X-SEA VERIFICATION REPORT

MONOPILE, JACKET, TRIPOD

STATIC CASE

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Hristo Ivanov
Senu Sirnivas
Rick Damiani

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401

Ki-Du Kim
Pasin Plodpradit

Konkuk University
120 Neungdong-ro, Gwangjin-gu,
Seoul 05029. KOREA

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1.0 MONOPILE SUBSTRUCTURE

1.1 Introduction

For the verification of X-SEA software, the static analysis of Monopile structures subjected to self-weight and Airy's wave are carried out using X-SEA, SACS, and OpenFAST software. The offshore monopile structure has 30.0 meters height from support to top and fixed supports in the bottom.

To compare the X-SEA with SACS and OpenFAST results, the reaction at supports, displacement and internal member force in X-SEA, SACS, and OpenFAST were calculated shown in the form of tables and plots. The reaction force is taken from supports. Displacement and internal force are compared in each node on the structure.

OpenFAST results were obtained for Airy wave simulations without wave stretching. Also, the x,y,z displacements are in reference to the global coordinate system while the member rotations and member loads use the local coordinate system.

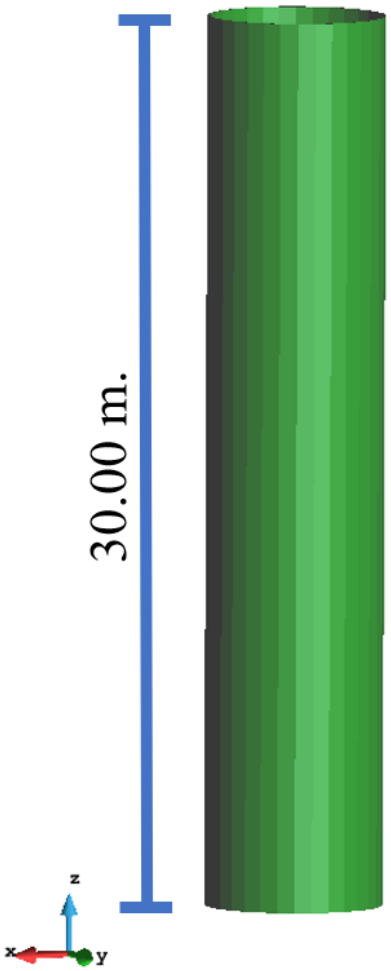

Figure 1.1 - X-SEA Monopile Model.

1.2 Geometry of Monopile

Structural dimension is as follows:

Monopile Height = 30.00 m.

Table 1.1 - Section of monopile.

Section	Diameter (m.)	Thickness (m.)
Circular Tube	6.00	0.06

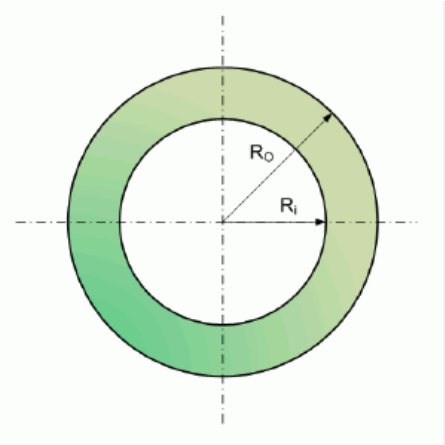

Figure 1.2 - Circular cross-section of monopile.

1.3 Material Properties

Elastic Modulus E = 2.1×10^{11} N/m2

Shear Modulus G = 8.08×10^{10} N/m2

Poisson's ratio (n) = 0.2995

Mass density = 8500 kg/m3

1.4 Airy Wave Loading

Environment condition	Wave parameter
Water depth = 20.00 m. Sea bed level = 0.00 m. Water density = 1027 kg/m3 Air Density = 1.25 kg/m3	Wave theory = Airy wave theory Water density = 1027 kg/m3 Wave height = 6.00 m Wave period = 10.00 seconds

1.5 Results

1.5.1 Self-weight Reactions

Table 1.2 - Reaction by software of monopile model subjected to self-weight load

	CASE – Self weight ---- Reaction by X-SEA, SACS, and OpenFAST					
Node	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	2799.74	0.000	0.000	0.000
SACS	0.000	0.000	2799.94	0.000	0.000	0.000
OpenFAST	0.000	0.000	2800.00	0.000	0.000	0.000

1.5.2 Wave Reactions

Table 1.3 – Reaction by software of monopile model from wave loading.

	Case 1 : Airy ----- Wave Reaction					
Node	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
X-SEA	-216.420	0.000	0.000	0.000	-3016.730	0.000
SACS	-215.747	0.000	0.000	0.000	-3000.755	0.000
OpenFAST	-207.100	0.000	0.000	0.000	-2413.000	0.000

1.5.3 Member Displacement

Table 1.4 - X-SEA Displacement of Monopile using Airy's wave.

	Case 1 : Airy ----- Displacement from X-SEA					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
30.00	0.658	0.000	0.000	0.000	0.025	0.000
29.00	0.633	0.000	0.000	0.000	0.025	0.000
28.00	0.609	0.000	0.000	0.000	0.025	0.000
27.00	0.584	0.000	0.000	0.000	0.025	0.000
26.00	0.559	0.000	0.000	0.000	0.025	0.000
25.00	0.534	0.000	0.000	0.000	0.025	0.000
24.00	0.509	0.000	0.000	0.000	0.025	0.000
23.00	0.484	0.000	0.000	0.000	0.025	0.000
22.00	0.459	0.000	0.000	0.000	0.025	0.000
21.00	0.434	0.000	0.000	0.000	0.025	0.000
20.00	0.408	0.000	0.000	0.000	0.025	0.000
19.00	0.382	0.000	0.000	0.000	0.025	0.000
18.00	0.356	0.000	0.000	0.000	0.024	0.000
17.00	0.330	0.000	0.000	0.000	0.024	0.000

16.00	0.304	0.000	0.000	0.000	0.024	0.000
15.00	0.278	0.000	0.000	0.000	0.023	0.000
14.00	0.252	0.000	0.000	0.000	0.023	0.000
13.00	0.227	0.000	0.000	0.000	0.022	0.000
12.00	0.202	0.000	0.000	0.000	0.022	0.000
11.00	0.178	0.000	0.000	0.000	0.021	0.000
10.00	0.154	0.000	0.000	0.000	0.020	0.000
9.00	0.132	0.000	0.000	0.000	0.018	0.000
8.00	0.110	0.000	0.000	0.000	0.017	0.000
7.00	0.090	0.000	0.000	0.000	0.016	0.000
6.00	0.072	0.000	0.000	0.000	0.014	0.000
5.00	0.054	0.000	0.000	0.000	0.012	0.000
4.00	0.039	0.000	0.000	0.000	0.010	0.000
3.00	0.026	0.000	0.000	0.000	0.008	0.000
2.00	0.015	0.000	0.000	0.000	0.005	0.000
1.00	0.006	0.000	0.000	0.000	0.003	0.000
0.00	0.000	0.000	0.000	0.000	0.000	0.000

Table 1.5 - SACS Displacement of Monopile using Airy's wave theory.

	Case 1 : Airy ----- Displacement from SACS					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
30.00	0.654	0.000	0.000	0.000	0.000	0.000
29.00	0.629	0.000	0.000	0.000	0.000	0.000
28.00	0.605	0.000	0.000	0.000	0.000	0.000
27.00	0.580	0.000	0.000	0.000	0.000	0.000
26.00	0.555	0.000	0.000	0.000	0.000	0.000
25.00	0.531	0.000	0.000	0.000	0.000	0.000
24.00	0.506	0.000	0.000	0.000	0.000	0.000
23.00	0.481	0.000	0.000	0.000	0.000	0.000
22.00	0.457	0.000	0.000	0.000	0.000	0.000
21.00	0.431	0.000	0.000	0.000	0.000	0.000
20.00	0.406	0.000	0.000	0.000	0.000	0.000
19.00	0.380	0.000	0.000	0.000	0.000	0.000
18.00	0.354	0.000	0.000	0.000	0.000	0.000
17.00	0.328	0.000	0.000	0.000	0.000	0.000
16.00	0.302	0.000	0.000	0.000	0.000	0.000
15.00	0.276	0.000	0.000	0.000	0.000	0.000
14.00	0.251	0.000	0.000	0.000	0.000	0.000
13.00	0.226	0.000	0.000	0.000	0.000	0.000
12.00	0.201	0.000	0.000	0.000	0.000	0.000
11.00	0.177	0.000	0.000	0.000	0.000	0.000
10.00	0.153	0.000	0.000	0.000	0.000	0.000
9.00	0.131	0.000	0.000	0.000	0.000	0.000

8.00	0.110	0.000	0.000	0.000	0.000	0.000
7.00	0.090	0.000	0.000	0.000	0.000	0.000
6.00	0.071	0.000	0.000	0.000	0.000	0.000
5.00	0.054	0.000	0.000	0.000	0.000	0.000
4.00	0.039	0.000	0.000	0.000	0.000	0.000
3.00	0.026	0.000	0.000	0.000	0.000	0.000
2.00	0.015	0.000	0.000	0.000	0.000	0.000
1.00	0.006	0.000	0.000	0.000	0.000	0.000

Table 1.6 - OpenFAST Displacement of Monopile using Airy's wave theory.

	Case 1 : Airy ----- Displacement from OpenFAST					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
26.66	0.414	0.000	0.000	0.000	0.000	0.000
23.33	0.358	0.000	0.000	0.000	0.000	0.000
20.00	0.302	0.000	0.000	0.000	0.000	0.000
16.66	0.244	0.000	0.000	0.000	0.000	0.000
13.33	0.183	0.000	0.000	0.000	0.000	0.000
9.99	0.123	0.000	0.000	0.000	0.000	0.000
6.67	0.069	0.000	0.000	0.000	0.000	0.000
3.33	0.026	0.000	0.000	0.000	0.000	0.000
0.00	0.000	0.000	0.000	0.000	0.000	0.000

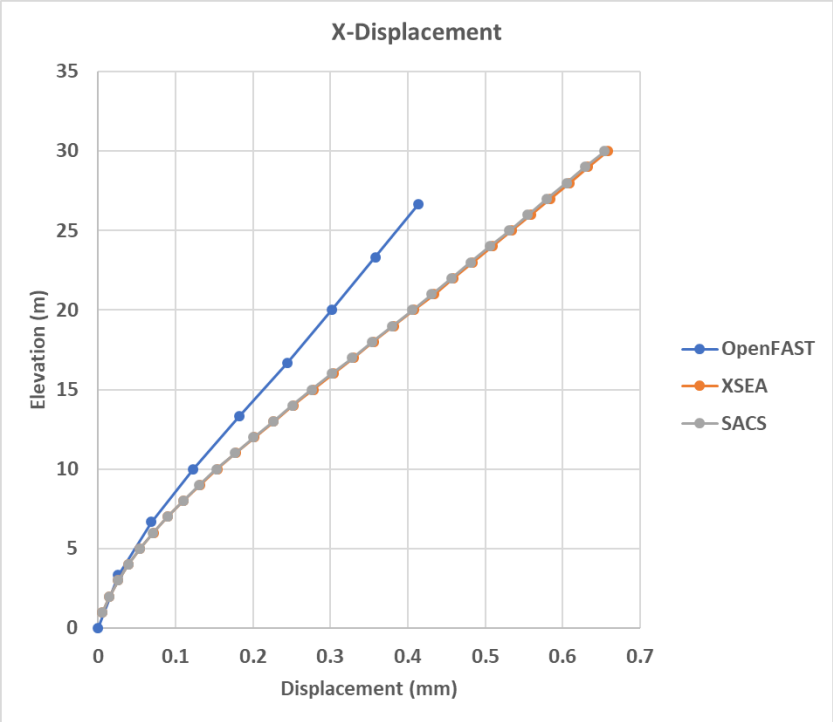

Figure 1.3 – Comparison of monopile x-displacement according to different software.

1.5.4 Member Forces

Table 1.7 - X-SEA Member Force of Monopile using Airy's wave theory.

	Case 1 : Airy ----- Member force from X-SEA					
Elevation (m)	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	0.000	0.000	0.000	0.000	0.000
27.00	0.000	0.000	0.000	0.000	0.000	0.000
26.00	0.000	0.000	0.000	0.000	0.000	0.000
25.00	0.000	0.000	0.000	0.000	0.000	0.000
24.00	0.000	0.000	0.000	0.000	0.000	0.000
23.00	0.000	-0.001	0.000	0.000	0.000	0.000
22.00	0.000	-9.712	0.000	0.000	0.000	-8.219
21.00	0.000	-26.848	0.000	0.000	0.000	-35.163
20.00	0.000	-42.610	0.000	0.000	0.000	-77.860
19.00	0.000	-57.137	0.000	0.000	0.000	-135.075
18.00	0.000	-70.555	0.000	0.000	0.000	-205.700
17.00	0.000	-82.977	0.000	0.000	0.000	-288.741
16.00	0.000	-94.506	0.000	0.000	0.000	-383.303
15.00	0.000	-105.234	0.000	0.000	0.000	-488.588
14.00	0.000	-115.247	0.000	0.000	0.000	-603.880
13.00	0.000	-124.620	0.000	0.000	0.000	-728.540
12.00	0.000	-133.424	0.000	0.000	0.000	-861.999
11.00	0.000	-141.722	0.000	0.000	0.000	-1003.750
10.00	0.000	-149.573	0.000	0.000	0.000	-1153.350
9.00	0.000	-157.030	0.000	0.000	0.000	-1310.410
8.00	0.000	-164.143	0.000	0.000	0.000	-1474.570
7.00	0.000	-170.957	0.000	0.000	0.000	-1645.550
6.00	0.000	-177.514	0.000	0.000	0.000	-1823.080
5.00	0.000	-183.853	0.000	0.000	0.000	-2006.940
4.00	0.000	-190.013	0.000	0.000	0.000	-2196.970
3.00	0.000	-196.028	0.000	0.000	0.000	-2393.010
2.00	0.000	-201.933	0.000	0.000	0.000	-2594.940
1.00	0.000	-207.759	0.000	0.000	0.000	-2802.710

Table 1.8 - SACS Member Force of Monopile using Airy's wave theory.

	Case 1 : Airy ----- Member force from SACS					
Elevation (m)	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	0.000	0.000	0.000	0.000	0.000
27.00	0.000	0.000	0.000	0.000	0.000	0.000

26.00	0.000	0.000	0.000	0.000	0.000	0.000
25.00	0.000	0.000	0.000	0.000	0.000	0.000
24.00	0.000	0.000	0.000	0.000	0.000	0.000
23.00	0.000	-17.860	0.000	0.000	0.000	9.058
22.00	0.000	-34.268	0.000	0.000	0.000	35.235
21.00	0.000	-49.377	0.000	0.000	0.000	77.160
20.00	0.000	-63.319	0.000	0.000	0.000	133.600
19.00	0.000	-76.214	0.000	0.000	0.000	203.450
18.00	0.000	-88.167	0.000	0.000	0.000	285.710
17.00	0.000	-99.277	0.000	0.000	0.000	379.500
16.00	0.000	-109.630	0.000	0.000	0.000	484.010
15.00	0.000	-119.310	0.000	0.000	0.000	598.540
14.00	0.000	-128.390	0.000	0.000	0.000	722.430
13.00	0.000	-136.930	0.000	0.000	0.000	855.130
12.00	0.000	-145.000	0.000	0.000	0.000	996.130
11.00	0.000	-152.640	0.000	0.000	0.000	1145.000
10.00	0.000	-159.920	0.000	0.000	0.000	1301.300
9.00	0.000	-166.880	0.000	0.000	0.000	1464.700
8.00	0.000	-173.570	0.000	0.000	0.000	1635.000
7.00	0.000	-180.010	0.000	0.000	0.000	1811.800
6.00	0.000	-186.260	0.000	0.000	0.000	1994.900
5.00	0.000	-192.350	0.000	0.000	0.000	2184.200
4.00	0.000	-198.310	0.000	0.000	0.000	2379.600
3.00	0.000	-204.170	0.000	0.000	0.000	2580.800
2.00	0.000	-209.980	0.000	0.000	0.000	2787.900
1.00	0.000	-215.750	0.000	0.000	0.000	3000.800

Table 1.9 - OpenFAST Internal Member Force of Monopile using Airy's wave theory.

	Case 1 : Airy ----- Member force from OpenFAST					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
26.66	0.000	-0.197	0.000	0.000	0.000	0.712
23.33	0.000	-0.198	0.000	0.000	0.000	0.885
20.00	0.000	-0.198	0.000	0.000	0.000	1.466
16.66	0.000	-53.970	0.000	0.000	0.000	72.700
13.33	0.000	-94.960	0.000	0.000	0.000	330.400
9.99	0.000	-111.700	0.000	0.000	0.000	702.300
6.67	0.000	-158.300	0.000	0.000	0.000	1183.000
3.33	0.000	-183.400	0.000	0.000	0.000	1755.000
0.00	0.000	-194.500	0.000	0.000	0.000	2402.000

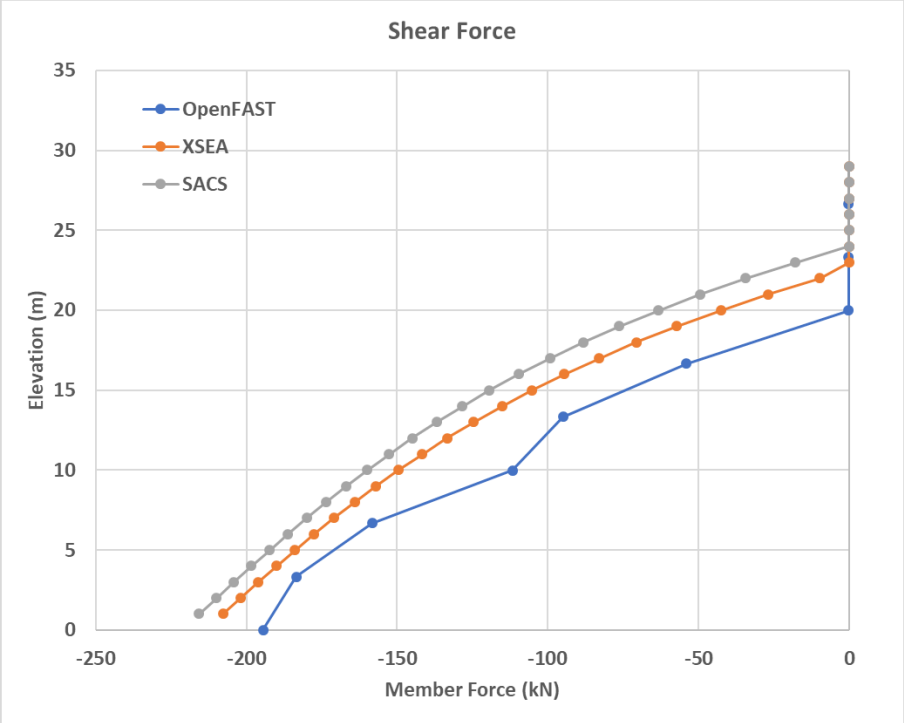

Figure 1.4 - Comparison of monopile x-displacement according to different software.

1.6 Discussion

Results relating to support reactions, displacements, and member forces were obtained for all software. It is important to note that the OC3 case was modified in OpenFAST by the following ways:

- All component mass and functions related to the turbine have been eliminated;
- Any terms related to inertia forces were eliminated by adjusting hydrodynamic coefficients;
- Regular/Airy wave theory was applied instead of JONSWAP.

When comparing all these parameters, the results obtained from OpenFAST are slightly different than that of XSEA and SACS. This difference can potentially be accounted for by the fact that OpenFAST does not currently have a functioning feature to incorporate wave stretching in fixed structures such as this monopile. Consequently, the results obtained from OpenFAST are consistently smaller than the other software since the wave kinematics are applied at mean sea level. This phenomenon can be seen when comparing the wave reactions, member displacements, and member loads.

2.0 JACKET SUBSTRUCTURE

2.1 Introduction

For the verification of X-SEA software, the static analysis of Wind Turbine offshore jacket structures subjected to self-weight and Airy's wave are carried out using X-SEA, SACS, and OpenFAST software. The offshore jacket structure has 70.15 meters height 4 fixed supports in the bottom of leg.

To compare the results, the reaction at supports, displacement of main legs and internal member force in all software were calculated and shown in the form of tables and plots. The reaction force is taken from the 4 fixed supports of the bottom of the structure. Displacement and internal force are compared in each node on all 4 main leg. All the node positions calculated from the X-SEA and SACS are illustrated in Figure 2.1. The 4 elements (4 meshes) are used for every single member. Total 446 nodes and 504 elements for this structure.

OpenFAST results were obtained for Airy wave simulations without wave stretching. Also, the x,y,z displacements are in reference to the global coordinate system while the member rotations and member loads use the local coordinate system.

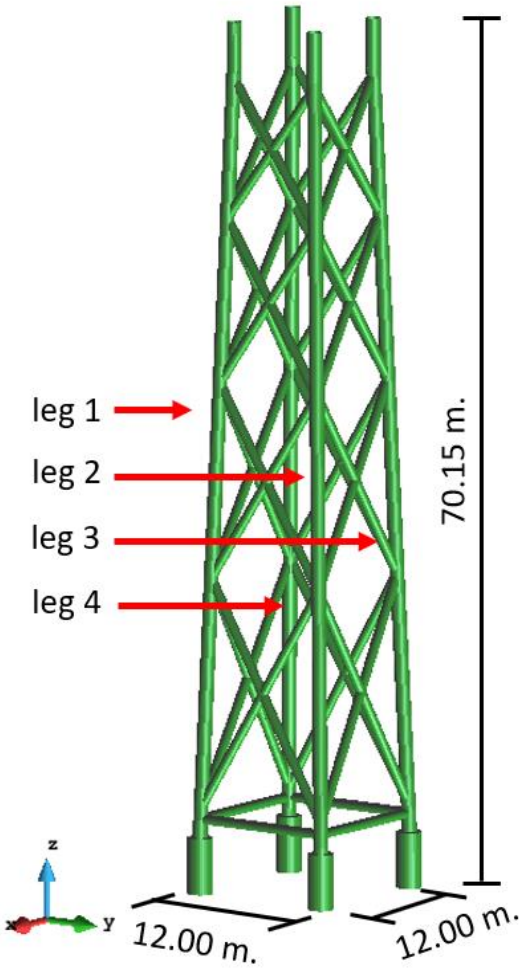

Figure 2.1 – X-SEA wind turbine jacket platform model.

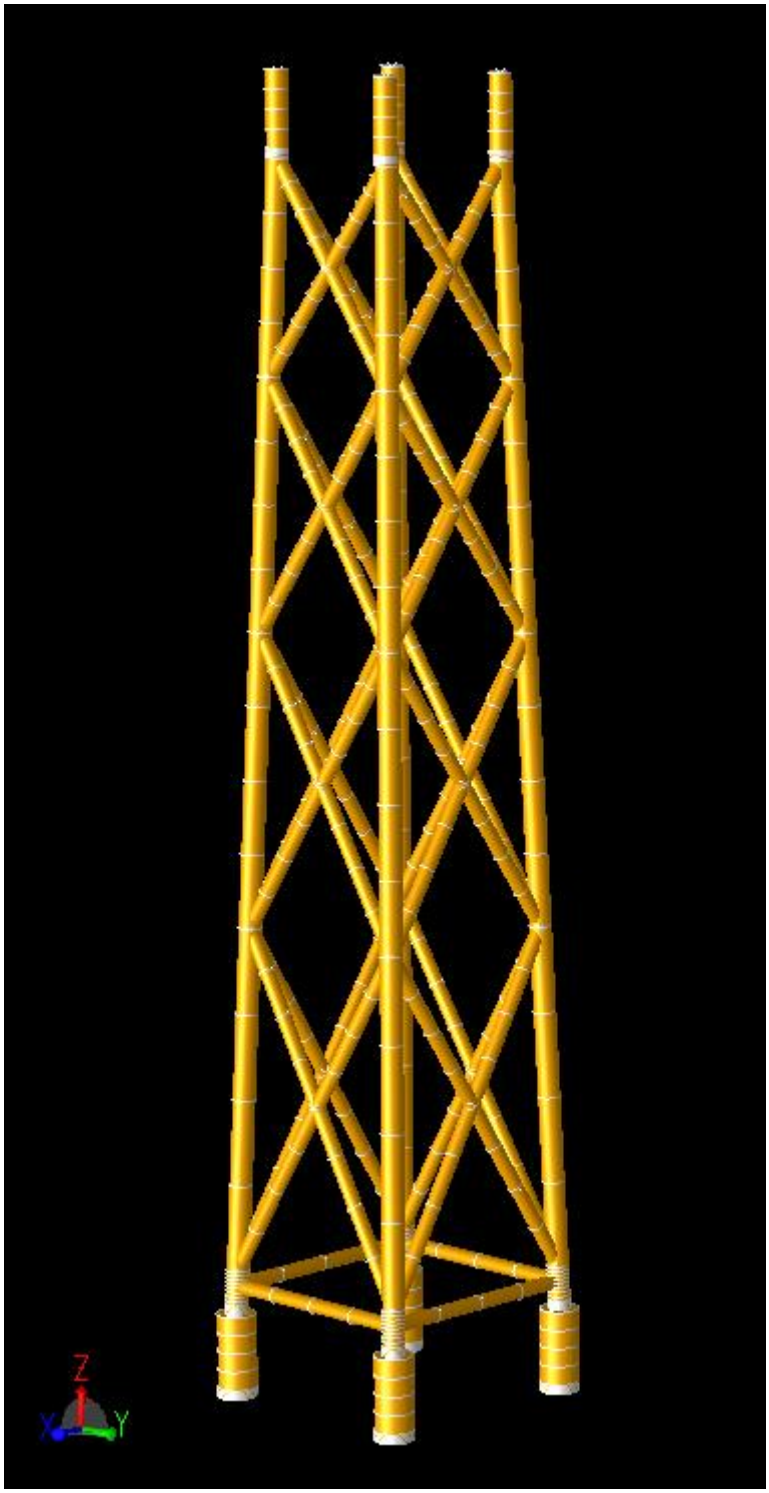

Figure 2.2 - SACS Wind turbine Jacket Platform Model.

2.2 Geometry of Jacket

Structural dimension are as follows:

- Jacket Height = 70.15 m.
- Base dimension = 12 x 12 m

Table 2.1 - Section of jacket structure.

Section	Diameter (m.)	Thickness (m.)
Bracing	0.800	0.020
Circular Type 2	1.200	0.050
Circular Type 3	1.200	0.035
Circular Type 4	1.200	0.040
Circular Type 5	2.082	0.491
Circular Type 6	2.082	0.060

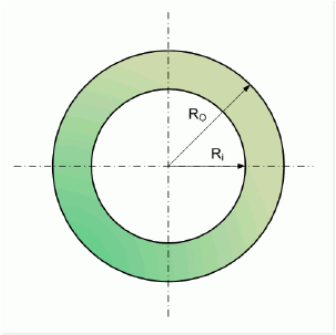

Figure 2.3 – Jacket member cross-section.

2.3 Material Properties

Elastic modulus E = 2.1×10^{11} N/m2

Shear Modulus G = 8.077×10^{10} N/m2

Poisson's ratio (n) = 0.2998

Mass density (Circular type 5) = 3339.12 kg/m3

Mass density (Other) = 7850 kg/m3

2.4 Airy Wave Loading

Environment condition	Wave parameter
Water depth = 50.00 m. Sea bed level = -50.00 m. Water density = 1025 kg/m3 Air Density = 1.25 kg/m3	Wave theory = Airy wave theory Water density = 1025 kg/m3 Wave height = 8 m Wave period = 10 seconds

2.5 Results

2.5.1 Self-weight Reactions

Table 2.2 - Reaction by X-SEA of jacket model subjected to self-weight loading (dry-weight).

	CASE – Self weight ---- Reaction by X-SEA					
Node	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
394(+x-y)	-37.736	37.736	1652.020	-174.646	-174.646	0.000
400(+x+y)	-37.736	-37.736	1652.020	174.646	-174.646	0.000
395(-x+y)	37.736	-37.736	1652.020	174.646	174.646	0.000
385(-x-y)	37.736	37.736	1652.020	-174.646	174.646	0.000

Table 2.3 - Reaction by SACS of jacket model subjected to self-weight loading (dry-weight).

	CASE – Self weight ---- Reaction by SACS					
Node	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
63(+x-y)	-40.797	40.797	1651.941	-194.779	-194.779	0.000
61(+x+y)	-40.797	-40.797	1651.941	194.779	-194.779	0.000
64(-x+y)	40.797	-40.797	1651.941	194.779	194.779	0.000
62(-x-y)	40.797	40.797	1651.941	-194.779	194.779	0.000

Table 2.4 - Reaction by OpenFAST of jacket model subjected to self-weight loading (dry-weight).

	CASE – Self weight ---- Reaction by OpenFAST					
Node	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
110 (+x-y)	-38.100	38.100	1652.000	-176.100	-176.100	0.000
109 (+x+y)	-38.100	-38.100	1652.000	176.100	-176.100	0.000
111 (-x+y)	38.100	-38.100	1652.000	176.100	176.100	0.000
112 (-x-y)	38.100	38.100	1652.000	-176.100	176.100	0.000

2.5.2 Wave Reactions

Table 2.5 - X-SEA reaction of Jacket structure using Airy's wave theory.

	Case 1 : Airy ----- Wave Reaction by X-SEA					
Node	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
394(+x-y)	-114.840	13.6941	662.916	-81.1841	-724.619	20.4597
400(+x+y)	-114.840	-13.6941	662.916	81.1841	-724.619	-20.4597
395(-x+y)	-110.808	12.6707	-623.825	-76.6736	-709.134	-12.4648
385(-x-y)	-110.808	-12.6707	-623.825	76.6736	-709.134	12.4648

Table 2.6 - SACS reaction of Jacket structure using Airy's wave theory.

	Case 1 : Airy ----- Wave Reaction by SACS					
Node	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
63(+x-y)	-114.688	15.122	660.804	-86.162	-723.086	32.688
61(+x+y)	-114.688	-15.122	660.804	86.162	-723.086	-32.688
64(-x+y)	-110.869	14.155	-626.919	-81.74	-709.201	-22.347
62(-x-y)	-110.869	-14.155	-626.919	81.74	-709.201	22.347

Table 2.7 - OpenFAST reaction of Jacket structure using Airy's wave theory.

	Case 1 : Airy ----- Wave Reaction by OpenFAST					
Node	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
M110J1 (+x-y)	-117.915	10.335	622.500	-62.350	-753.900	22.045
M109J1 (+x+y)	-117.855	-10.325	622.500	62.300	-753.900	-21.970
M111J1 (-x+y)	-122.610	14.975	-594.000	-88.100	-780.100	-22.155
M112J1 (-x-y)	-122.610	-14.965	-594.000	88.050	-780.150	22.225

2.5.3 Member Displacements

LEG 1

Table 2.8 - X-SEA Displacement of Jacket Structure (1st leg, +x-y) using Airy's wave.

	Case 1 : Airy ----- Displacement from X-SEA (1st Leg, +x-y)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
15.651	4.585	0.010	-0.308	-0.004	0.073	-0.023
12.833	4.373	-0.002	-0.315	-0.002	0.073	-0.029
10.015	4.168	-0.009	-0.322	-0.001	0.068	-0.034
7.196	3.983	-0.014	-0.328	0.000	0.059	-0.039
4.378	3.832	-0.014	-0.333	0.002	0.044	-0.044
1.053	3.680	-0.007	-0.332	0.004	0.055	-0.048

-2.272	3.444	0.000	-0.334	0.003	0.084	-0.053
-5.597	3.113	-0.002	-0.338	-0.001	0.105	-0.057
-8.922	2.749	-0.021	-0.344	-0.007	0.098	-0.061
-12.845	2.399	-0.073	-0.318	-0.015	0.083	-0.058
-16.768	2.067	-0.144	-0.291	-0.017	0.084	-0.056
-20.691	1.724	-0.210	-0.264	-0.012	0.085	-0.053
-24.614	1.395	-0.243	-0.238	0.000	0.074	-0.050
-29.242	1.079	-0.219	-0.190	0.011	0.063	-0.039
-33.871	0.788	-0.154	-0.142	0.016	0.061	-0.029
-38.499	0.495	-0.080	-0.095	0.015	0.062	-0.019
-43.127	0.205	-0.022	-0.047	0.008	0.059	-0.010

Table 2.9 - SACS Displacement of Jacket Structure (1st leg, +x-y) using Airy's wave theory.

	Case 1 : Airy ----- Displacement from SACS (1st Leg, +x-y)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
15.651	4.533	0.005	-0.303	0.000	0.001	0.000
12.833	4.332	-0.001	-0.310	0.000	0.001	0.000
10.015	4.131	-0.006	-0.317	0.000	0.001	0.000
7.196	3.945	-0.009	-0.323	0.000	0.001	0.000
4.378	3.787	-0.009	-0.328	0.000	0.000	0.000
1.053	3.616	-0.004	-0.328	0.000	0.001	0.000
-2.272	3.378	0.002	-0.330	0.000	0.001	0.000
-5.597	3.056	-0.001	-0.335	0.000	0.001	0.000
-8.922	2.709	-0.019	-0.340	0.000	0.001	0.000
-12.845	2.361	-0.069	-0.315	0.000	0.001	0.000
-16.768	2.028	-0.139	-0.288	0.000	0.001	0.000
-20.691	1.684	-0.203	-0.262	0.000	0.001	0.000
-24.614	1.358	-0.234	-0.237	0.000	0.001	0.000
-29.242	1.038	-0.209	-0.189	0.000	0.001	0.000
-33.871	0.746	-0.146	-0.142	0.000	0.001	0.000
-38.499	0.454	-0.074	-0.095	0.000	0.001	0.000
-43.127	0.167	-0.019	-0.047	0.000	0.001	0.000

Table 2.10 - OpenFAST Displacement of Jacket Structure (1st leg,+x-y) using Airy's wave theory.

	Case 1 : Airy ----- Displacement from SACS (1st Leg, +x-y)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
-8.92	2.571	0.044	0.259	0.059	0.065	0.064
-16.768	1.971	0.075	0.231	0.039	0.067	0.058
-24.614	1.373	0.189	0.202	0.049	0.054	0.053
-33.871	0.780	0.127	0.122	0.051	0.034	0.031
-43.127	0.214	0.018	0.042	0.048	0.039	0.009

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Table 2.11 - X-SEA Displacement of Jacket model (2nd leg, +x+y) using Airy's wave theory.

	Case 1 : Airy ----- Displacement from X-SEA (2nd Leg, +x+y)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
15.651	4.585	-0.010	-0.308	0.004	0.073	0.023
12.833	4.373	0.002	-0.315	0.002	0.073	0.029
10.015	4.168	0.009	-0.322	0.001	0.068	0.034
7.196	3.983	0.014	-0.328	0.000	0.059	0.039
4.378	3.832	0.014	-0.333	-0.002	0.044	0.044
1.053	3.680	0.007	-0.332	-0.004	0.055	0.048
-2.272	3.444	0.000	-0.334	-0.003	0.084	0.053
-5.597	3.113	0.002	-0.338	0.001	0.105	0.057
-8.922	2.749	0.021	-0.344	0.007	0.098	0.061
-12.845	2.399	0.073	-0.318	0.015	0.083	0.058
-16.768	2.067	0.144	-0.291	0.017	0.084	0.056
-20.691	1.724	0.210	-0.264	0.012	0.085	0.053
-24.614	1.395	0.243	-0.238	0.000	0.074	0.050
-29.242	1.079	0.219	-0.190	-0.011	0.063	0.039
-33.871	0.788	0.154	-0.142	-0.016	0.061	0.029
-38.499	0.495	0.080	-0.095	-0.015	0.062	0.019
-43.127	0.205	0.022	-0.047	-0.008	0.059	0.010

Table 2.12 - SACS Displacement of Jacket model (2nd leg, +x+y) using Airy's wave theory.

	Case 1 : Airy ----- Displacement from SACS (2nd Leg, +x+y)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
15.651	4.533	-0.005	-0.303	0.000	0.001	0.000
12.833	4.332	0.001	-0.310	0.000	0.001	0.000
10.015	4.131	0.006	-0.317	0.000	0.001	0.000
7.196	3.945	0.009	-0.323	0.000	0.001	0.000
4.378	3.787	0.009	-0.328	0.000	0.000	0.000
1.053	3.616	0.004	-0.328	0.000	0.001	0.000
-2.272	3.378	-0.002	-0.330	0.000	0.001	0.000
-5.597	3.056	0.001	-0.335	0.000	0.001	0.000
-8.922	2.709	0.019	-0.340	0.000	0.001	0.000
-12.845	2.361	0.069	-0.315	0.000	0.001	0.000
-16.768	2.028	0.139	-0.288	0.000	0.001	0.000
-20.691	1.684	0.203	-0.262	0.000	0.001	0.000
-24.614	1.358	0.234	-0.237	0.000	0.001	0.000
-29.242	1.038	0.209	-0.189	0.000	0.001	0.000
-33.871	0.746	0.146	-0.142	0.000	0.001	0.000
-38.499	0.454	0.074	-0.095	0.000	0.001	0.000

-43.127	0.167	0.019	-0.047	0.000	0.001	0.000

Table 2.13 - OpenFAST Displacement of Jacket Structure (2nd leg,+x+y) using Airy's wave theory.

	Case 1 : Airy ----- Displacement from SACS (2nd leg, +x+y)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
-8.92	2.571	0.044	0.259	0.059	0.065	0.064
-16.768	1.971	0.075	0.231	0.039	0.067	0.058
-24.614	1.373	0.189	0.202	0.049	0.054	0.053
-33.871	0.780	0.126	0.122	0.051	0.034	0.031
-43.127	0.214	0.018	0.042	0.048	0.039	0.009

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Table 2.14 - X-SEA Displacement of Jacket model (3rd leg, -x+y) using Airy's wave theory.

	Case 1 : Airy ----- Displacement from X-SEA (3rd leg, -x+y)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
15.651	4.608	0.005	0.253	-0.003	0.076	0.014
12.833	4.389	-0.003	0.260	-0.002	0.076	0.018
10.015	4.176	-0.008	0.267	0.000	0.072	0.022
7.196	3.979	-0.009	0.273	0.001	0.065	0.025
4.378	3.808	-0.008	0.279	0.002	0.054	0.029
1.053	3.628	-0.005	0.281	0.002	0.061	0.031
-2.272	3.387	-0.004	0.286	0.001	0.083	0.034
-5.597	3.070	-0.006	0.293	-0.001	0.101	0.037
-8.922	2.716	-0.017	0.301	-0.004	0.101	0.039
-12.845	2.348	-0.062	0.281	-0.014	0.088	0.037
-16.768	2.004	-0.130	0.260	-0.017	0.085	0.036
-20.691	1.667	-0.192	0.239	-0.011	0.083	0.034
-24.614	1.345	-0.219	0.218	0.001	0.076	0.032
-29.242	1.015	-0.195	0.175	0.010	0.065	0.025
-33.871	0.724	-0.140	0.132	0.014	0.059	0.018
-38.499	0.456	-0.075	0.088	0.013	0.056	0.012
-43.127	0.198	-0.021	0.044	0.008	0.055	0.006

Table 2.15 - Displacement of SACS Jacket model (3rd leg,-x+y) using Airy's wave theory.

	Case 1 : Airy ----- Displacement from SACS (3rd leg, -x+y)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
15.651	4.556	0.002	0.253	0.000	0.001	0.000
12.833	4.346	-0.003	0.260	0.000	0.001	0.000
10.015	4.137	-0.005	0.267	0.000	0.001	0.000

7.196	3.940	-0.006	0.273	0.000	0.001	0.000
4.378	3.763	-0.005	0.279	0.000	0.001	0.000
1.053	3.569	-0.002	0.283	0.000	0.001	0.000
-2.272	3.325	0.000	0.287	0.000	0.001	0.000
-5.597	3.014	-0.003	0.294	0.000	0.001	0.000
-8.922	2.676	-0.014	0.302	0.000	0.001	0.000
-12.845	2.312	-0.058	0.282	0.000	0.001	0.000
-16.768	1.969	-0.126	0.261	0.000	0.001	0.000
-20.691	1.631	-0.188	0.240	0.000	0.001	0.000
-24.614	1.310	-0.214	0.219	0.000	0.001	0.000
-29.242	0.979	-0.190	0.176	0.000	0.001	0.000
-33.871	0.688	-0.134	0.133	0.000	0.001	0.000

Table 2.16 - OpenFAST Displacement of Jacket Structure (3rd leg,-x+y) using Airy's wave theory.

	Case 1 : Airy ----- Displacement from SACS (3rd Leg, -x+y)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
-8.92	2.673	0.059	0.285	0.053	0.065	0.064
-16.768	2.053	0.156	0.245	0.048	0.067	0.058
-24.614	1.403	0.218	0.206	0.055	0.054	0.053
-33.871	0.792	0.136	0.125	0.052	0.034	0.031
-43.127	0.220	0.023	0.043	0.050	0.039	0.009

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Table 2.17 - X-SEA Displacement of Jacket model (the 4th leg, -x-y) using Airy's wave theory.

	Case 1 : Airy ----- Displacement from X-SEA (4th leg, -x-y)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
15.651	4.608	-0.005	0.253	0.003	0.076	-0.014
12.833	4.389	0.003	0.260	0.002	0.076	-0.018
10.015	4.176	0.008	0.267	0.000	0.072	-0.022
7.196	3.979	0.009	0.273	-0.001	0.065	-0.025
4.378	3.808	0.008	0.279	-0.002	0.054	-0.029
1.053	3.628	0.005	0.281	-0.002	0.061	-0.031
-2.272	3.387	0.004	0.286	-0.001	0.083	-0.034
-5.597	3.070	0.006	0.293	0.001	0.101	-0.037
-8.922	2.716	0.017	0.301	0.004	0.101	-0.039
-12.845	2.348	0.062	0.281	0.014	0.088	-0.037
-16.768	2.004	0.130	0.260	0.017	0.085	-0.036
-20.691	1.667	0.192	0.239	0.011	0.083	-0.034
-24.614	1.345	0.219	0.218	-0.001	0.076	-0.032
-29.242	1.015	0.195	0.175	-0.010	0.065	-0.025
-33.871	0.724	0.140	0.132	-0.014	0.059	-0.018

-38.499	0.456	0.075	0.088	-0.013	0.056	-0.012
-43.127	0.198	0.021	0.044	-0.008	0.055	-0.006

Table 2.18 - SACS Displacement of Jacket model (the 4th leg, -x-y) using Airy's wave theory.

	Case 1 : Airy ----- Displacement from SACS (4th leg -x,-y)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
15.651	4.556	-0.002	0.253	0.000	0.001	0.000
12.833	4.346	0.003	0.260	0.000	0.001	0.000
10.015	4.137	0.005	0.267	0.000	0.001	0.000
7.196	3.940	0.006	0.273	0.000	0.001	0.000
4.378	3.763	0.005	0.279	0.000	0.001	0.000
1.053	3.569	0.002	0.283	0.000	0.001	0.000
-2.272	3.325	0.000	0.287	0.000	0.001	0.000
-5.597	3.014	0.003	0.294	0.000	0.001	0.000
-8.922	2.676	0.014	0.302	0.000	0.001	0.000
-12.845	2.312	0.058	0.282	0.000	0.001	0.000
-16.768	1.969	0.126	0.261	0.000	0.001	0.000
-20.691	1.631	0.188	0.240	0.000	0.001	0.000
-24.614	1.310	0.214	0.219	0.000	0.001	0.000
-29.242	0.979	0.190	0.176	0.000	0.001	0.000
-33.871	0.688	0.134	0.133	0.000	0.001	0.000
-38.499	0.418	0.070	0.089	0.000	0.001	0.000
-43.127	0.160	0.019	0.045	0.000	0.001	0.000

Table 2.19 - OpenFAST Displacement of Jacket Structure (4th leg,-x-y) using Airy's wave theory.

	Case 1 : Airy ----- Displacement from SACS (4th Leg, -x-y)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
-8.92	2.673	0.059	0.285	0.053	0.065	0.064
-16.768	2.053	0.156	0.245	0.048	0.067	0.058
-24.614	1.403	0.218	0.206	0.055	0.054	0.053
-33.871	0.792	0.136	0.125	0.052	0.034	0.031
-43.127	0.220	0.023	0.043	0.050	0.039	0.009

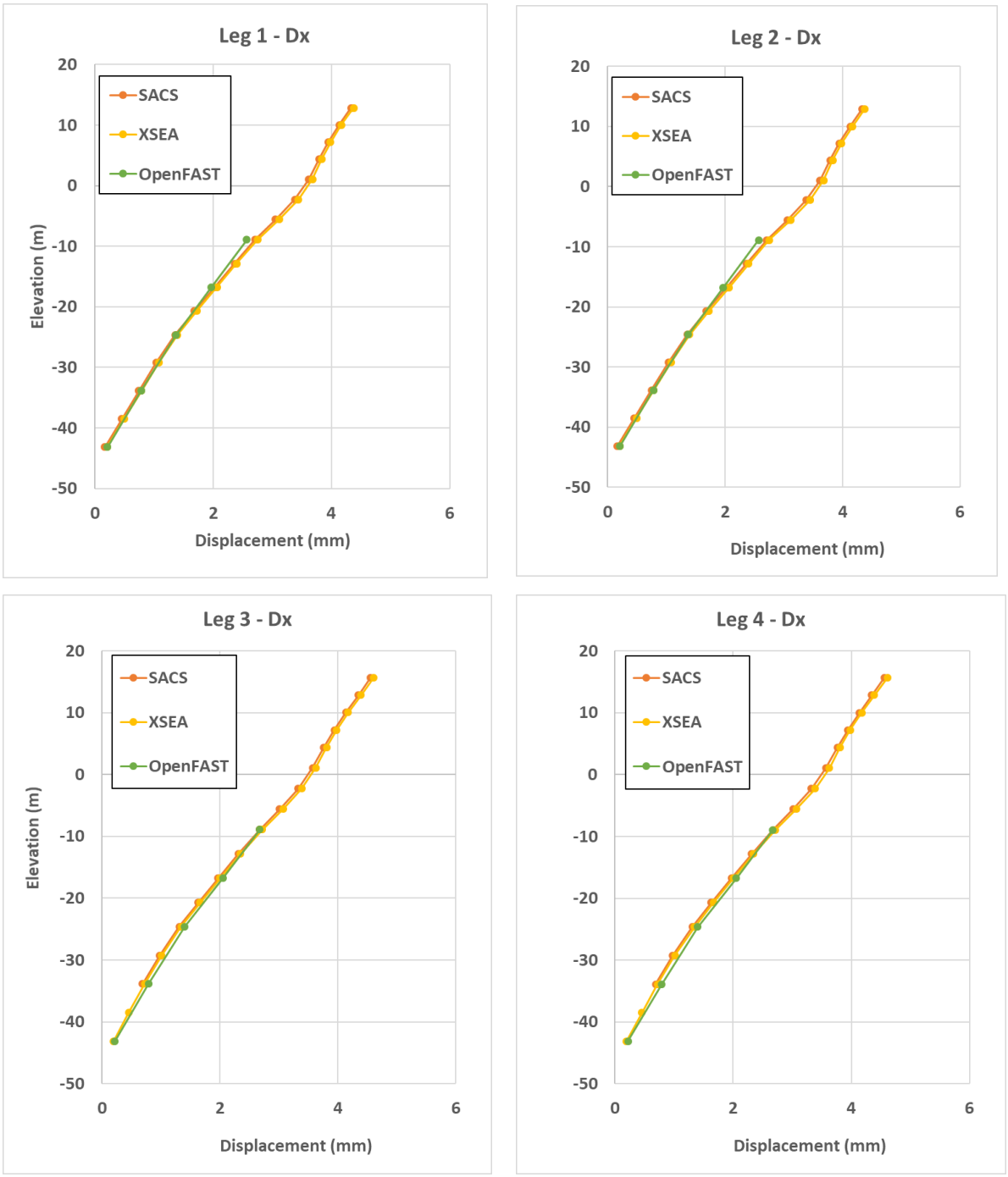

Figure 2.4 – Summary of x-displacement of jacket model main legs using Airy wave theory.

2.5.4 Member Forces

LEG 1

Table 2.20 - X-SEA Member Force of Jacket Model (1st leg, +x-y) using Airy's wave theory.

	Case 1 : Airy ----- Member force from X-SEA (1st leg, +x-y)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
12.833	0.751	1.927	2.027	6.749	-3.919	1.313
10.015	0.751	1.927	2.027	6.749	-9.637	6.751
7.196	0.751	1.927	2.027	6.749	-15.354	12.188
4.378	0.751	1.927	2.027	6.749	-21.072	17.625
1.053	-48.320	-8.362	-10.612	4.029	26.763	-26.936
-2.272	-48.366	-0.056	-1.940	4.019	32.788	-27.458
-5.597	-48.402	6.402	4.869	4.011	16.230	-6.398
-8.922	-48.429	11.461	10.233	4.005	-18.100	31.547
-12.845	-243.554	-6.347	-4.093	-2.293	1.878	6.066
-16.768	-243.575	-2.749	-0.230	-2.298	2.530	-4.877
-20.691	-243.591	0.039	2.780	-2.302	-8.568	-4.853
-24.614	-243.602	2.236	5.161	-2.305	-28.970	3.815
-29.242	-486.039	-1.536	-4.323	-10.189	-12.473	-3.967
-33.871	-486.047	0.135	-2.513	-10.192	-0.943	-3.461
-38.499	-486.052	1.531	-1.015	-10.193	3.684	3.510
-43.127	-486.055	2.755	0.280	-10.194	2.341	16.139

Table 2.21 - SACS Member Force of Jacket Model (1st leg, +x-y) using Airy's wave theory.

	Case 1 : Airy ----- Member force from SACS (1st leg, +x-y)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
12.833	1.596	1.984	-1.829	-11.949	0.204	-1.125
10.015	1.596	1.984	-1.829	11.949	4.957	-6.723
7.196	1.596	1.984	-1.829	11.949	10.117	-12.322
4.378	1.596	1.984	-1.829	11.949	15.277	-17.920
1.053	-46.255	-6.021	4.453	6.166	-22.046	22.057
-2.272	-46.255	1.630	-2.945	6.166	-24.049	28.851
-5.597	-46.255	1.630	-2.945	6.166	-24.049	28.851
-8.922	-46.255	12.422	-13.293	6.166	32.761	-20.733
-12.845	-239.840	-6.153	8.636	-8.620	31.809	-12.981
-16.768	-239.840	-1.756	4.460	-8.620	6.460	2.174
-20.691	-239.840	4.318	-1.255	-8.620	-4.280	-9.806
-24.614	-239.840	6.450	-3.248	-8.620	4.703	-31.100
-29.242	-481.830	-5.358	2.616	-20.620	4.714	-32.862
-33.871	-481.830	-3.338	0.730	-20.620	-2.874	-12.894
-38.499	-481.830	-0.313	-2.115	-20.620	4.240	3.233

-43.127	-481.830	0.914	-3.291	-20.620	16.799	1.795

Table 2.22 - OpenFAST Member Force of Jacket Model (1st leg, +x-y) using Airy's wave theory.

	Case 1 : Airy ----- Member force from OpenFAST (1st leg, +x-y)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
-8.92	-152.550	-0.899	4.231	-2.595	28.420	1.895
-16.768	-152.600	1.087	2.376	-2.595	-5.563	-4.959
-24.614	-416.285	-2.618	0.483	-11.415	1.177	25.460
-33.871	-416.250	1.815	-0.338	-11.415	-3.560	2.171
-43.127	-416.400	-1.064	-1.143	-11.415	7.242	-8.024

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Table 2.23 - X-SEA Member Force of Jacket Model (2nd leg, +x+y) using Airy's wave theory.

	Case 1 : Airy ----- Member force from X-SEA (2nd leg, +x+y)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
12.833	0.751	1.927	-2.027	-6.749	3.919	1.313
10.015	0.751	1.927	-2.027	-6.749	9.637	6.751
7.196	0.751	1.927	-2.027	-6.749	15.354	12.188
4.378	0.751	1.927	-2.027	-6.749	21.072	17.625
1.053	-48.332	-8.880	10.612	-3.692	-26.935	-26.936
-2.272	-48.377	-0.523	1.940	-3.754	-32.924	-27.458
-5.597	-48.411	6.037	-4.869	-3.803	-16.337	-6.398
-8.922	-48.438	11.175	-10.233	-3.841	18.016	31.547
-12.845	-243.562	-6.610	4.093	2.470	-1.969	6.066
-16.768	-243.582	-2.951	0.230	2.435	-2.601	-4.877
-20.691	-243.596	-0.119	-2.780	2.410	8.513	-4.853
-24.614	-243.607	2.111	-5.161	2.391	28.925	3.815
-29.242	-486.043	-1.655	4.323	10.285	12.423	-3.967
-33.871	-486.050	0.038	2.513	10.270	0.902	-3.461
-38.499	-486.054	1.448	1.015	10.260	-3.718	3.510
-43.127	-486.056	2.680	-0.280	10.254	-2.372	16.139

Table 2.24 - SACS Member Force of Jacket Model (2nd leg, +x+y) using Airy's wave theory.

	Case 1 : Airy ----- Member force from SACS (2nd leg, +x+y)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
12.833	1.596	-1.984	-1.829	-11.949	-0.204	1.125
10.015	1.596	-1.984	-1.829	-11.949	4.957	6.723
7.196	1.596	-1.984	-1.829	-11.949	10.117	12.322
4.378	1.596	-1.984	-1.829	-11.949	15.277	17.920

1.053	-46.255	6.021	4.453	-6.166	-22.046	-22.057
-2.272	-46.255	-1.630	-2.945	-6.166	-24.049	-28.851
-5.597	-46.255	-1.630	-2.945	-6.166	-24.049	-28.851
-8.922	-46.255	-12.422	-13.292	-6.166	32.761	20.733
-12.845	-239.840	6.153	8.636	8.620	31.809	12.981
-16.768	-239.840	1.756	4.460	8.620	6.460	-2.174
-20.691	-239.840	-4.318	-1.255	8.620	-4.280	9.806
-24.614	-239.840	-6.450	-3.248	8.620	4.703	31.100
-29.242	-481.830	5.358	2.616	20.620	4.714	32.862
-33.871	-481.830	3.338	0.730	20.620	-2.874	12.894
-38.499	-481.830	0.313	-2.115	20.620	4.240	-3.233
-43.127	-481.830	-0.914	-3.292	20.620	16.799	-1.795

Table 2.25 - OpenFAST Member Force of Jacket Model (2nd leg, +x+y) using Airy's wave theory.

	Case 1 : Airy ----- Member force from OpenFAST (2nd leg, +x+y)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
-8.92	-152.550	0.900	4.230	2.598	28.410	-1.897
-16.768	-152.600	1.087	2.375	2.598	-5.561	4.962
-24.614	-416.240	2.617	0.484	11.420	1.184	-25.455
-33.871	-416.300	-1.815	-0.337	11.420	-3.565	2.173
-43.127	-416.400	1.065	-1.143	11.420	7.246	8.026

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Table 2.26 - X-SEA Member Force of Jacket Model (3rd leg, -x+y) using Airy's wave theory.

	Case 1 : Airy ----- Member force from X-SEA (3rd leg, -x+y)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
12.833	-0.812	-1.489	-1.468	-4.931	3.425	-1.026
10.015	-0.812	-1.489	-1.468	-4.931	7.565	-5.225
7.196	-0.812	-1.489	-1.468	-4.931	11.706	-9.425
4.378	-0.812	-1.489	-1.468	-4.931	15.846	-13.624
1.053	27.174	7.906	7.642	-2.046	-20.337	19.827
-2.272	27.217	1.198	1.464	-2.101	-24.797	22.793
-5.597	27.250	-3.849	-3.107	-2.144	-14.132	9.201
-8.922	27.275	-7.607	-6.464	-2.176	7.624	-16.702
-12.845	206.272	4.972	1.339	1.521	-0.698	-9.150
-16.768	206.291	2.656	-0.647	1.494	2.050	0.827
-20.691	206.304	1.041	-1.993	1.474	10.023	4.600
-24.614	206.314	-0.075	-2.893	1.461	21.484	4.083
-29.242	446.213	0.405	2.123	6.604	14.349	-1.343
-33.871	446.219	-0.164	1.711	6.594	6.494	-2.252
-38.499	446.223	-0.509	1.482	6.587	-0.326	-4.704

-43.127	446.227	-0.702	1.367	6.583	-6.633	-8.014

Table 2.27 - SACS Member Force of Jacket Model (3rd leg, -x+y) using Airy's wave theory.

	Case 1 : Airy ----- Member force from SACS (3rd leg, -x+y)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
12.833	-1.624	-1.442	1.414	-9.199	0.293	1.331
10.015	-1.624	-1.442	1.414	-9.199	-3.697	5.399
7.196	-1.624	-1.442	1.414	-9.199	-7.687	9.467
4.378	-1.624	-1.442	1.414	-9.199	-11.677	13.535
1.053	26.273	4.308	-4.018	-3.959	16.046	-16.683
-2.272	26.273	-0.985	1.671	-3.959	19.495	-21.771
-5.597	26.273	-0.985	1.671	-3.959	19.495	-21.771
-8.922	26.273	-7.766	9.093	-3.959	-18.763	9.686
-12.845	205.950	2.406	-6.158	6.833	-27.311	2.981
-16.768	205.950	0.001	-3.454	6.833	-8.749	-1.453
-20.691	205.950	-2.7436	-0.252	6.833	4.291	10.718
-24.614	205.950	-3.476	0.652	6.833	3.394	23.030
-29.242	446.720	-2.444	0.713	15.402	-3.035	24.361
-33.871	446.720	-1.901	0.009	15.402	-1.488	14.407
-38.499	446.720	1.589	0.424	15.402	-2.534	6.393
-43.127	446.720	1.346	0.811	15.402	-8.627	-6.927

Table 2.28 - OpenFAST Member Force of Jacket Model (3rd leg, -x+y) using Airy's wave theory.

	Case 1 : Airy ----- Member force from OpenFAST (3rd leg, -x+y)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
-8.92	197.750	0.879	-2.887	2.560	-14.835	-1.869
-16.768	197.800	-1.092	-1.080	2.559	8.763	4.851
-24.614	427.095	2.624	-0.849	11.480	-5.694	-25.540
-33.871	427.200	1.824	-0.044	11.480	2.150	-2.173
-43.127	427.300	1.055	0.780	11.480	-5.273	8.072

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Table 2.29 - X-SEA Member Force of Jacket Model (4th leg, -x-y) using Airy's wave theory.

	Case 1 : Airy ----- Member force from X-SEA (4th leg, -x-y)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
12.833	-0.812	-1.489	1.468	4.931	-3.425	-1.026
10.015	-0.812	-1.489	1.468	4.931	-7.565	-5.225
7.196	-0.812	-1.489	1.468	4.931	-11.706	-9.425
4.378	-0.812	-1.489	1.468	4.931	-15.846	-13.624

1.053	27.191	7.484	-7.642	2.306	20.212	19.827
-2.272	27.231	0.832	-1.464	2.296	24.703	22.793
-5.597	27.262	-4.122	3.107	2.288	14.063	9.201
-8.922	27.285	-7.810	6.464	2.282	-7.674	-16.702
-12.845	206.283	4.799	-1.339	-1.416	0.649	-9.150
-16.768	206.299	2.535	0.647	-1.421	-2.084	0.827
-20.691	206.311	0.958	1.993	-1.425	-10.045	4.600
-24.614	206.319	-0.133	2.893	-1.427	-21.499	4.083
-29.242	446.218	0.360	-2.123	-6.574	-14.361	-1.343
-33.871	446.223	-0.192	-1.711	-6.576	-6.502	-2.252
-38.499	446.226	-0.525	-1.482	-6.578	0.323	-4.704
-43.127	446.228	-0.711	-1.367	-6.579	6.632	-8.014

Table 2.30 - SACS Member Force of Jacket Model (4th leg, -x-y) using Airy's wave theory.

	Case 1 : Airy ----- Member force from SACS (4th leg, -x-y)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
12.833	-1.624	1.442	1.414	9.199	0.293	-1.331
10.015	-1.624	1.442	1.414	9.199	-3.697	-5.399
7.196	-1.624	1.442	1.414	9.199	-7.687	-9.467
4.378	-1.624	1.442	1.414	9.199	-11.677	-13.535
1.053	26.273	-4.308	-4.018	3.959	16.046	16.683
-2.272	26.273	0.985	1.671	3.959	19.495	21.771
-5.597	26.273	0.985	1.671	3.959	19.495	21.771
-8.922	26.273	7.766	9.093	3.959	-18.763	-9.686
-12.845	205.950	-2.406	-6.158	-6.833	-27.311	-2.981
-16.768	205.950	-0.001	-3.454	-6.833	-8.749	1.453
-20.691	205.950	-2.744	0.252	-6.833	4.291	-10.718
-24.614	205.950	3.476	0.652	-6.833	3.394	-23.030
-29.242	446.720	-2.444	-0.713	-15.403	-3.035	-24.361
-33.871	446.720	-1.9005	-0.009	-15.403	-1.488	-14.407
-38.499	446.720	-1.589	0.424	-15.403	-2.534	-6.393
-43.127	446.720	-1.346	0.811	-15.403	-8.627	6.927

Table 2.31 - OpenFAST Member Force of Jacket Model (4th leg, -x-y) using Airy's wave theory.

	Case 1 : Airy ----- Member force from OpenFAST (4th leg, -x-y)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
-8.92	197.750	-0.880	-2.885	-2.560	-14.832	1.871
-16.768	197.800	1.092	-1.079	-2.560	8.757	-4.854
-24.614	427.080	-2.623	-0.849	-11.470	-5.690	25.535
-33.871	427.150	-1.824	0.044	-11.475	2.155	2.174
-43.127	427.300	-1.056	0.779	-11.475	-5.272	-8.076

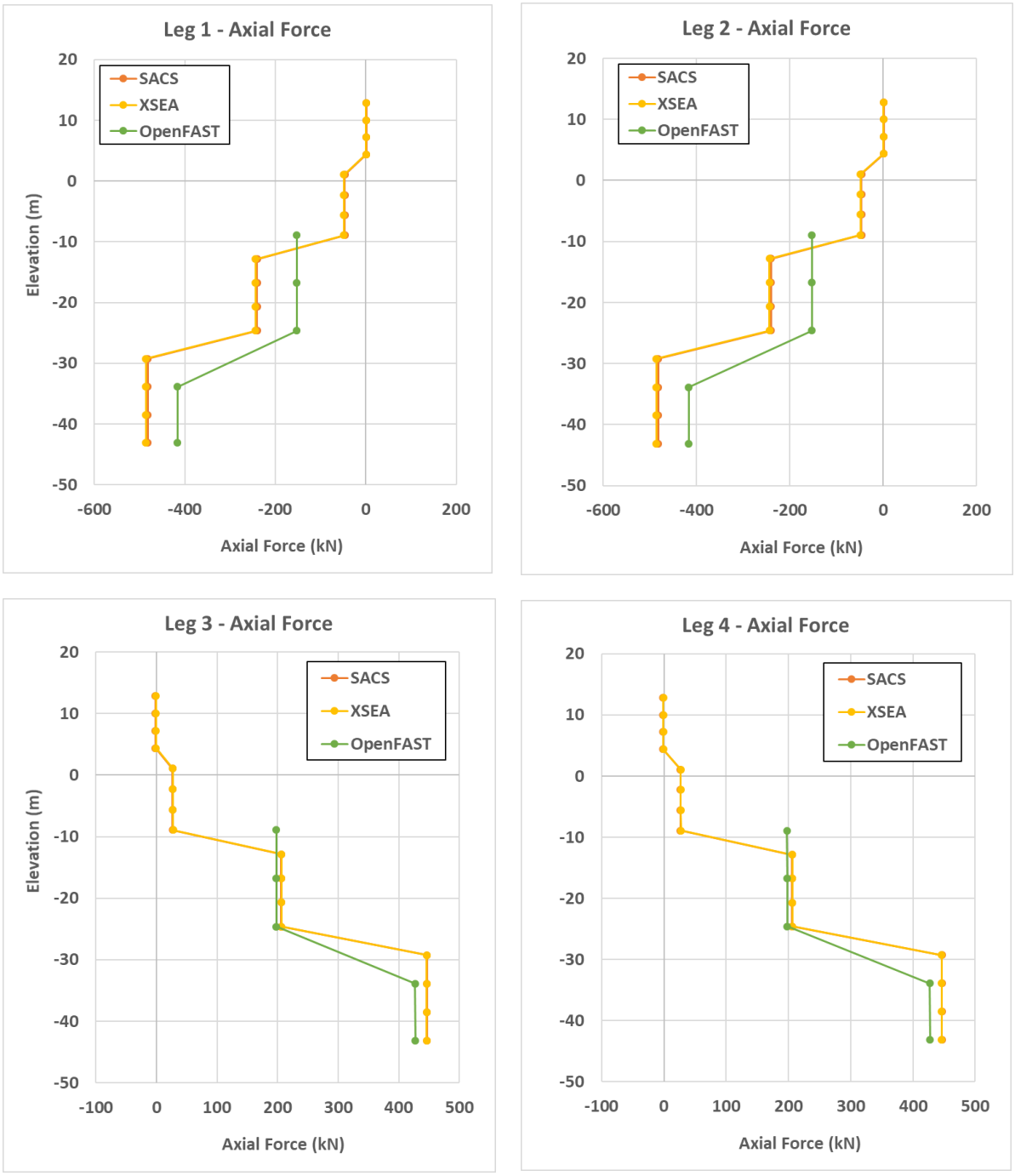

Figure 2.5 – Summary of axial force of jacket model main legs using Airy wave theory. OpenFAST output adjusted in graphs in order to compare similar members between jacket bays with other software.

2.6 Discussion

Results relating to support reactions, displacements, and member forces were obtained for all software. The standard OC4 case was modified in OpenFAST to simulate a static case for the jacket structure by the following ways:

- All component mass and functions related to the turbine have been eliminated,
- Any terms related to inertia forces were eliminated by adjusting hydrodynamic coefficients,
- All marine growth and filled members were removed,
- Regular/Airy wave model was applied instead of JONSWAP.

Overall, the results between the various software match well. Some small differences can be noticed when looking at the seabed leg reactions due to wave loading. Consequently, this error is then also observed at the local member loading. However, the individual member displacements seem to match very well between software. Some potential sources of error include,

- OpenFAST does not currently have a functioning feature to incorporate wave stretching in fixed structures such as this jacket which would explain the consistently smaller reactions and member forces;
- A difference in the way the software treats member connections at the joints;
- Local versus global axis convention of output between different software.

3.0 TRIPOD SUBSTRUCTURE

3.1 Introduction

For the verification of X-SEA software, the static analysis of Tripod offshore structures subjected to self-weight and Airy's wave are carried out using X-SEA, SACS and OpenFAST software. The tripod structure has 50 meters height from support to end of sub-structure and has 3 fixed supports at the bottom of leg.

To compare the results of the software, the reaction at supports, displacement of main legs, and internal member force in X-SEA, SACS, and OpenFAST were calculated and shown in the form of tables and plots. The reaction force is taken from the three fixed supports at the bottom of the structure. Displacement and internal force are compared for each main leg. All the node positions calculated from X-SEA and SACS are illustrated in figure 1. The 1 elements (1 meshes) are used for every single members resulting in a total of 158 nodes and 163 elements for this structure.

OpenFAST results were obtained for Airy wave simulations without wave stretching. Also, the x,y,z displacements are in reference to the global coordinate system while the member rotations and member loads use the local coordinate system.

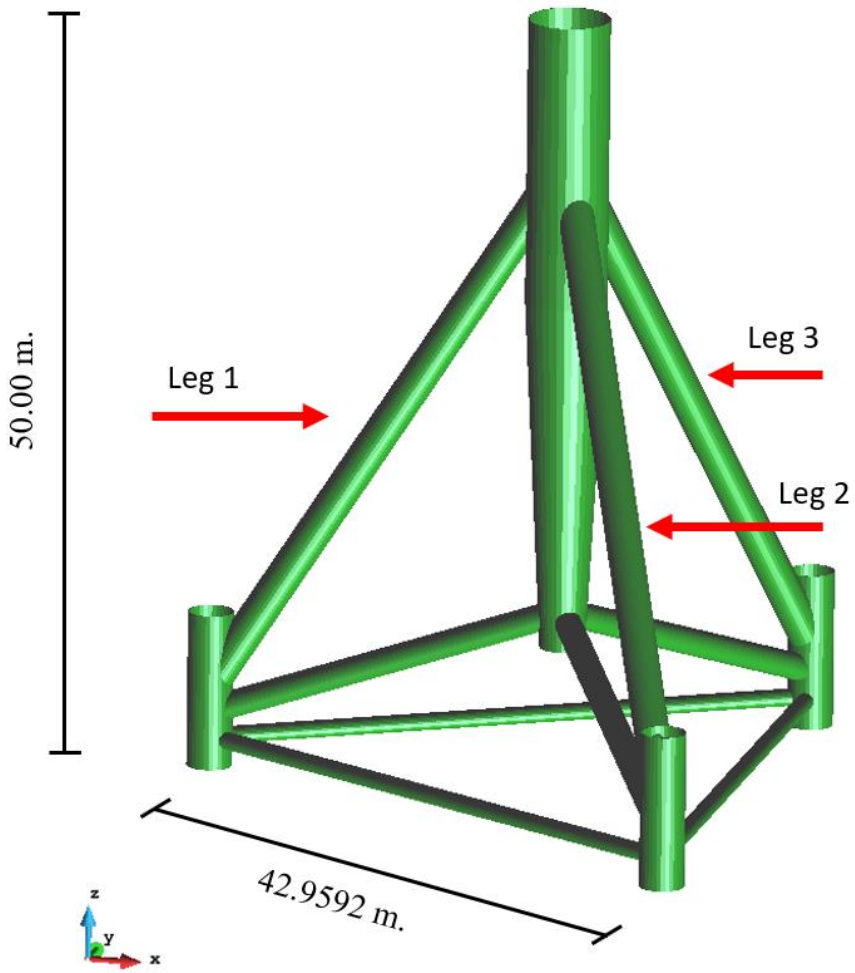

Figure 3.1 - X-SEA tripod structure model.

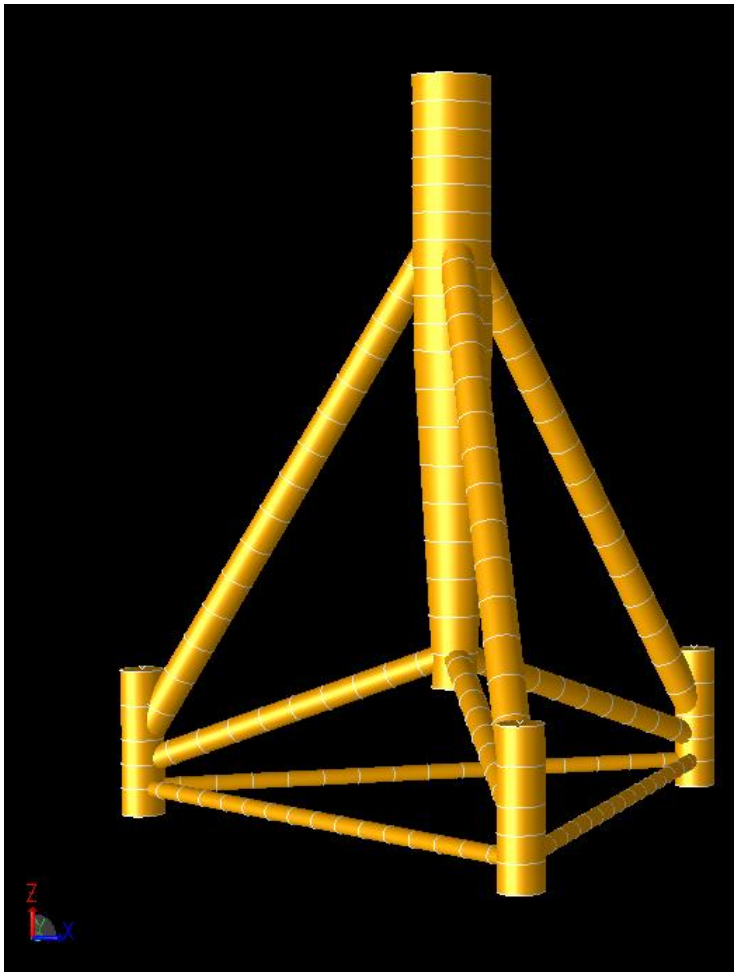

Figure 3.2 - SACS Tripod structure model.

3.2 Geometry of Tripod

Structural dimension is as follows:

- Jacket Height 50.00 m.
- Base dimension = 42.9592 m of base diameter

Table 3.1 - Cross-sections of tripod members.

Section - Circular Section	**Diameter (m.)**	**Thickness (m.)**
Main Leg Type 1	2.475	0.035
Bracing 1	1.875	0.025
Bracing 2	1.200	0.025
Support 1	3.150	0.035
Support 2	3.150	0.045
Top-section	5.700	0.050

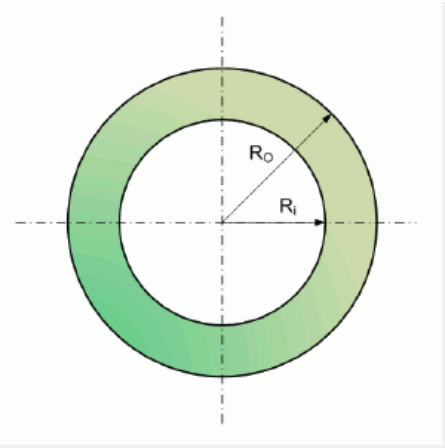

Figure 3.3 – Circular section of members.

Table 3.2 - Section detail of taper section.

Section - Circular Section	**Diameter (m.)**	**Thickness (m.)**
Taper section (Top)	5.700	0.050
Taper section (Bottom)	3.142	0.050

3.3 Material Properties

Elastic modulus E = 2.1×10^{11} N/m2

Shear Modulus G = 8.1×10^{10} N/m2

Poisson's ratio (n) = 0.2962

Mass density = 7850 kg/m3

3.4 Airy Wave Loading

Environment condition	**Wave parameter**
Water depth = 45.00 m. Sea bed level = -45.00 m. Water density = 1025 kg/m^3 Air Density = 1.25 kg/m^3	Wave theory = Airy wave theory Wave height = 8 m Wave period = 10 seconds

3.5 Results

3.5.1 Self-weight Reactions

Table 3.3 - Reaction by X-SEA of jacket model subjected to self-weight load.

	CASE – Self weight ---- Reaction by X-SEA					
Node	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
156	-	-	2838.750	-	-	-
157	-	-	2838.750	-	-	-
158	-	-	2838.750	-	-	-

Table 3.4 - Reaction by SACS of jacket model using self-weight loading.

	CASE – Self weight ---- Reaction by SACS					
Node	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
156	-	-	2804.794	-	-	-
158	-	-	2804.794	-	-	-
157	-	-	2804.794	-	-	-

Table 3.5 - Reaction by OpenFAST of tripod model using self-weight loading.

	CASE – Self weight ---- Reaction by OpenFAST					
Node	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
M1J1	-	-	2805.000	-	-	-
M3J1	-	-	2805.000	-	-	-
M2J1	-	-	2805.000	-	-	-

3.5.2 Wave Reactions

Table 3.6 - X-SEA reaction of Jacket structure using Airy's wave theory.

	Case 1 : Airy ----- Wave Reaction by X-SEA					
Node	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
156	-221.464	0.058	-386.073	-0.245	-1169.36	-2.714
157	-207.049	105.861	275.059	-206.230	-1256.63	337.895
158	-207.032	-105.919	275.067	206.309	-1256.73	-335.168

Table 3.7 - SACS reaction of tripod structure using Airy's wave theory.

	Case 1 : Airy ----- Wave Reaction by SACS					
Node	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
156	-226.273	0.000	-397.502	0.000	-1113.808	0.000
157	-204.289	103.845	265.702	-223.050	-1243.122	323.036
158	-204.289	-103.845	265.703	223.055	-1243.122	-323.035

Table 3.8 - OpenFAST reaction of tripod structure using Airy's wave theory.

	Case 1 : Airy ----- Wave Reaction by OpenFAST					
Node	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN-m)	M_y (kN-m)	M_z (kN-m)
M1J1	-336.500	0.000	-410.450	0.005	-1846.000	0.002
M3J1	-144.000	114.000	200.910	-565.500	-949.000	225.350
M2J1	-144.000	-114.000	200.915	565.500	-949.000	-225.350

3.5.3 Member Displacements

LEG 1

Table 3.9 - X-SEA Displacement of Jacket Structure (1st leg) using Airy's wave.

	Case 1 : Airy ----- Displacement from X-SEA (1st Leg)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
0.000	1.010	0.000	-0.072	0.000	-0.022	0.000
-2.000	1.084	0.000	-0.140	0.000	-0.041	0.000
-4.000	1.178	0.000	-0.221	0.000	-0.048	0.000
-6.000	1.274	0.000	-0.302	0.000	-0.046	0.000
-8.000	1.357	0.000	-0.375	0.000	-0.038	0.000
-10.000	1.417	0.000	-0.434	0.000	-0.027	0.000
-12.413	1.453	0.000	-0.481	0.000	-0.010	0.000
-14.827	1.444	0.000	-0.501	0.000	0.008	0.000

-17.240	1.392	0.000	-0.493	0.000	0.024	0.000
-19.654	1.301	0.000	-0.461	0.000	0.038	0.000
-22.110	1.178	0.000	-0.409	0.000	0.049	0.000
-24.567	1.034	0.000	-0.343	0.000	0.056	0.000
-27.023	0.877	0.000	-0.270	0.000	0.058	0.000
-29.480	0.719	0.000	-0.195	0.000	0.058	0.000
-31.936	0.567	0.000	-0.125	0.000	0.054	0.000
-34.393	0.428	0.000	-0.063	0.000	0.048	0.000
-36.850	0.308	0.000	-0.012	0.000	0.040	0.000
-39.306	0.207	0.000	0.026	0.000	0.033	0.000

Table 3.10 - SACS Displacement of Jacket Structure (1st leg) using Airy's wave theory.

	Case 1 : Airy ----- Displacement from SACS (1st Leg)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
0.000	1.002	0.000	-0.067	0.000	0.000	0.000
-2.000	1.034	0.000	-0.109	0.000	0.000	0.000
-4.000	1.088	0.000	-0.164	0.000	0.000	0.000
-6.000	1.146	0.000	-0.221	0.000	0.000	0.000
-8.000	1.196	0.000	-0.274	0.000	0.000	0.000
-10.000	1.229	0.000	-0.316	0.000	0.000	0.000
-12.413	1.241	0.000	-0.349	0.000	0.000	0.000
-14.827	1.220	0.000	-0.361	0.000	0.000	0.000
-17.240	1.166	0.000	-0.352	0.000	0.000	0.000
-19.654	1.083	0.000	-0.326	0.000	0.000	0.000
-22.110	0.978	0.000	-0.285	0.000	0.000	0.000
-24.567	0.857	0.000	-0.235	0.000	0.000	0.000
-27.023	0.731	0.000	-0.181	0.000	0.000	0.000
-29.480	0.605	0.000	-0.127	0.000	0.000	0.000
-31.936	0.486	0.000	-0.078	0.000	0.000	0.000
-34.393	0.378	0.000	-0.036	0.000	0.000	0.000
-36.850	0.282	0.000	-0.001	0.000	0.000	0.000

Table 3.11 - OpenFAST displacement of tripod structure (1st leg) using AIry's wave theory.

	Case 1 : Airy ----- Displacement from OpenFAST (1st Leg)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
-2.000	1.116	0.000	-0.067	0.034	0.000	0.000
-19.654	1.564	0.000	-0.538	0.019	0.000	0.000
-36.850	0.495	0.000	-0.052	0.065	0.000	0.000

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Table 3.12 - X-SEA Displacement of Tripod model (2nd leg) using Airy's wave theory.

	Case 1 : Airy ----- Displacement from X-SEA (2nd Leg)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
0.000	1.010	0.000	-0.072	0.000	-0.022	0.000
-2.000	1.078	-0.052	-0.065	-0.024	-0.031	-0.013
-4.000	1.172	-0.147	-0.074	-0.039	-0.036	-0.022
-6.000	1.276	-0.266	-0.091	-0.046	-0.037	-0.025
-8.000	1.380	-0.391	-0.112	-0.047	-0.035	-0.026
-10.000	1.475	-0.510	-0.133	-0.043	-0.031	-0.023
-12.413	1.567	-0.632	-0.154	-0.034	-0.022	-0.016
-14.827	1.624	-0.720	-0.167	-0.022	-0.012	-0.007
-17.240	1.639	-0.765	-0.169	-0.008	0.000	0.003
-19.654	1.608	-0.766	-0.162	0.007	0.013	0.013
-22.110	1.529	-0.723	-0.146	0.020	0.026	0.024
-24.567	1.404	-0.640	-0.122	0.031	0.039	0.033
-27.023	1.239	-0.525	-0.094	0.039	0.049	0.040
-29.480	1.042	-0.390	-0.065	0.043	0.057	0.045
-31.936	0.825	-0.249	-0.039	0.042	0.061	0.046
-34.393	0.603	-0.118	-0.020	0.035	0.061	0.042
-36.850	0.394	-0.014	-0.012	0.022	0.055	0.034
-39.306	0.219	0.043	-0.018	0.003	0.043	0.020

Table 3.13 - SACS Displacement of Tripod model (2nd leg) using Airy's wave theory.

	Case 1 : Airy ----- Displacement from SACS (2nd Leg)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
0.000	1.002	0.000	-0.067	0.000	0.000	0.000
-2.000	1.040	-0.047	-0.067	0.000	0.000	0.000
-4.000	1.111	-0.132	-0.077	0.000	0.000	0.000
-6.000	1.201	-0.238	-0.093	0.000	0.000	0.000
-8.000	1.297	-0.350	-0.110	0.000	0.000	0.000
-10.000	1.389	-0.458	-0.126	0.000	0.000	0.000
-12.413	1.481	-0.568	-0.140	0.000	0.000	0.000
-14.827	1.543	-0.647	-0.147	0.000	0.000	0.000
-17.240	1.565	-0.688	-0.146	0.000	0.000	0.000
-19.654	1.544	-0.688	-0.136	0.000	0.000	0.000
-22.110	1.475	-0.649	-0.119	0.000	0.000	0.000
-24.567	1.360	-0.573	-0.097	0.000	0.000	0.000
-27.023	1.205	-0.469	-0.072	0.000	0.000	0.000
-29.480	1.017	-0.346	-0.047	0.000	0.000	0.000
-31.936	0.807	-0.218	-0.026	0.000	0.000	0.000

-34.393	0.592	-0.099	-0.012	0.000	0.000	0.000
-36.850	0.388	-0.005	-0.008	0.000	0.000	0.000
-39.306	0.217	0.045	-0.017	0.000	0.000	0.000

Table 3.14 - OpenFAST displacement of tripod structure (2nd leg) using AIry's wave theory.

	Case 1 : Airy ----- Displacement from OpenFAST (2nd Leg)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
-2.000	1.128	0.013	0.049	0.020	0.026	0.006
-19.654	1.555	0.181	0.319	0.009	0.030	0.003
-36.850	0.304	0.128	0.031	0.036	0.044	0.000

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Table 3.15 - X-SEA Displacement of Tripod model (3rd leg) using Airy's wave theory.

	Case 3 : Airy ----- Displacement from X-SEA (3rd Leg)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
0.000	1.010	0.000	-0.072	0.000	-0.022	0.000
-2.000	1.078	0.052	-0.065	0.024	-0.031	0.013
-4.000	1.172	0.148	-0.074	0.039	-0.036	0.022
-6.000	1.276	0.266	-0.091	0.046	-0.037	0.025
-8.000	1.380	0.391	-0.112	0.047	-0.035	0.025
-10.000	1.475	0.510	-0.133	0.043	-0.031	0.023
-12.413	1.567	0.632	-0.154	0.034	-0.022	0.016
-14.827	1.624	0.720	-0.167	0.022	-0.012	0.007
-17.240	1.639	0.765	-0.169	0.008	0.000	-0.003
-19.654	1.608	0.766	-0.162	-0.007	0.013	-0.013
-22.110	1.529	0.723	-0.146	-0.020	0.026	-0.024
-24.567	1.405	0.640	-0.122	-0.031	0.039	-0.033
-27.023	1.239	0.525	-0.094	-0.039	0.049	-0.040
-29.480	1.042	0.391	-0.065	-0.043	0.057	-0.045
-31.936	0.825	0.250	-0.039	-0.042	0.061	-0.046
-34.393	0.603	0.118	-0.020	-0.035	0.061	-0.042
-36.850	0.394	0.014	-0.012	-0.022	0.055	-0.034
-39.306	0.219	-0.043	-0.018	-0.003	0.043	-0.021

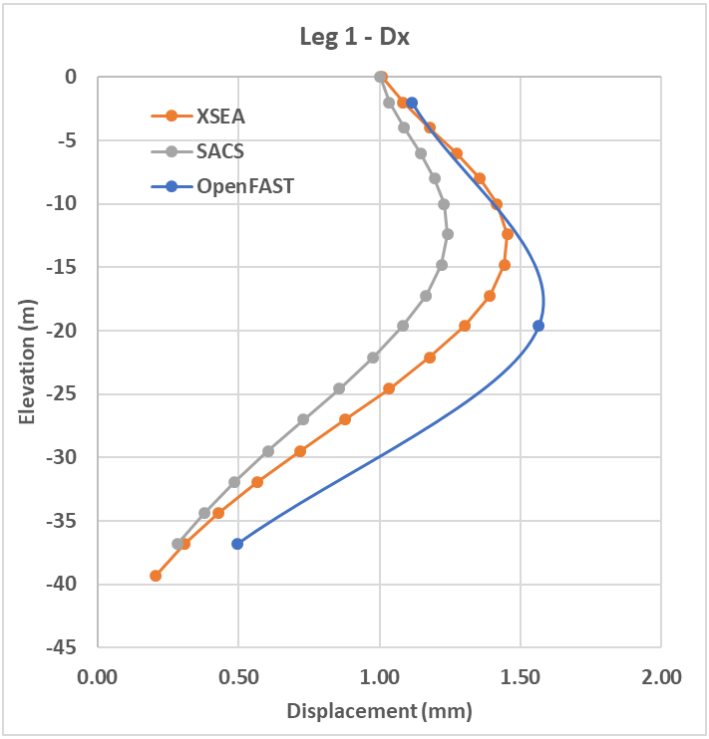
Table 3.16 - SACS Displacement of Tripod model (3rd leg) using Airy's wave theory.

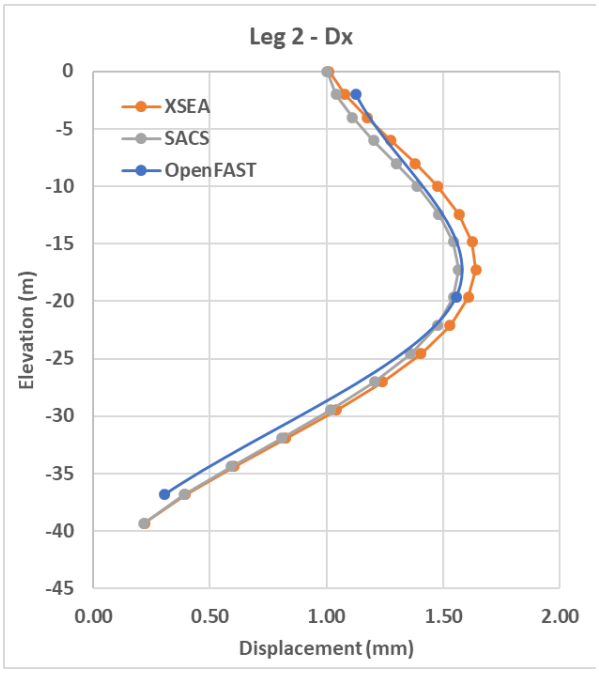
	Case 1 : Airy ----- Displacement from SACS (3rd Leg)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
0.000	1.002	-0.000	-0.067	0.000	0.000	0.000
-2.000	1.040	-0.047	-0.067	0.000	0.000	0.000

-4.000	1.111	-0.132	-0.077	0.000	0.000	0.000
-6.000	1.201	-0.238	-0.093	0.000	0.000	0.000
-8.000	1.297	-0.350	-0.110	0.000	0.000	0.000
-10.000	1.389	-0.458	-0.126	0.000	0.000	0.000
-12.413	1.481	-0.568	-0.140	0.000	0.000	0.000
-14.827	1.543	-0.647	-0.147	0.000	0.000	0.000
-17.240	1.565	-0.688	-0.146	0.000	0.000	0.000
-19.654	1.544	-0.688	-0.136	0.000	0.000	0.000
-22.110	1.475	-0.649	-0.119	0.000	0.000	0.000
-24.567	1.360	-0.573	-0.097	0.000	0.000	0.000
-27.023	1.205	-0.469	-0.072	0.000	0.000	0.000
-29.480	1.017	-0.346	-0.047	0.000	0.001	0.000
-31.936	0.807	-0.218	-0.026	0.000	0.001	0.000
-34.393	0.592	-0.099	-0.012	0.000	0.001	0.000
-36.850	0.388	-0.005	-0.008	0.000	0.001	0.000
-39.306	0.217	0.045	-0.017	0.000	0.000	0.000

Table 3.17 - OpenFAST displacement of tripod structure (3rd leg) using AIry's wave theory.

	Case 1 : Airy ----- Displacement from OpenFAST (3rd Leg)					
Elevation (m)	Dx (mm.)	Dy (mm.)	Dz (mm.)	Rx (rad)	Ry (rad)	Rz (rad)
-2.000	1.128	0.013	0.049	0.020	0.026	0.006
-19.654	1.555	0.181	0.319	0.009	0.030	0.003
-36.850	0.304	0.128	0.031	0.036	0.044	0.000





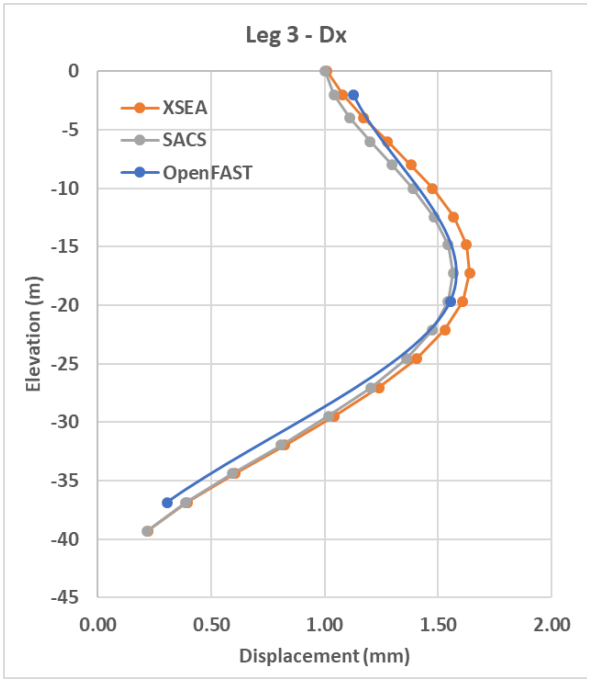


Figure 3.4 – Summary of tripod x-displacement of each main leg.

3.5.4 Member Forces

LEG 1

Table 3.18 - X-SEA Member Force of Tripod Model (1st leg) using Airy's wave theory.

	Case 1 : Airy ----- Member force from X-SEA (1st leg)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
-2.000	411.069	101.274	0.003	3.316	0.038	-214.448
-4.000	412.058	76.579	0.003	2.839	0.030	-35.380
-6.000	412.962	55.463	0.003	2.403	0.022	94.006
-8.000	413.785	37.618	0.003	2.006	0.014	181.428
-10.000	414.529	22.743	0.003	1.646	0.006	233.889
-12.413	414.725	9.804	0.003	1.900	-0.003	261.632
-14.827	415.581	-1.517	0.003	1.399	-0.013	255.854
-17.240	416.329	-9.753	0.003	0.961	-0.023	226.867
-19.654	416.979	-15.326	0.003	0.579	-0.032	182.234
-22.110	417.542	-18.565	0.003	0.257	-0.042	127.654
-24.567	418.046	-19.785	0.003	-0.045	-0.052	69.691
-27.023	418.481	-19.185	0.003	-0.304	-0.061	13.651
-29.480	418.857	-17.037	0.003	-0.529	-0.071	-35.994
-31.936	419.182	-13.553	0.003	-0.723	-0.081	-75.385
-34.393	419.465	-8.887	0.003	-0.892	-0.091	-101.107
-36.850	419.714	-3.221	0.003	-1.040	-0.100	-110.271
-39.306	419.933	3.353	0.003	-1.170	-0.110	-100.257

Table 3.19 - SACS Member Force of Tripod Model (1st leg) using Airy's wave theory.

	Case 1 : Airy ----- Member force from SACS (1st leg)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
-2.000	424.360	0.000	-100.240	0.000	-430.530	0.000
-4.000	424.360	0.000	-76.873	0.000	-221.790	0.000
-6.000	424.360	0.000	-56.843	0.000	-64.303	0.000
-8.000	424.360	0.000	-25.520	0.000	126.140	0.000
-10.000	424.360	0.000	-13.793	0.000	172.140	0.000
-12.413	424.360	0.000	-2.661	0.000	194.880	0.000
-14.827	424.360	0.000	-2.660	0.000	194.880	0.000
-17.240	424.360	0.000	5.523	0.000	190.130	0.000
-19.654	424.360	0.000	11.090	0.000	165.850	0.000
-22.110	424.360	0.000	14.390	0.000	128.990	0.000
-24.567	424.360	0.000	15.715	0.000	84.799	0.000
-27.023	424.360	0.000	15.248	0.000	39.430	0.000
-29.480	424.360	0.000	9.891	0.000	-36.182	0.000
-31.936	424.360	0.000	5.383	0.000	-58.625	0.000

-34.393	424.360	0.000	-0.139	0.000	-66.473	0.000
-36.850	424.360	0.000	-0.141	0.000	-66.473	0.000
-39.306	424.360	0.000	-6.550	0.000	-56.954	0.000

Table 3.20 - OpenFAST Member Force of Tripod Model (1st leg) using Airy's wave theory.

	Case 1 : Airy ----- Member force from OpenFAST (1st leg)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
-2.000	450.100	0.000	-64.300	0.001	-281.000	-0.004
-19.654	450.400	0.000	8.435	0.001	238.000	-0.002
-36.850	450.500	0.000	24.550	0.001	-104.000	0.001

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Table 3.21 - X-SEA Member Force of Tripod Model (2nd leg) using Airy's wave theory.

	Case 1 : Airy ----- Member force from X-SEA (2nd leg)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
-2.000	-286.353	45.612	-80.106	-9.970	-334.166	-230.576
-4.000	-286.480	36.980	-67.825	-9.901	-173.867	-136.805
-6.000	-286.587	29.226	-56.630	-9.837	-40.030	-62.028
-8.000	-286.678	22.293	-46.371	-9.778	69.555	-4.260
-10.000	-286.755	16.126	-36.919	-9.724	156.799	38.351
-12.413	-286.627	9.896	-27.341	-9.859	235.187	72.824
-14.827	-286.703	4.332	-17.645	-9.774	285.458	89.919
-17.240	-286.764	-0.349	-8.680	-9.707	310.157	92.851
-19.654	-286.813	-4.184	-0.333	-9.634	311.047	84.082
-22.110	-286.835	-7.286	7.564	-9.587	289.060	65.504
-24.567	-286.865	-9.650	15.096	-9.527	245.158	39.336
-27.023	-286.886	-11.299	22.254	-9.470	180.477	7.709
-29.480	-286.899	-12.278	29.123	-9.418	95.848	-27.378
-31.936	-286.904	-12.612	35.763	-9.367	-8.065	-64.035
-34.393	-286.901	-12.349	42.240	-9.320	-130.783	-100.508
-36.850	-286.890	-11.459	48.614	-9.284	-272.011	-134.960
-39.306	-286.871	-10.005	54.941	-9.236	-431.610	-165.740

Table 3.22 - SACS Member Force of Tripod Model (2nd leg) using Airy's wave theory.

	Case 1 : Airy ----- Member force from SACS (2nd leg)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
-2.000	-279.520	87.971	-38.859	3.463	-237.430	571.840
-4.000	-279.520	75.093	-32.190	3.463	-153.520	379.280
-6.000	-279.520	63.422	-26.042	3.463	-84.767	215.710

-8.000	-279.520	52.769	-20.410	3.463	-29.942	78.505
-10.000	-279.520	33.923	-10.668	3.463	42.766	-125.350
-12.413	-279.520	23.821	-5.744	3.463	66.014	-207.550
-14.827	-279.520	14.499	-1.518	3.462	76.214	-262.050
-17.240	-279.520	5.864	2.036	3.463	75.316	-290.950
-19.654	-279.520	-2.192	4.942	3.464	65.207	-296.070
-22.110	-279.520	-2.192	4.941	3.463	65.207	-296.070
-24.567	-279.520	-9.915	7.254	3.464	47.342	-278.390
-27.023	-279.520	-17.255	8.939	3.463	23.674	-238.840
-29.480	-279.520	-24.275	10.025	3.463	-4.009	-178.450
-31.936	-279.520	-31.031	10.526	3.463	-33.997	-98.072
-34.393	-279.520	-44.004	9.836	3.463	-94.217	120.150
-36.850	-279.520	-50.361	8.666	3.463	-121.220	257.200
-39.306	-279.520	-56.717	6.947	3.464	-144.030	412.710

Table 3.23 - OpenFAST Member Force of Tripod Model (2nd leg) using Airy's wave theory.

	Case 1 : Airy ----- Member force from OpenFAST (2nd leg)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
-2.000	55.775	40.650	-224.000	187.000	-215.400	4.324
-19.654	-10.495	-5.045	-223.700	-141.500	202.000	4.324
-36.850	-30.105	-15.850	-223.800	78.000	-210.750	4.325

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Table 3.24 - X-SEA Member Force of Tripod Model (3rd leg) using Airy's wave theory.

	Case 1 : Airy ----- Member force from X-SEA (3rd leg)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
-2.000	-293.682	52.032	80.102	10.944	331.716	-230.590
-4.000	-293.112	42.759	67.822	10.801	171.643	-136.818
-6.000	-292.592	34.411	56.626	10.682	38.002	-62.039
-8.000	-292.117	26.922	46.367	10.582	-71.413	-4.271
-10.000	-291.681	20.235	36.916	10.499	-158.508	38.340
-12.413	-291.935	14.203	27.338	10.936	-237.468	72.815
-14.827	-291.406	7.984	17.641	10.836	-287.550	89.911
-17.240	-290.926	2.697	8.677	10.769	-312.089	92.844
-19.654	-290.486	-1.703	0.330	10.707	-312.843	84.075
-22.110	-290.119	-5.302	-7.567	10.718	-290.800	65.498
-24.567	-289.734	-8.178	-15.100	10.690	-246.797	39.332
-27.023	-289.379	-10.309	-22.258	10.672	-182.031	7.706
-29.480	-289.048	-11.747	-29.127	10.667	-97.333	-27.381
-31.936	-288.740	-12.518	-35.767	10.671	6.634	-64.037
-34.393	-288.449	-12.678	-42.243	10.689	129.393	-100.508

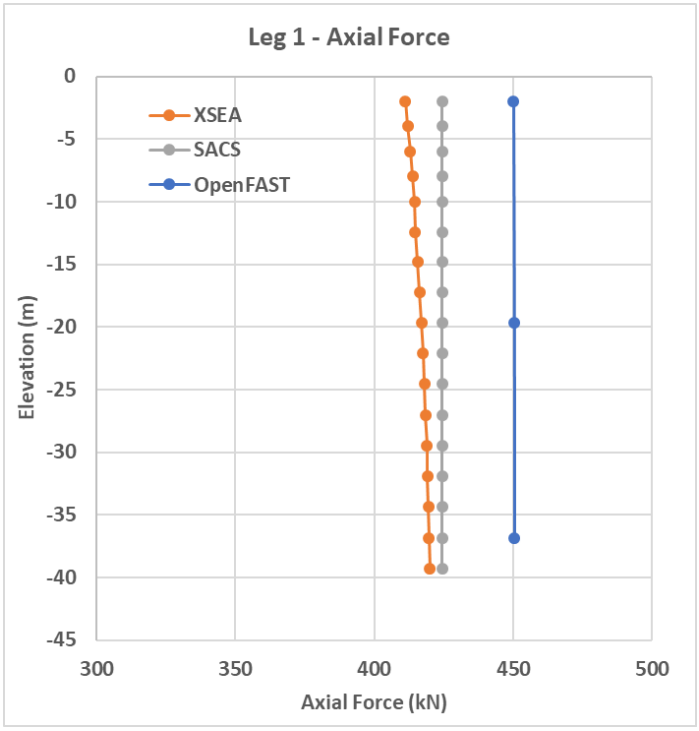
-36.850	-288.174	-12.199	-48.618	10.727	270.647	-134.960
-39.306	-287.912	-11.148	-54.945	10.763	430.258	-165.738

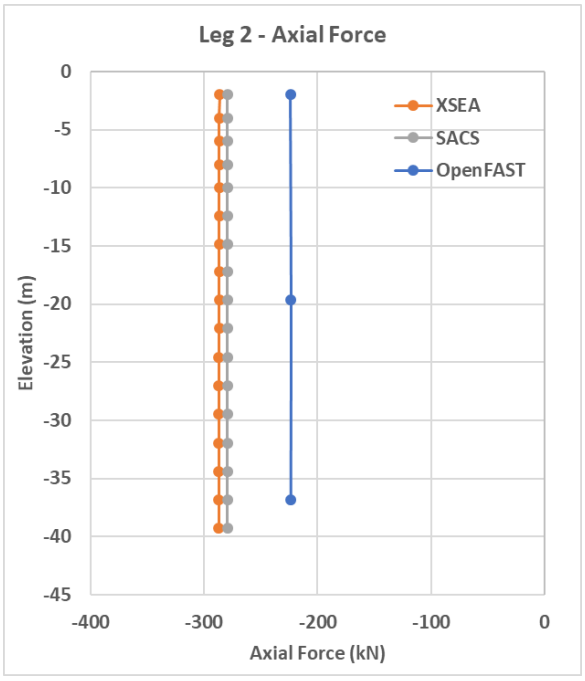
Table 3.25 - SACS Member Force of Tripod Model (3rd leg) using Airy's wave theory.

	Case 1 : Airy ----- Member force from SACS (3rd leg)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
-2.000	-279.520	-87.971	-38.859	-3.463	-237.430	-571.840
-4.000	-279.520	-75.093	-32.190	-3.463	-153.520	-379.280
-6.000	-279.520	-63.423	-26.042	-3.463	-84.768	-215.710
-8.000	-279.520	-52.769	-20.410	-3.463	-29.942	-78.505
-10.000	-279.520	-33.923	-10.668	-3.463	42.766	125.350
-12.413	-279.520	-23.821	-5.744	-3.463	66.014	207.550
-14.827	-279.520	-14.499	-1.518	-3.462	76.215	262.050
-17.240	-279.520	-5.864	2.036	-3.463	75.317	290.950
-19.654	-279.520	2.191	4.942	-3.464	65.208	296.070
-22.110	-279.520	2.192	4.941	-3.463	65.208	296.070
-24.567	-279.520	9.915	7.254	-3.463	47.343	278.390
-27.023	-279.520	17.255	8.939	-3.463	23.675	238.840
-29.480	-279.520	24.275	10.025	-3.463	-4.008	178.450
-31.936	-279.520	31.031	10.526	-3.463	-33.997	98.073
-34.393	-279.520	44.004	9.837	-3.463	-94.217	-120.150
-36.850	-279.520	50.361	8.666	-3.462	-121.220	-257.210
-39.306	-279.520	56.718	6.947	-3.463	-144.030	-412.710

Table 3.26 - OpenFAST Member Force of Tripod Model (3rd leg) using Airy's wave theory.

	Case 1 : Airy ----- Member force from OpenFAST (3rd leg)					
Elevation (m)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN)	Moment-S (kN-m)	Moment-T (kN-m)
-2.000	-55.775	40.650	-224.000	187.000	215.350	-4.322
-19.654	10.500	-5.045	-223.700	-141.500	-202.000	-4.322
-36.850	30.105	-15.850	-223.800	78.000	210.750	-4.323





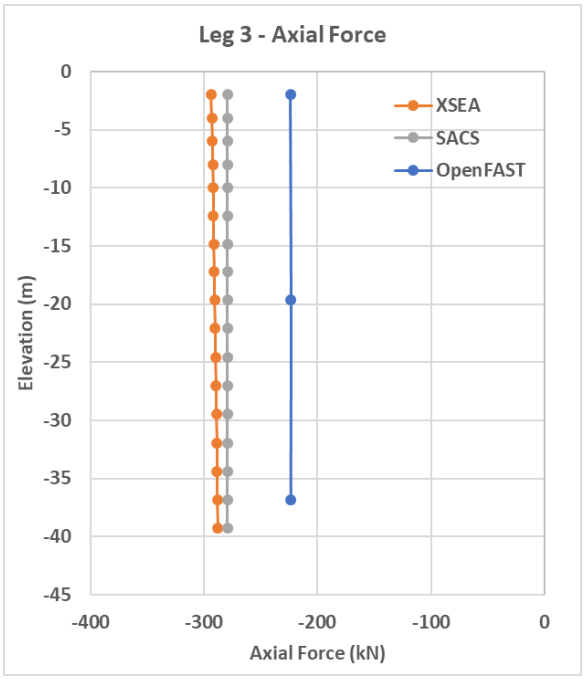


Figure 3.5 – Summary of tripod axial force of each main leg.

3.6 Discussion

Results relating to support reactions, displacements, and member forces were obtained for all software. The standard OC3 case was modified in OpenFAST to simulate a static case for the tripod structure by the following ways:

- All component mass and functions related to the turbine have been eliminated,
- Any terms related to inertia forces were eliminated by adjusting hydrodynamic coefficients and axial member coefficients,
- Regular/Airy wave model was applied instead of JONSWAP.

When comparing all the results, parameters obtained from OpenFAST generally trend with those of XSEA and SACS. Differences are first observed when comparing wave reactions. OpenFAST displays that more of the wave force is taken by the upstream leg and less by the downstream legs. Consequently, this difference is then observed at the individual member forces as well. Some potential sources of error include,

- OpenFAST does not currently have a functioning feature to incorporate wave stretching in fixed structures such as this tripod;
- The local axis convention of the member forces between the different software;
- Geometry/model buildup may be different between software.