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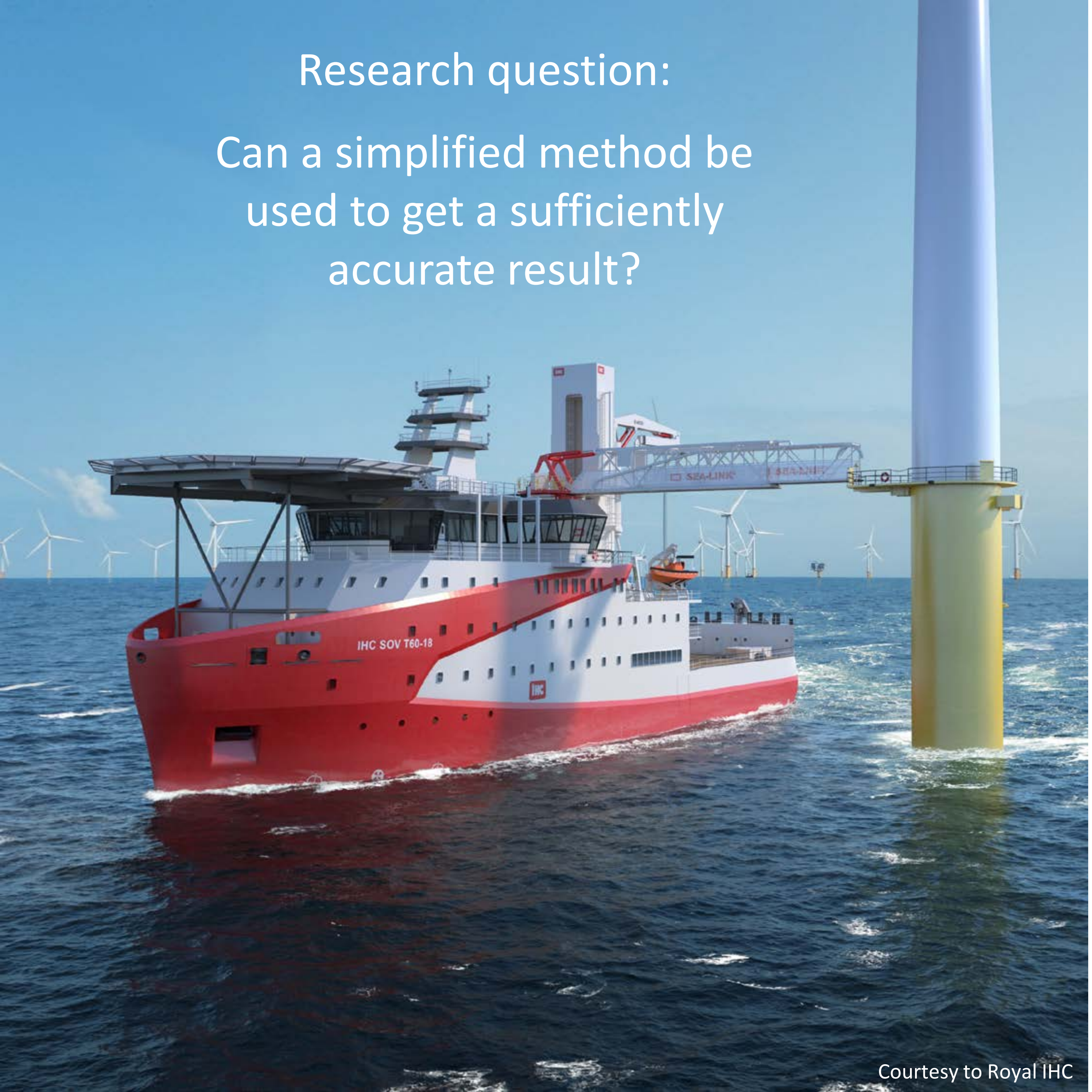
Investigation towards efficient W2W operability simulations

NORTH WIND

Outline

- Problem statement
- Time-domain vs. frequency-domain simulations
- Used simulation models
- Results
- Lessons learned
- Open research questions

Courtesy to Salt Ship Design

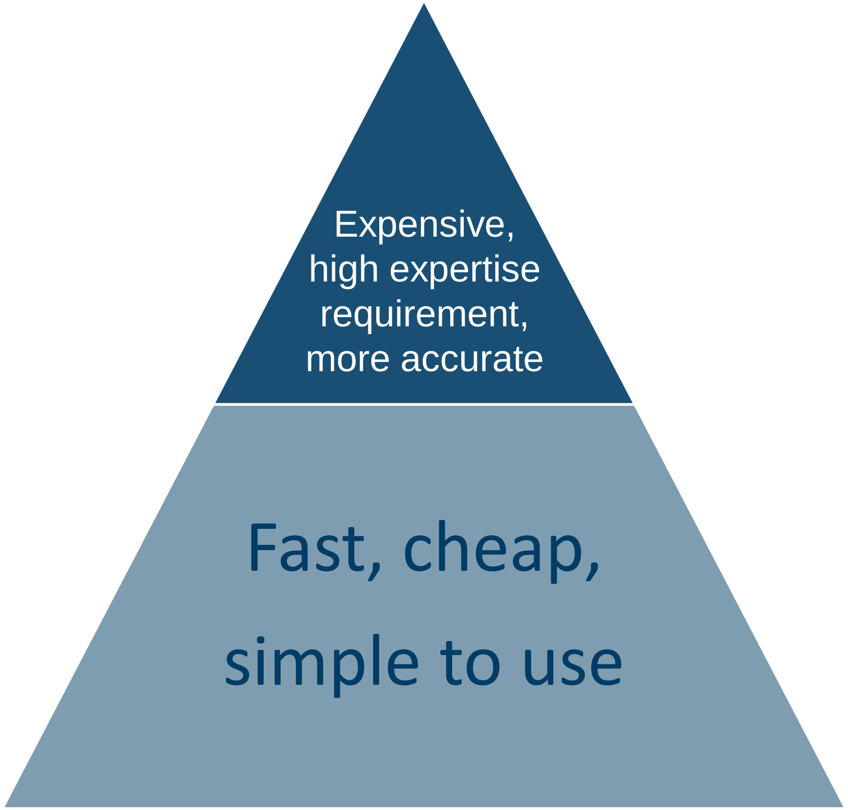


Courtesy to Royal IHC

Problem Statement

1. Time consuming and costly time-domain W2W analysis including non-linear DP performance.
2. Assumed requirement of time-domain analysis for floating OWT gangway W2W analysis.

Time-domain vs. frequency-domain simulation



Time domain simulations of dynamic vessel motion including non-linear DP behavior (e.g., DP3)

Examples: **SIMO, VeSim**

Required input

- First and secondary order wave forces
- Wind and current coefficients
- Physical DP configuration
- Dynamic DP characteristics
- Gangway configuration and characteristics
- Possibly: Floating OWT model, riser behavior, etc.

Simplified station-keeping **frequency domain** analysis (linear approach)

Example: **ShipX/VERES(3D)**

- Vessel motion RAOs
- Gangway configuration and characteristics

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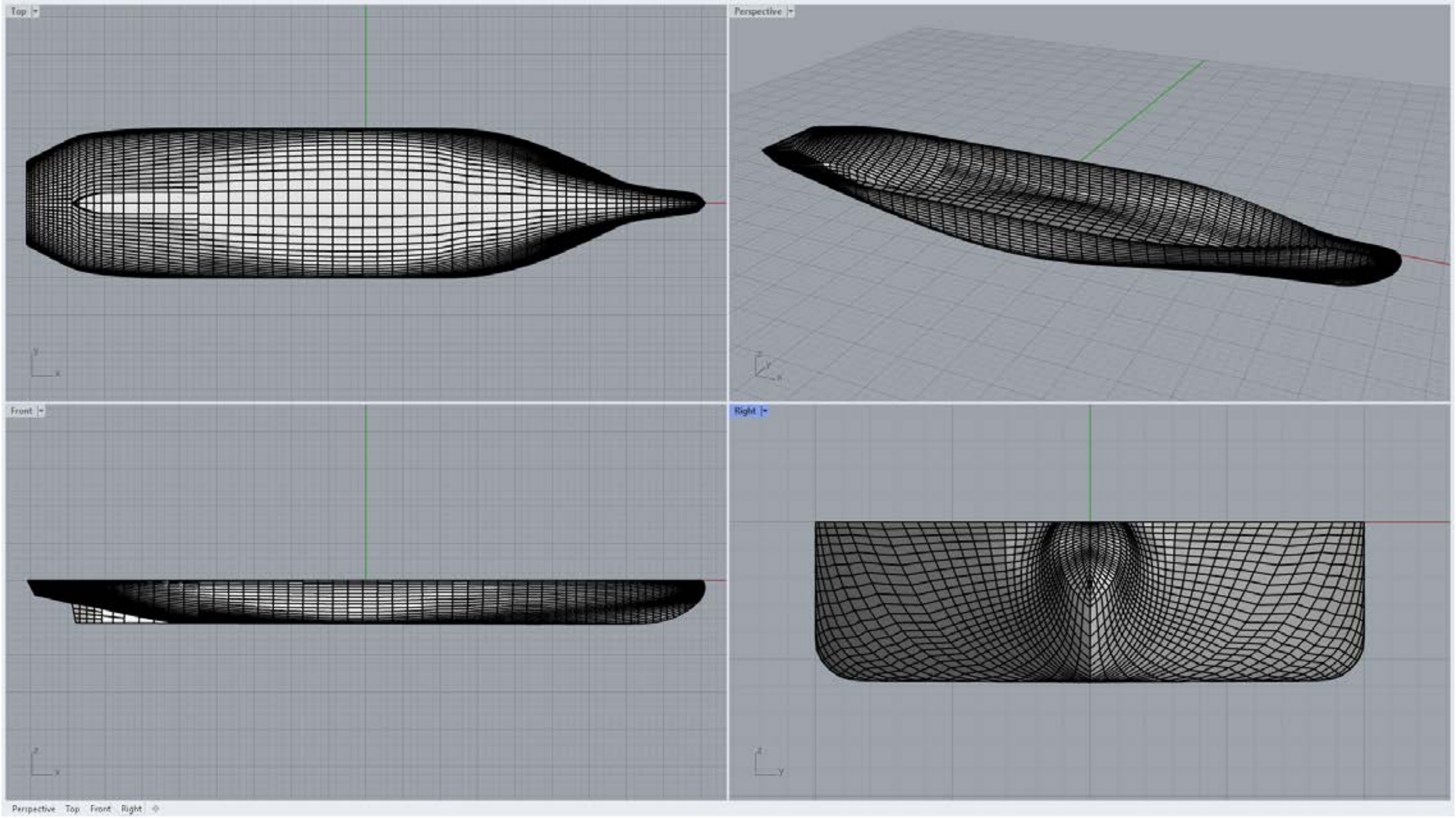
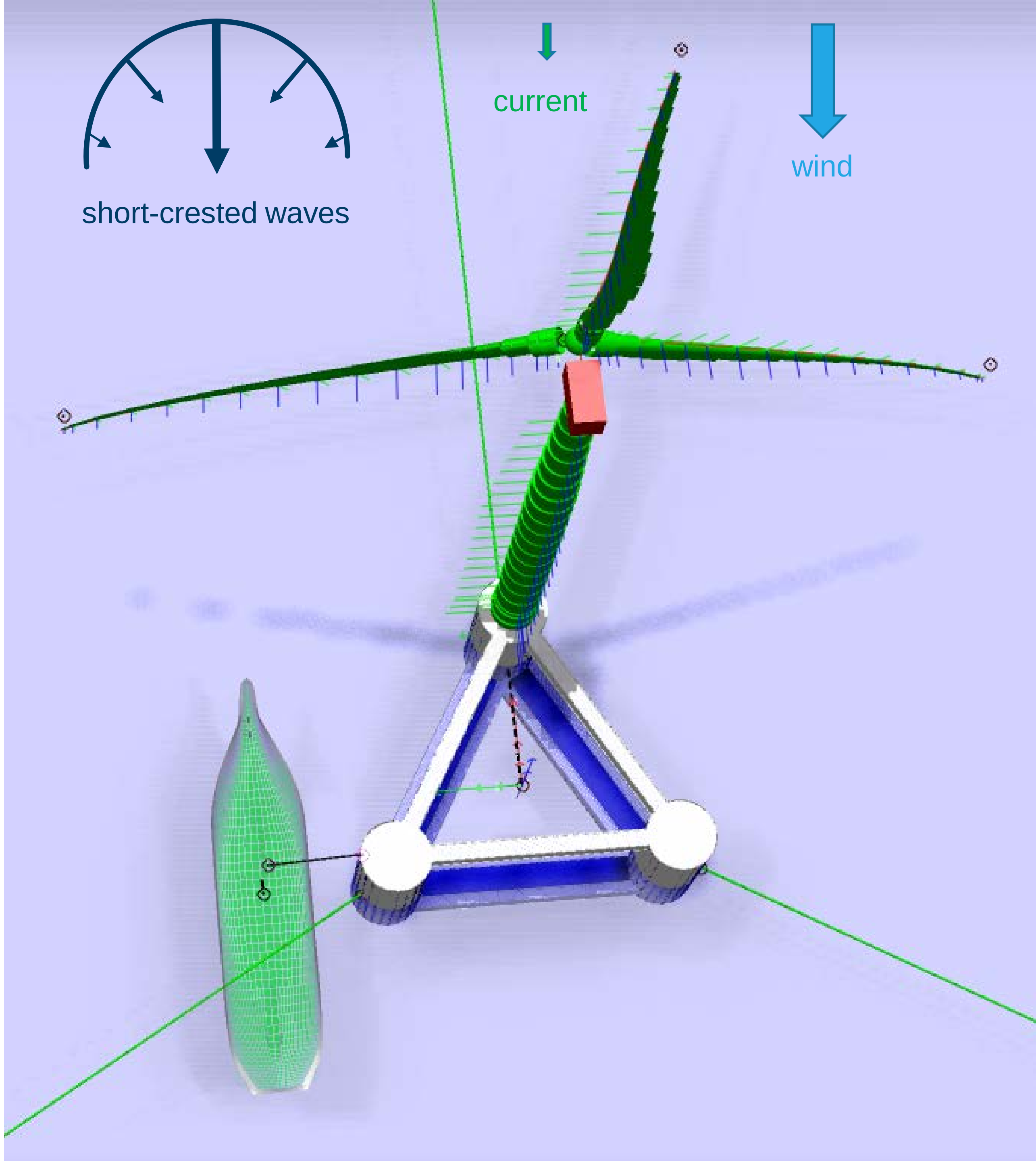
Models used for the calculation

Service Operation Vessel (Typical size SOV in operations since approx. 2015)	
Length (L_{PP}) [m]	80.8
Beam [m]	20.0
Draught [m]	5.8
Displacement [t]	6972.5
Natural heave period (beam seas) [s]	6.8
Natural roll period (beam seas) [s]	12.7
Natural pitch period (head seas) [s]	8.5



Models used for the calculation

INO 12MW WINDMOOR (Advanced Wave and Wind Load Models for Floating Wind Turbine Mooring System Design).	
Displacement [t]	14176.1
Draught [m]	15.5
Hub height [m]	131.7
Natural surge period [s]	97.3
Natural sway period (beam seas) [s]	98.0
Natural heave period (beam seas) [s]	16.3
Natural roll period (beam seas) [s]	29.5
Natural pitch period (head seas) [s]	31.4
Natural yaw period (beam seas) [s]	88.0



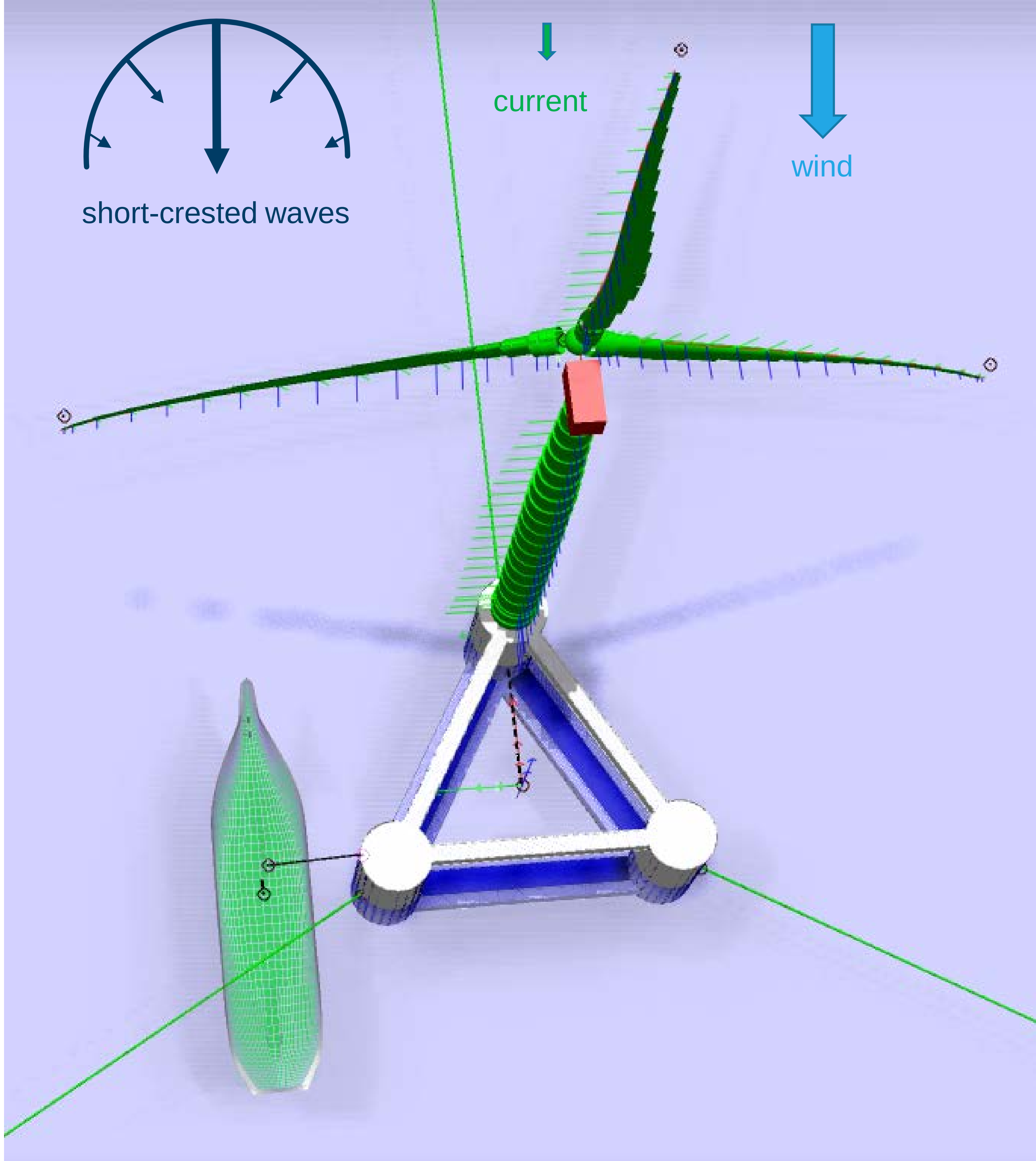
Models used for the calculation

Vessel:

- One loading condition
- Zero ship speed (0kn)
- Head waves (0°)

Collinear weather:

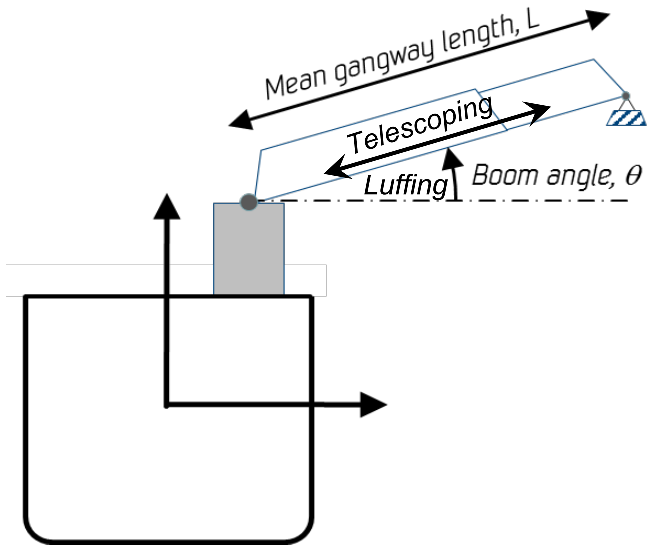
- Short-crested (±90° cos-squared) JONSWAP wave spectrum
- Significant wave height H_S = 3.0m, 3.5m, 4.0m
- Peak periods of 6s ≤ T_P ≤ 20s
- Variable peakedness parameter of 1 ≤ γ ≤ 5 according to DNVGL-RP-C205
- Wind speed 15 m/s (for TD model)
- Current speed 0.3 m/s (for TD model)

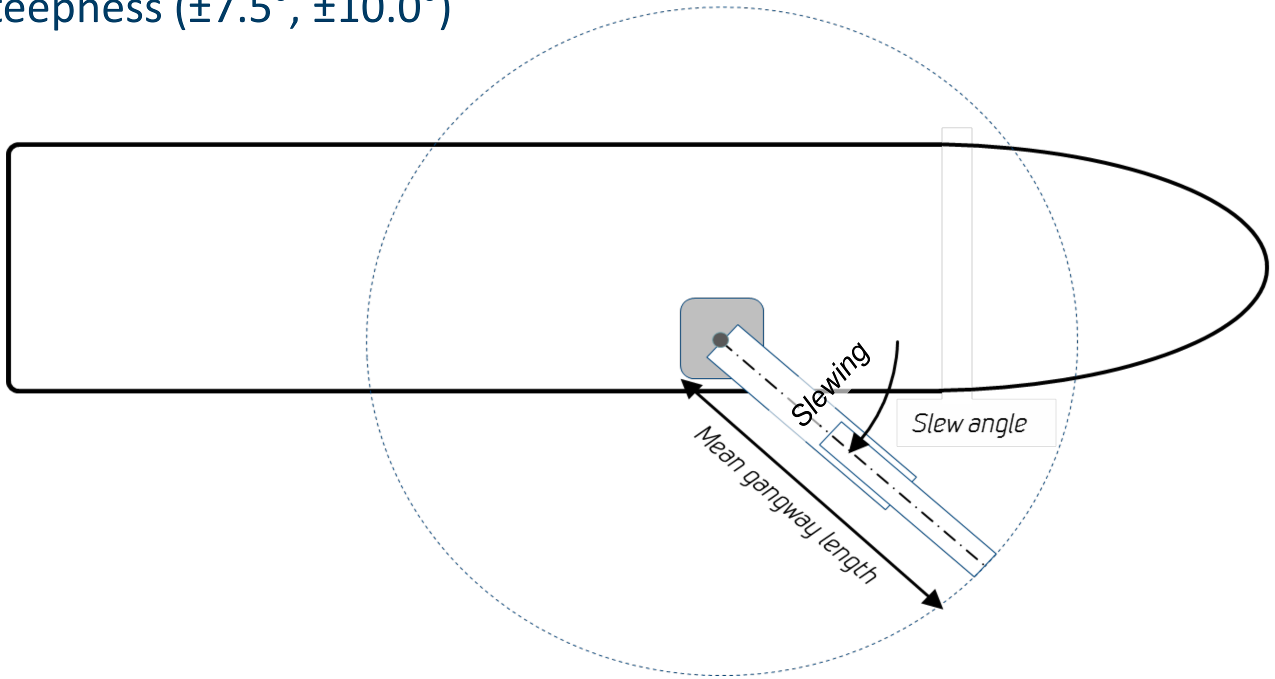


Study parameters

Gangway limitations:

- Telescoping displacement (±2.5m, ±3.0m), velocity (1.5m/s, 2.0m/s)
- Luffing angle (±12°, ±15°) and rate (4°/s, 5°/s)
- Slewing rate (3°/s, 4°/s)
- Steepness (±7.5°, ±10.0°)





Results in terms of:

- Maximum expected H_S for each T_P applying typical AHC gangway limitations.
- Differentiation between
  - People transfer (green)
  - Staying connected (yellow)
  - Disconnect (red)

people transfer	staying connected	disconnect

Bottom-fixed OWT (stationary LP)

Expected Maxima for a 3 hours duration indicate

- Similar results for frequency (FD) vs. time-domain (TD) analysis.
- 2nd order wave force are leading to increased difference at short wave periods (non-linear behavior).

Hs [m]	Tp [s]	Telescoping						Luffing						Slewing			Steepness		
		Displacement [m]			Velocity [m/s]			Range [°]			Rate [°/s]			Rate [°/s]			Range [°]		
		FD	TD	Δ	FD	TD	Δ	FD	TD	Δ	FD	TD	Δ	FD	TD	Δ	FD	TD	Δ
3.0	6	0.405	1.054	160 %	0.418	0.721	72 %	2.368	4.095	73 %	2.462	2.629	7 %	2.187	1.720	-21 %	2.066	3.161	53 %
3.0	7	0.621	1.023	65 %	0.525	0.721	37 %	2.768	3.850	39 %	2.485	2.591	4 %	2.407	1.816	-25 %	2.441	3.003	23 %
3.0	8	0.953	1.103	16 %	0.695	0.779	12 %	3.516	3.900	11 %	2.756	2.704	-2 %	2.151	1.782	-17 %	3.041	3.074	1 %
3.0	9	1.280	1.256	-2 %	0.840	0.849	1 %	4.299	4.385	2 %	3.023	2.937	-3 %	1.991	1.647	-17 %	3.613	3.477	-4 %
3.0	10	1.560	1.430	-8 %	0.957	0.905	-5 %	5.038	5.199	3 %	3.246	3.222	-1 %	1.838	1.532	-17 %	4.140	4.063	-2 %
3.0	11	1.750	1.528	-13 %	1.023	0.914	-11 %	5.635	5.818	3 %	3.383	3.372	0 %	1.707	1.408	-18 %	4.574	4.487	-2 %
3.0	12	1.848	1.495	-19 %	1.041	0.864	-17 %	6.068	6.090	0 %	3.436	3.360	-2 %	1.610	1.415	-12 %	4.919	4.663	-5 %
3.0	13	1.871	1.445	-23 %	1.024	0.820	-20 %	6.356	6.211	-2 %	3.420	3.307	-3 %	1.544	1.434	-7 %	5.191	4.731	-9 %
3.0	14	1.843	1.354	-27 %	0.984	0.772	-22 %	6.529	6.058	-7 %	3.355	3.167	-6 %	1.499	1.454	-3 %	5.403	4.749	-12 %
3.0	15	1.784	1.262	-29 %	0.931	0.733	-21 %	6.622	5.836	-12 %	3.258	3.027	-7 %	1.467	1.461	0 %	5.567	4.730	-15 %
3.0	16	1.710	1.198	-30 %	0.874	0.710	-19 %	6.661	5.662	-15 %	3.144	2.923	-7 %	1.443	1.454	1 %	5.695	4.712	-17 %
3.0	17	1.633	1.190	-27 %	0.816	0.704	-14 %	6.665	5.616	-16 %	3.022	2.872	-5 %	1.422	1.448	2 %	5.794	4.714	-19 %
3.0	18	1.558	1.189	-24 %	0.761	0.699	-8 %	6.649	5.596	-16 %	2.897	2.829	-2 %	1.403	1.445	3 %	5.871	4.727	-19 %
3.0	19	1.489	1.189	-20 %	0.709	0.694	-2 %	6.620	5.567	-16 %	2.775	2.786	0 %	1.384	1.434	4 %	5.930	4.727	-20 %
3.0	20	1.428	1.185	-17 %	0.661	0.687	4 %	6.586	5.511	-16 %	2.657	2.736	3 %	1.364	1.416	4 %	5.975	4.696	-21 %
3.5	6	0.473	1.288	173 %	0.488	0.855	75 %	2.763	5.125	85 %	2.872	3.177	11 %	2.552	2.019	-21 %	2.410	3.956	64 %
3.5	7	0.716	1.252	75 %	0.609	0.857	41 %	3.242	4.871	50 %	2.914	3.139	8 %	2.901	2.117	-27 %	2.870	3.803	33 %
3.5	8	1.116	1.319	18 %	0.820	0.915	12 %	4.141	4.826	17 %	3.243	3.232	0 %	2.545	2.076	-18 %	3.595	3.828	6 %
3.5	9	1.504	1.490	-1 %	0.991	1.000	1 %	5.057	5.269	4 %	3.553	3.481	-2 %	2.298	1.927	-16 %	4.260	4.172	-2 %
3.5	10	1.820	1.638	-10 %	1.117	1.041	-7 %	5.878	5.985	2 %	3.787	3.713	-2 %	2.144	1.816	-15 %	4.831	4.678	-3 %
3.5	11	2.042	1.786	-13 %	1.193	1.070	-10 %	6.574	6.844	4 %	3.947	3.963	0 %	1.992	1.663	-16 %	5.336	5.295	-1 %
3.5	12	2.156	1.768	-18 %	1.215	1.019	-16 %	7.080	7.242	2 %	4.009	3.976	-1 %	1.879	1.649	-12 %	5.739	5.553	-3 %
3.5	13	2.183	1.708	-22 %	1.195	0.964	-19 %	7.415	7.388	0 %	3.990	3.911	-2 %	1.801	1.671	-7 %	6.056	5.639	-7 %
3.5	14	2.150	1.603	-25 %	1.148	0.908	-21 %	7.617	7.215	-5 %	3.914	3.748	-4 %	1.748	1.694	-3 %	6.303	5.662	-10 %
3.5	15	2.081	1.499	-28 %	1.087	0.864	-20 %	7.725	6.961	-10 %	3.802	3.588	-6 %	1.711	1.700	-1 %	6.495	5.643	-13 %
3.5	16	1.995	1.426	-29 %	1.020	0.839	-18 %	7.771	6.768	-13 %	3.668	3.472	-5 %	1.683	1.689	0 %	6.645	5.623	-15 %
3.5	17	1.905	1.420	-25 %	0.952	0.834	-12 %	7.776	6.721	-14 %	3.525	3.418	-3 %	1.659	1.680	1 %	6.760	5.623	-17 %
3.5	18	1.817	1.421	-22 %	0.887	0.829	-7 %	7.757	6.700	-14 %	3.380	3.372	0 %	1.637	1.675	2 %	6.850	5.637	-18 %
3.5	19	1.737	1.422	-18 %	0.827	0.823	0 %	7.724	6.667	-14 %	3.237	3.323	3 %	1.614	1.662	3 %	6.918	5.635	-19 %
3.5	20	1.666	1.419	-15 %	0.771	0.816	6 %	7.684	6.605	-14 %	3.100	3.267	5 %	1.591	1.641	3 %	6.971	5.598	-20 %
4.0	6	0.540	1.541	185 %	0.558	0.986	77 %	3.158	6.178	96 %	3.282	3.728	14 %	2.916	2.325	-20 %	2.754	4.774	73 %
4.0	7	0.813	1.487	83 %	0.693	0.991	43 %	3.706	5.925	60 %	3.333	3.692	11 %	3.358	2.420	-28 %	3.286	4.633	41 %
4.0	8	1.279	1.552	21 %	0.947	1.056	12 %	4.769	5.855	23 %	3.734	3.788	1 %	2.941	2.367	-20 %	4.153	4.638	12 %
4.0	9	1.743	1.734	-1 %	1.156	1.151	0 %	5.872	6.244	6 %	4.119	4.044	-2 %	2.580	2.202	-15 %	4.966	4.933	-1 %
4.0	10	2.080	1.896	-9 %	1.276	1.203	-6 %	6.718	6.935	3 %	4.328	4.292	-1 %	2.450	2.082	-15 %	5.521	5.426	-2 %
4.0	11	2.334	2.033	-13 %	1.364	1.223	-10 %	7.513	7.826	4 %	4.511	4.535	1 %	2.276	1.932	-15 %	6.098	6.070	0 %
4.0	12	2.464	2.046	-17 %	1.388	1.176	-15 %	8.091	8.409	4 %	4.582	4.600	0 %	2.147	1.877	-13 %	6.559	6.459	-2 %
4.0	13	2.495	1.977	-21 %	1.365	1.109	-19 %	8.474	8.593	1 %	4.560	4.521	-1 %	2.058	1.904	-7 %	6.921	6.571	-5 %
4.0	14	2.457	1.858	-24 %	1.312	1.043	-21 %	8.706	8.392	-4 %	4.474	4.331	-3 %	1.998	1.933	-3 %	7.204	6.597	-8 %
4.0	15	2.378	1.742	-27 %	1.242	0.993	-20 %	8.829	8.106	-8 %	4.345	4.149	-5 %	1.956	1.935	-1 %	7.423	6.576	-11 %
4.0	16	2.280	1.654	-27 %	1.165	0.966	-17 %	8.881	7.896	-11 %	4.192	4.023	-4 %	1.924	1.921	0 %	7.594	6.554	-14 %
4.0	17	2.177	1.651	-24 %	1.088	0.962	-12 %	8.887	7.848	-12 %	4.029	3.966	-2 %	1.896	1.909	1 %	7.726	6.554	-15 %
4.0	18	2.077	1.655	-20 %	1.014	0.958	-6 %	8.865	7.830	-12 %	3.863	3.917	1 %	1.871	1.901	2 %	7.828	6.567	-16 %
4.0	19	1.985	1.658	-17 %	0.945	0.952	1 %	8.827	7.795	-12 %	3.700	3.865	4 %	1.845	1.887	2 %	7.907	6.564	-17 %
4.0	20	1.904	1.654	-13 %	0.882	0.944	7 %	8.781	7.724	-12 %	3.542	3.802	7 %	1.818	1.862	2 %	7.967	6.520	-18 %

LP: landing point — FD: frequency domain

Δ: difference — TD: time domain

people transfer | staying connected | disconnect

Windmoor OWT (floating LP)

Expected Maxima for a 3 hours duration indicate

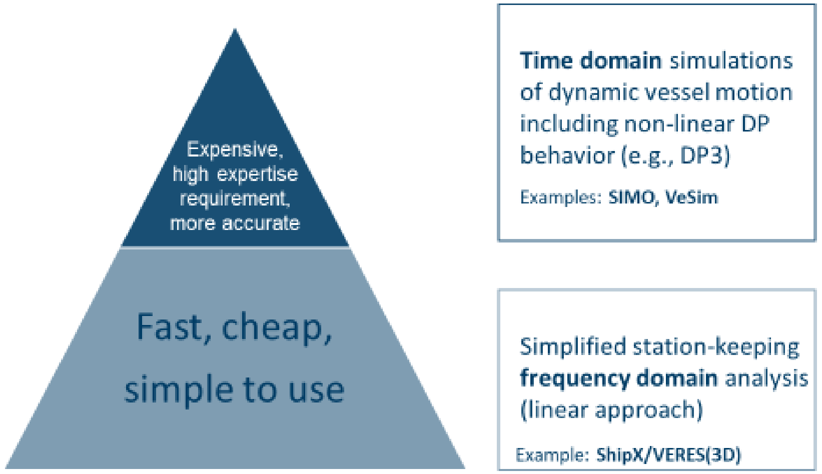
- Generally increased horizontal position deviation towards moving landing point.
- More weather sensitive marine W2W operation.
- Frequency domain simulation results do not sufficiently cover the expected W2W performance behavior.

LP: landing point	FD: frequency domain
Δ: difference	TD: time domain

people transfer	staying connected	disconnect

Hs [m]	Tp [s]	Telescoping						Luffing						Slewing			Steepness		
		Displacement [m]			Velocity [m/s]			Range [°]			Rate [°/s]			Rate [°/s]			Range [°]		
		FD	TD	Δ	FD	TD	Δ	FD	TD	Δ	FD	TD	Δ	FD	TD	Δ	FD	TD	Δ
3.0	6	0.405	2.454	506 %	0.418	0.620	48 %	2.368	2.771	17 %	2.462	2.455	0 %	2.187	3.002	37 %	2.066	2.134	3 %
3.0	7	0.621	1.794	189 %	0.525	0.707	35 %	2.768	3.126	13 %	2.485	2.514	1 %	2.407	3.041	26 %	2.441	2.541	4 %
3.0	8	0.953	1.873	97 %	0.695	0.868	25 %	3.516	3.917	11 %	2.756	2.838	3 %	2.151	2.718	26 %	3.041	3.292	8 %
3.0	9	1.280	2.040	59 %	0.840	1.006	20 %	4.299	4.710	10 %	3.023	3.140	4 %	1.991	2.612	31 %	3.613	4.007	11 %
3.0	10	1.560	2.266	45 %	0.957	1.109	16 %	5.038	5.403	7 %	3.246	3.364	4 %	1.838	2.498	36 %	4.140	4.616	11 %
3.0	11	1.750	2.381	36 %	1.023	1.165	14 %	5.635	6.033	7 %	3.383	3.528	4 %	1.707	2.419	42 %	4.574	5.122	12 %
3.0	12	1.848	2.492	35 %	1.041	1.173	13 %	6.068	6.533	8 %	3.436	3.600	5 %	1.610	2.420	50 %	4.919	5.551	13 %
3.0	13	1.871	2.585	38 %	1.024	1.154	13 %	6.356	7.011	10 %	3.420	3.642	6 %	1.544	2.419	57 %	5.191	5.994	15 %
3.0	14	1.843	2.611	42 %	0.984	1.109	13 %	6.529	7.412	14 %	3.355	3.634	8 %	1.499	2.430	62 %	5.403	6.453	19 %
3.0	15	1.784	2.746	54 %	0.931	1.065	14 %	6.622	7.810	18 %	3.258	3.626	11 %	1.467	2.482	69 %	5.567	6.858	23 %
3.0	16	1.710	2.611	53 %	0.874	0.989	13 %	6.661	7.991	20 %	3.144	3.547	13 %	1.443	2.438	69 %	5.695	7.184	26 %
3.0	17	1.633	2.667	63 %	0.816	0.930	14 %	6.665	8.275	24 %	3.022	3.502	16 %	1.422	2.449	72 %	5.794	7.518	30 %
3.0	18	1.558	2.741	76 %	0.761	0.874	15 %	6.649	8.513	28 %	2.897	3.444	19 %	1.403	2.478	77 %	5.871	7.835	33 %
3.0	19	1.489	2.800	88 %	0.709	0.825	16 %	6.620	8.669	31 %	2.775	3.378	22 %	1.384	2.504	81 %	5.930	8.073	36 %
3.0	20	1.428	2.855	100 %	0.661	0.776	17 %	6.586	8.814	34 %	2.657	3.290	24 %	1.364	2.533	86 %	5.975	8.276	38 %
3.5	6	0.473	3.427	625 %	0.488	0.751	54 %	2.763	3.365	22 %	2.872	2.898	1 %	2.552	3.588	41 %	2.410	2.530	5 %
3.5	7	0.716	2.407	236 %	0.609	0.839	38 %	3.242	3.726	15 %	2.914	2.983	2 %	2.901	3.706	28 %	2.870	2.981	4 %
3.5	8	1.116	2.397	115 %	0.820	1.029	25 %	4.141	4.646	12 %	3.243	3.355	3 %	2.545	3.214	26 %	3.595	3.898	8 %
3.5	9	1.504	2.576	71 %	0.991	1.186	20 %	5.057	5.563	10 %	3.553	3.700	4 %	2.298	3.065	33 %	4.260	4.722	11 %
3.5	10	1.820	2.720	49 %	1.117	1.299	16 %	5.878	6.335	8 %	3.787	3.936	4 %	2.144	2.940	37 %	4.831	5.388	12 %
3.5	11	2.042	2.845	39 %	1.193	1.362	14 %	6.574	7.052	7 %	3.947	4.124	4 %	1.992	2.838	42 %	5.336	5.968	12 %
3.5	12	2.156	2.948	37 %	1.215	1.370	13 %	7.080	7.620	8 %	4.009	4.203	5 %	1.879	2.839	51 %	5.739	6.465	13 %
3.5	13	2.183	3.097	42 %	1.195	1.352	13 %	7.415	8.116	9 %	3.990	4.228	6 %	1.801	2.840	58 %	6.056	6.942	15 %
3.5	14	2.150	3.082	43 %	1.148	1.296	13 %	7.617	8.631	13 %	3.914	4.248	9 %	1.748	2.850	63 %	6.303	7.459	18 %
3.5	15	2.081	3.192	53 %	1.087	1.236	14 %	7.725	9.014	17 %	3.802	4.228	11 %	1.711	2.909	70 %	6.495	7.939	22 %
3.5	16	1.995	3.058	53 %	1.020	1.149	13 %	7.771	9.203	18 %	3.668	4.099	12 %	1.683	2.855	70 %	6.645	8.266	24 %
3.5	17	1.905	3.091	62 %	0.952	1.079	13 %	7.776	9.515	22 %	3.525	4.038	15 %	1.659	2.852	72 %	6.760	8.654	28 %
3.5	18	1.817	3.176	75 %	0.887	1.019	15 %	7.757	9.817	27 %	3.380	3.980	18 %	1.637	2.894	77 %	6.850	9.029	32 %
3.5	19	1.737	3.249	87 %	0.827	0.960	16 %	7.724	10.023	30 %	3.237	3.898	20 %	1.614	2.924	81 %	6.918	9.289	34 %
3.5	20	1.666	3.399	104 %	0.771	0.912	18 %	7.684	10.202	33 %	3.100	3.805	23 %	1.591	2.961	86 %	6.971	9.541	37 %
4.0	6	0.540	4.907	808 %	0.558	0.889	59 %	3.158	3.938	25 %	3.282	3.347	2 %	2.916	4.165	43 %	2.754	2.952	7 %
4.0	7	0.813	2.788	243 %	0.693	0.967	39 %	3.706	4.319	17 %	3.333	3.448	3 %	3.358	4.295	28 %	3.286	3.431	4 %
4.0	8	1.279	3.000	134 %	0.947	1.203	27 %	4.769	5.408	13 %	3.734	3.891	4 %	2.941	3.707	26 %	4.153	4.517	9 %
4.0	9	1.743	3.141	80 %	1.156	1.383	20 %	5.872	6.489	10 %	4.119	4.300	4 %	2.580	3.478	35 %	4.966	5.501	11 %
4.0	10	2.080	3.252	56 %	1.276	1.485	16 %	6.718	7.249	8 %	4.328	4.495	4 %	2.450	3.384	38 %	5.521	6.162	12 %
4.0	11	2.334	3.259	40 %	1.364	1.556	14 %	7.513	8.069	7 %	4.511	4.717	5 %	2.276	3.263	43 %	6.098	6.828	12 %
4.0	12	2.464	3.373	37 %	1.388	1.564	13 %	8.091	8.684	7 %	4.582	4.793	5 %	2.147	3.243	51 %	6.559	7.357	12 %
4.0	13	2.495	3.508	41 %	1.365	1.542	13 %	8.474	9.261	9 %	4.560	4.832	6 %	2.058	3.256	58 %	6.921	7.906	14 %
4.0	14	2.457	3.567	45 %	1.312	1.476	12 %	8.706	9.790	12 %	4.474	4.835	8 %	1.998	3.276	64 %	7.204	8.456	17 %
4.0	15	2.378	3.598	51 %	1.242	1.411	14 %	8.829	10.195	15 %	4.345	4.775	10 %	1.956	3.306	69 %	7.423	8.926	20 %
4.0	16	2.280	3.523	55 %	1.165	1.319	13 %	8.881	10.429	17 %	4.192	4.658	11 %	1.924	3.271	70 %	7.594	9.345	23 %
4.0	17	2.177	3.504	61 %	1.088	1.240	14 %	8.887	10.814	22 %	4.029	4.615	15 %	1.896	3.270	72 %	7.726	9.796	27 %
4.0	18	2.077	3.578	72 %	1.014	1.166	15 %	8.865	11.097	25 %	3.863	4.508	17 %	1.871	3.315	77 %	7.828	10.167	30 %
4.0	19	1.985	3.715	87 %	0.945	1.093	16 %	8.827	11.310	28 %	3.700	4.402	19 %	1.845	3.352	82 %	7.907	10.483	33 %
4.0	20	1.904	3.840	102 %	0.882	1.041	18 %	8.781	11.573	32 %	3.542	4.344	23 %	1.818	3.378	86 %	7.967	10.785	35 %

Lessons learned: Time-domain vs. frequency-domain simulation



When to use time-domain simulations?

- When absolute W2W performance results are required.
- For (accurate) floater to floater simulations.
- For non-collinear waves (wind and swell sea).
- For highly non-linear sea states (large and steep waves with significant wave drift force contribution).
- For the evaluation of discrete events.
- When the performance of the DP-system is questionable or of special interest (DP3 site analysis).

When is frequency-domain analysis sufficient?

- For bottom fixed landing points.
- For generalized weather conditions and headings.
- As time efficient analysis method.
- For screening of operability limits using historical wave data.

Courtesy to Salt Ship Design

Open research questions

- Is there a feasible approach to simplify the level of details or to substitute time-domain simulations for W2W simulations towards floating OWT?
- Is it realistic to use a simplified method and add a generally applicable safety or correction factor to compensate for reduced simulation model complexity?
- Is it sufficient to apply frequency-domain analysis on a pre-calculated *Difference-RAO*, describing relative motions between two bodies?

Thank you for your Questions & Contributions

NORTH WIND