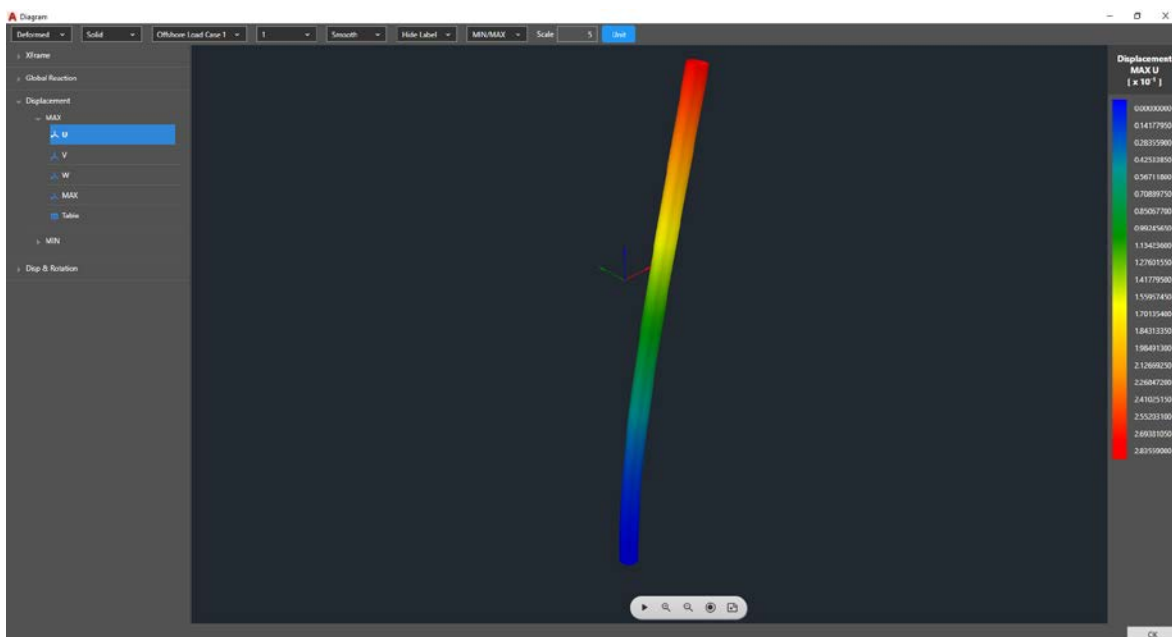


AutoCAD Embedded Finite Element Structural Analysis Software for Offshore Wind Turbine Structure

“X-SEA AutoCAD”

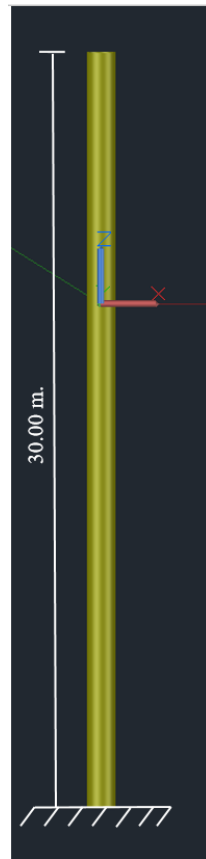
Verification Report of Offshore Monopile Structure



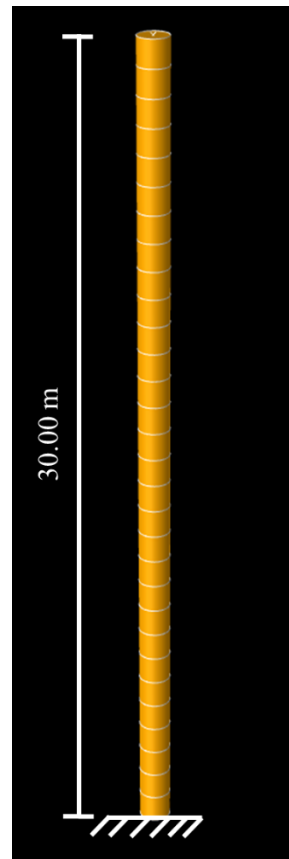
Professor Goangseup Zi
Structural Engineering & Mechanics Lab.
Department of Civil Engineering
Korea University, Seoul, Korea

Title: Verification of Monopile subjected to wave loads using X-SEA and SACS**Problem Description**

The static analysis of Monopile structures subjected to self-weight, Airy's wave, Stokes's wave and Stream Function wave are carried out using X-SEA and SACS 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 result, the reaction at support, displacement and internal member force in both X-SEA and SACS were calculated shown in the form of tables and plots.



(a) X-SEA



(b) SACS

Fig.1 Monopile Model (a) X-SEA (b) SACS

Monopile Height 30.00 m.

Section properties

Section type	Diameter (m.)	Thickness (m.)
Circular section	1.129	0.030

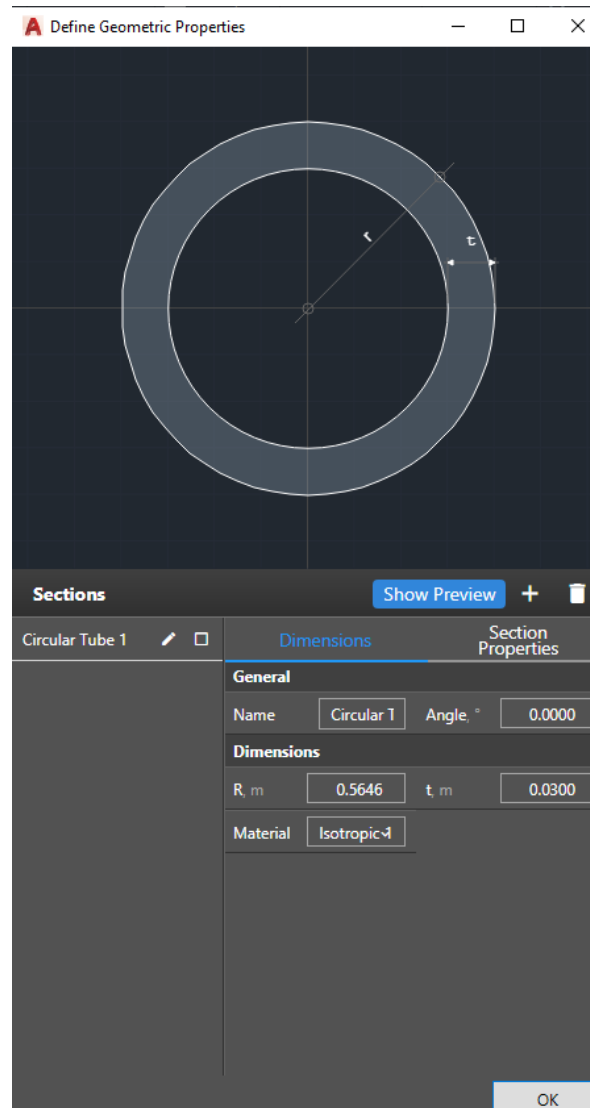


Fig 2 Section properties information in X-SEA interface

Material Properties

Elastic Modulus	$2.0 \times 10^{11} \text{ N/m}^2$
Poisson Ratio	0.3
Mass density	7850 kg/m^3

Results

Analysis Results of X-SEA and SACS

1.1 Monopile subjected to Self-Weight Load

Reaction at Fix-support by X-SEA and SACS						
Program	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	239.254	0.000	0.000	0.000
Nominal	-	-	1.000	-	-	-

1.2 Monopile subjected to Airy's wave

Environment condition		Wave parameter	
Water Depth	22.860 m.	Wave theory	Airy wave theory
Sea bed level	-20.000 m	Wave height	10.660 m.
Water density	1025.00 kg/m ³	Wave period	9.27 second
Air Density	1.25 kg/m ³		

1.2.1 Reaction force

Reaction at Fix-support 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	-133.390	0.000	0.000	0.000	-2466.900	0.000
SACS	-133.123	0.000	0.000	0.000	-2478.245	0.000
Normalize	1.002	-	-	-	0.995	-

1.2.2 Structure's displacement

Monopile's displacement reported by X-SEA

Elevation	D _x (m.)	D _y (m.)	D _z (m.)	Ø _x (Rad)	Ø _y (Rad)	Ø _z (Rad)
+10.00 m.	0.192	0.000	0.000	0.000	0.009	0.000
+5.00 m.	0.149	0.000	0.000	0.000	0.009	0.000
+0.00 m.	0.106	0.000	0.000	0.000	0.008	0.000
-5.00 m.	0.067	0.000	0.000	0.000	0.007	0.000
-10.00 m.	0.033	0.000	0.000	0.000	0.006	0.000
-15.00 m.	0.009	0.000	0.000	0.000	0.003	0.000
-20.00 m.	0.000	0.000	0.000	0.000	0.000	0.000

Monopile's displacement reported by SACS

Elevation	D _x (m.)	D _y (m.)	D _z (m.)	Ø _x (Rad)	Ø _y (Rad)	Ø _z (Rad)
+10.00 m.	0.192	0.000	0.000	0.000	0.009	0.000
+5.00 m.	0.149	0.000	0.000	0.000	0.009	0.000
+0.00 m.	0.106	0.000	0.000	0.000	0.008	0.000
-5.00 m.	0.067	0.000	0.000	0.000	0.007	0.000
-10.00 m.	0.033	0.000	0.000	0.000	0.006	0.000
-15.00 m.	0.009	0.000	0.000	0.000	0.003	0.000
-20.00 m.	0.000	0.000	0.000	0.000	0.000	0.000

Normalize solution of monopole displacement reported by X-SEA and SACS

Elevation	D _x (m.)	D _y (m.)	D _z (m.)	Ø _x (Rad)	Ø _y (Rad)	Ø _z (Rad)
+10.00 m.	0.998	-	-	-	0.995	-
+5.00 m.	0.999	-	-	-	0.995	-
+0.00 m.	1.000	-	-	-	0.995	-
-5.00 m.	1.002	-	-	-	0.995	-
-10.00 m.	1.004	-	-	-	0.995	-
-15.00 m.	1.013	-	-	-	0.995	-
-20.00 m.	-	-	-	-	-	-

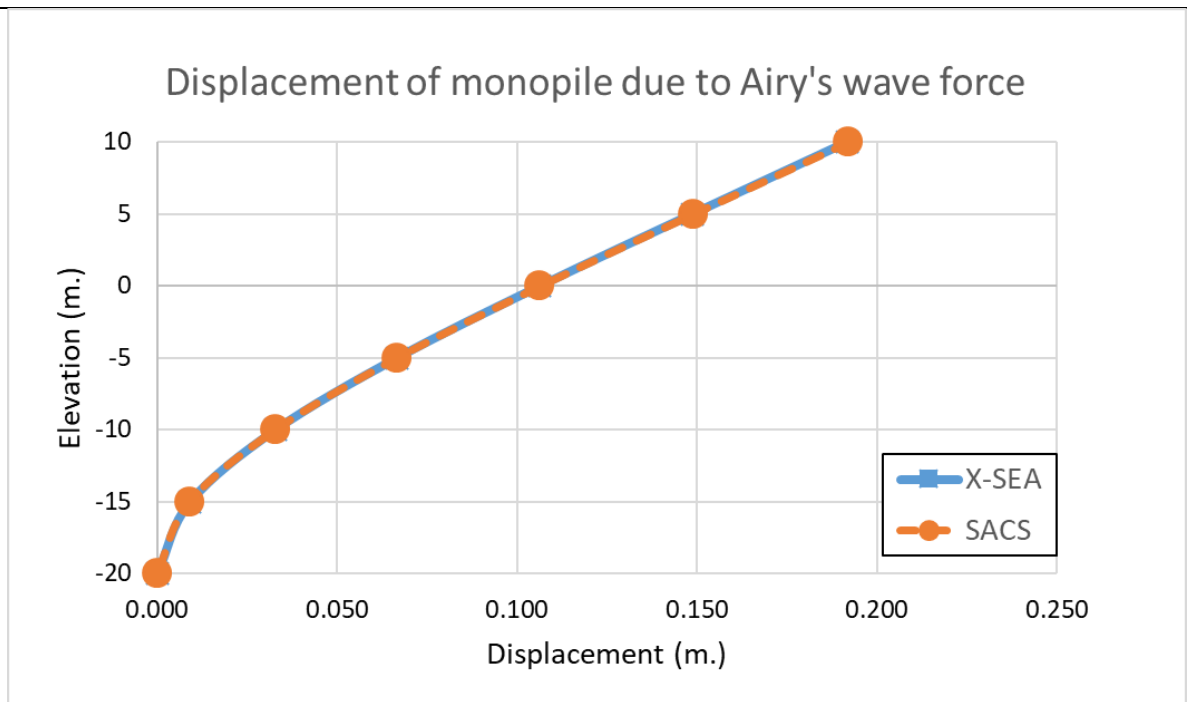


Fig 3 Displacement of monopile due to Airy's Wave force

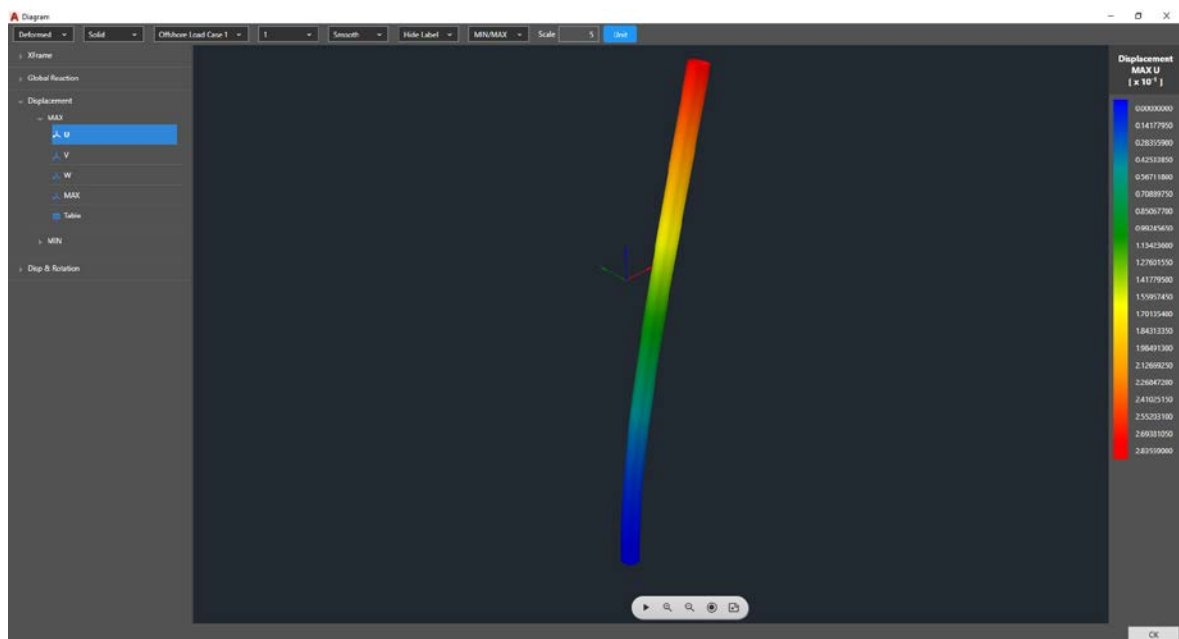


Fig 4 Displacement of monopile due to Airy's Wave force in X-SEA interface

1.2.3 Member force

Monopile's member force reported by X-SEA

Member	Elevation (m.)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN-m)	Moment-S (kN-m)	Moment-T (kN-m)
30	+10.00 m.	0.000	0.000	0.000	0.000	0.000	0.000
25	+5.00 m.	0.000	42.830	0.000	0.000	0.000	96.129
20	+0.00 m.	0.000	75.850	0.000	0.000	0.000	399.093
15	-5.00 m.	0.000	97.330	0.000	0.000	0.000	835.582
10	-10.00 m.	0.000	112.400	0.000	0.000	0.000	7361.760
5	-15.00 m.	0.000	124.000	0.000	0.000	0.000	1953.720
1	-20.00 m.	0.000	132.400	0.000	0.000	0.000	2466.690

Monopile's member force reported by SACS

Member	Elevation (m.)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN-m)	Moment-S (kN-m)	Moment-T (kN-m)
30	+10.00 m.	0.000	0.000	0.000	0.000	0.000	0.000
25	+5.00 m.	0.000	42.940	0.000	0.000	0.000	96.110
20	+0.00 m.	0.000	76.160	0.000	0.000	0.000	400.140
15	-5.00 m.	0.000	97.790	0.000	0.000	0.000	838.560
10	-10.00 m.	0.000	112.900	0.000	0.000	0.000	1367.320
5	-15.00 m.	0.000	124.700	0.000	0.000	0.000	1962.410
1	-20.00 m.	0.000	133.100	0.000	0.000	0.000	2478.240

Normalize Solution of monopile's member force reported by X-SEA and SACS

Member	Elevation (m.)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN-m)	Moment-S (kN-m)	Moment-T (kN-m)
30	+10.00 m.	-	-	-	-	-	-
25	+5.00 m.	-	0.998	-	-	-	1.000
20	+0.00 m.	-	0.996	-	-	-	0.997
15	-5.00 m.	-	0.995	-	-	-	0.996
10	-10.00 m.	-	0.995	-	-	-	0.996
5	-15.00 m.	-	0.995	-	-	-	0.996
1	-20.00 m.	-	0.994	-	-	-	0.995

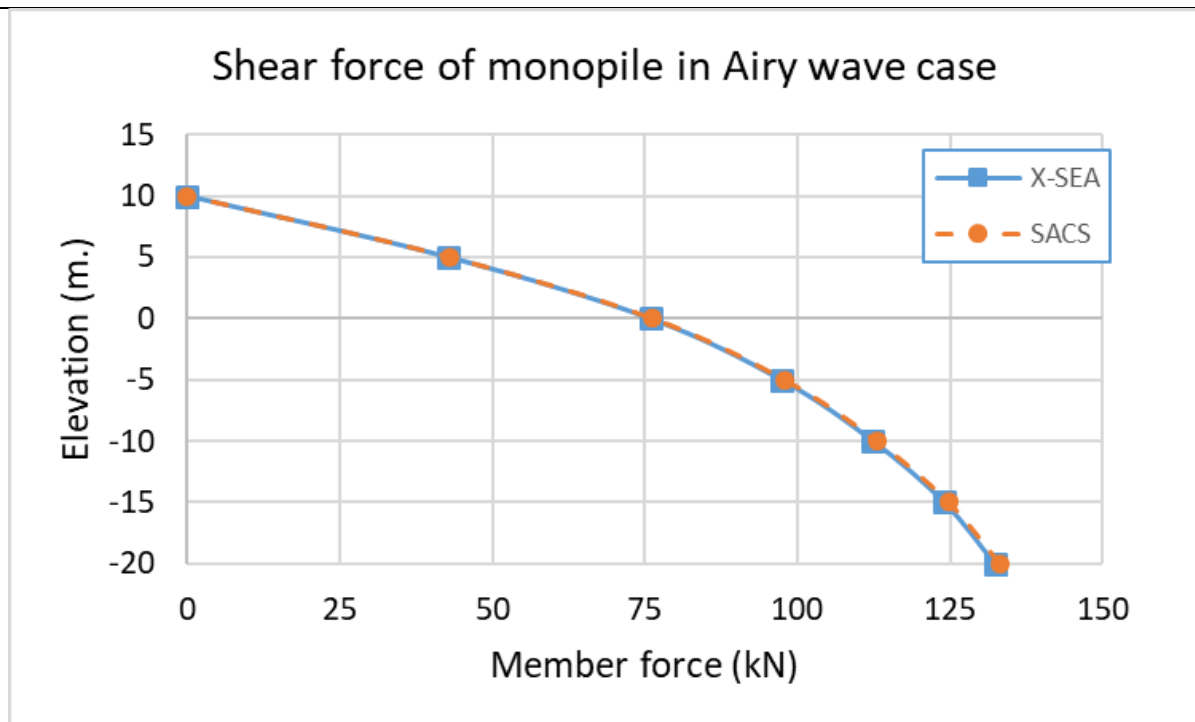


Fig 5 Shear force of monopile members due to Airy's Wave force

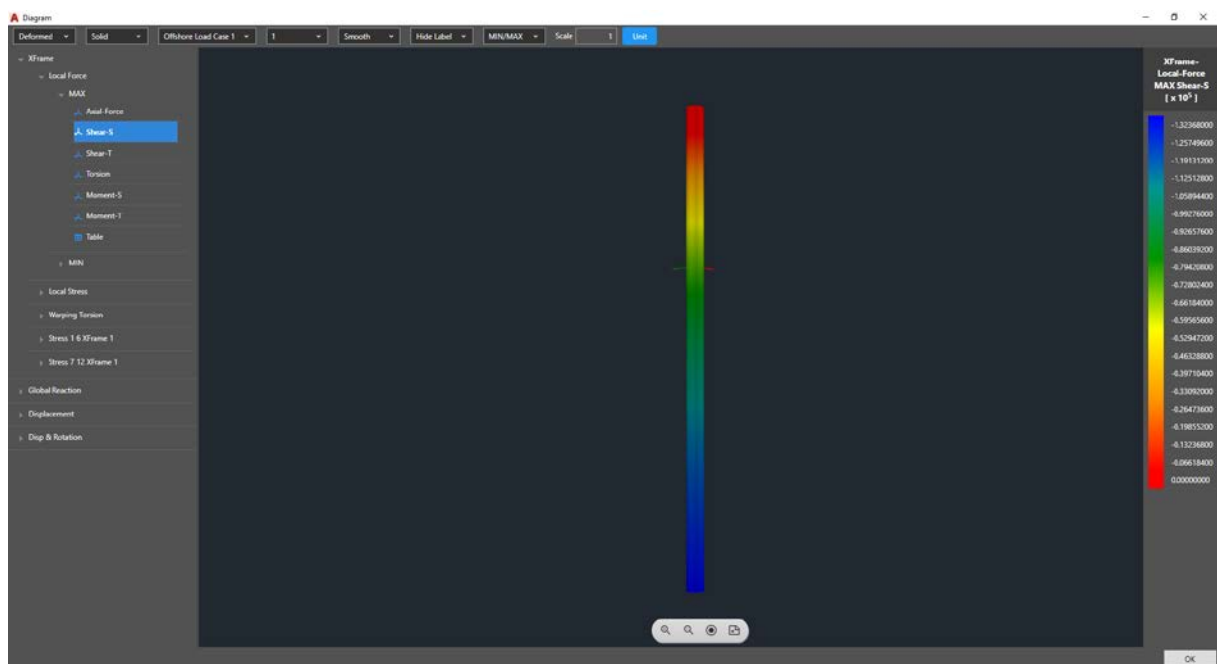


Fig 6 Shear force of monopile members due to Airy's Wave force in X-SEA interface

1.3 Monopile subjected to Stoke's wave

Environment condition		Wave parameter	
Water Depth	22.860 m.	Wave theory	Stoke wave theory
Sea bed level	-20.000 m	Wave height	10.660 m.
Water density	1025.00 kg/m ³	Wave period	9.27econd
Air Density	1.25 kg/m ³		

1.3.1 Reaction force

Reaction at Fix-support by X-SEA and SACS						
Program	F _x (kN)	F _y (kN)	F _z (kN)	M _x (kN-m)	M _y (kN-m)	M _z (kN-m)
X-SEA	167.778	0.000	0.000	0.000	3,415.350	0.000
SACS	166.520	0.000	0.000	0.000	3,449.000	0.000
Normalize	1.008	-	-	-	0.990	-

1.3.2 Structure's displacement

Monopile's displacement reported by X-SEA

Elevation	D _x (m.)	D _y (m.)	D _z (m.)	Ø _x (Rad)	Ø _y (Rad)	Ø _z (Rad)
+10.00 m.	0.279	0.000	0.000	0.000	0.013	0.000
+5.00 m.	0.215	0.000	0.000	0.000	0.013	0.000
+0.00 m.	0.153	0.000	0.000	0.000	0.012	0.000
-5.00 m.	0.095	0.000	0.000	0.000	0.011	0.000
-10.00 m.	0.046	0.000	0.000	0.000	0.008	0.000
-15.00 m	0.013	0.000	0.000	0.000	0.005	0.000
-20.00 m.	0.000	0.000	0.000	0.000	0.000	0.000

Monopile's displacement reported by SACS

Elevation	D _x (m.)	D _y (m.)	D _z (m.)	Ø _x (Rad)	Ø _y (Rad)	Ø _z (Rad)
+10.00 m.	0.279	0.000	0.000	0.000	0.013	0.000
+5.00 m.	0.215	0.000	0.000	0.000	0.013	0.000
+0.00 m.	0.153	0.000	0.000	0.000	0.012	0.000
-5.00 m.	0.095	0.000	0.000	0.000	0.011	0.000
-10.00 m.	0.046	0.000	0.000	0.000	0.008	0.000
-15.00 m	0.013	0.000	0.000	0.000	0.005	0.000
-20.00 m.	0.000	0.000	0.000	0.000	0.000	0.000

Normalize Solution of monopile displacement reported by X-SEA and SACS

Elevation	D_x (m.)	D_y (m.)	D_z (m.)	ϕ_x (Rad)	ϕ_y (Rad)	ϕ_z (Rad)
+10.00 m.	0.995	-	-	-	-	-
+5.00 m.	0.995	-	-	-	-	-
+0.00 m.	0.996	-	-	-	-	-
-5.00 m.	0.997	-	-	-	-	-
-10.00 m.	0.999	-	-	-	-	-
-15.00 m	1.007	-	-	-	-	-
-20.00 m.	-	-	-	-	-	-

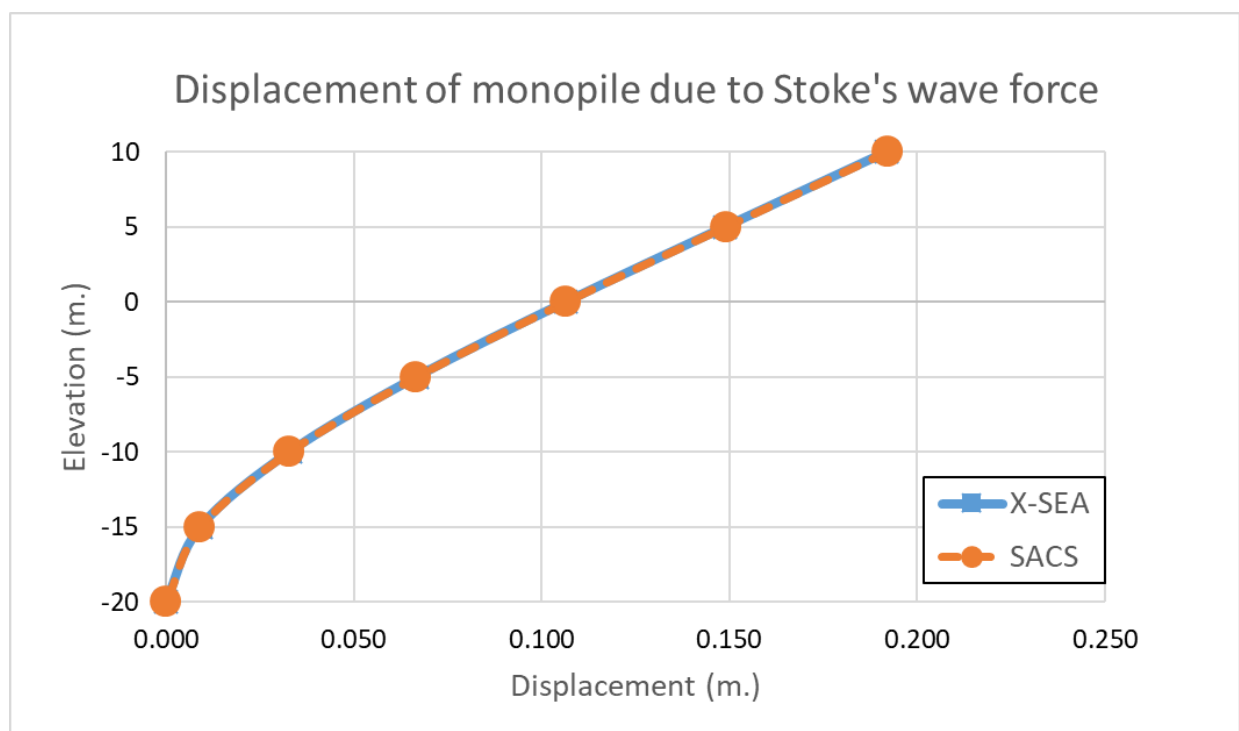


Fig 7 Displacement of monopile due to Stoke's Wave

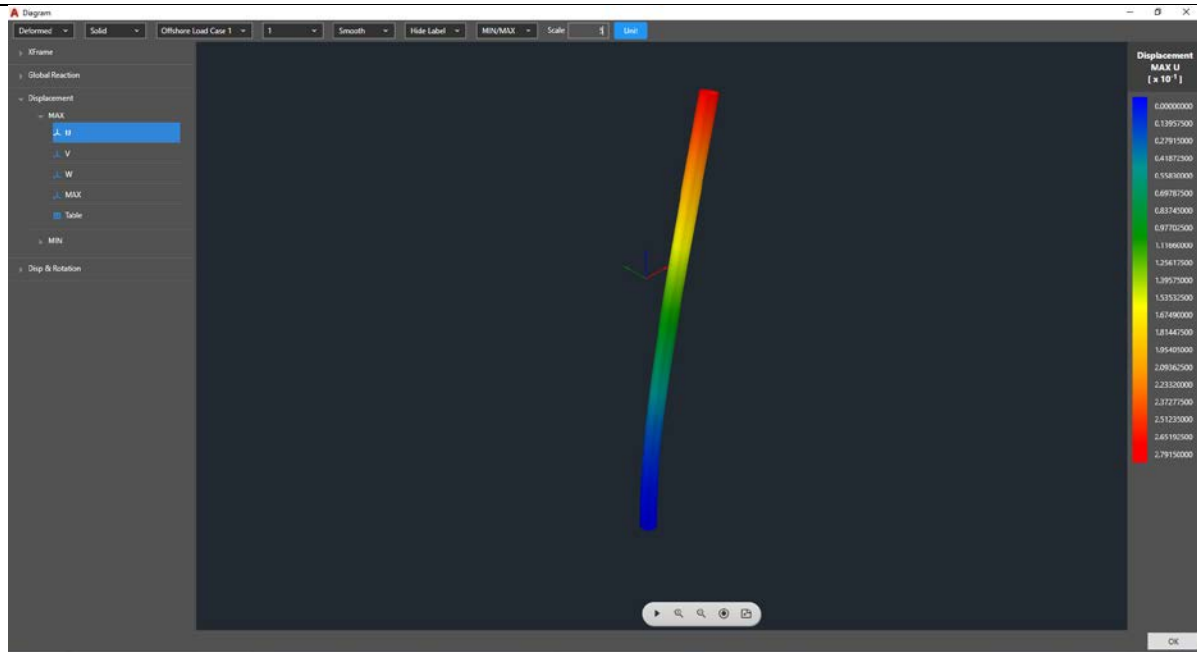


Fig 8 Displacement of monopile due to Stoke's Wave force in X-SEA interface

1.3.3 Member force

Table Monopile's member force reported by X-SEA

Member	Elevation (m.)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN-m)	Moment-S (kN-m)	Moment-T (kN-m)
30	+10.00 m.	0.000	11.855	0.000	0.000	0.000	4.207
25	+5.00 m.	0.000	73.464	0.000	0.000	0.000	232.087
20	+0.00 m.	0.000	109.259	0.000	0.000	0.000	696.462
15	-5.00 m.	0.000	131.564	0.000	0.000	0.000	1302.500
10	-10.00 m.	0.000	146.790	0.000	0.000	0.000	2000.460
5	-15.00 m	0.000	158.474	0.000	0.000	0.000	2764.570
1	-20.00 m.	0.000	166.759	0.000	0.000	0.000	3415.180

Table Monopile's member force reported by SACS

Member	Elevation (m.)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN-m)	Moment-S (kN-m)	Moment-T (kN-m)
30	+10.00 m.	0.000	11.600	0.000	0.000	0.000	4.000
25	+5.00 m.	0.000	79.850	0.000	0.000	0.000	232.27
20	+0.00 m.	0.000	110.110	0.000	0.000	0.000	699.8
15	-5.00 m.	0.000	132.770	0.000	0.000	0.000	1311.04
10	-10.00 m.	0.000	148.280	0.000	0.000	0.000	2015.77
5	-15.00 m	0.000	160.200	0.000	0.000	0.000	2787.95
1	-20.00 m.	0.000	168.670	0.000	0.000	0.000	3445.830

Table Normalize Solution of monopile's member force reported by X-SEA and SACS

Member	Elevation (m.)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN-m)	Moment-S (kN-m)	Moment-T (kN-m)
30	+10.00 m.	-	1.022	-	-	-	1.052
25	+5.00 m.	-	0.995	-	-	-	0.999
20	+0.00 m.	-	0.992	-	-	-	0.995
15	-5.00 m.	-	0.991	-	-	-	0.993
10	-10.00 m.	-	0.990	-	-	-	0.992
5	-15.00 m.	-	0.989	-	-	-	0.992
1	-20.00 m.	-	0.989	-	-	-	0.991

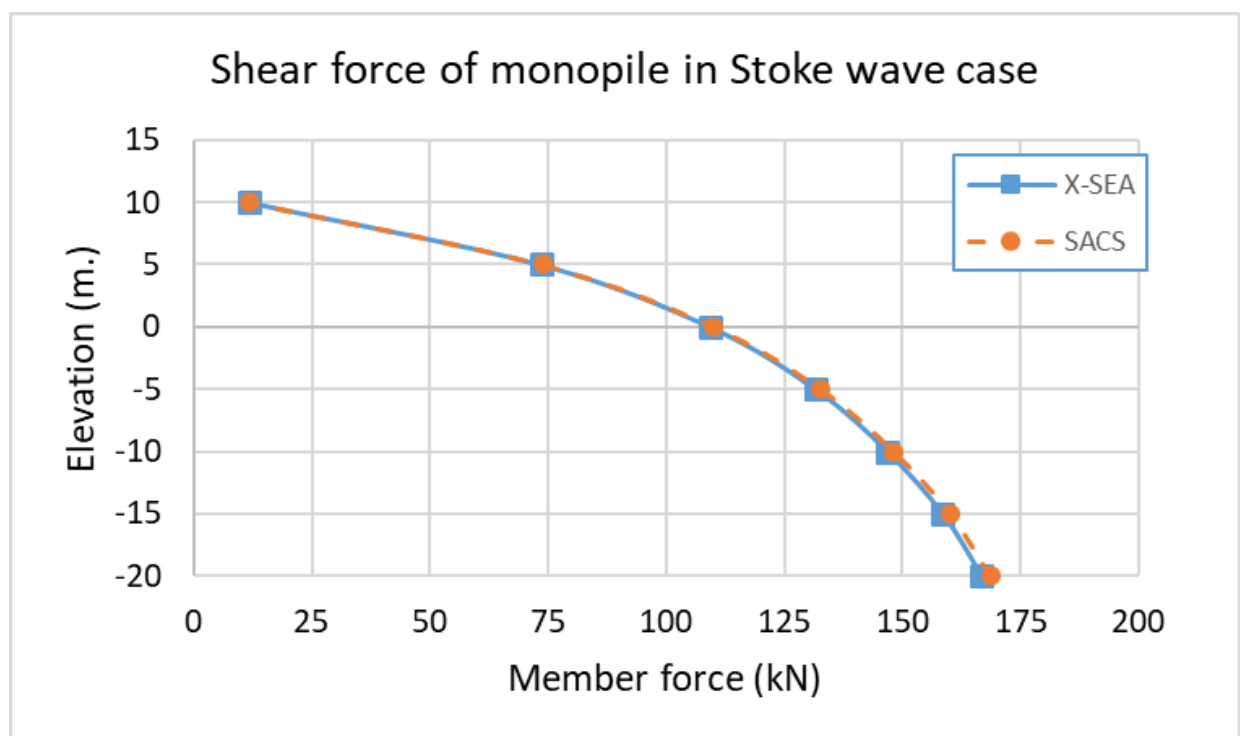


Fig 9 Shear force of monopole members due to Stoke's Wave force

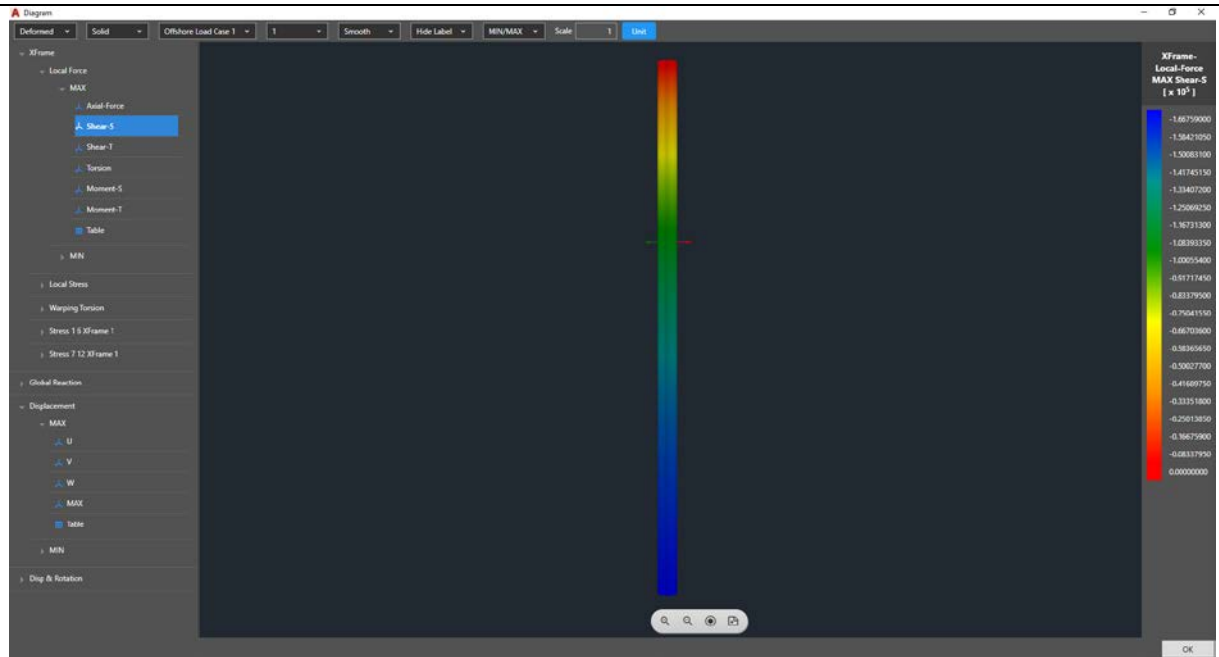


Fig 10 Shear force of monopole members due to Stoke's Wave force in X-SEA interface

1.4 Monopile subjected to Steam's wave

Environment condition		Wave parameter	
Water Depth	22.860 m.	Wave theory	Stream wave theory
Sea bed level	-20.000 m	Wave height	10.660 m.
Water density	1025.00 kg/m ³	Wave period	9.27 second
Air Density	1.25 kg/m ³		

1.4.1 Reaction force

Reaction at Fix-support 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	166.811	0.000	0.000	0.000	3,444.420	0.000
SACS	166.518	0.000	0.000	0.000	3,449.016	0.000
Normalize	1.002	-	-	-	0.999	-

1.4.2 Structure's displacement

Monopile's displacement reported by X-SEA

Elevation	D _x (m.)	D _y (m.)	D _z (m.)	Ø _x (Rad)	Ø _y (Rad)	Ø _z (Rad)
+10.00 m.	0.284	0.000	0.000	0.000	0.013	0.000
+5.00 m.	0.218	0.000	0.000	0.000	0.013	0.000
+0.00 m.	0.155	0.000	0.000	0.000	0.012	0.000
-5.00 m.	0.096	0.000	0.000	0.000	0.011	0.000
-10.00 m.	0.047	0.000	0.000	0.000	0.008	0.000
-15.00 m	0.013	0.000	0.000	0.000	0.005	0.000
-20.00 m.	0.000	0.000	0.000	0.000	0.000	0.000

Monopile's displacement reported by SACS

Elevation	D _x (m.)	D _y (m.)	D _z (m.)	Ø _x (Rad)	Ø _y (Rad)	Ø _z (Rad)
+10.00 m.	0.283	0.000	0.000	0.000	0.000	0.000
+5.00 m.	0.217	0.000	0.000	0.000	0.000	0.000
+0.00 m.	0.154	0.000	0.000	0.000	0.000	0.000
-5.00 m.	0.095	0.000	0.000	0.000	0.000	0.000
-10.00 m.	0.046	0.000	0.000	0.000	0.000	0.000
-15.00 m	0.013	0.000	0.000	0.000	0.000	0.000
-20.00 m.	0.000	0.000	0.000	0.000	0.000	0.000

Normalize Solution of monopile displacement reported by X-SEA and SACS

Elevation	D_x (m.)	D_y (m.)	D_z (m.)	ϕ_x (Rad)	ϕ_y (Rad)	ϕ_z (Rad)
+10.00 m.	1.003	-	-	-	-	-
+5.00 m.	1.004	-	-	-	-	-
+0.00 m.	1.004	-	-	-	-	-
-5.00 m.	1.005	-	-	-	-	-
-10.00 m.	1.007	-	-	-	-	-
-15.00 m.	1.015	-	-	-	-	-
-20.00 m.	-	-	-	-	-	-

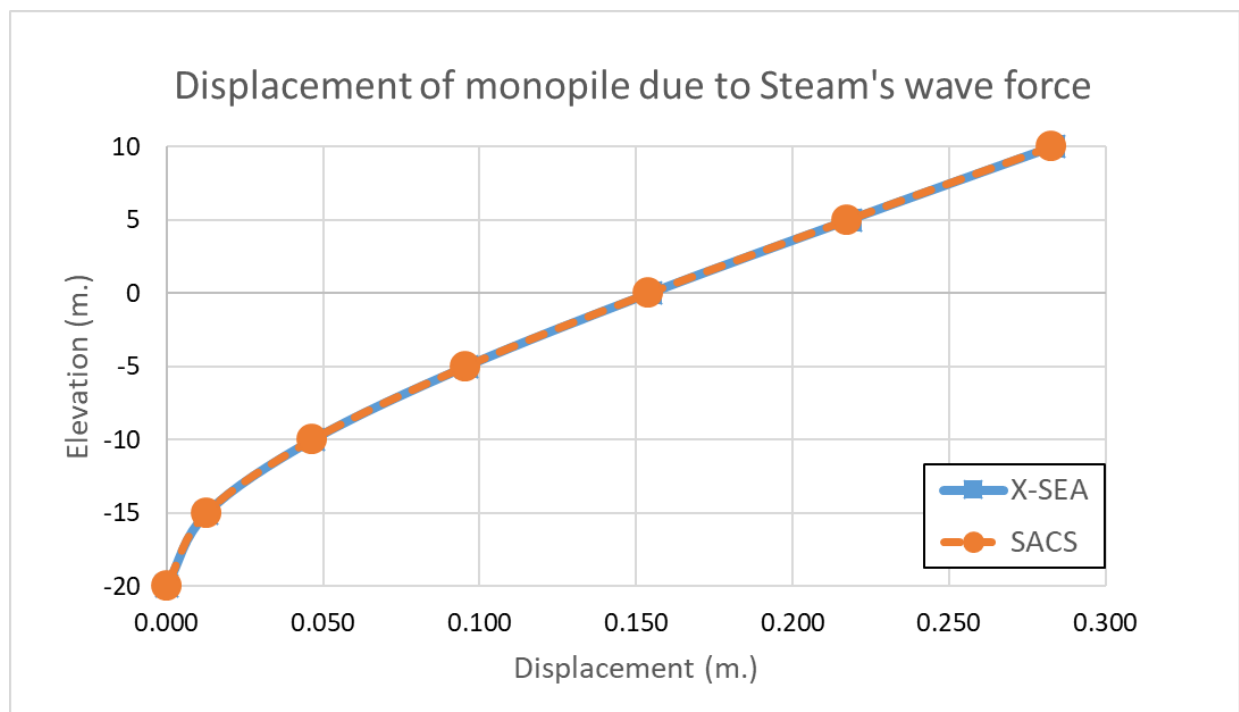


Fig 11 Displacement of monopile due to Stream's Wave

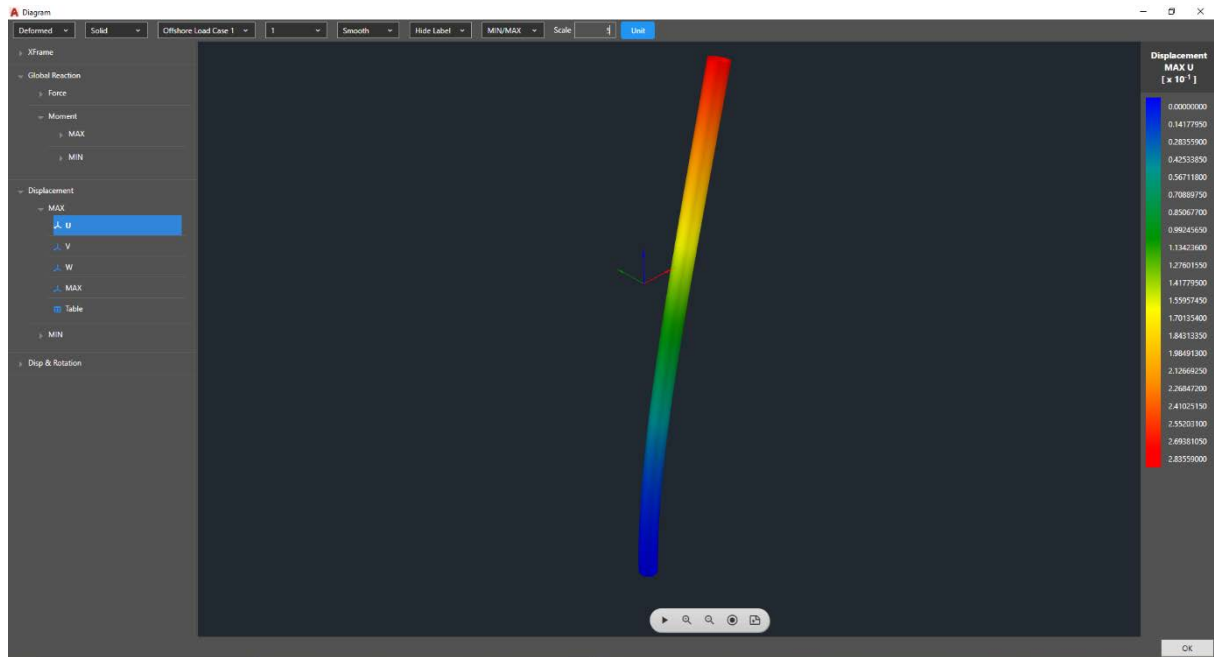


Fig 12 Displacement of monopile due to Stream's Wave force in X-SEA interface

1.4.3 Member force

Monopile's member force reported by X-SEA

Member	Elevation (m.)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN-m)	Moment-S (kN-m)	Moment-T (kN-m)
30	+10.00 m.	0.000	15.763	0.000	0.000	0.000	7.497
25	+5.00 m.	0.000	75.905	0.000	0.000	0.000	251.174
20	+0.00 m.	0.000	110.562	0.000	0.000	0.000	696.462
15	-5.00 m.	0.000	132.067	0.000	0.000	0.000	1302.500
10	-10.00 m.	0.000	146.708	0.000	0.000	0.000	2000.460
5	-15.00 m	0.000	157.914	0.000	0.000	0.000	2764.570
1	-20.00 m.	0.000	165.838	0.000	0.000	0.000	3415.180

Monopile's member force reported by SACS

Member	Elevation (m.)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN-m)	Moment-S (kN-m)	Moment-T (kN-m)
30	+10.00 m.	0.000	14.168	0.000	0.000	0.000	5.904
25	+5.00 m.	0.000	75.714	0.000	0.000	0.000	245.77
20	+0.00 m.	0.000	110.84	0.000	0.000	0.000	699.800
15	-5.00 m.	0.000	132.51	0.000	0.000	0.000	1311.040
10	-10.00 m.	0.000	147.25	0.000	0.000	0.000	2015.770
5	-15.00 m	0.000	158.52	0.000	0.000	0.000	2787.950
1	-20.00 m.	0.000	166.52	0.000	0.000	0.000	3445.830

Normalize Solution of monopile's member force reported by X-SEA and SACS

Member	Elevation (m.)	Axial (kN)	Shear-S (kN)	Shear-T (kN)	Torsion (kN-m)	Moment-S (kN-m)	Moment-T (kN-m)
30	+10.00 m.	-	1.113	-	-	-	1.270
25	+5.00 m.	-	1.003	-	-	-	1.022
20	+0.00 m.	-	0.997	-	-	-	0.995
15	-5.00 m.	-	0.997	-	-	-	0.993
10	-10.00 m.	-	0.996	-	-	-	0.992
5	-15.00 m.	-	0.996	-	-	-	0.992
1	-20.00 m.	-	0.996	-	-	-	0.991

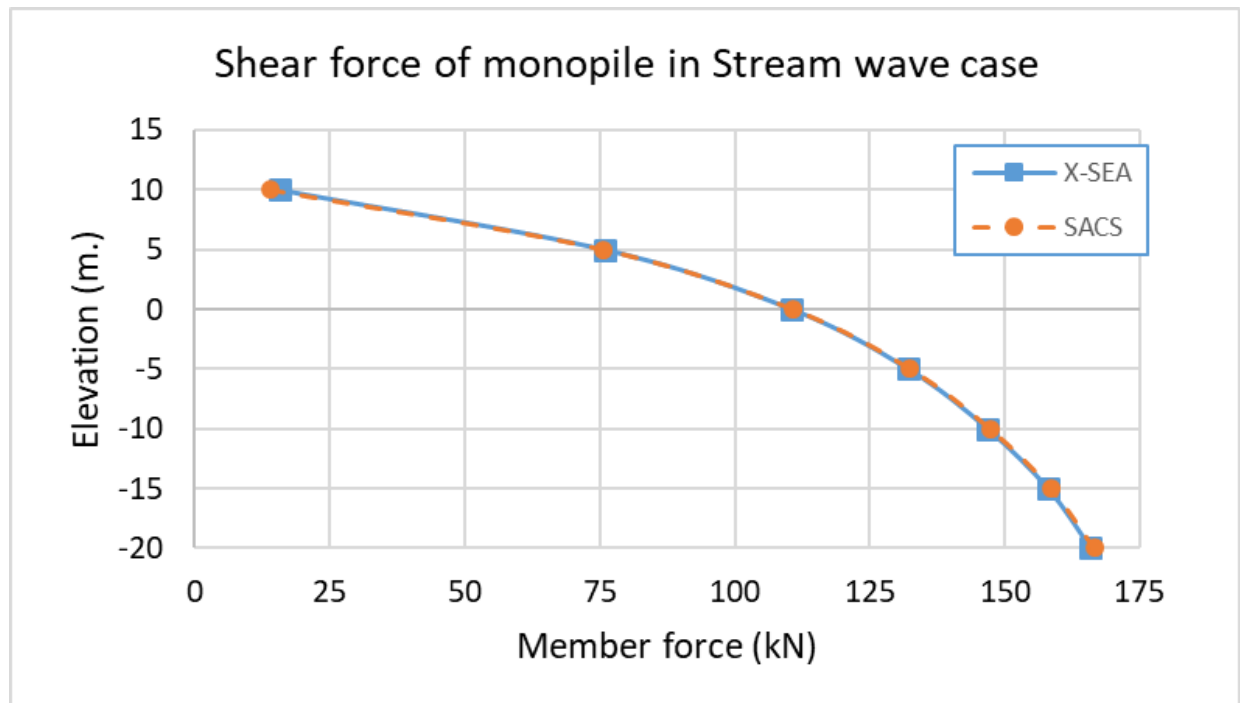


Fig 13 Shear force of monopole members due to Stream's Wave force

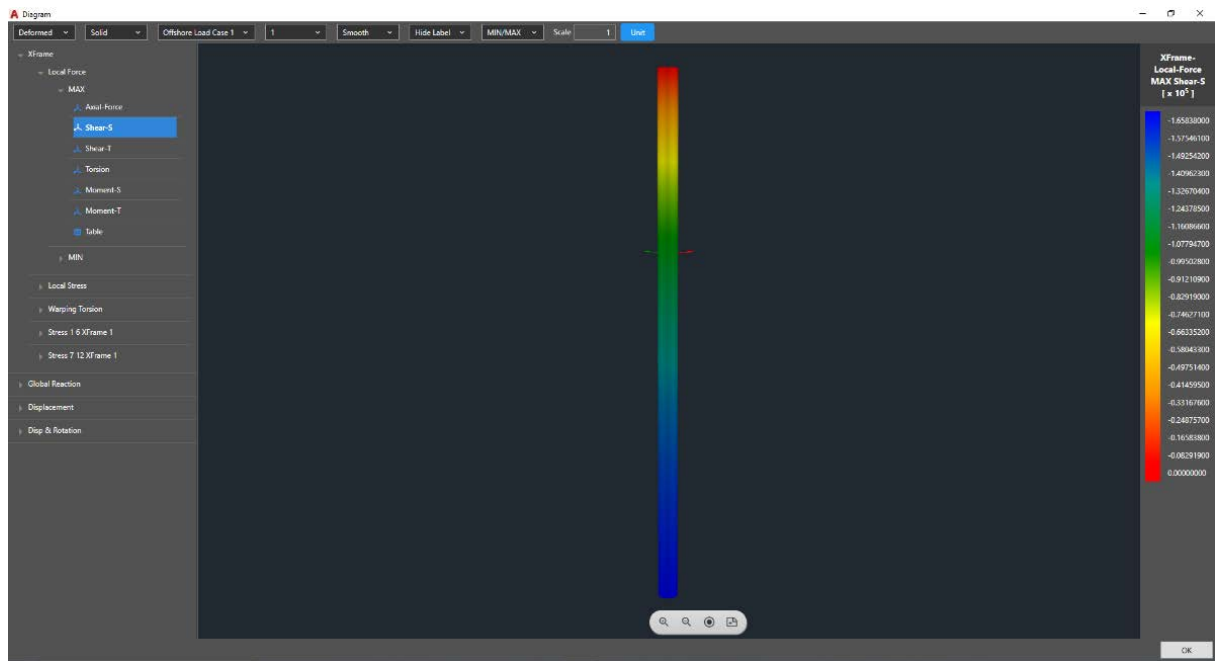


Fig 14 Shear force of monopole members due to Stream's Wave force in X-SEA interface