X-SEA VERIFICATION REPORT 4
Offshore Monopile Structures

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Document control:

Version	Date	Document History	Prepared by	Approved by
01	24/12/2019	Offshore tripod structure subjected to self-weight, Airy's wave, and Stoke's 5th order wave.	Van Nguyen Dinh	Ki-Du Kim

Summary:

This document reports the verification of X-SEA software using the static analysis of an offshore monopile structure subjected to self-weight, Airy's wave, and Stoke's 5th order wave and comparing with the SACS software results. The jacket structure has 30 meters height with a fixed pile support at the bottom. The reaction at the support, displacement and internal forces calculated in X-SEA and SACS are in good agreement.

Table of Contents

Offshore Monopile Structure

1   Introduction

For the verification of X-SEA software, the static analysis of an offshore monopile structure subjected to self-weight, Airy's wave, and Stoke's 5th order wave is carried out using X-SEA and SACS software. The monopile structure has 30 meters height and a fixed pile support at the bottom.

In order to compare the X-SEA results with those of SACS, the reaction at supports, displacement of main legs and internal member forces in both X-SEA and SACS were calculated as shown in the form of tables and plots. The reaction force is taken from the fixed support at the bottom of the structure. Displacement and internal forces are compared at several node in the structure. All the node positions calculated from the X-SEA and SACS are illustrated in **Figure 1** and **Figure 2**, respectively. There are total 31 nodes and 30 elements in each model.
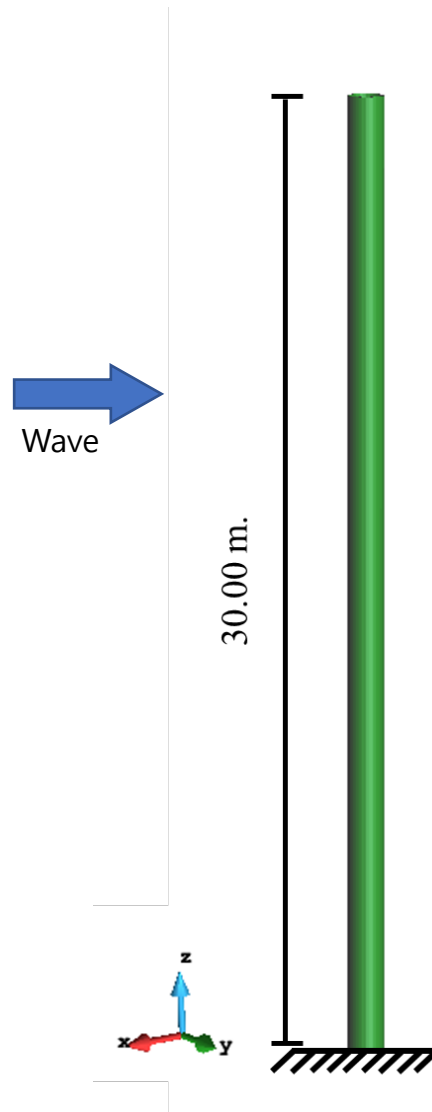
Figure 1. Model of the offshore monopile substructure in X-SEA
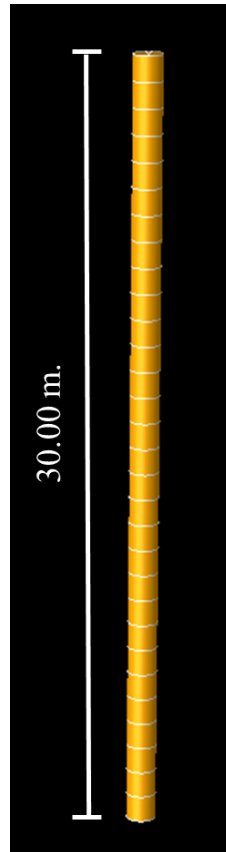
Figure 2. Model of the offshore monopile substructure in SACS.

2   Geometric and Material Properties of Offshore Monopile Structure

The monopile height is 30 m and in circular hollow section illustrated in **Figure 3** with outer diameter of 1.129 m and thickness of 0.030m.
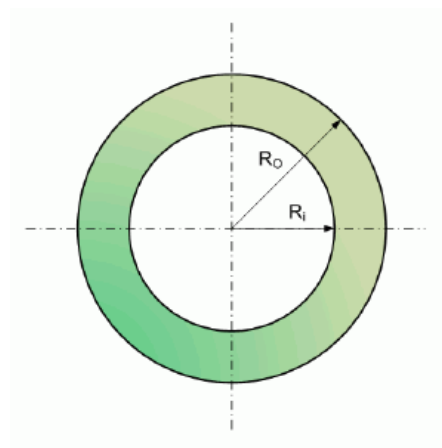
Figure 3. Circular hollow section

The material properties of steel for the tripod top, legs and bracings to be used in the analysis are elastic modulus E = 2.0×10^{11} N/m2; Poisson's ratio (ν) = 0.30 and mass density = 7850 kg/m3.

3   Analysis Results of X-SEA and SACS

3.1   Monopile structure subjected to self-weight loads

The reactions of the monopile subjected to self-weight loads by X-SEA model and SACS model are in **Table 1** that shows good agreement in the results from the two software.

Table 1. Reaction of the monopile subjected to self-weight load by X-SEA and SACS models

Node	CASE – Self weight ---- Reaction by X-SEA and SACS					
	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
X-SEA	0.000	0.000	239.261	0.000	0.000	0.000
SACS	0.000	0.000	239.210	0.000	0.000	0.000
Nominal	-	-	1.000	-	-	-

3.2   Monopile structure subjected to Airy's wave

Table 2. Environment condition and Airy's wave parameters

Environment condition	Wave parameter
Water depth = 22.86 m.	Wave theory = Airy wave theory
Sea bed level = 0.00 m.	Water density = 1025 kg/m^3
Water density = 1025 kg/m^3	Wave height = 10.66 m
Air Density = 1.25 kg/m^3	Wave period = 9.27 seconds

3.2.1 Wave force

Table 3. Wave forces on the offshore monopile structure by using to Airy's wave

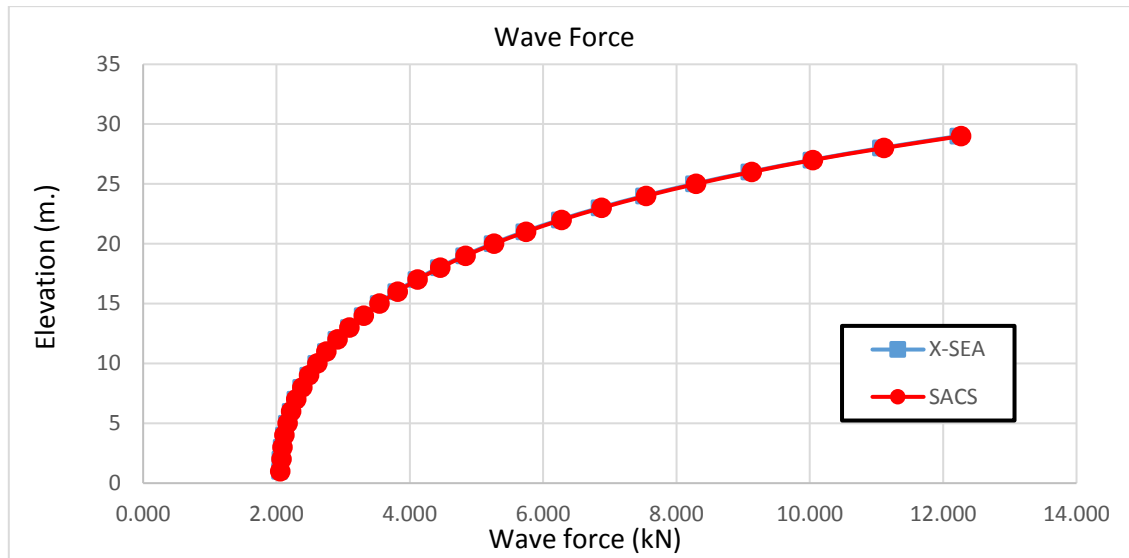| Wave Force						
	X-SEA			SACS		
Elevation (m)	F_X(kN)	F_Y(kN)	F_Z(kN)	F_X(kN)	F_Y(kN)	F_Z(kN)
29.00	12.222	0.000	0.000	12.271	0.000	0.000
28.00	11.059	0.000	0.000	11.11	0.000	0.000
27.00	10.018	0.000	0.000	10.647	0.000	0.000
26.00	9.087	0.000	0.000	9.128	0.000	0.000
25.00	8.253	0.000	0.000	8.293	0.000	0.000
24.00	7.507	0.000	0.000	7.545	0.000	0.000
23.00	6.840	0.000	0.000	6.877	0.000	0.000
22.00	6.243	0.000	0.000	6.277	0.000	0.000
21.00	5.710	0.000	0.000	5.743	0.000	0.000
20.00	5.233	0.000	0.000	5.264	0.000	0.000
19.00	4.808	0.000	0.000	4.837	0.000	0.000
18.00	4.429	0.000	0.000	4.458	0.000	0.000
17.00	4.091	0.000	0.000	4.115	0.000	0.000
16.00	3.791	0.000	0.000	3.817	0.000	0.000
15.00	3.524	0.000	0.000	3.543	0.000	0.000
14.00	3.287	0.000	0.000	3.312	0.000	0.000
13.00	3.078	0.000	0.000	3.095	0.000	0.000
12.00	2.894	0.000	0.000	2.917	0.000	0.000
11.00	2.732	0.000	0.000	2.749	0.000	0.000
10.00	2.592	0.000	0.000	2.614	0.000	0.000
9.00	2.470	0.000	0.000	2.488	0.000	0.000
8.00	2.366	0.000	0.000	2.386	0.000	0.000
7.00	2.278	0.000	0.000	2.299	0.000	0.000
6.00	2.205	0.000	0.000	2.221	0.000	0.000
5.00	2.147	0.000	0.000	2.169	0.000	0.000
4.00	2.103	0.000	0.000	2.119	0.000	0.000
3.00	2.071	0.000	0.000	2.091	0.000	0.000
2.00	2.052	0.000	0.000	2.074	0.000	0.000
1.00	2.046	0.000	0.000	2.058	0.000	0.000

Figure 4. Comparison of wave forces in X-direction of the ponopile between X-SEA and SACS results using Airy's wave theory according to the height

3.2.2   Reaction

Table 4. Reactions of the monopile structure by X-SEA using Airy's wave theory

| Node	Case 1 : Airy ----- Wave Reaction					
	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
X-SEA	-132.368	0.000	0.000	0.000	-2466.690	0.000
SACS	-133.123	0.000	0.000	0.000	-2478.245	0.000
Normalised	0.994	-	-	-	0.995	-

3.2.3   Displacement

Table 5. Displacement of the offshore monopile structure by X-SEA using Airy's wave

Elevation (m)	Case 1 : Airy ----- Displacement from X-SEA					
	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
30.00	191.815	-0.015	0.000	0.000	0.009	0.000
29.00	183.223	-0.014	0.000	0.000	0.009	0.000
28.00	174.631	-0.014	0.000	0.000	0.009	0.000
27.00	166.037	-0.013	0.000	0.000	0.009	0.000
26.00	157.443	-0.012	0.000	0.000	0.009	0.000
25.00	148.857	-0.012	0.000	0.000	0.009	0.000
24.00	140.286	-0.011	0.000	0.000	0.009	0.000
23.00	131.744	-0.010	0.000	0.000	0.009	0.000
22.00	123.247	-0.010	0.000	0.000	0.008	0.000
21.00	114.810	-0.009	0.000	0.000	0.008	0.000
20.00	106.455	-0.008	0.000	0.000	0.008	0.000
19.00	98.203	-0.008	0.000	0.000	0.008	0.000
18.00	90.077	-0.007	0.000	0.000	0.008	0.000
17.00	82.102	-0.006	0.000	0.000	0.008	0.000
16.00	74.305	-0.006	0.000	0.000	0.008	0.000
15.00	66.715	-0.005	0.000	0.000	0.007	0.000
14.00	59.360	-0.005	0.000	0.000	0.007	0.000
13.00	52.271	-0.004	0.000	0.000	0.007	0.000
12.00	45.480	-0.004	0.000	0.000	0.007	0.000
11.00	39.019	-0.003	0.000	0.000	0.006	0.000
10.00	32.922	-0.003	0.000	0.000	0.006	0.000
9.00	27.224	-0.002	0.000	0.000	0.005	0.000
8.00	21.960	-0.002	0.000	0.000	0.005	0.000
7.00	17.167	-0.001	0.000	0.000	0.005	0.000
6.00	12.882	-0.001	0.000	0.000	0.004	0.000
5.00	9.142	-0.001	0.000	0.000	0.003	0.000
4.00	5.986	0.000	0.000	0.000	0.003	0.000
3.00	3.454	0.000	0.000	0.000	0.002	0.000
2.00	1.585	0.000	0.000	0.000	0.001	0.000
1.00	0.420	0.000	0.000	0.000	0.001	0.000

Table 5. Displacement of the offshore monopile structure by X-SEA using Airy's wave

Table 6. Displacement of the offshore monopile structure by SACS using Airy's wave theory.

Elevation (m)	Case 1 : Airy ----- Displacement from SACS					
	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
30.00	192.107	0.000	0.000	0.000	0.009	0.000
29.00	183.476	0.000	0.000	0.000	0.009	0.000
28.00	174.844	0.000	0.000	0.000	0.009	0.000
27.00	166.213	0.000	0.000	0.000	0.009	0.000
26.00	157.585	0.000	0.000	0.000	0.009	0.000
25.00	148.966	0.000	0.000	0.000	0.009	0.000
24.00	140.366	0.000	0.000	0.000	0.009	0.000
23.00	131.797	0.000	0.000	0.000	0.009	0.000
22.00	123.273	0.000	0.000	0.000	0.008	0.000
21.00	114.813	0.000	0.000	0.000	0.008	0.000
20.00	106.436	0.000	0.000	0.000	0.008	0.000
19.00	98.163	0.000	0.000	0.000	0.008	0.000
18.00	90.018	0.000	0.000	0.000	0.008	0.000
17.00	82.027	0.000	0.000	0.000	0.008	0.000
16.00	74.215	0.000	0.000	0.000	0.008	0.000
15.00	66.611	0.000	0.000	0.000	0.007	0.000
14.00	59.245	0.000	0.000	0.000	0.007	0.000
13.00	52.146	0.000	0.000	0.000	0.007	0.000
12.00	45.347	0.000	0.000	0.000	0.007	0.000
11.00	38.881	0.000	0.000	0.000	0.006	0.000
10.00	32.782	0.000	0.000	0.000	0.006	0.000
9.00	27.084	0.000	0.000	0.000	0.005	0.000
8.00	21.822	0.000	0.000	0.000	0.005	0.000
7.00	17.034	0.000	0.000	0.000	0.005	0.000
6.00	12.757	0.000	0.000	0.000	0.004	0.000
5.00	9.029	0.000	0.000	0.000	0.003	0.000
4.00	5.888	0.000	0.000	0.000	0.003	0.000
3.00	3.374	0.000	0.000	0.000	0.002	0.000
2.00	1.527	0.000	0.000	0.000	0.001	0.000
1.00	0.389	0.000	0.000	0.000	0.001	0.000
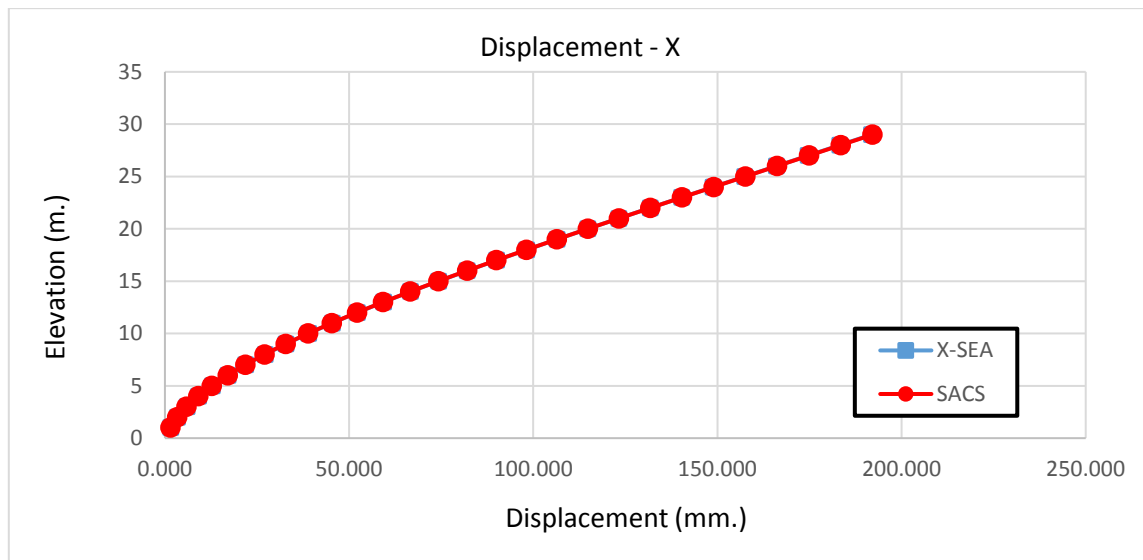
Figure 5. Comparison of X-displacement of the offshore monopile between X-SEA and SACS results using Airy's wave theory according to the height

3.2.4   Member Force

Table 7. Member forces of the offshore monopile by X-SEA model using Airy's wave theory

Elevation (m)	Case 1 : Airy ----- Member force from X-SEA					
	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
29.00	0.000	-0.089	0.000	0.000	0.000	-0.061
28.00	0.000	-8.400	0.000	0.001	0.000	-7.669
27.00	0.000	-19.468	0.000	0.003	0.000	-27.210
26.00	0.000	-29.493	0.000	0.005	0.000	-56.769
25.00	0.000	-38.586	0.000	0.006	0.000	-95.414
24.00	0.000	-46.845	0.000	0.008	0.000	-142.311
23.00	0.000	-54.357	0.000	0.009	0.000	-196.716
22.00	0.000	-61.202	0.000	0.010	0.000	-257.959
21.00	0.000	-67.449	0.000	0.011	0.000	-325.446
20.00	0.000	-73.162	0.000	0.012	0.000	-398.642
19.00	0.000	-78.399	0.000	0.013	0.000	-477.071
18.00	0.000	-83.211	0.000	0.013	0.000	-560.308
17.00	0.000	-87.642	0.000	0.014	0.000	-647.975
16.00	0.000	-91.736	0.000	0.015	0.000	-739.732
15.00	0.000	-95.529	0.000	0.015	0.000	-835.280
14.00	0.000	-99.055	0.000	0.016	0.000	-934.351
13.00	0.000	-102.343	0.000	0.017	0.000	-1036.710
12.00	0.000	-105.423	0.000	0.017	0.000	-1142.150
11.00	0.000	-108.318	0.000	0.018	0.000	-1250.480
10.00	0.000	-111.052	0.000	0.018	0.000	-1361.540
9.00	0.000	-113.645	0.000	0.018	0.000	-1475.190
8.00	0.000	-116.116	0.000	0.019	0.000	-1591.310
7.00	0.000	-118.482	0.000	0.019	0.000	-1709.800
6.00	0.000	-120.761	0.000	0.020	0.000	-1830.570
5.00	0.000	-122.968	0.000	0.020	0.000	-1953.540
4.00	0.000	-125.116	0.000	0.020	0.000	-2078.660
3.00	0.000	-127.219	0.000	0.021	0.000	-2205.880
2.00	0.000	-129.291	0.000	0.021	0.000	-2335.180
1.00	0.000	-131.345	0.000	0.021	0.000	-2466.520

Table 7. Member forces of the offshore monopile by X-SEA model using Airy's wave theory

Table 8. Member force of the offshore monopile by SACS model using Airy's wave theory

Elevation (m)	Case 1 : Airy ----- Member force from SACS					
	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
29.00	0.000	0.000	0.000	0.000	0.000	0.000
28.00	0.000	-2.356	0.000	0.000	0.000	0.225
27.00	0.000	-14.046	0.000	0.000	0.000	8.522
26.00	0.000	-24.633	0.000	0.000	0.000	27.949
25.00	0.000	-34.229	0.000	0.000	0.000	57.458
24.00	0.000	-42.940	0.000	0.000	0.000	96.112
23.00	0.000	-50.859	0.000	0.000	0.000	143.070
22.00	0.000	-58.067	0.000	0.000	0.000	197.590
21.00	0.000	-64.644	0.000	0.000	0.000	259.000
20.00	0.000	-70.654	0.000	0.000	0.000	326.690
19.00	0.000	-76.157	0.000	0.000	0.000	400.140
18.00	0.000	-81.208	0.000	0.000	0.000	478.850
17.00	0.000	-85.855	0.000	0.000	0.000	562.420
16.00	0.000	-90.141	0.000	0.000	0.000	650.440
15.00	0.000	-94.108	0.000	0.000	0.000	742.590
14.00	0.000	-97.788	0.000	0.000	0.000	838.560
13.00	0.000	-101.220	0.000	0.000	0.000	938.080
12.00	0.000	-104.420	0.000	0.000	0.000	1040.900
11.00	0.000	-107.430	0.000	0.000	0.000	1146.900
10.00	0.000	-110.260	0.000	0.000	0.000	1255.700
9.00	0.000	-112.940	0.000	0.000	0.000	1367.300
8.00	0.000	-115.490	0.000	0.000	0.000	1481.500
7.00	0.000	-117.930	0.000	0.000	0.000	1598.300
6.00	0.000	-120.270	0.000	0.000	0.000	1717.400
5.00	0.000	-122.530	0.000	0.000	0.000	1838.800
4.00	0.000	-124.730	0.000	0.000	0.000	1962.400
3.00	0.000	-126.870	0.000	0.000	0.000	2088.200
2.00	0.000	-128.970	0.000	0.000	0.000	2216.100
1.00	0.000	-131.060	0.000	0.000	0.000	2346.200

Table 8. Member force of the offshore monopile by SACS model using Airy's wave theory
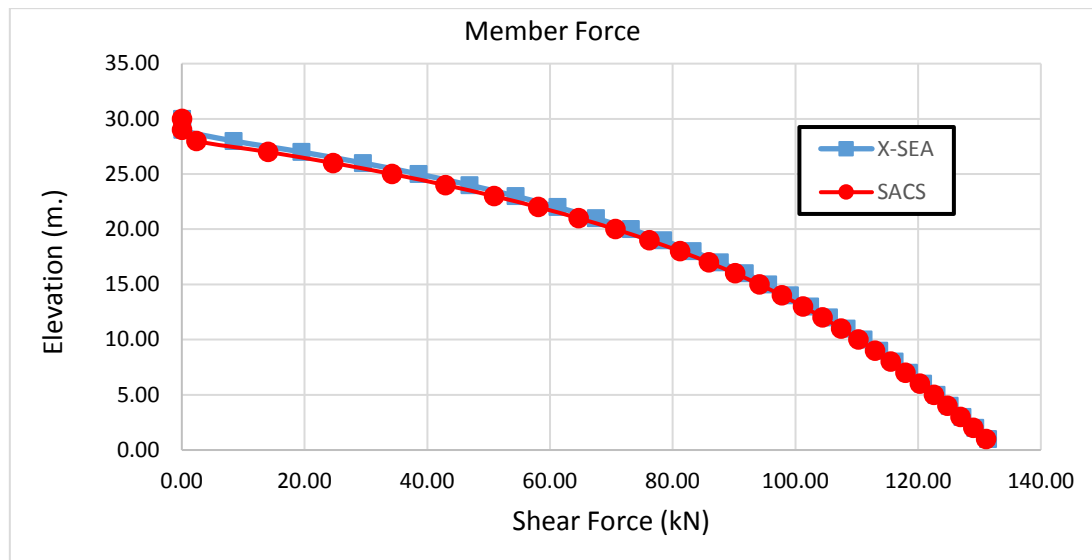
Figure 6. Comparison of axial force of monopile between X-SEA and SACS results using Airy's wave theory according to the height

3.3   Offshore monopile structure subjected to Stoke's wave

Table 9. Environment condition and wave parameters

Environment condition	Wave parameter
Water depth = 22.86 m.	Wave theory = Stoke wave theory
Sea bed level = 0.00 m.	Water density = 1025 kg/m^3
Water density = 1025 kg/m^3	Wave height = 10.66 m
Air Density = 1.25 kg/m^3	Wave period = 9.27 seconds

3.3.1   Wave forces

Table 10. Wave forces of offshore monopile due to Stoke's wave

	Wave Force					
	X-SEA			SACS		
Elevation (m)	F_X(kN)	F_Y(kN)	F_Z(kN)	F_X(kN)	F_Y(kN)	F_Z(kN)
29.00	14.427	0.000	0.000	14.540	0.000	0.000
28.00	12.844	0.000	0.000	12.958	0.000	0.000
27.00	11.459	0.000	0.000	11.569	0.000	0.000
26.00	10.247	0.000	0.000	10.350	0.000	0.000
25.00	9.184	0.000	0.000	9.283	0.000	0.000
24.00	8.251	0.000	0.000	8.346	0.000	0.000
23.00	7.433	0.000	0.000	7.521	0.000	0.000
22.00	6.714	0.000	0.000	6.800	0.000	0.000
21.00	6.082	0.000	0.000	6.162	0.000	0.000
20.00	5.525	0.000	0.000	5.601	0.000	0.000
19.00	5.036	0.000	0.000	5.110	0.000	0.000
18.00	4.606	0.000	0.000	4.671	0.000	0.000
17.00	4.227	0.000	0.000	4.295	0.000	0.000
16.00	3.894	0.000	0.000	3.952	0.000	0.000
15.00	3.601	0.000	0.000	3.663	0.000	0.000
14.00	3.344	0.000	0.000	3.398	0.000	0.000
13.00	3.119	0.000	0.000	3.175	0.000	0.000
12.00	2.922	0.000	0.000	2.975	0.000	0.000
11.00	2.751	0.000	0.000	2.801	0.000	0.000
10.00	2.603	0.000	0.000	2.655	0.000	0.000
9.00	2.475	0.000	0.000	2.517	0.000	0.000
8.00	2.367	0.000	0.000	2.412	0.000	0.000
7.00	2.276	0.000	0.000	2.321	0.000	0.000
6.00	2.201	0.000	0.000	2.245	0.000	0.000
5.00	2.141	0.000	0.000	2.189	0.000	0.000
4.00	2.095	0.000	0.000	2.134	0.000	0.000
3.00	2.063	0.000	0.000	2.109	0.000	0.000
2.00	2.043	0.000	0.000	2.091	0.000	0.000
1.00	2.037	0.000	0.000	2.073	0.000	0.000
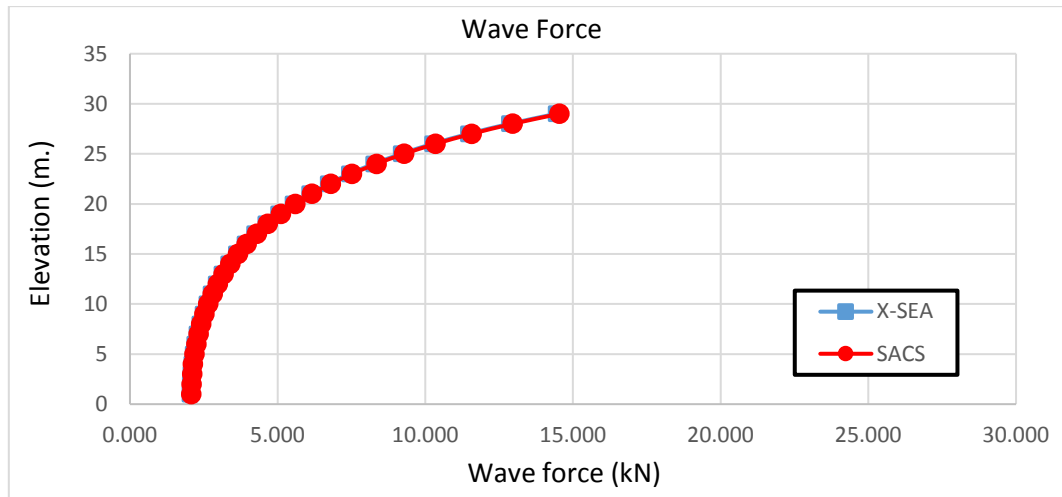
Figure 7. Comparison of wave force in X-direction of the offshore monopile between X-SEA and SACS results using Stoke's wave theory according to the height

3.3.2   Reaction

Table 11. Reactions of the offshore monopile structure modelled in X-SEA using Stoke's wave theory

| Node	Case 2 : Stoke ----- Wave Reaction					
	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
X-SEA	-166.758	0.000	0.000	0.000	-3415.150	0.000
SACS	-168.668	0.000	0.000	0.000	-3445.830	0.000
Nominal	0.989	-	-	-	0.991	-

3.3.3   Displacement

Table 12. Displacement of the offshore monopile modelled in X-SEA using Stoke's wave theory

Elevation (m)	Case 2 : Stoke ----- Displacement from X-SEA					
	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
30.00	279.150	-0.022	0.000	0.000	0.013	0.000
29.00	266.336	-0.021	0.000	0.000	0.013	0.000
28.00	253.520	-0.020	0.000	0.000	0.013	0.000
27.00	240.708	-0.019	0.000	0.000	0.013	0.000
26.00	227.912	-0.018	0.000	0.000	0.013	0.000
25.00	215.147	-0.017	0.000	0.000	0.013	0.000
24.00	202.432	-0.016	0.000	0.000	0.013	0.000
23.00	189.789	-0.015	0.000	0.000	0.013	0.000
22.00	177.243	-0.014	0.000	0.000	0.012	0.000
21.00	164.821	-0.013	0.000	0.000	0.012	0.000
20.00	152.555	-0.012	0.000	0.000	0.012	0.000
19.00	140.476	-0.011	0.000	0.000	0.012	0.000
18.00	128.617	-0.010	0.000	0.000	0.012	0.000
17.00	117.016	-0.009	0.000	0.000	0.011	0.000
16.00	105.710	-0.008	0.000	0.000	0.011	0.000
15.00	94.736	-0.007	0.000	0.000	0.011	0.000
14.00	84.137	-0.006	0.000	0.000	0.010	0.000
13.00	73.952	-0.006	0.000	0.000	0.010	0.000
12.00	64.225	-0.005	0.000	0.000	0.009	0.000
11.00	55.000	-0.004	0.000	0.000	0.009	0.000
10.00	46.321	-0.004	0.000	0.000	0.008	0.000
9.00	38.233	-0.003	0.000	0.000	0.008	0.000
8.00	30.784	-0.002	0.000	0.000	0.007	0.000
7.00	24.020	-0.002	0.000	0.000	0.006	0.000
6.00	17.990	-0.001	0.000	0.000	0.006	0.000
5.00	12.742	-0.001	0.000	0.000	0.005	0.000
4.00	8.327	-0.001	0.000	0.000	0.004	0.000
3.00	4.793	0.000	0.000	0.000	0.003	0.000
2.00	2.193	0.000	0.000	0.000	0.002	0.000
1.00	0.578	0.000	0.000	0.000	0.001	0.000

Table 13. Displacement of the offshore monopile modelled in SACS using Stoke's wave theory

Elevation (m)	Case 2 : Stoke ----- Displacement from SACS					
	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
30.00	280.645	0.000	0.000	0.000	0.013	0.000
29.00	267.730	0.000	0.000	0.000	0.013	0.000
28.00	254.816	0.000	0.000	0.000	0.013	0.000
27.00	241.910	0.000	0.000	0.000	0.013	0.000
26.00	229.023	0.000	0.000	0.000	0.013	0.000
25.00	216.170	0.000	0.000	0.000	0.013	0.000
24.00	203.369	0.000	0.000	0.000	0.013	0.000
23.00	190.643	0.000	0.000	0.000	0.013	0.000
22.00	178.016	0.000	0.000	0.000	0.013	0.000
21.00	165.517	0.000	0.000	0.000	0.012	0.000
20.00	153.174	0.000	0.000	0.000	0.012	0.000
19.00	141.021	0.000	0.000	0.000	0.012	0.000
18.00	129.092	0.000	0.000	0.000	0.012	0.000
17.00	117.422	0.000	0.000	0.000	0.012	0.000
16.00	106.050	0.000	0.000	0.000	0.011	0.000
15.00	95.015	0.000	0.000	0.000	0.011	0.000
14.00	84.357	0.000	0.000	0.000	0.010	0.000
13.00	74.117	0.000	0.000	0.000	0.010	0.000
12.00	64.340	0.000	0.000	0.000	0.010	0.000
11.00	55.069	0.000	0.000	0.000	0.009	0.000
10.00	46.348	0.000	0.000	0.000	0.008	0.000
9.00	38.225	0.000	0.000	0.000	0.008	0.000
8.00	30.747	0.000	0.000	0.000	0.007	0.000
7.00	23.960	0.000	0.000	0.000	0.006	0.000
6.00	17.913	0.000	0.000	0.000	0.006	0.000
5.00	12.656	0.000	0.000	0.000	0.005	0.000
4.00	8.240	0.000	0.000	0.000	0.004	0.000
3.00	4.714	0.000	0.000	0.000	0.003	0.000
2.00	2.130	0.000	0.000	0.000	0.002	0.000
1.00	0.542	0.000	0.000	0.000	0.001	0.000
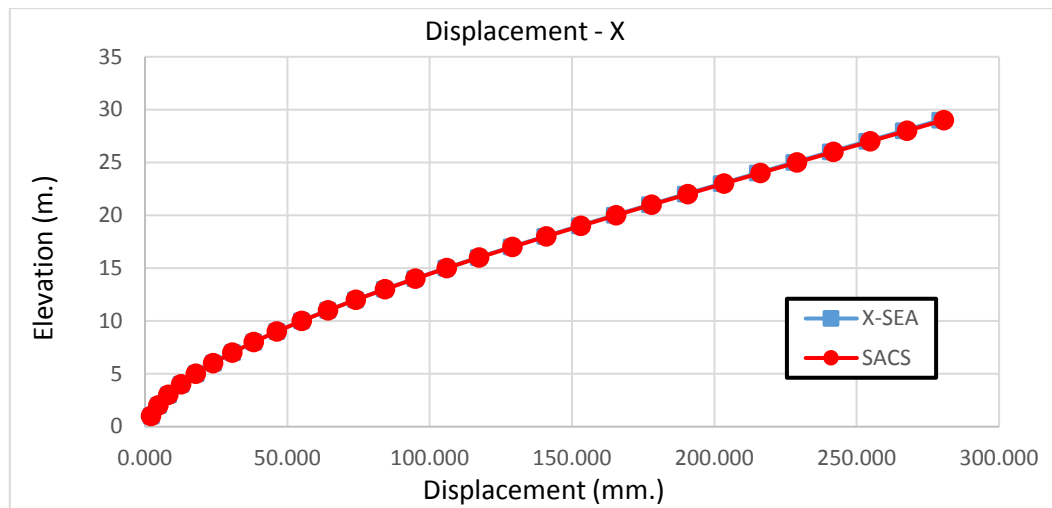
Figure 8. Comparison of X-displacement of the monopile between X-SEA and SACS results using Stoke's wave theory according to the height

3.3.4   Member forces

Table 14. Member force of the offshore monopile modelled in X-SEA using Stoke's wave theory

Elevation (m)	Case 2 : Stoke ----- Member force from X-SEA					
	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
29.00	0.000	-3.845	0.000	0.001	0.000	-2.911
28.00	0.000	-19.692	0.000	0.003	0.000	-22.608
27.00	0.000	-34.134	0.000	0.006	0.000	-56.855
26.00	0.000	-46.991	0.000	0.008	0.000	-103.945
25.00	0.000	-58.462	0.000	0.009	0.000	-162.493
24.00	0.000	-68.719	0.000	0.011	0.000	-231.287
23.00	0.000	-77.911	0.000	0.013	0.000	-309.265
22.00	0.000	-86.170	0.000	0.014	0.000	-395.493
21.00	0.000	-93.610	0.000	0.015	0.000	-489.154
20.00	0.000	-100.329	0.000	0.016	0.000	-589.528
19.00	0.000	-106.416	0.000	0.017	0.000	-695.983
18.00	0.000	-111.946	0.000	0.018	0.000	-807.963
17.00	0.000	-116.986	0.000	0.019	0.000	-924.980
16.00	0.000	-121.595	0.000	0.020	0.000	-1046.600
15.00	0.000	-125.825	0.000	0.020	0.000	-1172.450
14.00	0.000	-129.721	0.000	0.021	0.000	-1302.190
13.00	0.000	-133.325	0.000	0.022	0.000	-1435.540
12.00	0.000	-136.671	0.000	0.022	0.000	-1572.220
11.00	0.000	-139.791	0.000	0.023	0.000	-1712.030
10.00	0.000	-142.715	0.000	0.023	0.000	-1854.760
9.00	0.000	-145.468	0.000	0.024	0.000	-2000.230
8.00	0.000	-148.072	0.000	0.024	0.000	-2148.310
7.00	0.000	-150.548	0.000	0.024	0.000	-2298.870
6.00	0.000	-152.916	0.000	0.025	0.000	-2451.790
5.00	0.000	-155.193	0.000	0.025	0.000	-2606.990
4.00	0.000	-157.395	0.000	0.025	0.000	-2764.390
3.00	0.000	-159.536	0.000	0.026	0.000	-2923.930
2.00	0.000	-161.632	0.000	0.026	0.000	-3085.570
1.00	0.000	-163.696	0.000	0.026	0.000	-3249.260

Table 15. Member force of the offshore monopile modelled in SACS using Stoke's wave theory

Elevation (m)	Case 2 : Stoke ----- Member force from SACS					
	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
29.00	0.000	-11.601	0.000	0.000	0.000	3.996
28.00	0.000	-27.057	0.000	0.000	0.000	23.476
27.00	0.000	-40.807	0.000	0.000	0.000	57.540
26.00	0.000	-53.071	0.000	0.000	0.000	104.590
25.00	0.000	-64.030	0.000	0.000	0.000	163.250
24.00	0.000	-73.847	0.000	0.000	0.000	232.270
23.00	0.000	-82.662	0.000	0.000	0.000	310.610
22.00	0.000	-90.592	0.000	0.000	0.000	397.300
21.00	0.000	-97.752	0.000	0.000	0.000	491.530
20.00	0.000	-104.230	0.000	0.000	0.000	592.580
19.00	0.000	-110.110	0.000	0.000	0.000	699.800
18.00	0.000	-115.470	0.000	0.000	0.000	812.630
17.00	0.000	-120.360	0.000	0.000	0.000	930.580
16.00	0.000	-124.840	0.000	0.000	0.000	1053.200
15.00	0.000	-128.970	0.000	0.000	0.000	1180.100
14.00	0.000	-132.770	0.000	0.000	0.000	1311.000
13.00	0.000	-136.310	0.000	0.000	0.000	1445.600
12.00	0.000	-139.590	0.000	0.000	0.000	1583.600
11.00	0.000	-142.670	0.000	0.000	0.000	1724.700
10.00	0.000	-145.560	0.000	0.000	0.000	1868.800
9.00	0.000	-148.280	0.000	0.000	0.000	2015.800
8.00	0.000	-150.870	0.000	0.000	0.000	2165.400
7.00	0.000	-153.340	0.000	0.000	0.000	2317.500
6.00	0.000	-155.700	0.000	0.000	0.000	2472.000
5.00	0.000	-157.990	0.000	0.000	0.000	2628.800
4.00	0.000	-160.200	0.000	0.000	0.000	2787.900
3.00	0.000	-162.370	0.000	0.000	0.000	2949.200
2.00	0.000	-164.490	0.000	0.000	0.000	3112.700
1.00	0.000	-166.590	0.000	0.000	0.000	3278.200
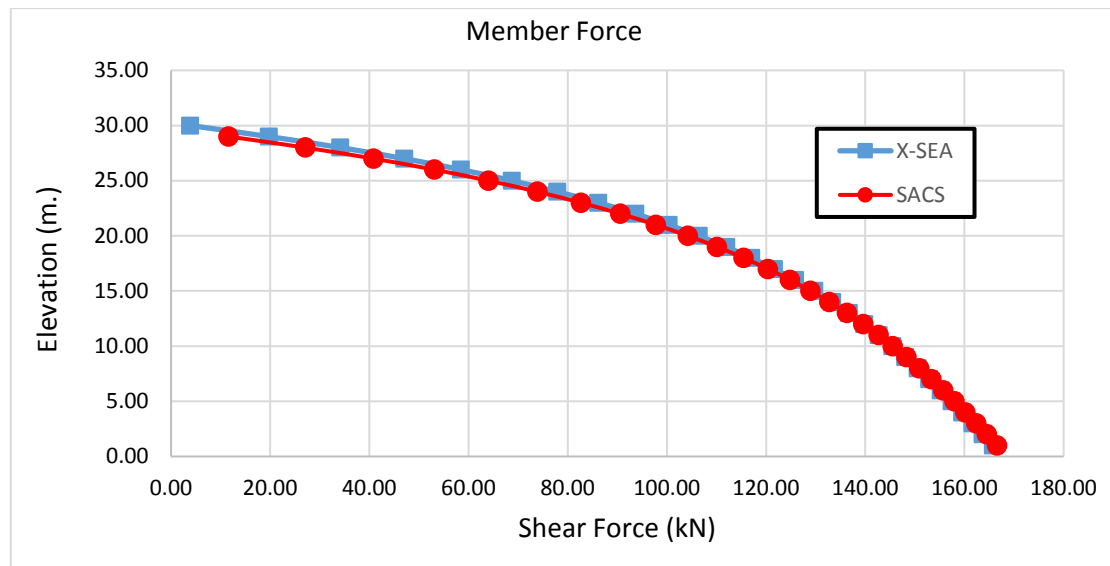
Figure 9. Comparison of axial forces of the tripod tapper between X-SEA and SACS results using Stoke's wave theory according to the height