lower than 0.1hz or 10s. This is beyond the expected wave period range; therefore Surge motion is expected not to exceed the stated limit of 0.8m.

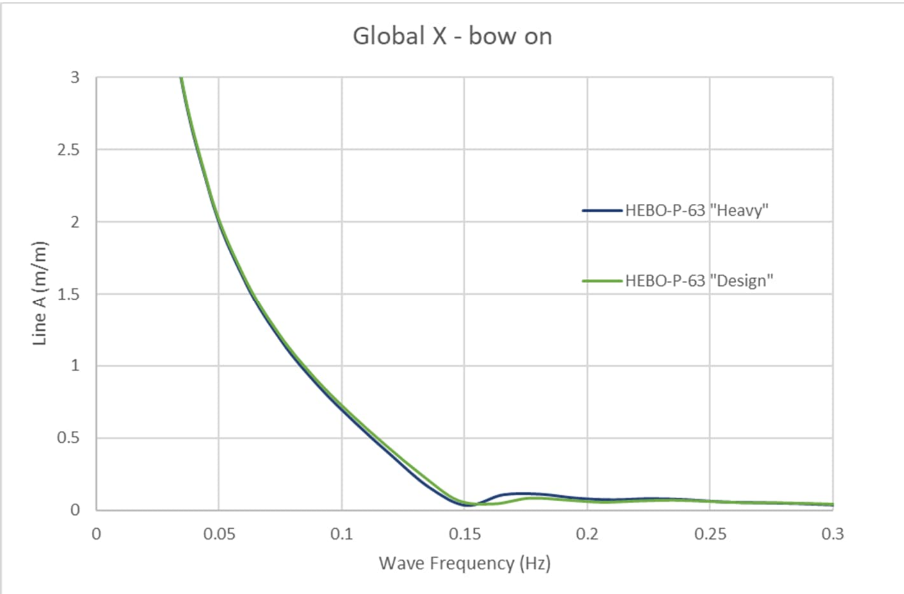

Figure 6: Comparison of surge motion RAO – Head-on waves

The heave motion (Figure 7) also shows decreasing behaviour with increasing frequency. A “bump “is shown in the line where the heave is slightly increased for a frequency of 0.18 Hz (~6s).

The limit for heave motion is 0.8m. With bow on wave heights of up to 1.2m (1/1 year condition), this limit will be exceed by the pontoon for wave frequencies lower than 0.1hz or 10s. This is beyond the expected wave period range; therefore Heave motion is not expected to exceed the stated limit of 0.8m.

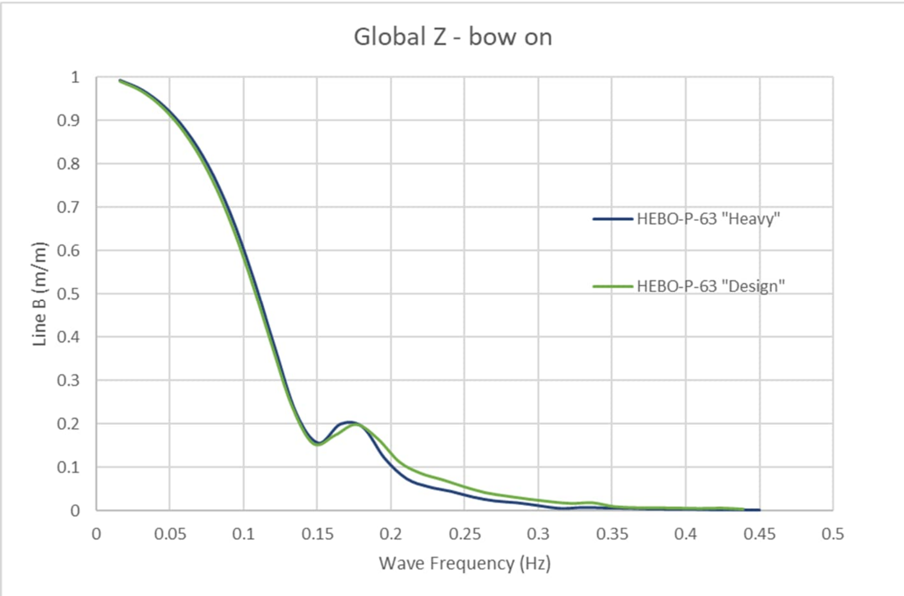

Figure 7: Comparison of heave motion RAO – Head-on waves

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The pitch motions (Figure 8) shows a sharp increase in response for low frequencies and a drop in response for frequencies in excess of 1.12 Hz (~8s).
The design weight pontoon yields slightly lower pitch motions than the heavy pontoon.

The limit for Pitch motion is 1°. With bow on wave heights of up to 1.2m (1/1year condition), this limit will be exceed by the pontoon for wave frequencies between 0.05hz to 0.17 or 6s to 20s. This is beyond the expected wave period range; therefore Pitch motion is not expected to be exceeding the stated limit of 1° during working conditions

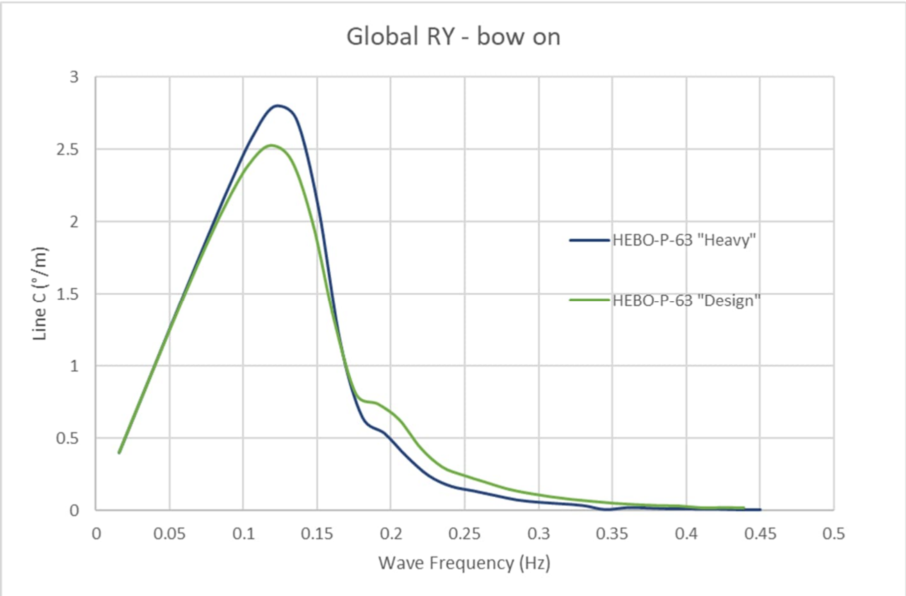

Figure 8: Comparison of pitch motion RAO – Head-on waves

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Beam-on waves

The RAO's of the HEBO P63 pontoon for both loading conditions are plotted on the same scale for the beam-on wave conditions. The pontoon shows similar behaviour between "heavy" and "design" condition for the motions (surge and heave), indicating that the loading condition has a limited effect on the sway and heave motions of the pontoon in beam-on waves.

As with the Surge motion, the sway motion decreases for increasing wave frequency (Figure 9). The heavy HEBO pontoon shows very similar behavior to the design weight pontoon; the main difference is the frequency at which the "dip" in motion occurs..

The limit for Sway motion is 0.6m (peak-to-peak). With beam on wave heights of up to 0.7m (1/1year condition), this limit will be exceed by the pontoon for wave frequencies lower than 0.18hz or 5.5s. This is beyond the expected wave period range from this direction; therefore Surge motion is expected not to exceed the stated limit of 0.6m.

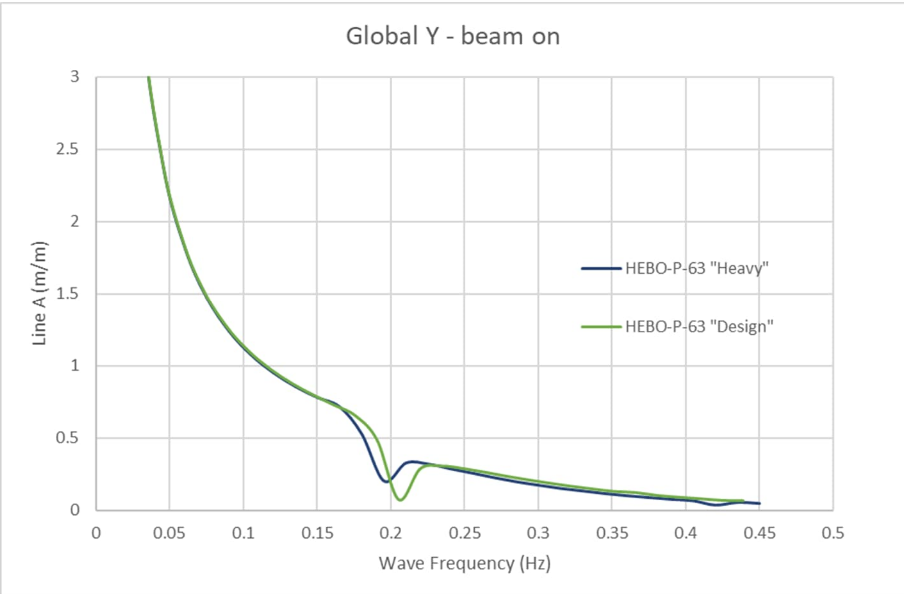

Figure 9: Comparison of sway motion RAO – Beam-on waves

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The Heave motion (Figure 10) shows a slight increase for lower wave frequencies followed by a sharp decrease in response for frequencies in excess of around 0.17 Hz (~5.9s). In the heave motion a significant difference is noted between “heavy” and “design weight” pontoon. The frequency of the maximum decreases while the maximum motion itself increases with increased weight of the pontoon.

The limit for heave motion is 0.8m. With beam on wave heights of up to 0.7m (1/1year condition), this limit will be exceed by all pontoons for wave frequencies lower than 0.2hz or 5s. This is beyond the expected wave period range; therefore Heave motion is expected not to exceed the stated limit of 0.8m.

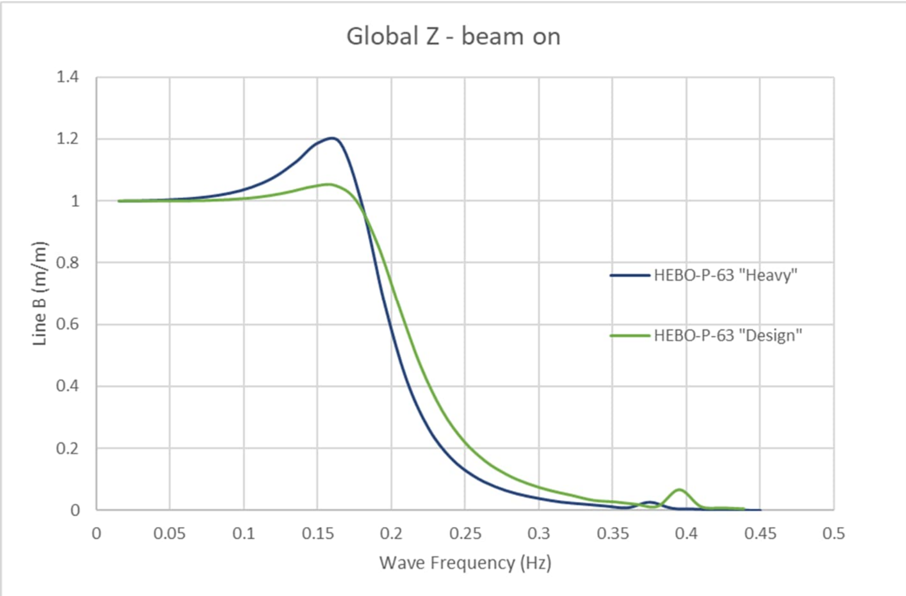

Figure 10: Comparison of heave motion RAO – Beam-on waves

The Roll motion (Figure 11) shows a sharp increase for lower wave frequencies followed by a sharp decrease in response for frequencies in excess of around 0.16 to 0.2 Hz (~5 to 5.5s). In the roll motion a significant difference is noted between “heavy” and “design weight” pontoon. The frequency of the maximum decreases while the maximum motion itself increases with increased weight of the pontoon. The design weight pontoon yields slightly lower pitch motions than the heavy pontoon.

The limit for Roll motion is 4°. With beam on wave heights of up to 0.7m (1/1year condition), this limit will be exceed by the pontoon for wave frequencies between 0.12 and 0.24hz or 4-6s. This is just beyond the expected wave period range; therefore roll motion is not expected to be exceeding the stated limit of 1° during 1/1year conditions.

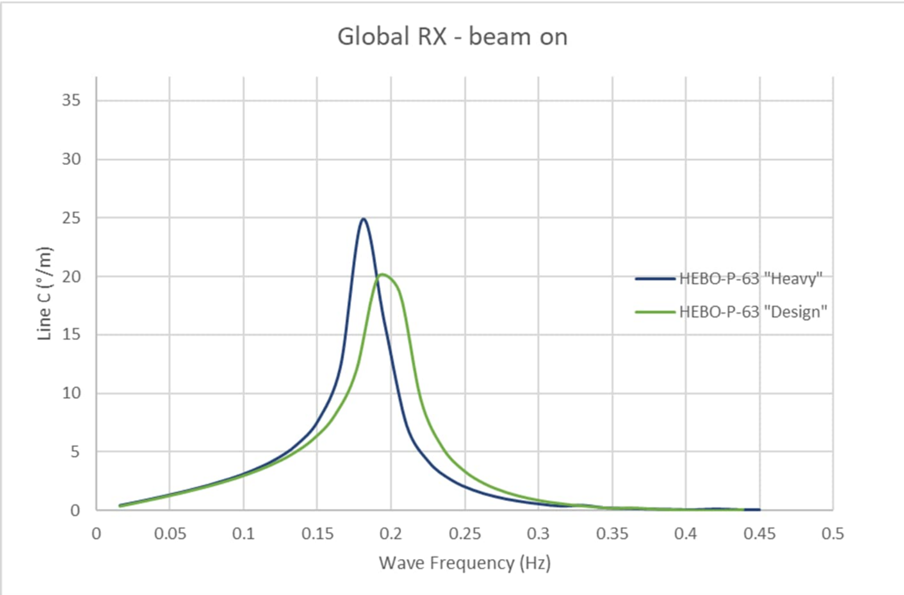

Figure 11: Comparison of roll motion RAO – Beam-on waves

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5. Mooring design

The HEBO P63 pontoon in 2.3m draft configuration is selected as design pontoon, because it performs slightly better in terms of roll and pitch compared to the heavier pontoon. To keep this pontoon in place a series of mooring piles is envisaged as indicated in the figures below. A total number of 12 piles is applied with 3 piles on either end of the pontoon (stern and bow). Along the side of the pontoon 6 piles are placed in groups of 3. The behaviour of this system is modelled in the hydrodynamic response module of ANSYS AQWA.

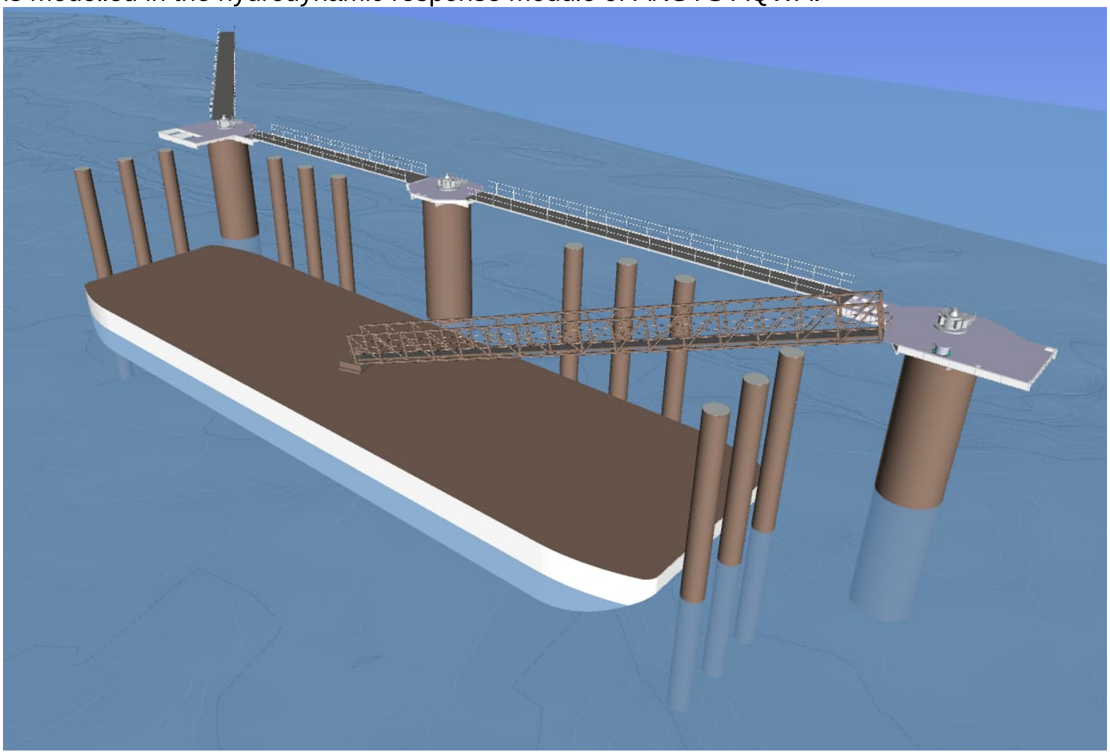

Figure 12: Pontoon layout with piles

In the ANSYS AQWA model the mooring piles have been schematised as a combination of 4 linear fenders working in different directions. Each fender only acts in a single direction (X or Y) and allows pressure only. No tension load can be transferred to the fender; therefore two opposing fenders are modelled for each direction. In vertical direction the pontoon is free to move; no friction is applied on the fenders and no fender is modelled in vertical direction. In the resting position the fenders are not loaded (0 kN/m).

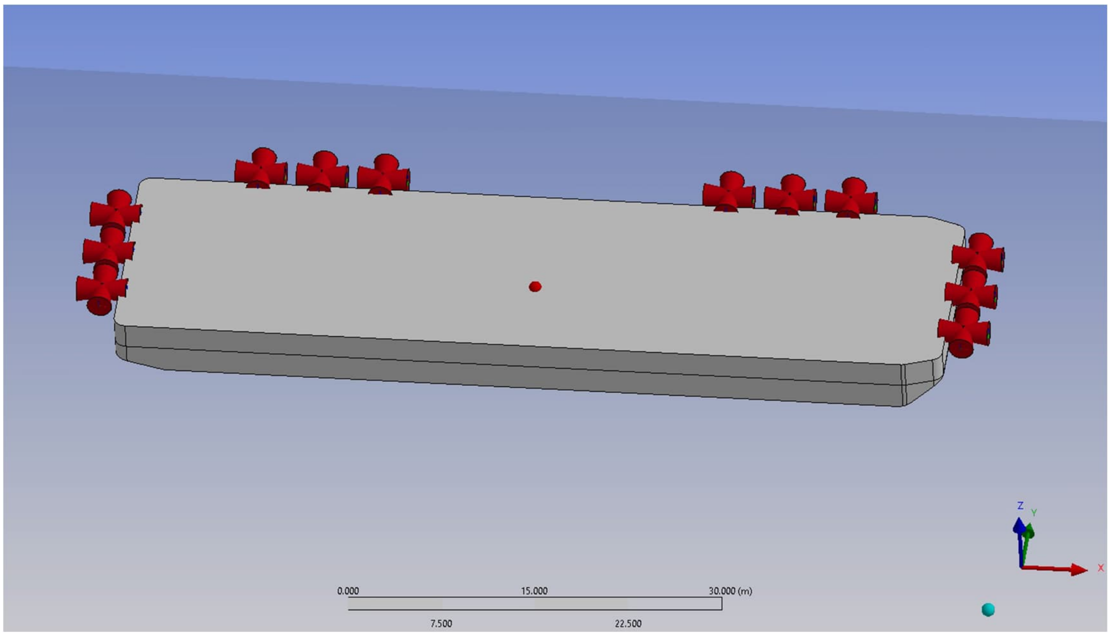

Figure 13: Model of moored pontoon with a maximum of 3 mooring piles at each side of the pontoon

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Results hydrodynamic response

The stiffness of the mooring piles depends on the pile characteristics and the water depth, assuming the bottom level is fixed.
As a first estimate a 1400mm pile with thickness 45mm is chosen as mooring pile. This pile has a different stiffness at high water compared to low water, because at high water a longer length of the pile is free standing and therefore this pile has a lower stiffness. Note that the final pile dimensions will be determined in the pile design report.

The following stiffnesses have been assumed for the 1:100 year conditions:

- Low water: 9224kN/m
- High water: 831kN/m

The dynamic mooring analysis has been performed for these two configurations. For this purpose also a low water model (with 10m water depth) has been prepared. The high water model contains a water depth of 21m.

Results 1/100 year condition

The model has been subjected to the hydraulic conditions as given in section 3. These include wind waves and swell wave conditions. On top of that also wave only and current only conditions have been checked, see Table 1 and Table 2. It turns out that the wave only conditions (with beam on direction) yields the largest forces on the piles. This is found for all investigated pile / fender stiffnesses. Considering waves only is a conservative case as these waves are typically induced by strong winds coming from the same direction, Subject **Pontoon motions analysis**

Table 1: Results pontoon analysis 1:100 year condition high stiffness pile (9224kN/m)

Wind Speed [m/s]	Wind Direction [deg]	Wave Direction [deg]	Significant Wave Height [m]	Wave Peak Period [s]	Irregular Wave Gamma [-]	Current Speed [m/s]	Current Direction [deg]	Pile stiffness [kN/m]	max longitudinal force (fx) [kN]	max lateral force (FY) [kN]	maximum total force (Fcombined) [kN]	maximum surge motion (dx) [m]	maximum sway motion (dx) [m]
27.2	321.75	334.55	2.1	5.1	2.3	1.88	0	9224	235	167	289	0.06	0.04
22.6	291.75	312.35	1.6	4.4	2.8	1.88	0	9224	109	133	172	0.02	0.03
18	261.75	270.65	1.2	3.8	3.3	1.88	180	9224	19	611	612	0.00	0.17
21	231.75	227.55	1.3	3.8	3.4	1.88	180	9224	58	109	124	0.01	0.01
17.9	201.75	198.95	1.1	3.7	3.5	1.88	180	9224	53	50	73	0.01	0.00
16.8	171.75	182.95	1	3.7	2.4	1.88	180	9224	78	47	91	0.01	0.00
21.6	141.75	171.85	0.6	3.2	1.7	1.88	180	9224	42	26	50	0.01	0.00
24.2	111.75	150.75	1.2	3.8	1.5	1.88	180	9224	37	70	80	0.01	0.01
26.4	81.75	82.25	1	3	2.9	1.88	0	9224	26	384	385	0.00	0.04
26	51.75	7.45	1.3	4.3	1.5	1.88	0	9224	163	102	192	0.02	0.01
26.8	21.75	-11.75	1.8	4.9	1.9	1.88	0	9224	185	114	218	0.04	0.01
27.8	-8.25	-17.25	2.1	5.2	2	1.88	0	9224	252	160	299	0.06	0.03
1	0	0	0.1	2	3.3	1.88	0	9224	22	16	27	0.00	0.00
1	180	180	0.1	2	3.3	1.88	180	9224	18	13	22	0.00	0.00
1	-23.25	-23.25	0.1	13.5	1.8	0.1	0	9224	8	6	10	0.01	0.00
1	-26.25	-26.25	0.1	14.7	1.8	0.1	0	9224	8	6	9	0.01	0.00
1	-34.25	-34.25	0.2	15.4	1.8	0.1	0	9224	17	14	22	0.01	0.01
1	-36.25	-36.25	0.4	8.7	1.1	0.1	0	9224	65	36	74	0.03	0.01
1	321.75	321.75	0.4	6.7	1.7	0.1	0	9224	40	30	50	0.02	0.02
1	-35.25	-35.25	0.3	12.1	1.5	0.1	0	9224	31	20	37	0.02	0.01
1	51.75	7.45	1.3	4.3	1.5	0.1	0	9224	98	47	109	0.02	0.01
1	81.75	82.25	1	3	2.9	0.1	0	9224	24	466	467	0.00	0.06
1	261.75	270.65	1.2	3.8	3.3	0.1	0	9224	13	587	587	0.00	0.16

Subject Pontoon motions analysis

Table 2: Results pontoon analysis 1:100 year condition low stiffness pile (831kN/m)

Wind Speed [m/s]	Wind Direction [deg]	Wave Direction [deg]	Significant Wave Height [m]	Wave Peak Period [s]	Irregular Wave Gamma [-]	Current Speed [m/s]	Current Direction [deg]	Pile stiffness [kN/m]	max longitudinal force (fx) [kN]	max lateral force (FY) [kN]	maximum total force (Fcombined) [kN]	maximum surge motion (dx) [m]	maximum sway motion (dx) [m]
27.2	321.75	334.55	2.1	5.1	2.3	1.88	0	831	260	311	406	0.30	0.14
22.6	291.75	312.35	1.6	4.4	2.8	1.88	0	831	420	377	565	0.47	0.14
18	261.75	270.65	1.2	3.8	3.3	1.88	180	831	38	616	617	0.04	0.77
21	231.75	227.55	1.3	3.8	3.4	1.88	180	831	199	188	274	0.23	0.08
17.9	201.75	198.95	1.1	3.7	3.5	1.88	180	831	78	117	141	0.08	0.03
16.8	171.75	182.95	1	3.7	2.4	1.88	180	831	80	87	119	0.09	0.01
21.6	141.75	171.85	0.6	3.2	1.7	1.88	180	831	26	22	34	0.03	0.01
24.2	111.75	150.75	1.2	3.8	1.5	1.88	180	831	107	140	176	0.12	0.06
26.4	81.75	82.25	1	3	2.9	1.88	0	831	27	340	341	0.03	0.38
26	51.75	7.45	1.3	4.3	1.5	1.88	0	831	227	160	278	0.26	0.03
26.8	21.75	-11.75	1.8	4.9	1.9	1.88	0	831	311	211	376	0.35	0.05
27.8	-8.25	-17.25	2.1	5.2	2	1.88	0	831	276	252	374	0.32	0.10
1	0	0	0.1	2	3.3	1.88	0	831	4	2	4	0.00	0.00
1	180	180	0.1	2	3.3	1.88	180	831	4	2	5	0.01	0.00
1	-23.25	-23.25	0.1	13.5	1.8	0.1	0	831	7	6	9	0.00	0.01
1	-26.25	-26.25	0.1	14.7	1.8	0.1	0	831	7	7	9	0.00	0.01
1	-34.25	-34.25	0.2	15.4	1.8	0.1	0	831	13	16	20	0.01	0.01
1	-36.25	-36.25	0.4	8.7	1.1	0.1	0	831	32	46	56	0.02	0.03
1	321.75	321.75	0.4	6.7	1.7	0.1	0	831	33	53	62	0.04	0.04
1	-35.25	-35.25	0.3	12.1	1.5	0.1	0	831	20	26	33	0.01	0.02
1	51.75	7.45	1.3	4.3	1.5	0.1	0	831	206	147	253	0.23	0.02
1	81.75	82.25	1	3	2.9	0.1	0	831	20	355	355	0.02	0.38
1	261.75	270.65	1.2	3.8	3.3	0.1	0	831	27	648	649	0.03	0.83

Governing force direction is in transverse direction (“beam on”) as this is the side of the pontoon with the largest exposure to wind and waves. It appears that at the high water level the forces are largest, even though the stiffness of the pile is lower than at low water level, see table below.

Pile stiffness [kN/m]	Water depth [m]	Max Fx [kN]	Max Fy [kN]
831	21	420	648
9224	10	241	619

In the next section motions of the pontoon for the given stiffness values is elaborated. The shown positions are for the COG of the pontoon. The position of the centre of gravity (COG) in longitudinal (X) direction is 33cm aft of the centreline of the pontoon. This is reflected in the results below. The motions demonstrated by the pontoon for the given stiffness are around this position.

Pile stiffness [kN/m]	COG X (**) (min) [m]	COG X (**) (max) [m]	COG Y (min) [m]	COG Y (max) [m]	COG Z (min) [m]	COG Z (max) [m]
831	-0.77	0.14	-0.83	0.70	-0.06	0.44
9224 (*)	-0.37	-0.27	-0.17	0.11	-0.07	0.42

NOTE(*): determined with high water level model (water depth is 21m)
NOTE(**): The position of the centre of gravity (COG) in longitudinal (X) direction is 33cm aft of the centreline of the pontoon.

Rotations of the pontoon are summarised in the table below. The pontoon demonstrates a roll (RX) of more than 5° to port and starboard for the low stiffness pile (HW). Pitch motion, rotation around Y axis, is more than 1° for both investigated stiffnesses. It occurs the pile stiffness has little effect on the pitch.

Pile stiffness [kN/m]	RX (min) [deg]	RX (max) [deg]	RY (min) [deg]	RY (max) [deg]	RZ (min) [deg]	RZ (max) [deg]
831	-5.39	5.68	-1.36	1.27	-0.49	0.52
9224 (*)	-3.84	3.51	-1.33	1.22	-0.02	0.04

NOTE(*): determined with high water level model (water depth is 21m)

Subject Pontoon motions analysis

Results 1/1 year condition

The model has been subjected to the 1/1 year hydraulic conditions as given in section 3. These include wind waves and swell wave conditions. On top of that also wave only and current only conditions have been checked, see Table 3 and Table 4. It turns out that the wave only conditions (with beam on direction) yields the largest forces on the piles. This is found for all investigated pile / fender stiffnesses.

Table 3: Results pontoon analysis 1:1 year condition low stiffness pile (1599kN/m)

Wind Speed [m/s]	Wind Direction [deg]	Wave Direction [deg]	Significant Wave Height [m]	Wave Peak Period [s]	Irregular Wave Gamma [-]	Current Speed [m/s]	Current Direction [deg]	Pile stiffness [kN/m]	max longitudinal force (fx) [kN]	max lateral force (FY) [kN]	maximum total force (Fcombined) [kN]	maximum surge motion (dx) [m]	maximum sway motion (dx) [m]
14.8	321.75	332.65	1.2	4.1	2.4	1.88	0	1599	72	83	110	0.04	0.02
13.5	291.75	309.45	1	3.7	2.8	1.88	0	1599	103	164	194	0.06	0.07
12.1	261.75	270.05	0.7	3.5	3.3	1.88	180	1599	15	307	308	0.01	0.19
12.3	231.75	231.35	0.7	3	3.2	1.88	180	1599	64	95	115	0.04	0.04
11.4	201.75	199.85	0.7	3.1	3.5	1.88	180	1599	44	59	73	0.03	0.01
12	171.75	183.05	0.6	3.1	2.2	1.88	180	1599	79	67	104	0.05	0.00
13.8	141.75	170.05	0.9	3.6	1.7	1.88	180	1599	109	87	140	0.07	0.01
16.4	111.75	149.25	0.8	3.2	1.5	1.88	180	1599	46	50	68	0.03	0.02
17	81.75	81.45	0.6	2.5	2.8	1.88	0	1599	28	289	290	0.01	0.17
16.7	51.75	9.15	0.9	3.6	1.7	1.88	0	1599	162	118	200	0.09	0.01
16.9	21.75	-12.85	1.2	4.2	1.9	1.88	0	1599	136	107	173	0.09	0.01
17	-8.25	-17.85	1.4	4.4	2.1	1.88	0	1599	120	101	156	0.07	0.03
1	261.75	270.05	0.7	3.5	3.3	0.1	0	1599	10	312	312	0.01	0.19

Table 4: Results pontoon analysis 1:1 year condition high stiffness pile (7538kN/m)

Wind Speed [m/s]	Wind Direction [deg]	Wave Direction [deg]	Significant Wave Height [m]	Wave Peak Period [s]	Irregular Wave Gamma [-]	Current Speed [m/s]	Current Direction [deg]	Pile stiffness [kN/m]	max longitudinal force (fx) [kN]	max lateral force (FY) [kN]	maximum total force (Fcombined) [kN]	maximum surge motion (dx) [m]	maximum sway motion (dx) [m]
14.8	321.75	332.65	1.2	4.1	2.4	1.88	0	7538	71	76	104	0.01	0.01
13.5	291.75	309.45	1	3.7	2.8	1.88	0	7538	60	145	157	0.01	0.02
12.1	261.75	270.05	0.7	3.5	3.3	1.88	180	7538	19	298	299	0.00	0.06
12.3	231.75	231.35	0.7	3	3.2	1.88	180	7538	26	98	101	0.01	0.01
11.4	201.75	199.85	0.7	3.1	3.5	1.88	180	7538	38	30	48	0.01	0.00
12	171.75	183.05	0.6	3.1	2.2	1.88	180	7538	68	49	83	0.01	0.00
13.8	141.75	170.05	0.9	3.6	1.7	1.88	180	7538	60	41	72	0.01	0.00
16.4	111.75	149.25	0.8	3.2	1.5	1.88	180	7538	29	43	52	0.01	0.01
17	81.75	81.45	0.6	2.5	2.8	1.88	0	7538	41	336	339	0.01	0.04
16.7	51.75	9.15	0.9	3.6	1.7	1.88	0	7538	105	70	126	0.01	0.00
16.9	21.75	-12.85	1.2	4.2	1.9	1.88	0	7538	125	80	148	0.02	0.01
17	-8.25	-17.85	1.4	4.4	2.1	1.88	0	7538	130	101	165	0.02	0.01
1	261.75	270.05	0.7	3.5	3.3	0.1	0	7538	15	248	248	0.00	0.06

Governing force direction is in transverse direction as this is the side of the pontoon with the largest exposure to wind and waves. It appears that at the high water level the forces are largest, even though the stiffness of the pile is lower than at low water level. Water levels and therefore pile stiffness differs from the 1/100 year condition.

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Pile stiffness [kN/m]	Water depth [m]	Max Fx [kN]	Max Fy [kN]
1599	21	162	312
7538	10	130	336

In the next section motions of the pontoon for the given stiffness values is elaborated. The shown positions are for the COG of the pontoon. The position of the centre of gravity (COG) in longitudinal (X) direction is 0.33m aft of the centreline of the pontoon. This is reflected in the results below. The motions demonstrated by the pontoon for the given stiffness are around this position. All pontoon motions are within the limits as stated in section 2.

Pile stiffness [kN/m]	COG X ** (min) [m]	COG X ** (max) [m]	COG Y (min) [m]	COG Y (max) [m]	COG Z (min) [m]	COG Z (max) [m]
1599	-0.42	-0.24	-0.19	0.18	0.09	0.29
7538 (*)	-0.35	-0.31	-0.06	0.05	0.09	0.29

NOTE(*): determined with high water level model (water depth is 21m)
NOTE(**): The position of the centre of gravity (COG) in longitudinal (X) direction is 33cm aft of the centreline of the pontoon.

Rotations of the pontoon are summarised in the table below. The pontoon demonstrates a roll (RX) of more than 1° to port and starboard for the high stiffness pile (LW). Pitch motion, rotation around Y axis, and yaw motion are less than 1° for both investigated stiffnesses.

Pile stiffness [kN/m]	RX (min) [deg]	RX (max) [deg]	RY (min) [deg]	RY (max) [deg]	RZ (min) [deg]	RZ (max) [deg]
1599	-0.73	0.80	-0.30	0.23	-0.12	0.11
7538(*)	-1.10	1.02	-0.29	0.18	-0.02	0.02

NOTE(*): determined with high water level model (water depth is 21m)

Subject Pontoon motions analysis

Sensitivity checks

In the previous sections the results of environmental loads with return periods of 1 year and 100 year have been investigated. In the coming section the sensitivity of the system to variations in certain parameters is investigated. The following checks have been performed:

- Variation in stiffness
- Variation in Seed number
- Variation in bracket height

Variation in stiffness

As pile stiffness changes with changing water level intermittent stiffnesses are investigated for the governing direction. From the above described calculations it can be concluded that for the governing condition is the beam on wind and wave condition (60°N and 260/270° in the AQWA model). The effect on pile forces for varying stiffness is investigated for this condition. The deep water model is used for this analysis.

The result of this analysis are shown in the figure below. The high water stiffness (1/100 year) of 831kN/m is on the left hand side of the horizontal axis. The low water stiffness (1/100 year) is on the right hand side (9224kN/m). It is found that a peak occurs in pile forces around 3000kN/m with a maximum force of 1126kN.

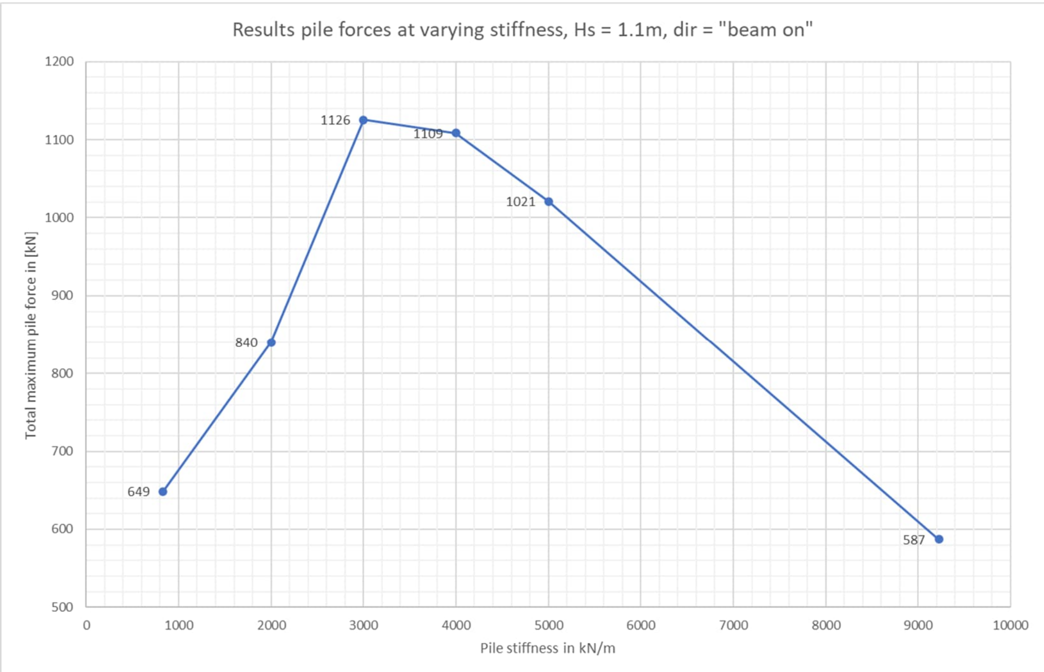

Figure 14: Total maximum pile forces at varying pile stiffness (1/100 year wave condition; beam on)

The pile force shown in this graph the resultant pile force consisting of the square root of the sum of the maximum force in longitudinal direction (x) and maximum force in transverse direction (y)

The same analysis has been performed for wind and waves coming from a bow on direction (351.75° AQWA or 330°N).a lower return period is assumed for this direction; the 1/10 year wave condition has been taken with a wave height (H_s) of 1.7m. The result of the analysis is shown below. it appears a maximum force occurs for a stiffness of around 5000kN/m. The maximum force reached is 241 kN.

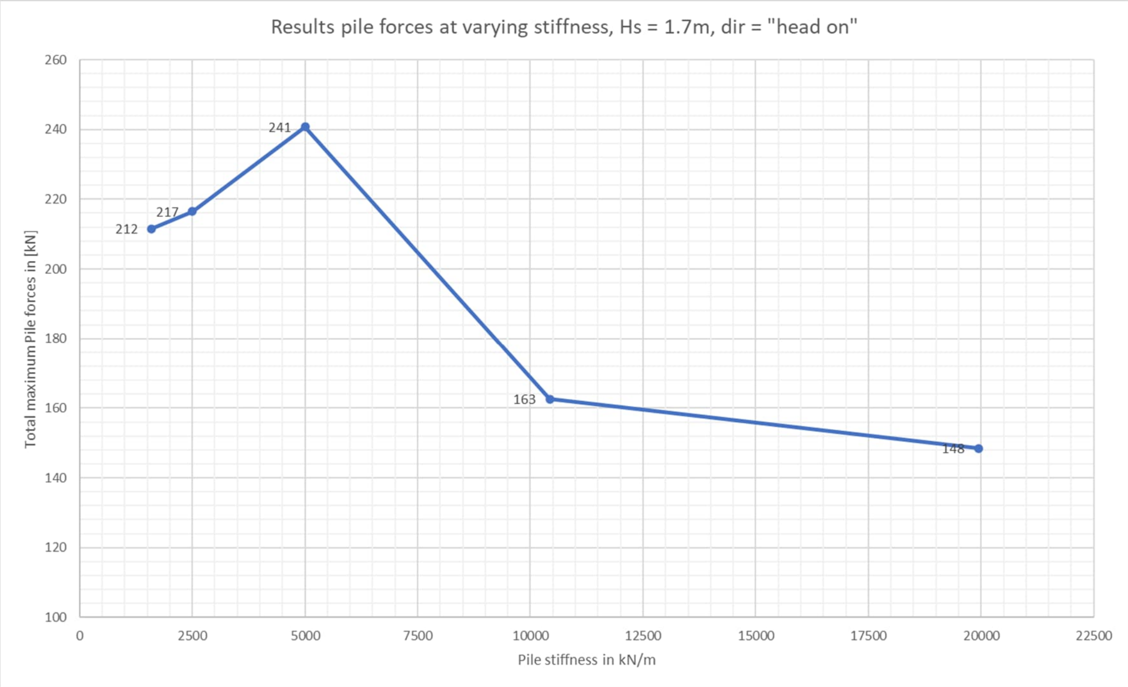

Figure 15: Total maximum pile forces at varying pile stiffness (1/10 year wave condition; head on)

The pile force shown in this graph the resultant pile force consisting of the square root of the sum of the maximum force in longitudinal direction (x) and maximum force in transverse direction (y)

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SEED analysis

Dynamic simulations use seed numbers to calculate a time series of wind and waves from stochastic parameters such as significant wave height (H_s), peak wave period (T_p) and a peak enhancement factor (γ). For any given seed number the time series is always the same. This way calculations are repeatable. As these timeseries are fluctuating by nature and limited in time it possibly does not include all peaks that could occur in a timeseries with specifics such as determined (H_s, T_p, and γ). To investigate this possibility (of underestimating peaks) and to derive at a conservative estimate of the forces the effect of change in seed number is investigated in this section.

The previous value has been determined for a single seed number. Common practice is to investigate the influence of the SEED number on the maximum determined force. In this analysis the seed number is varied 7 times. See Results below.

Table 5: results SEED number analysis

Stiffness [kN/m]	SEED nr [-]	max Fx [kN]	max Fy [kN]
3333	1	72	1118
3333	10	76	982
3333	100	55	1044
3333	1000	70	981
3333	10000	73	1017
3333	100000	58	1017
3333	1E+06	61	863
3333	1E+07	65	936

It appears that the initially chosen seed number of 1 [-] leads to the highest value in transverse forces. All other seed numbers yield lower loads. It is therefore safe to assume that the maximum force determined with the low water model (WD = 10m) of 1164kN is the highest probable maximum force.

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Height of bracket

In all of the calculations a fender connection at the piles at a height of 2.0m (above water level) is assumed. A higher level of connection might be applied than originally assumed. To assess the effect of this change in height a check has been performed with a connection level at +3.3m (above water level). The check has been performed for the 1year condition and the 100 year condition.

Pile stiffness [kN/m]	Water depth [m]	Condition [RP]	Max Fx [kN]	Max Fy [kN]
3333	21	1 year	26	424
3333	21	100 year	57	1024

The resulting loads at a higher connection points are slightly higher for the 1:1 year condition and slightly lower for the 1:100 year condition. For the current design stage this effect is neglected as a higher connection point leads to a lower stiffness of the pile. This has already been considered in the section above.

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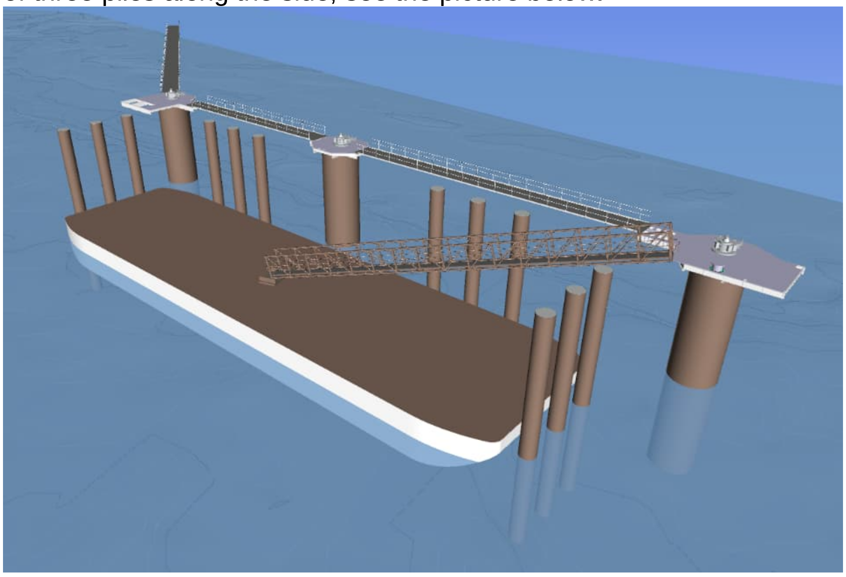
6. Conclusion

In this memo the behaviour of a HEBOP-63 pontoon is investigated for the location of the new jetty in Willemshaven.

The pontoons is investigated both “heavy condition” and “design condition”
It is found that the design weight pontoon behaves better in wave conditions (demonstrating lower pitch and roll motions). From this point of view a HEBO P63 pontoon in design weight condition is chosen in this study.

Proposed arrangement
The moored behaviour of this pontoon is investigated assuming piles at the ends of the pontoon and along the port side. The piles are modelled as fenders with varying stiffness in order to find the optimum arrangement.

A total number of 12 piles is assumed with 3 piles at each end (bow and stern) and two sets of three piles along the side, see the picture below.



It is found that for this configuration of mooring piles and the HEBO P63 pontoon the motions of the pontoon for the stated 1:1year conditions remain within the requirements stated in section 2.

Numerous calculations have been performed varying stiffness, environmental conditions and different seed numbers. It is found that stiffness has a large effect on the resulting pile forces. Based on the calculations a peak in the forces is found for a stiffness of around 3000kN/m. The maximum force corresponding to this pile stiffness and for a “beam on” wave of 1.2m (1:100 year) is 1126kN;

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For bow on waves the peak is noted at 5000kN/m. The maximum force corresponding to this pile stiffness for a “bow on” wave of 1.7m (1:10 year) is 241kN. This value is used in the fatigue analysis in the pile design report [DMC-232011-M-00001-SBE]

The SEED number analysis showed that the originally used SEED number of 1[-] yielded the highest results.