MECHCOMP 2019

5th International Conference on Mechanics of Composites

Instituto Superior Técnico, Lisbon, Portugal

1-4 July 2019

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Paper Number 20005, Wednesday 3rd July, 2019 @ 16h30

TITLE: **Local and Global Design of Composite Risers on Truss SPAR Platform in Deep waters**

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ABSTRACT:

The application of risers in offshore deep waters have been necessitated due to the increase in the water depths. Thus, the number of marine riser segments increase, which also increase the weight of the offshore platform. To reduce the weight of the risers, composite risers are proposed. The material property of composites can be harnessed to develop composite marine risers, which will reduce the weight on the offshore platform. Numerical tools are employed and the system is coupled using ANSYS 19.2 System Coupling tool, ANSYS ACP and ANSYS AQWA. The local design of the composite risers involved 18 layers and an inner liner. Composite materials used include AS4/PEEK, AS4/Epoxy and different configurations were investigated. Other liner materials on the composite risers were also looked at in the study. Hydrodynamic investigations were also carried out using environmental conditions. Results of the local analysis of the riser were applied in the global design on a Truss SPAR Platform in a deep water condition of 2000m water depth. Comparative studies of the composite risers and the steel risers were carried out. From the results of the study, the composite risers local and global designs applied in deep water conditions were satisfactory. Recommendations too were given in line with the industry standards.

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Local and Global Design of Composite Risers on Truss SPAR Platform in Deep waters

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Amaechi Chiemela Victor[1,5,*], **Nathaniel Gillett**[2], **Agbomerie Charles Odijie**[3], **Xiaonan Hou**[1], **Fa-Cheng Wang**[2], **Jianqiao Ye**[1],

Paper 20005, Room 4, Applications of composites

Presentation Date: Wed, 3rd July, 2019

Venue: Instituto Superior Tecnico, Lisbon, Portugal

Affiliation: [1]*Engineering Department, Lancaster University, Lancaster, LA1 4YR, UK.*

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Research Sponsors:

1. NDDC (Niger Delta Development Commission), Nigeria.
2. Engineering Department, Lancaster University, Lancaster, UK.

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Abstract

- The application of risers in offshore deep waters have been necessitated due to the increase in the water depths. Thus, the number of marine riser segments increase, which also increase the weight of the offshore platform. To reduce the weight of the risers, composite risers are proposed. The material property of composites can be harnessed to develop composite marine risers, which will reduce the weight on the offshore platform. Numerical tools are employed and the system is coupled using ANSYS 19.2 System Coupling tool, ANSYS ACP and ANSYS AQWA. The local design of the composite risers involved 18 layers and an inner liner. Composite materials used include AS4/PEEK, AS4/Epoxy and different configurations were investigated. Other liner materials on the composite risers were also looked at in the study. Hydrodynamic investigations were also carried out using environmental conditions. Results of the local analysis of the riser were applied in the global design on a Truss SPAR Platform in a deep water condition of 2000m water depth. Comparative studies of the composite risers and the steel risers were carried out. From the results of the study, the composite risers local and global designs applied in deep water conditions were satisfactory. Recommendations too were given in line with the industry standards.

Brief on Research

Oil and Gas Industry

Onshore

Mainstream

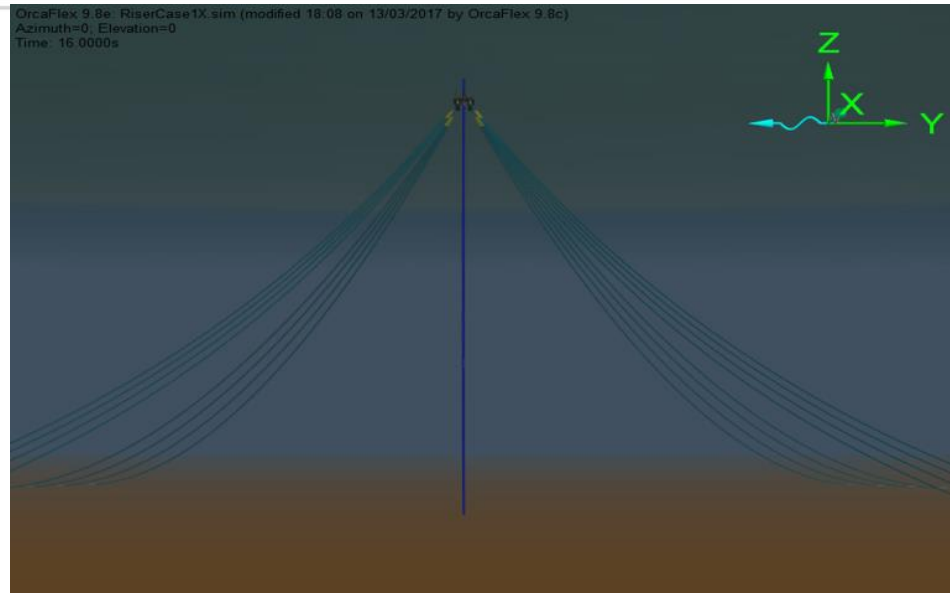
Offshore

Mooring lines

Platforms

Pipelines, etc.

Risers & Hoses



Flexible Risers

Rigid Risers

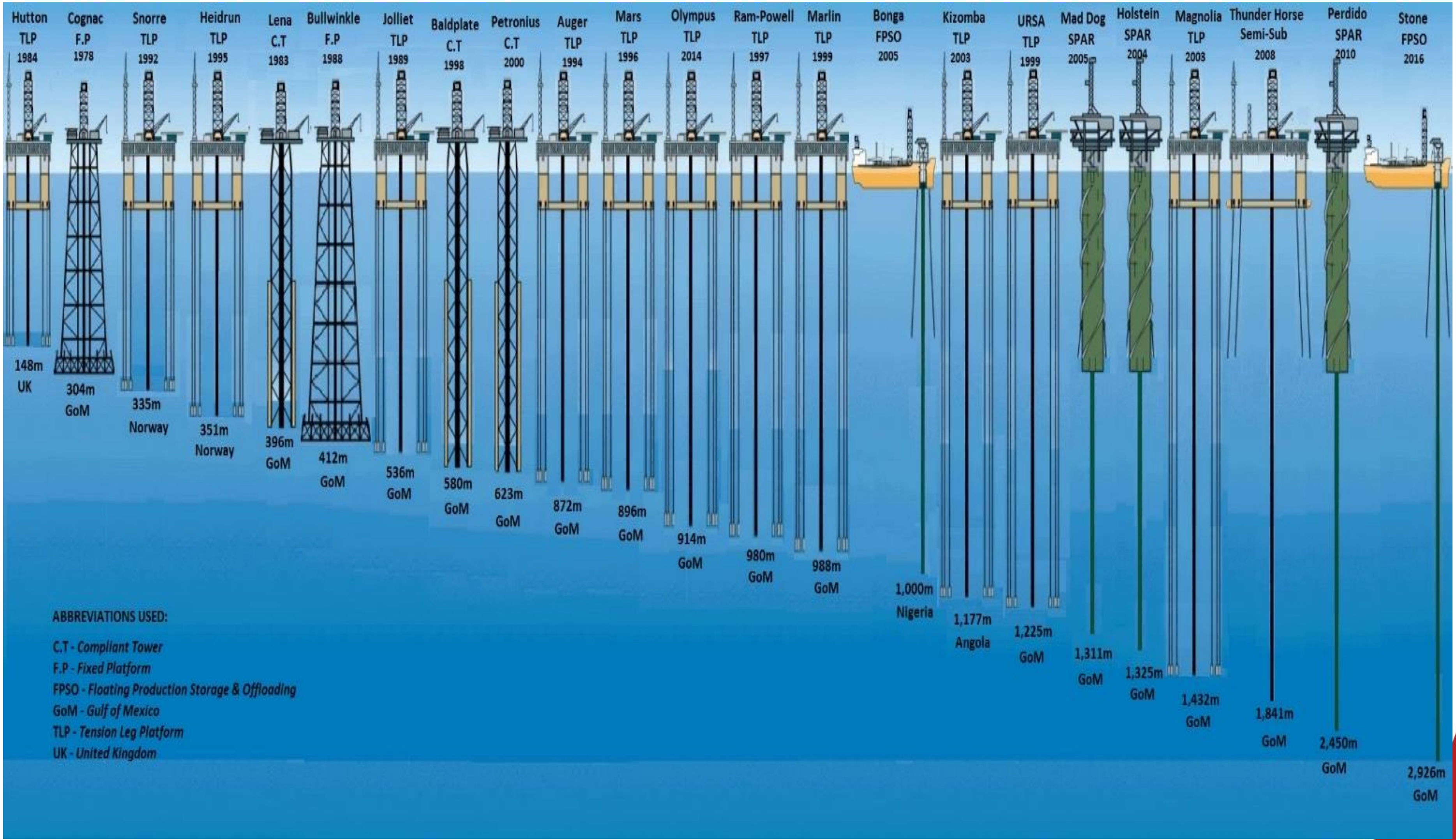
Hybrid Risers

Composite Risers

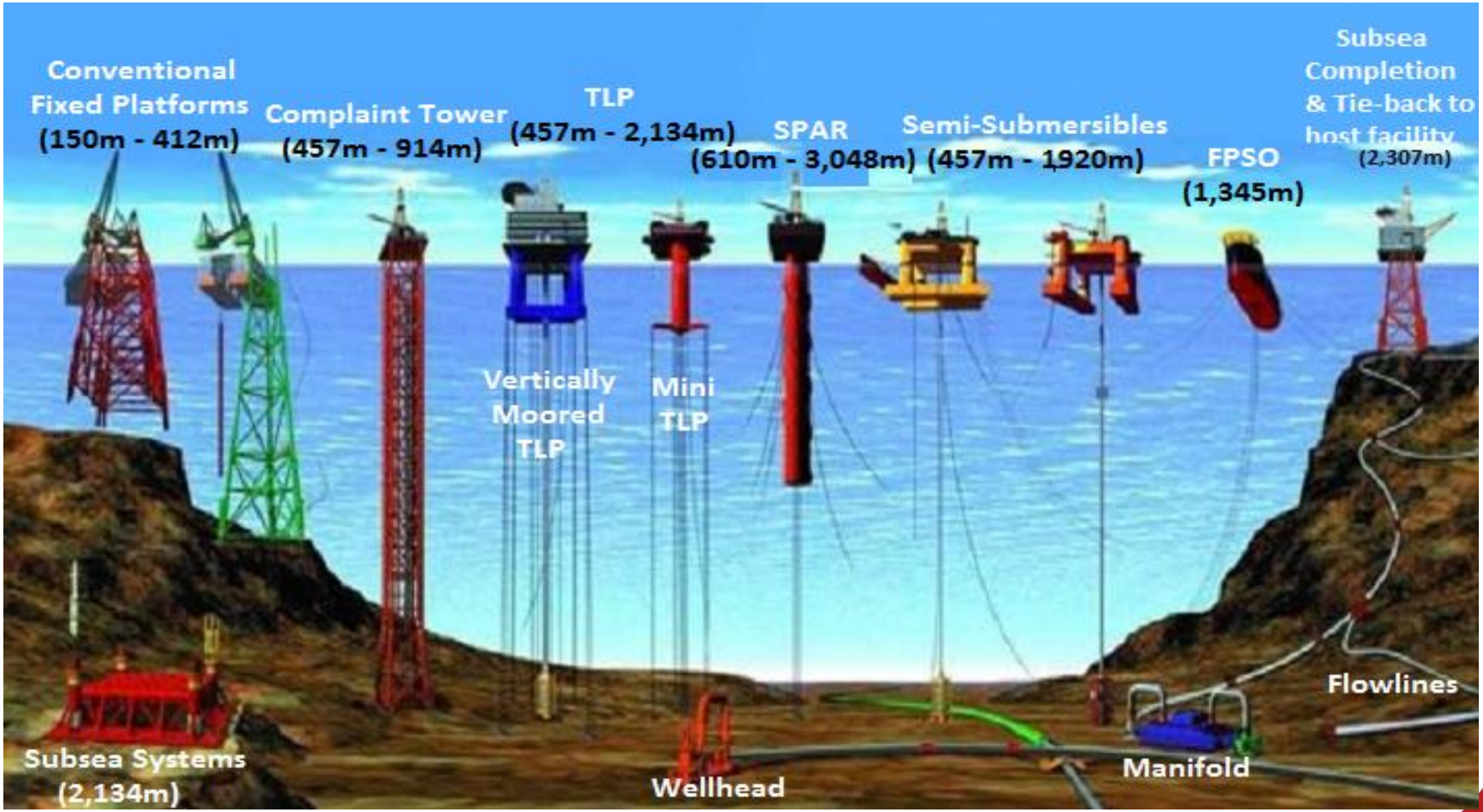
Floating Hoses

Submarine Hoses

History of Offshore Deepwaters



Deepwater systems, platforms& risers (NOAA)



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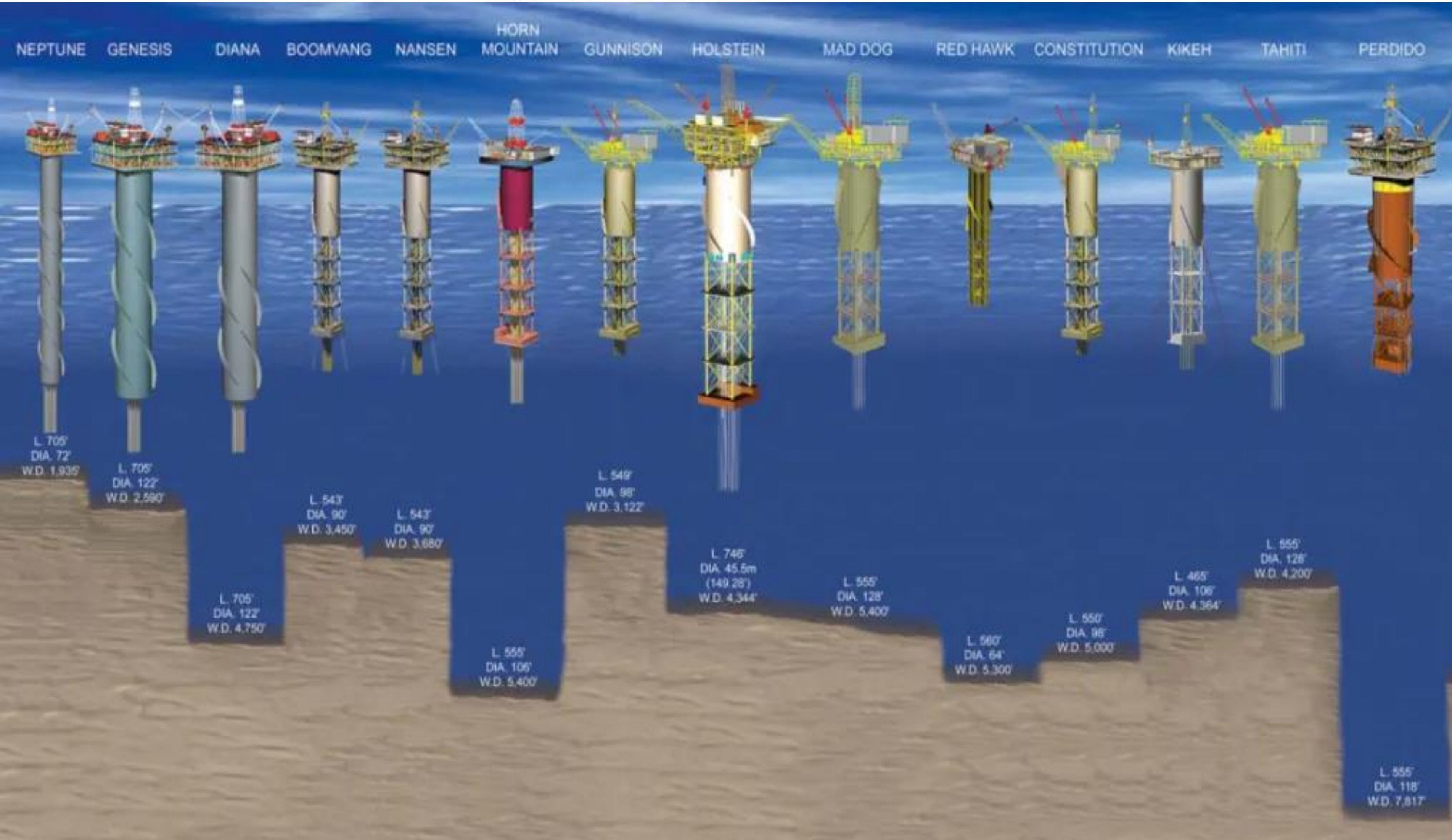
SPAR Designs (Courtesy: Technip)



Background

- Current exploration activities in deepwater has been faced with challenge of composite riser applications, thus the need for research on this. Submarine hoses thus face fatigue and strength issues.
- Looking at the deep water challenges as regards the use of composite risers in the offshore industry, this research will study the current concepts being deployed, the numerical analyses, materials modelling and the optimization of these models considering the layered structure of composites, the laminates and the effects of the hydrodynamic behaviour, fatigue, VIV and the loading conditions.
- This is necessary as this area of offshore technology will also provide needed guidelines and new design concepts for composite risers as there is the need to utilize composites in offshore engineering in addition to the huge interests in using the fluid-structure interaction model in ANSYS to analyse the behaviour.

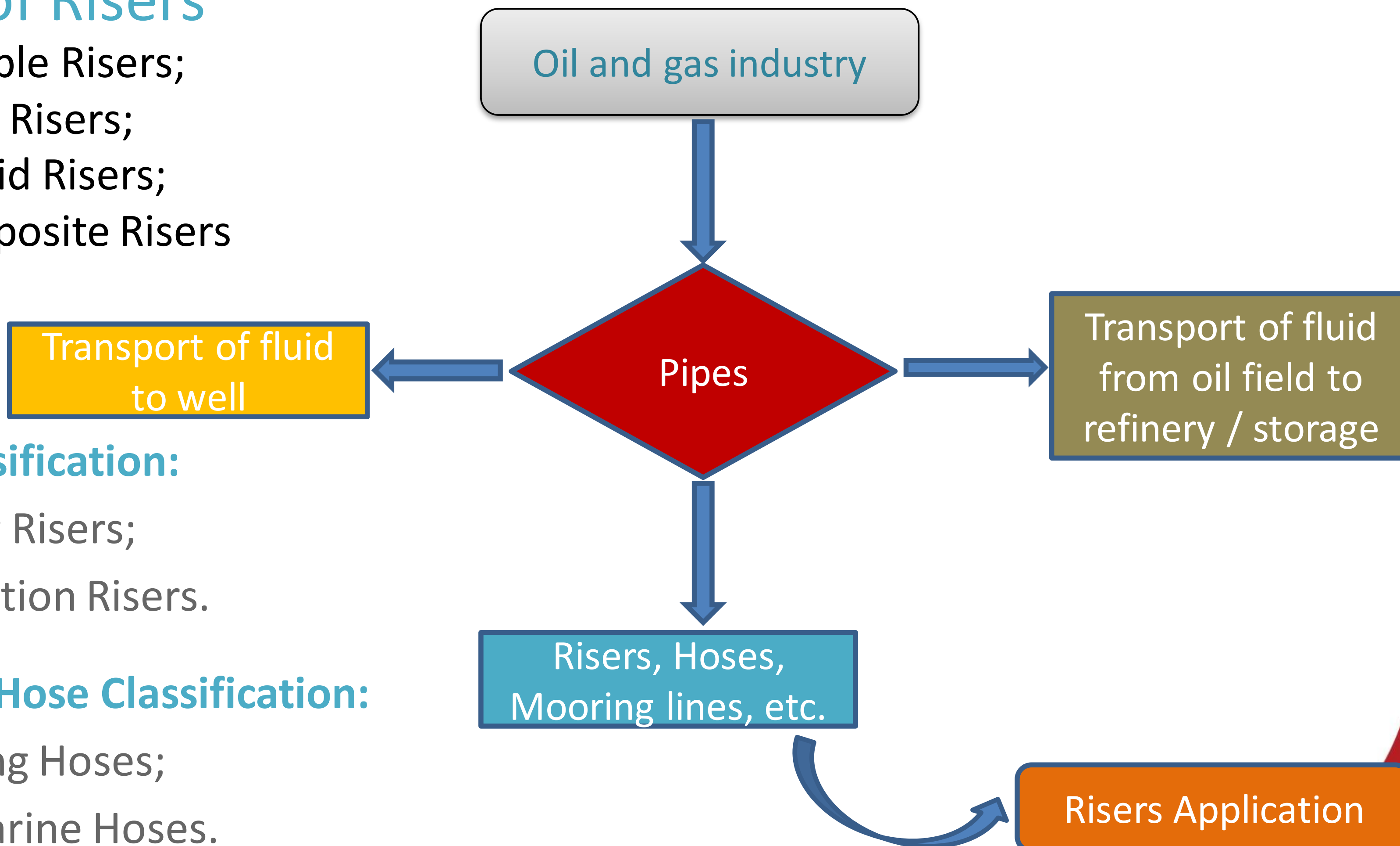
Background of Composite Risers

- The various uses of a riser system determines its description, and thus its purpose-drilling, production / injection, export / import, fluids circulation, completion/workover. (Bai *et al*, *2013*).
- Composite materials offer a range of benefits that could improve riser technology (Hopkins *et al.*, 2015, Hatton, 2015).
- Ochoa (2001) opined that fiber reinforced polymeric composites are emerging as strong alternatives for ultra-deepwater drilling and production application; considering that they have light weight, strength, and durability.
- Salama (1986) presented a study on the application of composites in offshore, demonstrating using Conoco's Hutton TLP, the cost comparison against fabricated steel and proposed an evaluation program for future design

Composite Risers / Pipes / Offshore Hoses

Types of Risers

- ❖ Flexible Risers;
- ❖ Rigid Risers;
- ❖ Hybrid Risers;
- ❖ Composite Risers



- **Riser Classification:**

❑ Drilling Risers;

❑ Production Risers.

- **Offshore Hose Classification:**

❑ Floating Hoses;

❑ Submarine Hoses.

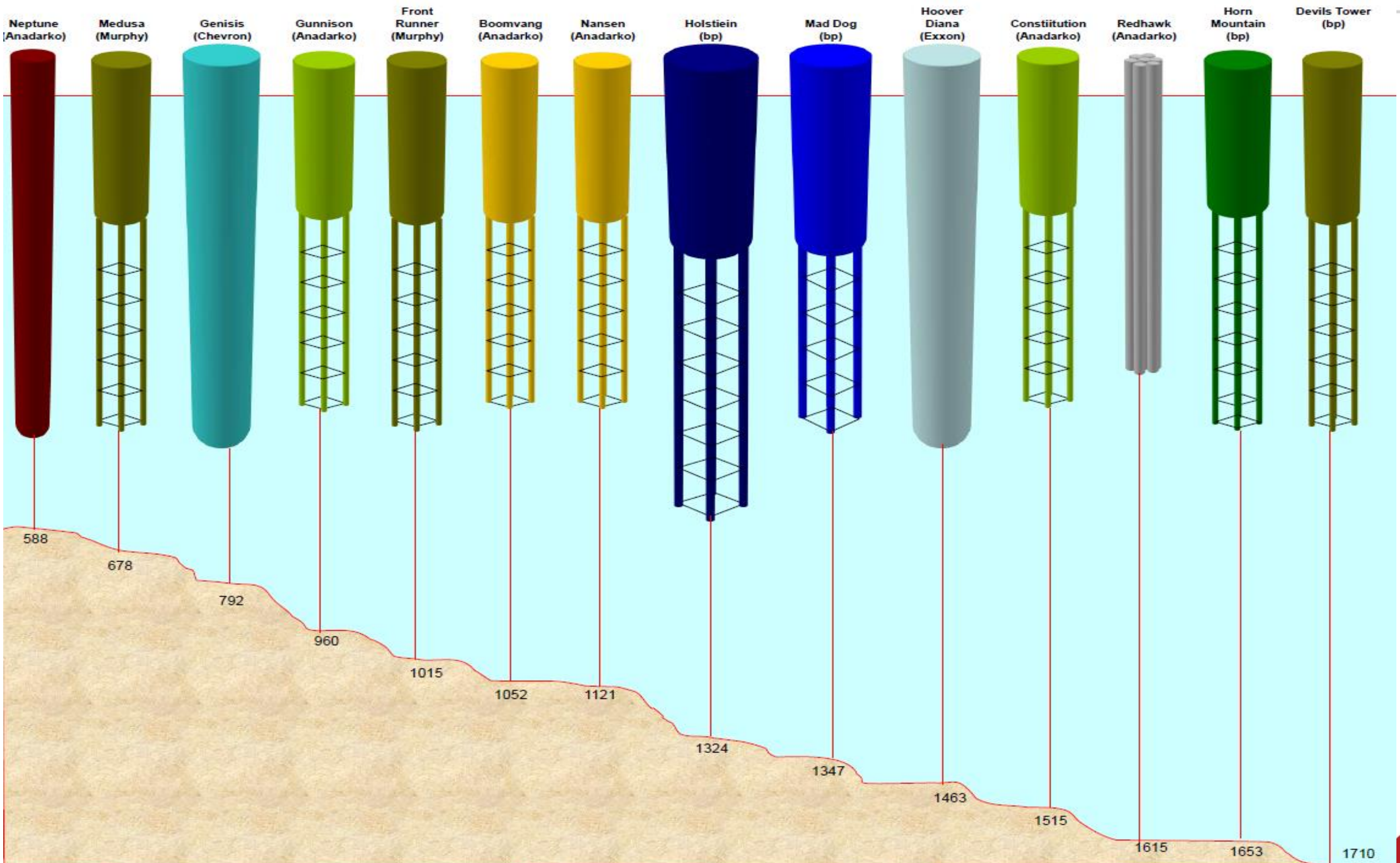
Background on SPARS

- Currently, they are 17 SPAR platforms in operation
- 1 Cell SPAR, 3 Classic SPARs, and 13 Truss SPARs.
- 16 of these SPARs are located in the Gulf of Mexico.
- 1 is located off the Malaysian coast, KikehTruss SPAR (see Fig.1)
- SPAR platforms are used in deep and ultra-deep waters

Considerations for SPAR Design

- The world's first production SPAR was used in 1996
- SPARs in the past were used as oil storage vessels (Brent project)
- SPARs have strakes to reduce vortex induced motions (VIM)
- SPAR hulls have anodes to reduce corrosion
- Different topside decks can be attached to SPARs depending on the design. Some of these decks are :full drilling rig (3,000hp), or workover rig (600-1,000hp) or Production equipment.
- The type of risers also determine the SPAR design to be used. Currently, they are 17 SPAR platforms in operation
- 1 Cell SPAR, 3 Classic SPARs, and 13 Truss SPARs.
- 16 of these SPARs are located in the Gulf of Mexico.
- 1 is located off the Malaysian coast, called the KikehTruss SPAR
- SPAR platforms are used in deep and ultra-deep waters

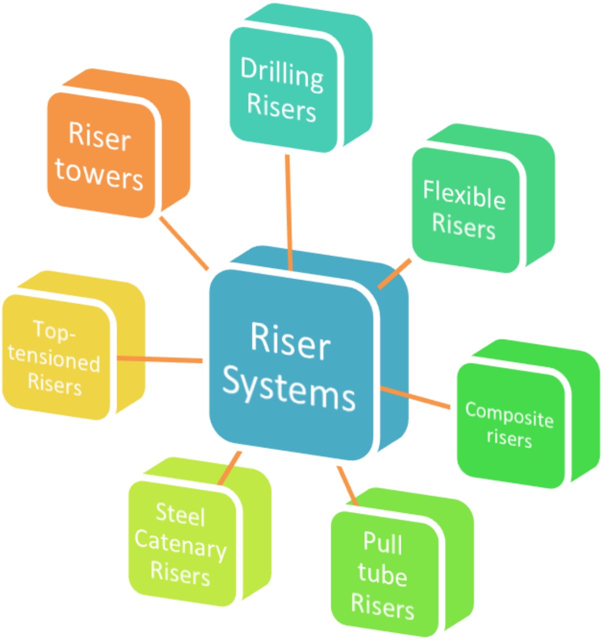
SPAR fabrication & transportation



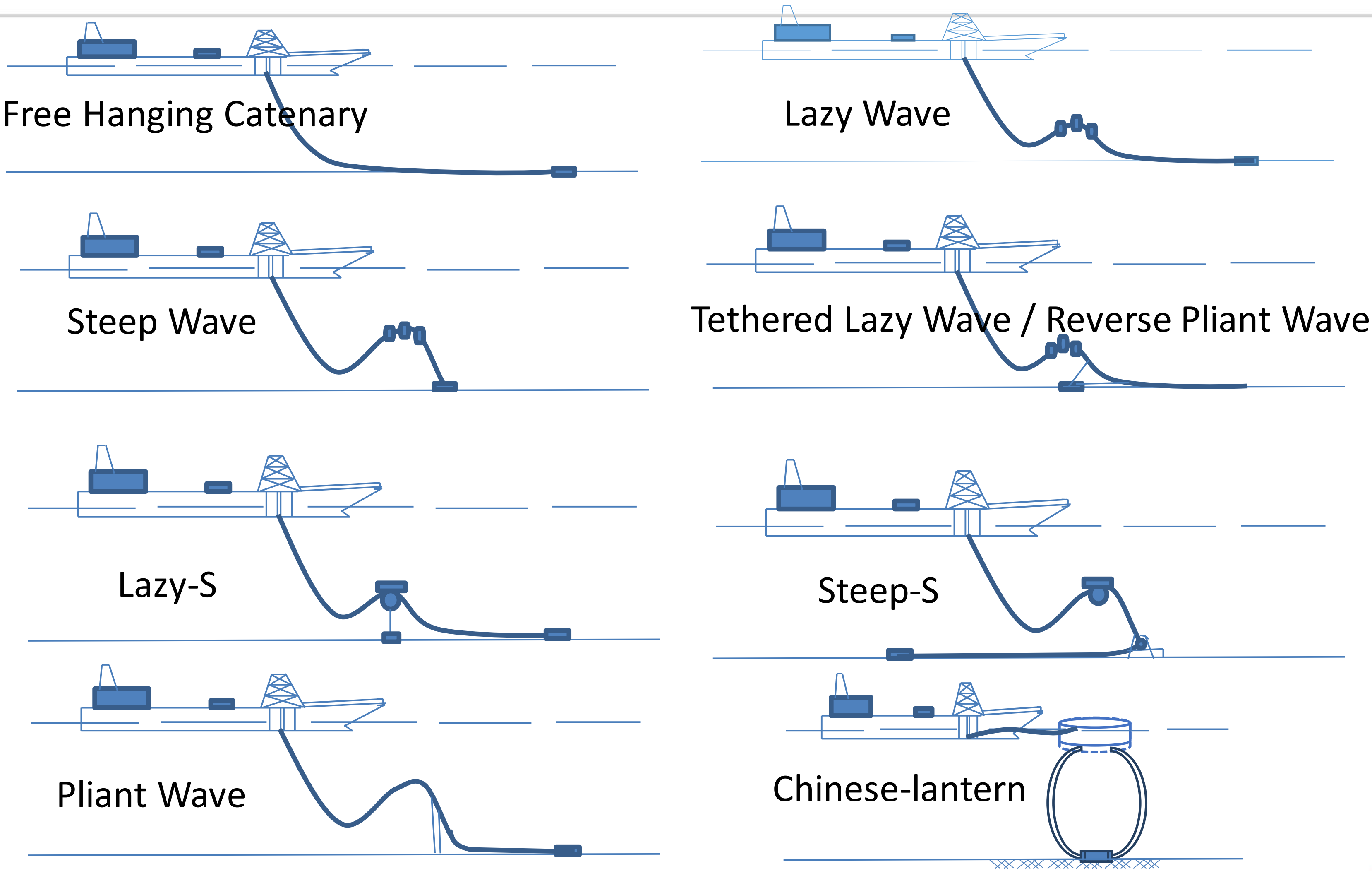
Neptune (Anadarko)
Medusa (Murphy)
Genisis (Chevron)
Gunnison (Anadarko)
Front Runner (Murphy)
Boomvang (Anadarko)
Nansen (Anadarko)
Holstiein (bp)
Mad Dog (bp)
Hoover Diana (Exxon)
Constiitution (Anadarko)
Redhawk (Anadarko)
Horn Mountain (bp)
Devils Tower (bp)
588
678
792
960
1015
1052
1121
1324
1347
1463
1515
1615
1653
1710

SPAR Topside Deck Installation for Riser Application

- Risers are applied using different models, depending on the offshore structure;
- For deep waters, you can apply risers on SPAR platforms, Semisubmersibles, etc.;
- For shallow waters, risers are used as offshore hoses for buoys, FPSO vessels, etc.



Hoses & Riser Configurations

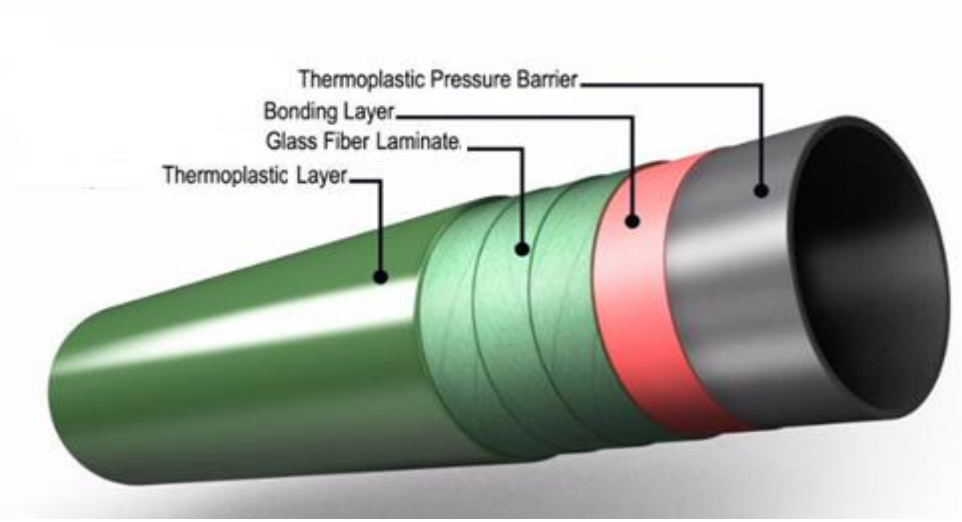


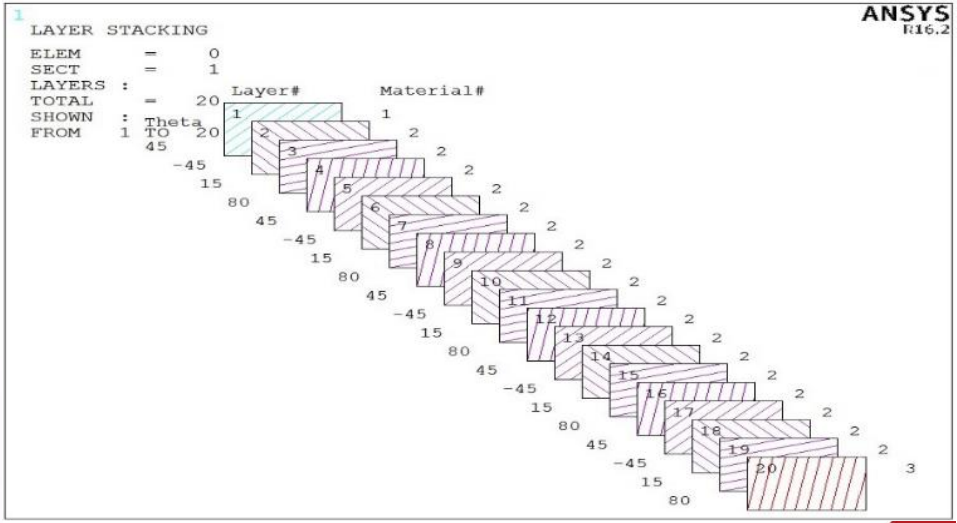
For Composite Riser Design

- Metal Composite Interface (MCI)
- End-Fitting,
- Liners,
- Resins
- Composite Riser Pipe

Riser Load Categories (DNV, 2010)

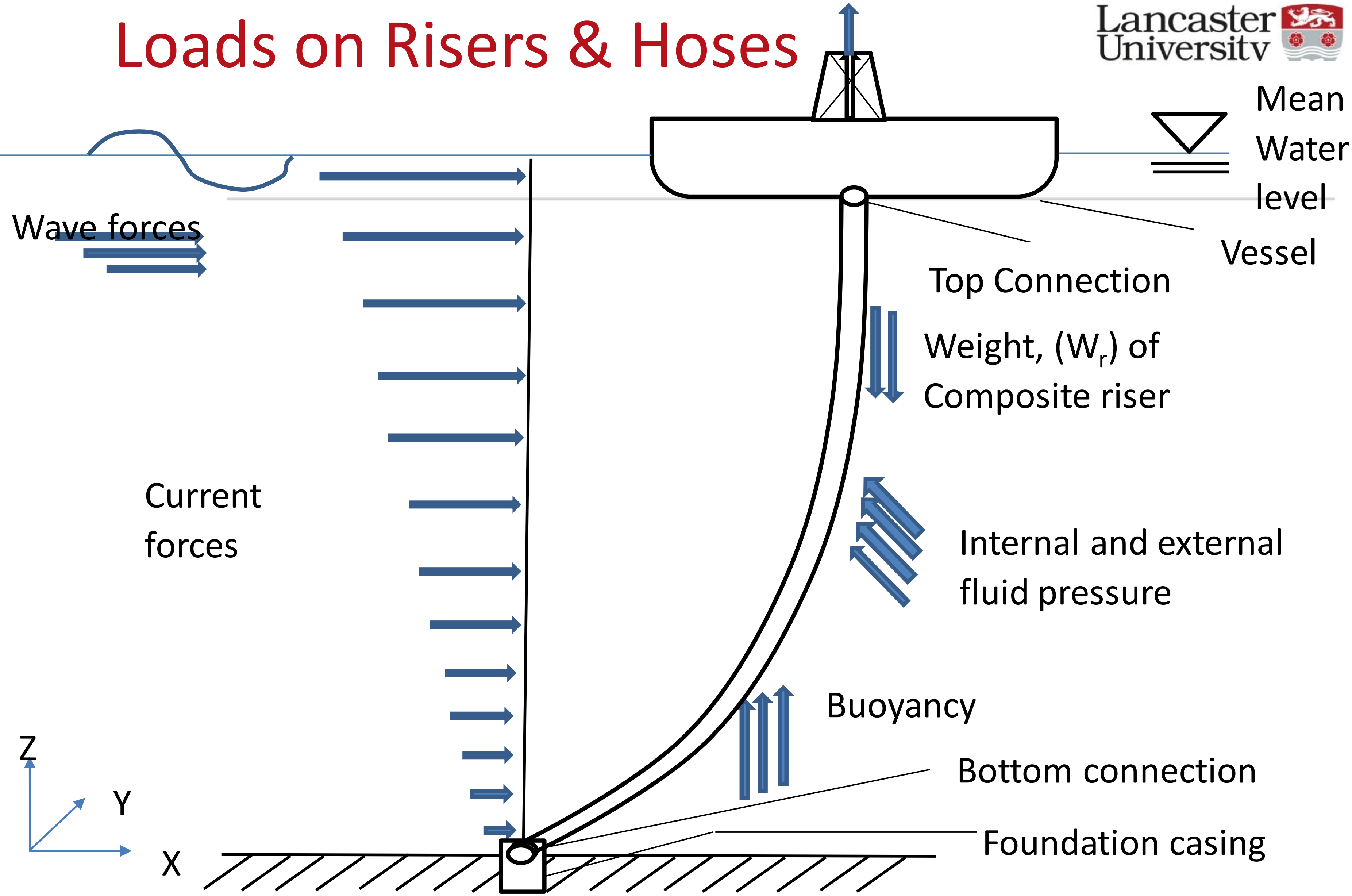
- Functional loads,
- Environmental loads,
- Accidental loads, and
- Pressure loads.





Parametric Composite Riser lay-up

Loads on Risers & Hoses

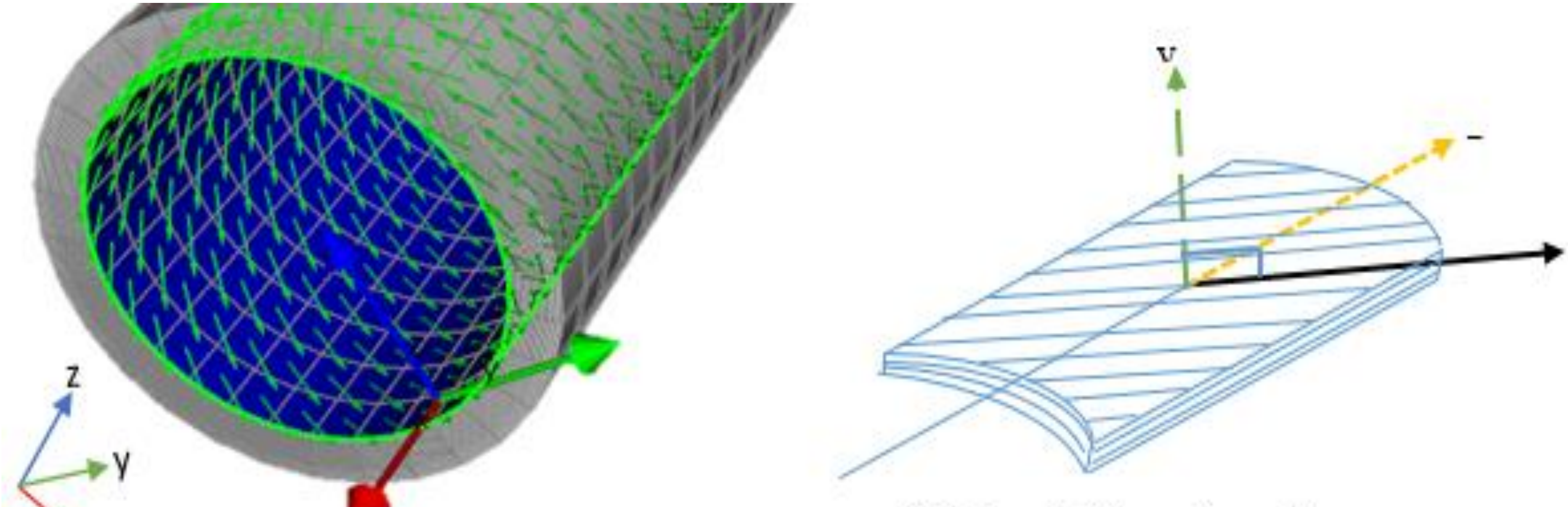


Composite risers for deep waters using a numerical modelling approach, Composite Structures, Volume 210, 2019, Pages 429-442, https://doi.org/10.1016/j.compstruct.2018.11.057.

Brief Summary Of Current Research

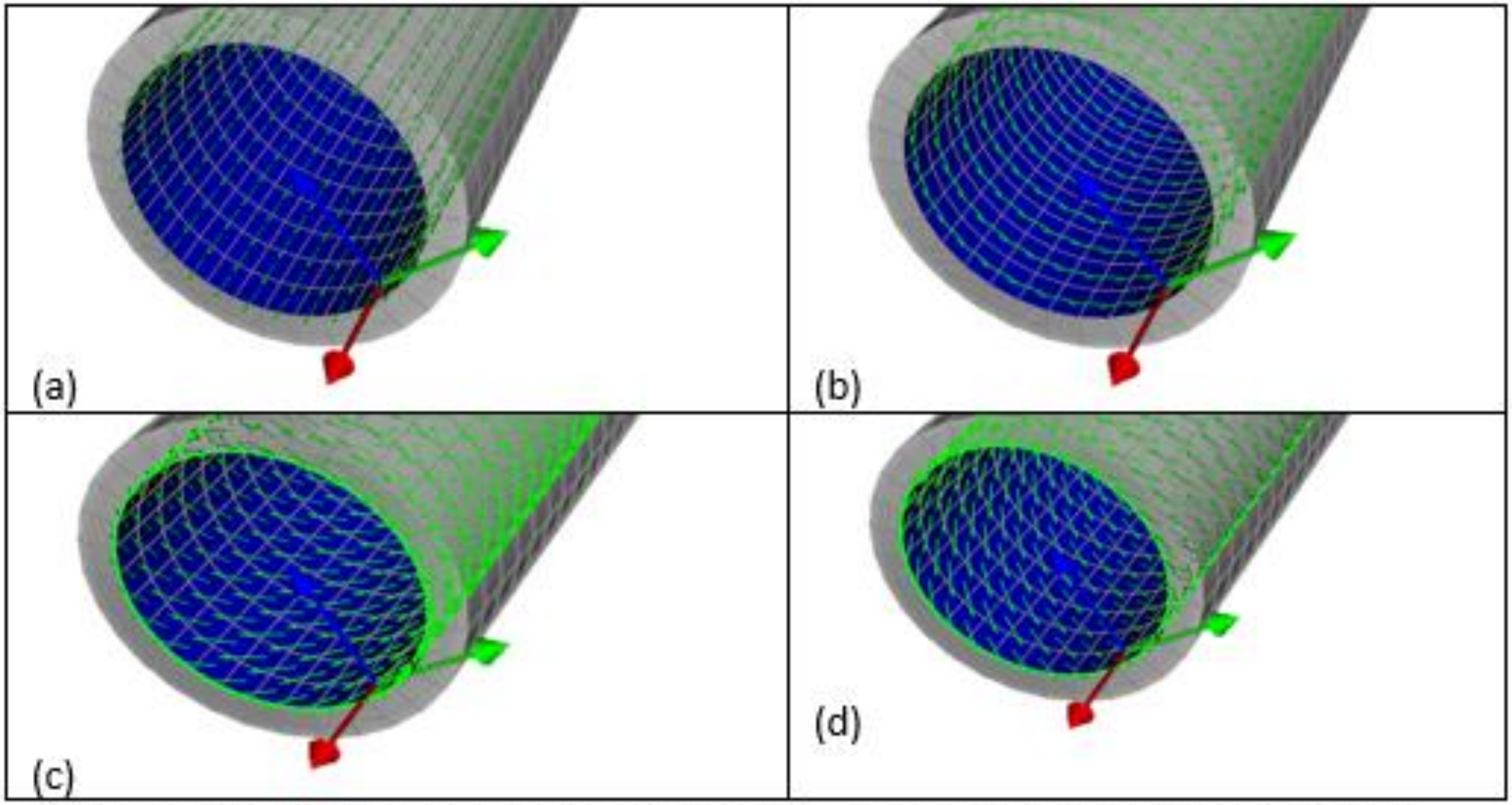
- Based on the application of composite risers, submarine hoses attached to CALM buoys have been chosen, published in https://doi.org/10.1016/j.oceaneng.2018.11.010.
- The research work on the hydrodynamics and mechanics of composite risers in oil and gas applications involves local design and global design. The local design has been published, as in https://doi.org/10.1016/j.compstruct.2018.11.057.
- Based on the global design, ANSYS AQWA and Orcaflex have been utilized for the design and analysis of the risers attached to Truss SPAR and Paired Column Semisubmersible Platforms.
- Previous work on PC Semis were developed as in published in https://doi.org/10.1142/S0219455415400192 and https://doi.org/10.1016/j.engstruct.2017.04.013.

composite riser coordinate system for the material rosette



(a) Global Coordinate System (b) Material Coordinate System

Composite riser section showing the orientations of fibre reinforcements



Composite riser section showing the orientations of fibre reinforcements in ANSYS ACP (Pre) version 19.0 at (a) 0°, (b) 90°, (c)+53.5° and (d) -53.5°

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Parameters for composite riser

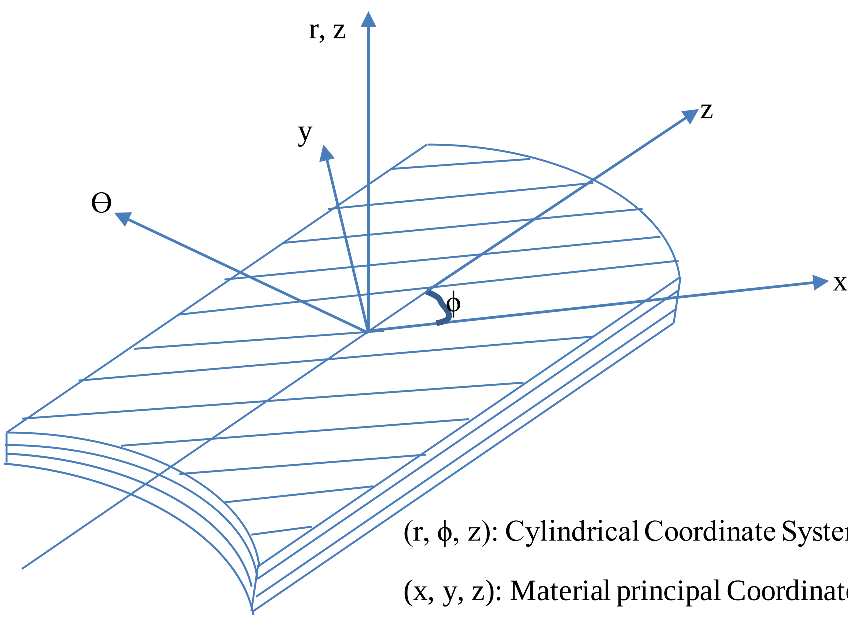
Parameter	Value
Length of Riser (m)	3
Outer Diameter (m)	0.3048
Surface Area (m^2)	7.6605
Number of Layers	18
Water Depth (m)	2000

Mechanical Properties of the liner

Material	Density (kg/m^3)	E_1 (GPa)	$E_2 = E_3$ (GPa)	$G_{12} = G_{13}$ (GPa)	G_{23} (GPa)	σ_1^T (GPa)	σ_1^c (GPa)	σ_2^T (GPa)	σ_2^c (GPa)	τ_{12} (GPa)	$\upsilon_{12} = \upsilon_{13}$	υ_{23}
AS4/PEEK (APC2)	1561	131	8.7	5.0	2.78	1648	864	62.4	156.8	125.6	0.28	0.48
IM7/PEEK (APC2)	1320	172	8.3	5.5	2.8	2900	1300	48.3	152	68	0.27	0.48
P75/PEEK (APC2)	1773	280	6.7	3.43	1.87	668	364	24.8	136	68	0.30	0.69
AS4/Epoxy (938)	1530	135.4	9.37	4.96	3.2	1732	1256	49.4	167.2	71.2	0.32	0.46
P75/Epoxy (938)	1776	310	6.6	4.1	2.12	720	328	22.4	55.2	176	0.29	0.70
Glass fibre/Epoxy (S-2)	2464	87.93	16.0	9.0	2.81	4890	1586	55.0	148	70	0.26	0.28
Carbon fibre/Epoxy (T700)	1580	230	20.9	27.6	2.7	4900	1470	69	146	98	0.2	0.27

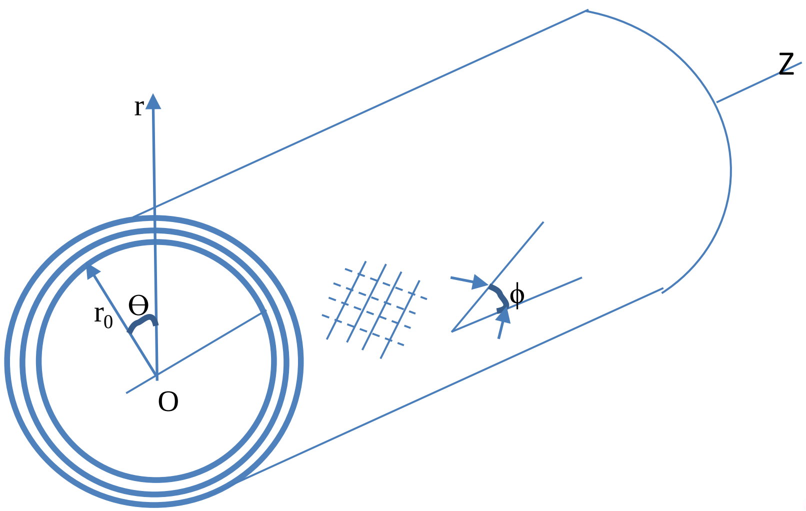
Design load cases for composite riser

Load Case	Name	Description
Load Case 1	Burst Case with end load effect	An internal pressure of 155.25 MPa is applied
Load Case 2	Collapse Case	An external pressure of 60 MPa is applied
Load Case 3	Pure Tension Case	The load factor of 2.25 with maximum tension
Load Case 4	Internal Pressure and Tension Case	An internal pressure of 155.25 MPa is applied on the tension
Load Case 5	External Pressure and Tension Case	The load factor of 2.25 is applied on 19.5 MPa external pressure
Load Case 6	Buckling Case	An external pressure of 60 MPa is applied



(r, ϕ, z): Cylindrical Coordinate System

(x, y, z): Material principal Coordinate System



Stack-up Sequence and Orientation of Composite Plies

Layer	Thickness (mm)	Orientation (°)	Description
0	2.0	0	Liner
1	1.58	0	Hoop Layers
2	1.58	0	
3	1.58	0	
4	1.58	0	
5	1.88	53.5	Off-axis Layers
6	1.88	−53.5	
7	1.88	53.5	
8	1.88	−53.5	
9	1.88	53.5	
10	1.88	−53.5	
11	1.88	53.5	
12	1.88	−53.5	
13	1.88	53.5	
14	1.88	−53.5	
15	1.62	90	Axial Layers
16	1.62	90	
17	1.62	90	
18	1.62	90	

Local design cases

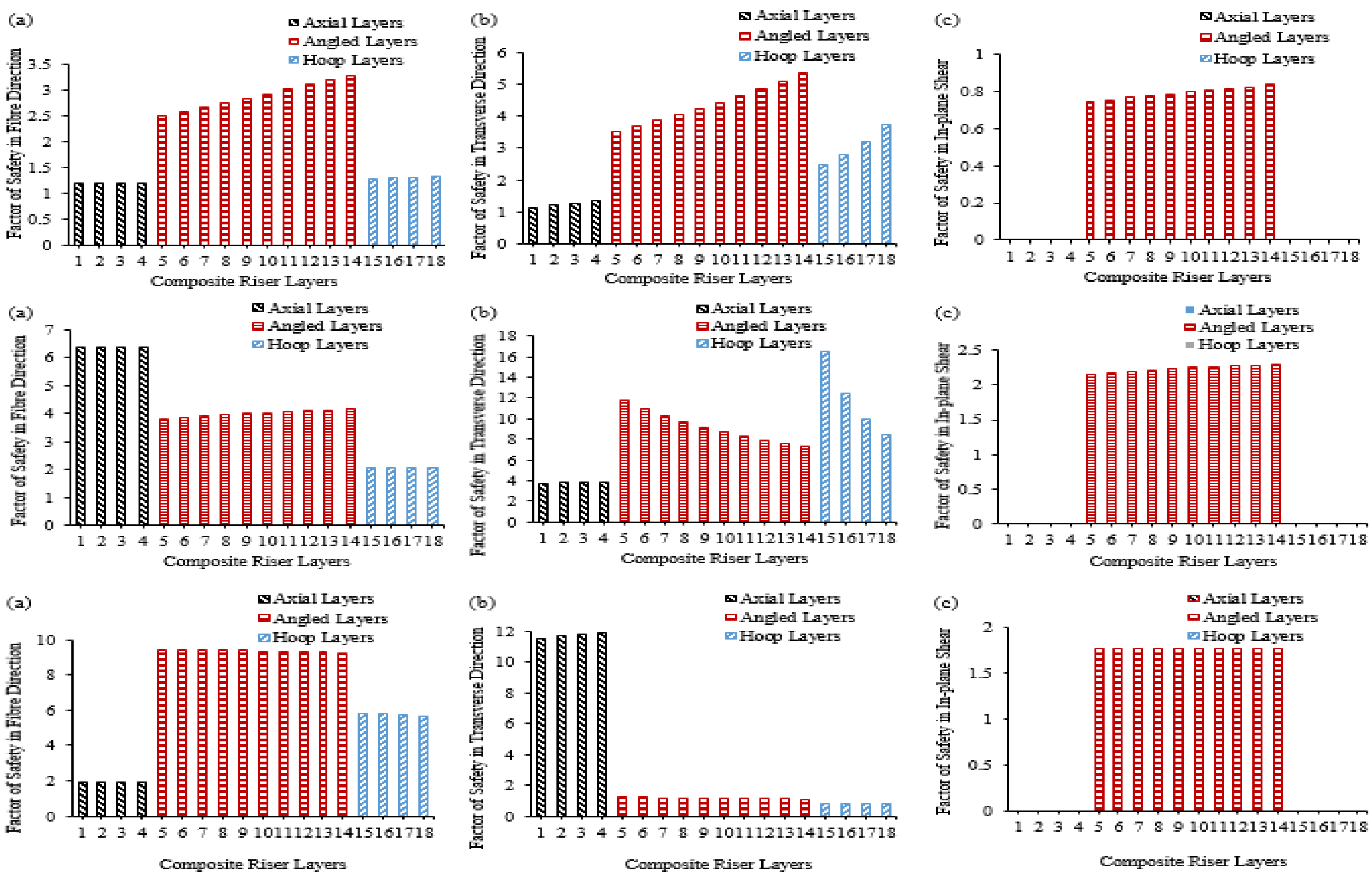


Figure 4 Factor of Safety profiles for the layers of the composite riser using AS4/Epoxy and titanium liner with $[0_4,(\pm 53.5)_5,90_4]$ configuration under: i) burst load case in (a) Fibre Direction, (b) Transverse Direction, (c) In-plane Shear Direction; ii) collapse load case in (a) Fibre Direction, (b) Transverse Direction, (c) In-plane Shear Direction; and iii) pure tension load case in (a) Fibre Direction, (b) Transverse Direction, (c) In-plane Shear Direction.

Local design cases (cont'd)

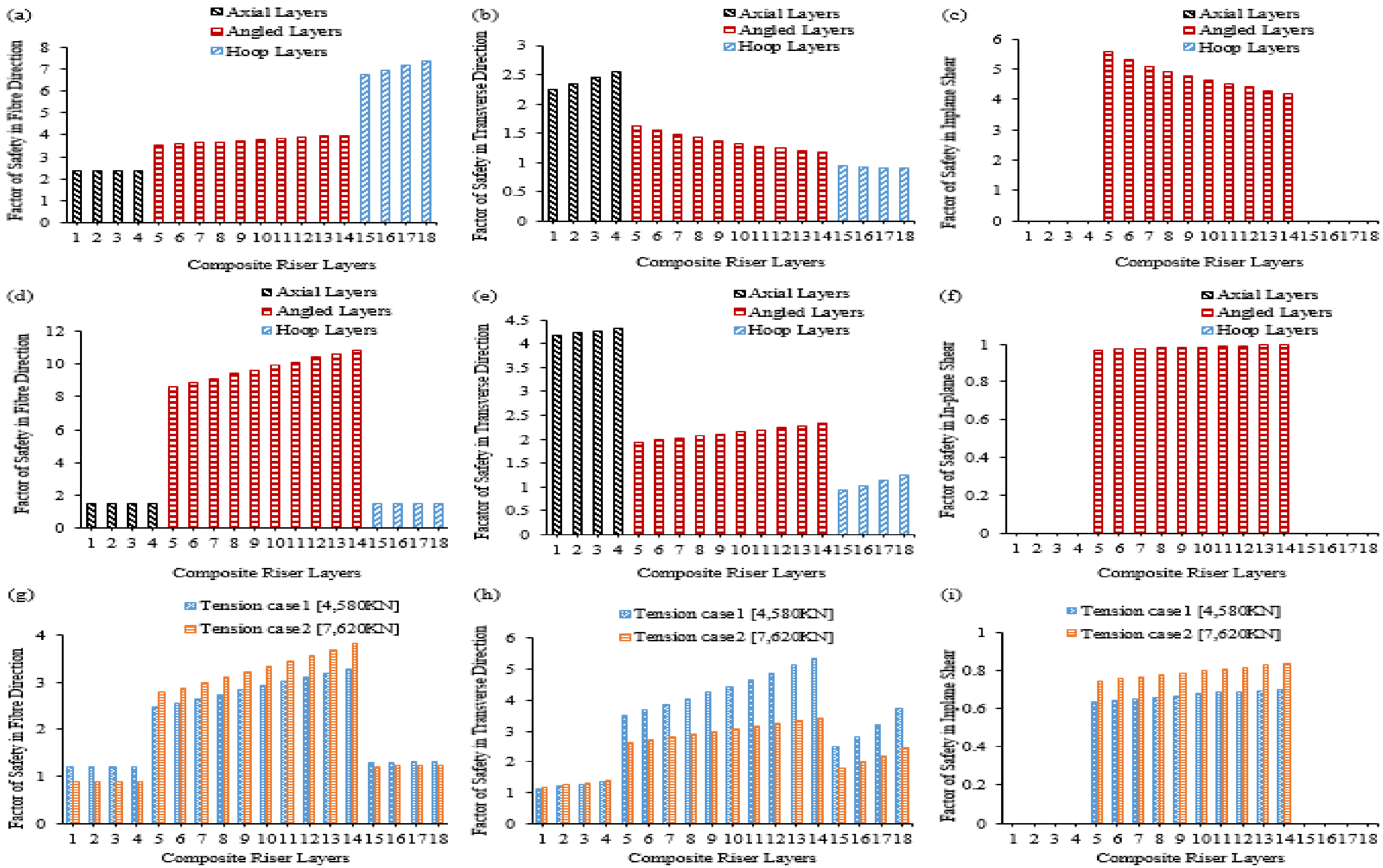
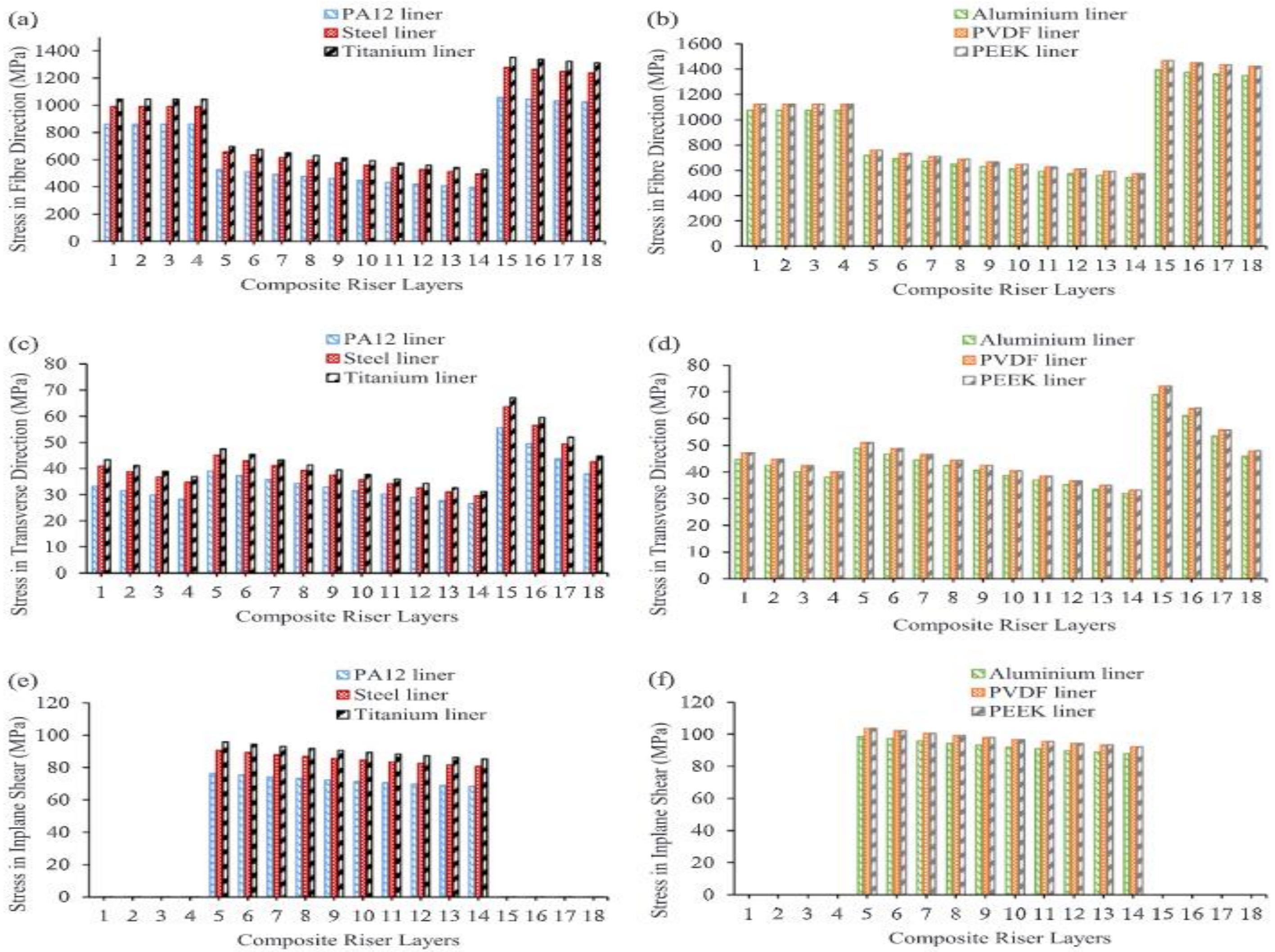
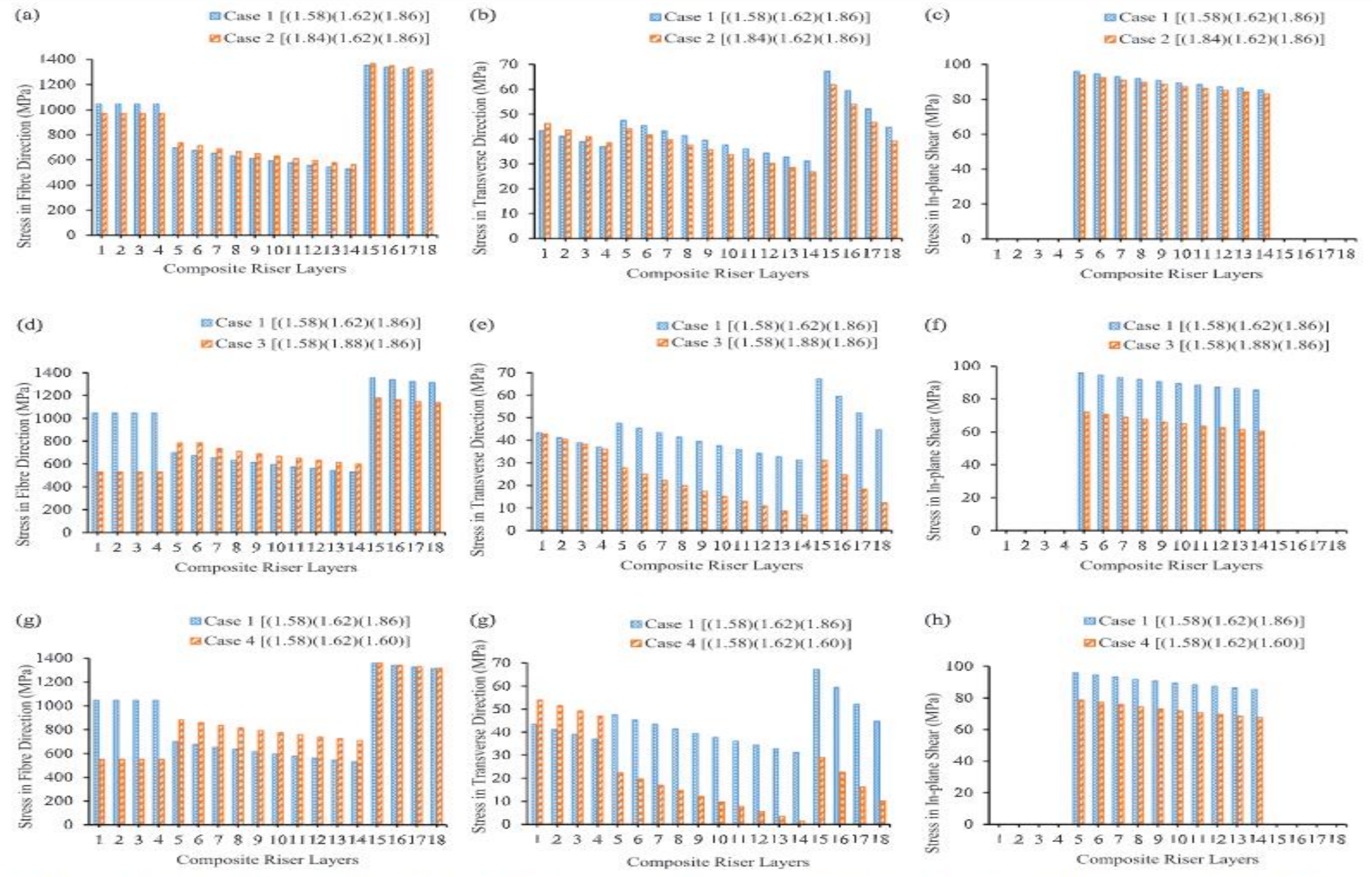


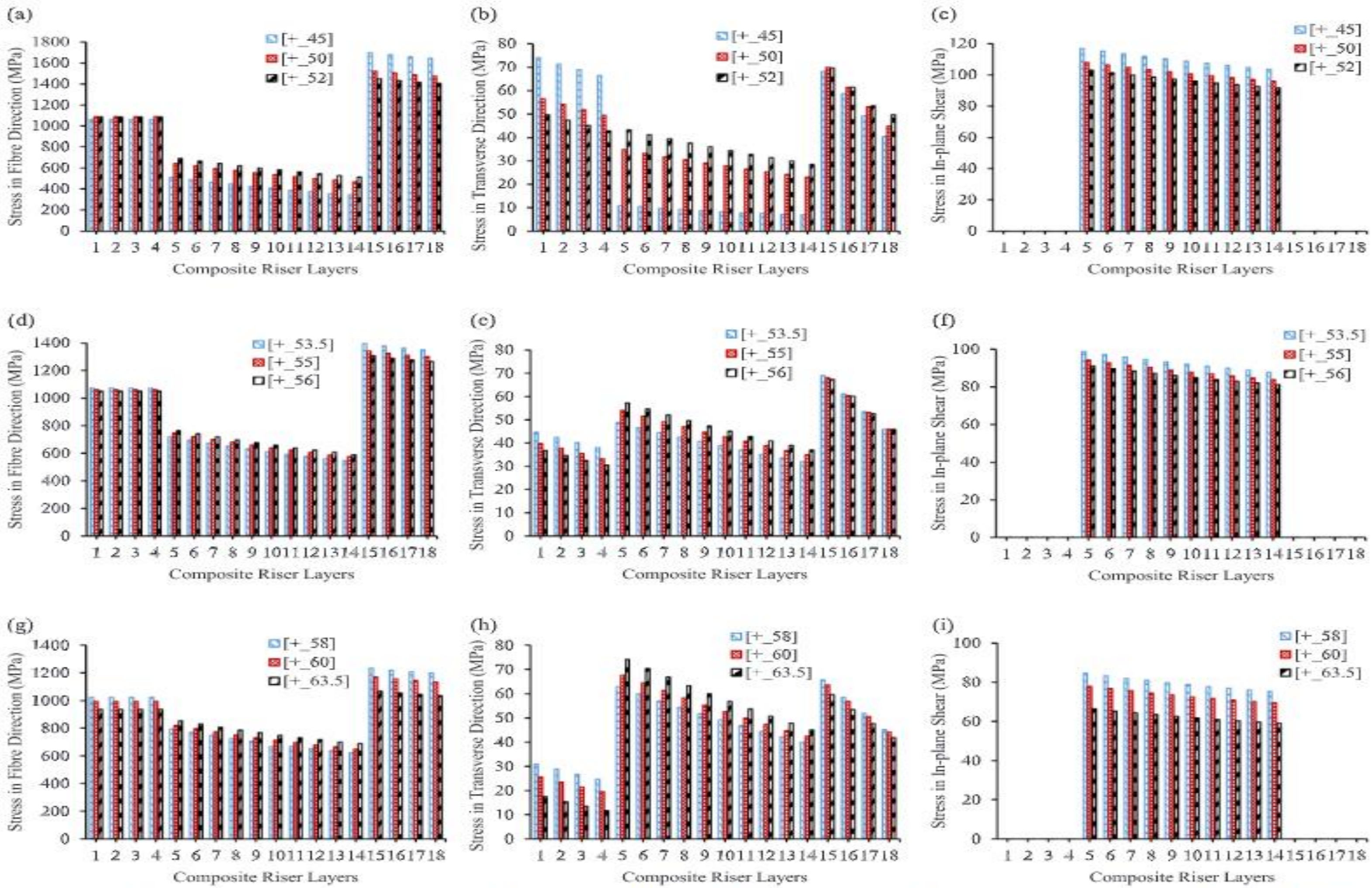
Figure 5 Factor of Safety profiles for the layers of the composite riser configured with AS4/Epoxy and $[0_4,(\pm 53.5)_5,90_4]$ configuration under: i) tension with internal pressure load case using titanium liner in (a) Fibre Direction, (b) Transverse Direction, (c) In-plane Shear Direction; ii) tension with external pressure load case using titanium liner in (d) Fibre Direction, (e) Transverse Direction, (f) In-plane Shear Direction; and iii) burst load case with end load effect using aluminium liner to investigate the effect of tension force during installation in (g) Fibre Direction, (h) Transverse Direction, (i) In-plane Shear Direction.



Stress profiles of composite riser design configured using AS4/Epoxy in $[0_4,(\pm 53.5)_5,90_4]$ to investigate the effect of different liner materials in
on (a, b); the transverse direction (c, d); and the in-plane shear direction (e, f).



AS4/Epoxy and Aluminium liner with [0_4,($\pm$ 53.5)$_5$,90_4] configuration of composite riser on the effect of: i) the axial layer thickness in the (a) Fibre Direction, (b) Transverse Direction, (c) In-plane Shear Direction; ii) the off-axis layer thickness in the (d) Fibre Direction, (e) Transverse Direction, (f) In-plane Shear Direction; iii) and the hoop layer thickness in the (g) Fibre Direction, (h) Transverse Direction, and (i) In-plane Shear Direction.



Stress profiles for composite riser configured using AS4/Epoxy and Aluminium liner to investigate off-axis layer orientation on: i) $[0_4,(\pm 45)_5,90_4]$, $[0_4,(\pm 50)_5,90_4]$, $[0_4,(\pm 52)_5,90_4]$ in: (a) Fibre Direction, (b) Transverse Direction, (c) In-plane Shear Direction; ii) $[0_4,(\pm 53.5)_5,90_4]$, $[0_4,(\pm 55)_5,90_4]$, $[0_4,(\pm 56)_5,90_4]$ in: (d) Fibre Direction, (e) Transverse Direction, (f) In-plane Shear Direction; and iii) $[0_4,(\pm 58)_5,90_4]$, $[0_4,(\pm 60)_5,90_4]$, $[0_4,(\pm 63.5)_5,90_4]$ in: (g) Fibre Direction, (h) Transverse Direction, and (i) In-plane Shear Direction.

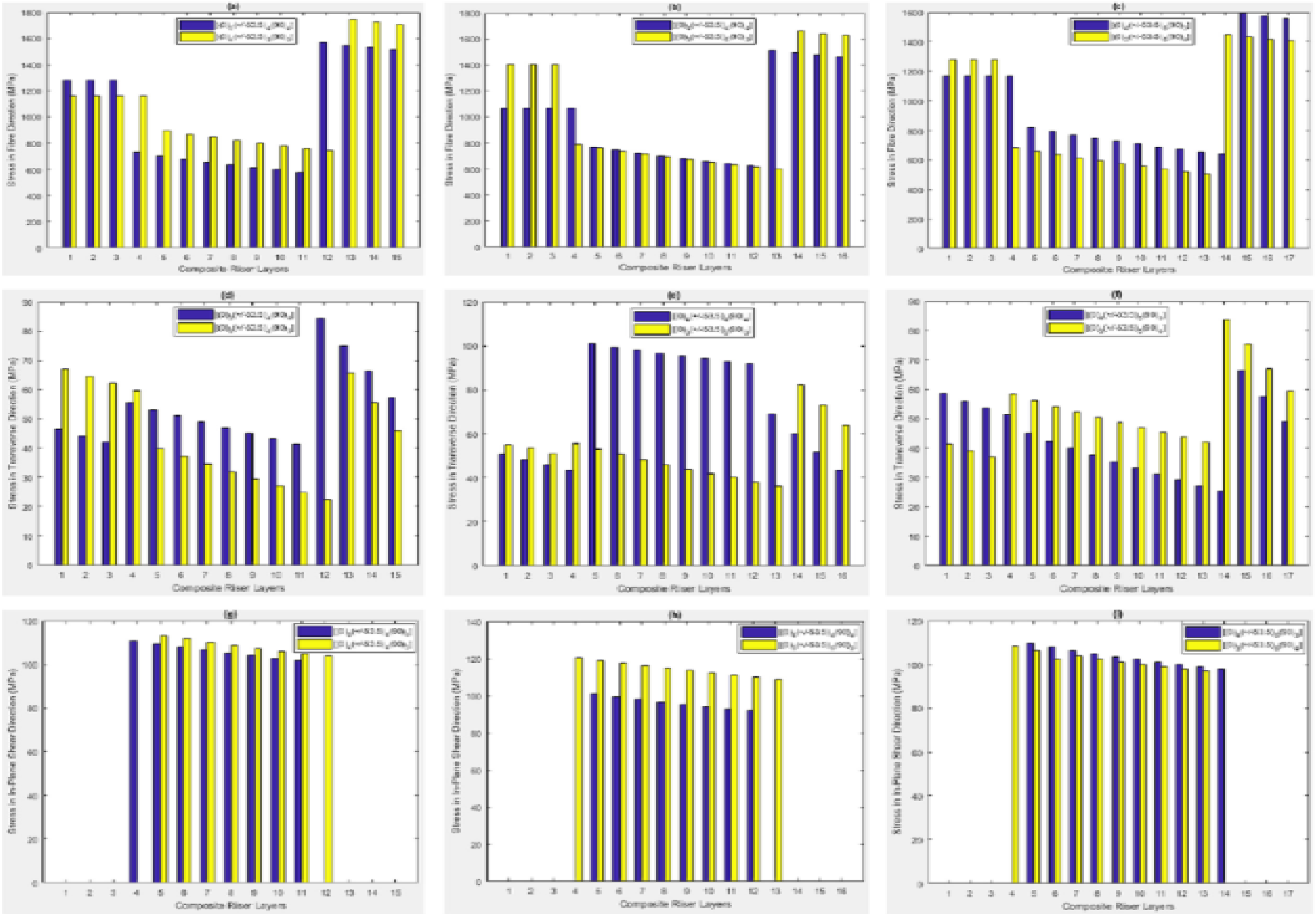
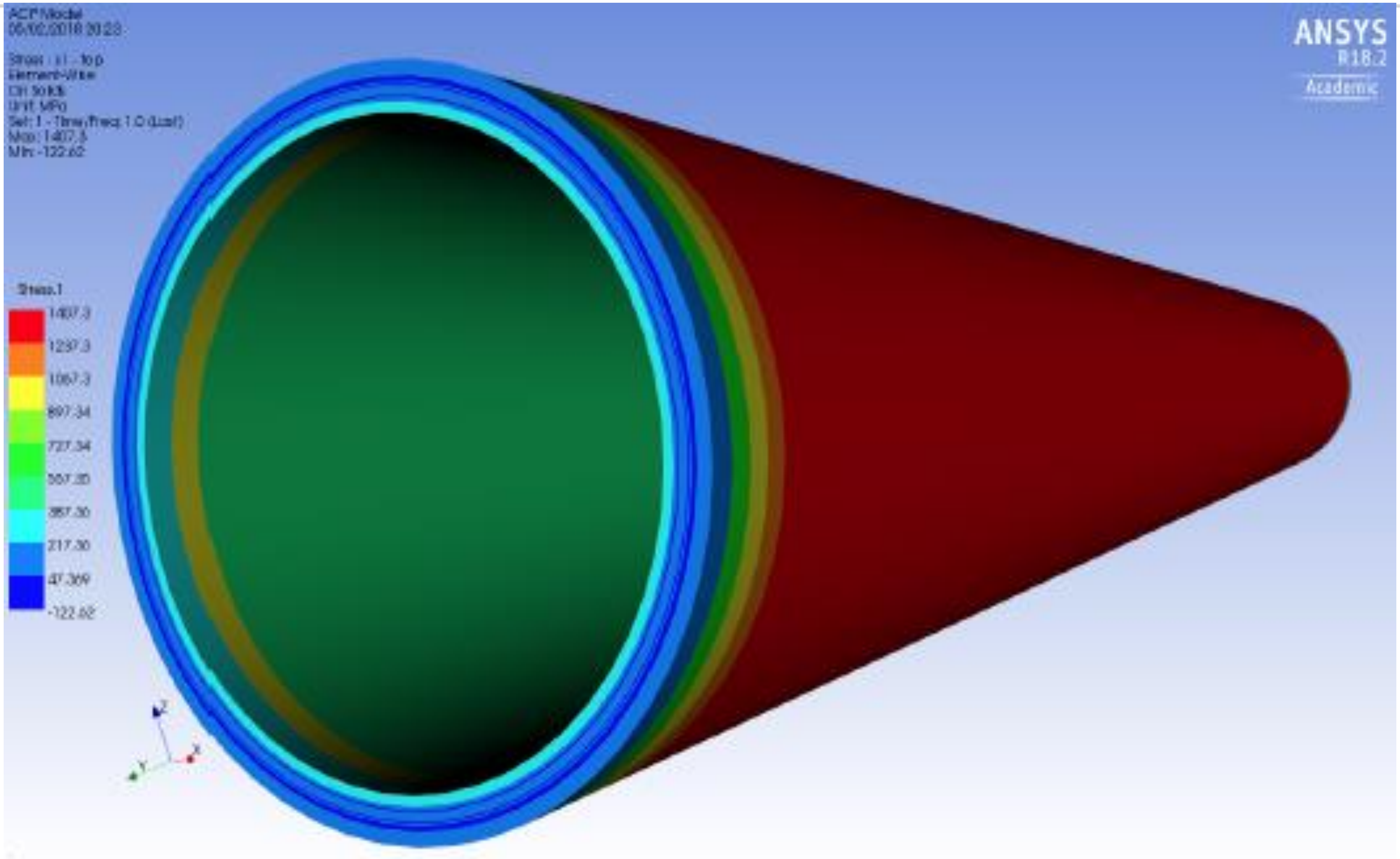
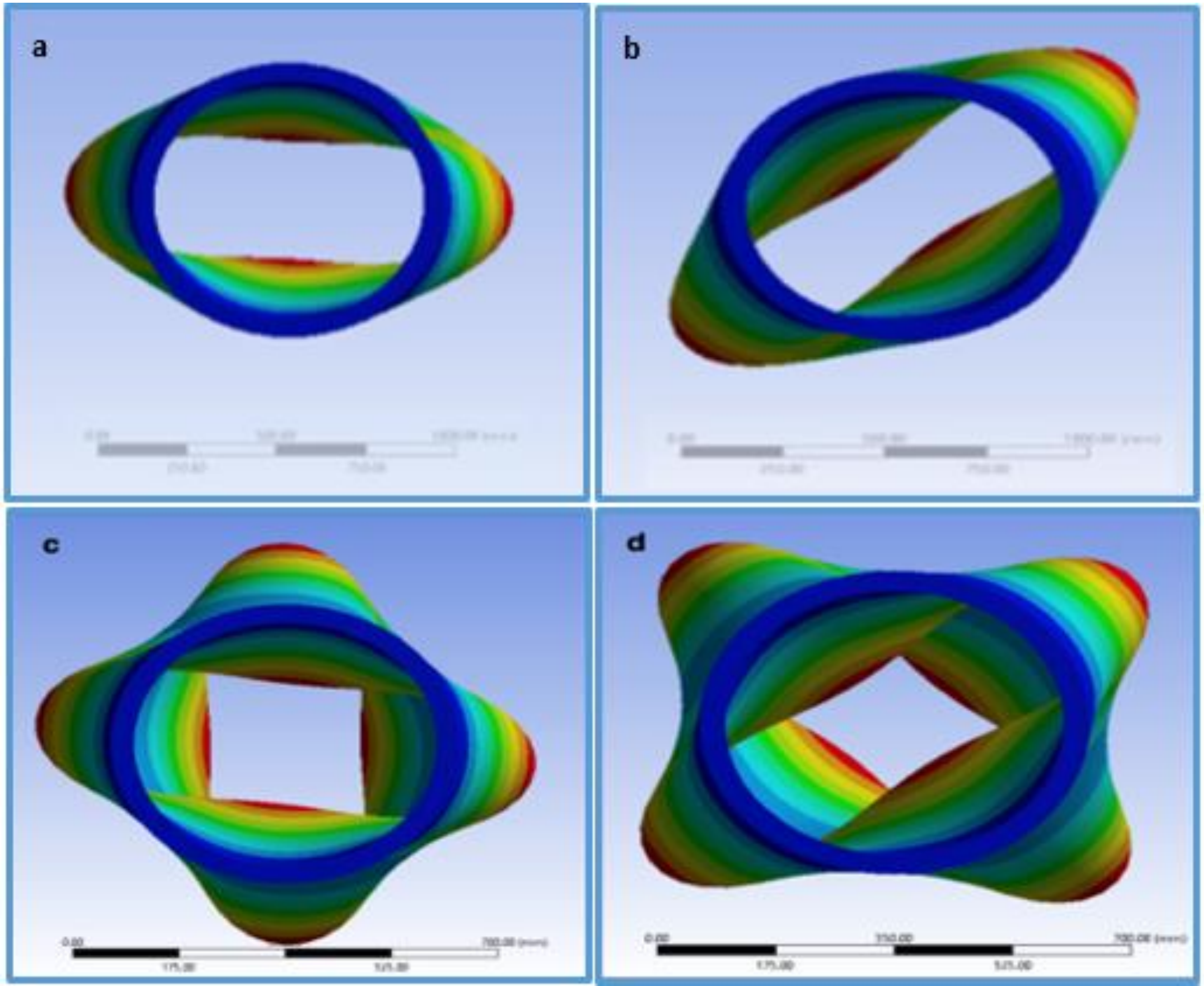


Fig. 10. Stress profiles for the layers of AS4/Epoxy Composite Riser design with aluminium liner applied in optimization consideration (5) to investigate the effect of the number of layers in the fibre direction (a, b, c); the transverse direction (d, e, f) and the In-plane Shear Direction (g, h, i) on $[0_3,(\pm 53.5)_4,90_4]$, $[0_4,(\pm 53.5)_3,90_3]$, $[0_4,(\pm 53.5)_4,90_4]$, $[0_3,(\pm 53.5)_5,90_3]$, $[0_4,(\pm 53.5)_5,90_3]$ and $[0_3,(\pm 53.5)_5,90_4]$.

Burst Case – Hoop Ply Fibre Direction Stress

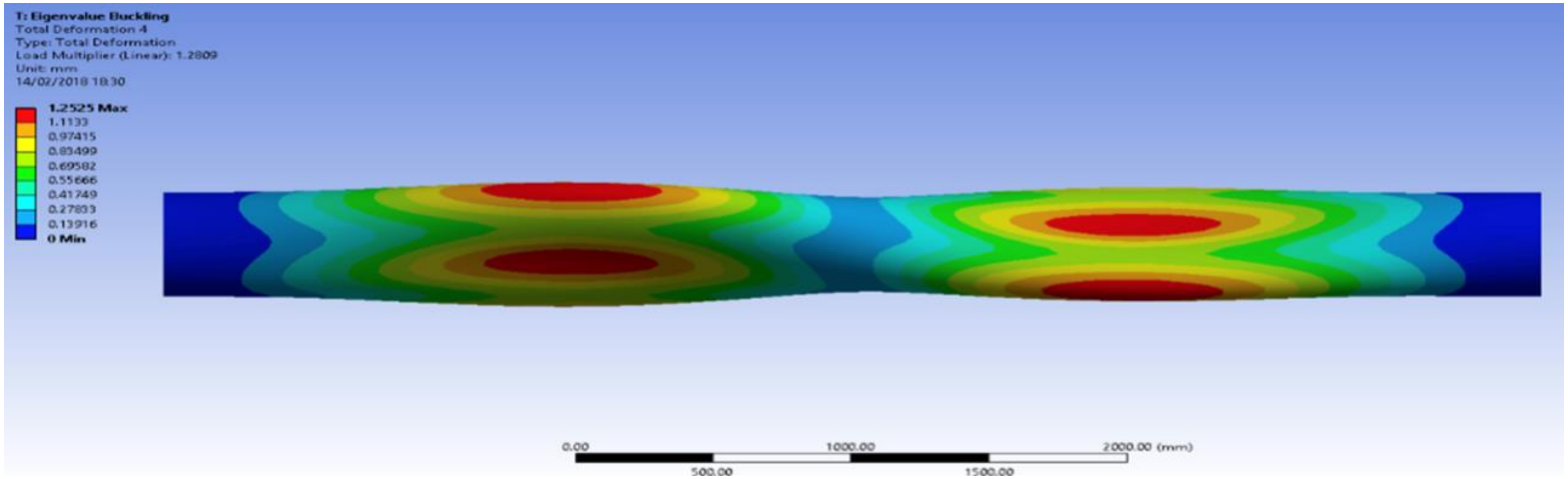


End view of modes 1-4 Buckling



Eigenvalue buckling analysis

Results of Eigenvalue Buckling Analysis				
Mode	1	2	3	4
Buckling Pressure (MPa)	75.6	75.6	76.8	76.8
Number of Axial Half-Waves	1	1	2	2
Number of Circumferential Waves	2	2	2	2
Maximum Deformation (mm)	1.00	1.33	1.00	1.25



Optimisation Summary

Optimisation	Impact on the Design
Decrease axial laminae orientation	There is noticeable reduction in the tensile stresses in fibre direction under the pure tension load case. The axial fibres have an increase in the stresses in the in-plane shear component.
Decrease hoop laminae orientation	There is noticeable reduction in the tensile stresses in fibre direction. The hoop fibres have an increase in the stresses in the in-plane shear component.
Increase off-axis laminae orientation	There is redistribution of stress. The equivalent stress in the liner decreases. Maximum stress in the fibre direction in both the hoop and axial layers slightly change in non-critical off-axis laminae.
Increase axial layer thickness	Reduction in the equivalent stress in the liner. Reduction in the maximum stress in the fibre direction of the hoop layers. Maximum stress in the transverse direction of the axial layers decrease.
Increase hoop layer thickness	Reduction in the equivalent stress in the liner. Maximum stress in the fibre direction of the hoop layers decrease. Maximum stress in the transverse direction of the axial layers decrease.
Iteratively decrease liner and hoop laminae thickness	The equivalent stress in the liner increases to a value slightly below the allowable stress of the aluminium liner. There is an increase in the maximum stresses in both the fibre direction and transverse direction to within 97% and 99% of the corresponding allowable stresses, respectively.

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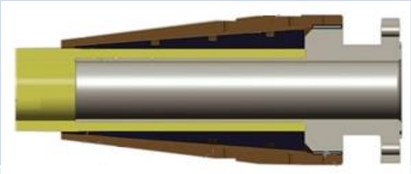
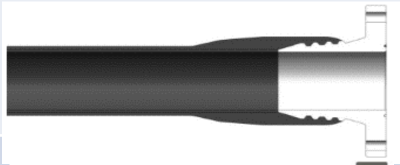
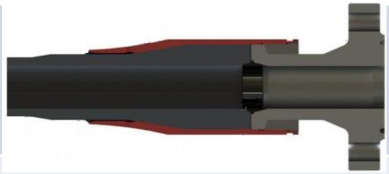
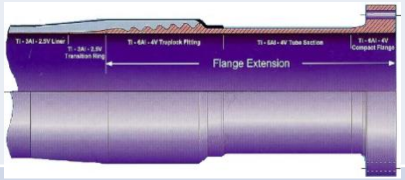
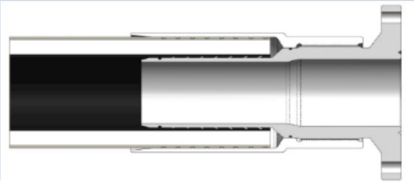
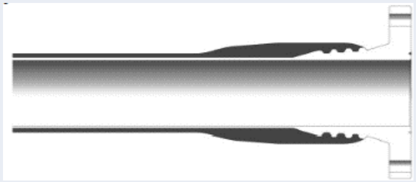
Composite Riser End-fitting Designs

End-fitting	Description of the design	Reference
Airborne end-fitting design		Airborne, (2016)
Traplock end-fitting design		Hatton et al., (2013)
Magma end-fitting design		Magma, (2016)
Swagged End-fitting		Hatton et al., (2013)
Heidrun End-fitting		Salama et al. (2005)
Metallic liner end-fitting		Hatton et al., (2013)

KeyPoints of Composite Risers

- First time composite risers were successfully deployed was in 1995 on Heidrun Platform;
- Composites have high strength and light weight properties that can be harnessed in the offshore industry;
- Composite materials can be modeled using softwares and codes -ANSYS ACP;
- Composite Materials offer a range of benefits which could be utilised in the offshore riser application to improve riser technology;
- Research on Composite Risers have been on for about 27 years;
- Companies like Airborne and Magma have successful applications of composite pipes and composite risers;

Importance of Composite Risers

- Composites are light – High specific strength
- Can be formed into complex shapes
- Very good fatigue resistance claimed
- High corrosion resistance
- Maintenance cost is low
- Comparatively low axial and bending stiffness when compared to steel
- Potential ease of installation (i.e. Reeled pipe)
- Can be designed into desired form

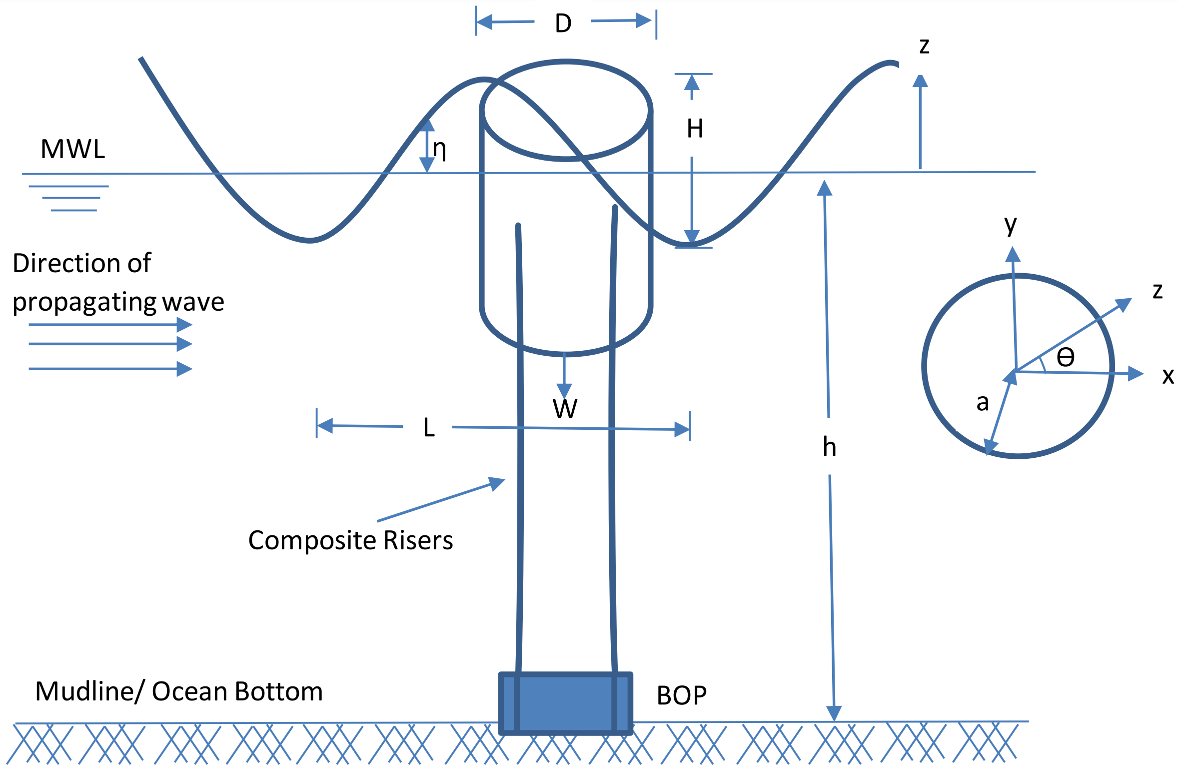
Issues with Composite Risers

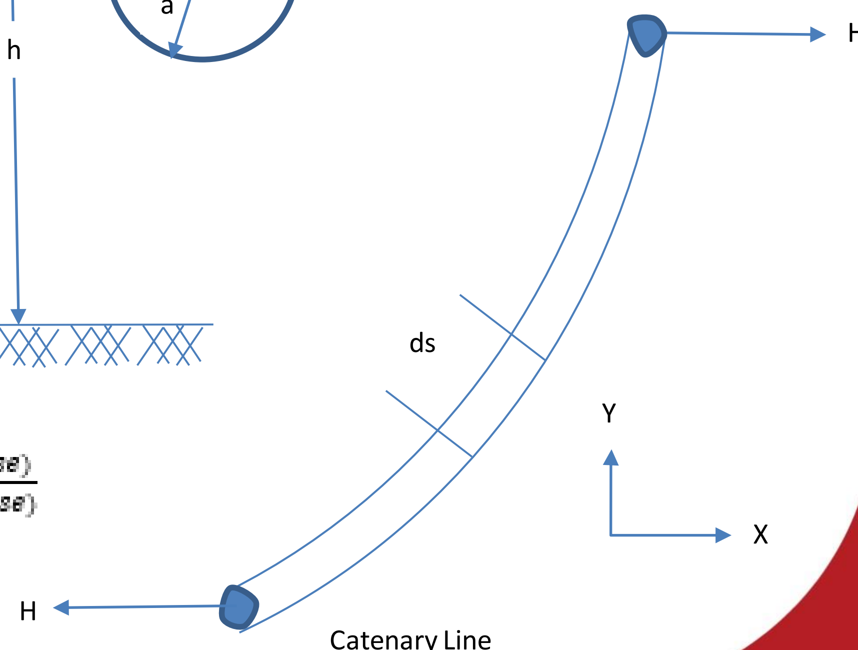
- Need more work due to more deep water needs
- Very expensive (high cost of material)
- Limited track record in the offshore industry but it has high applications in other industries
- Design codes, specifications and standards are limited as regards direct applicability to composite risers (recent ones by ABS and DNV have been introduced)
- Hard to inspect sub-laminar damage
- More design models on composite risers are needed on both the composite materials and composite riser structure

Brief on composite risers project

- Current trend in oil and gas led to more technologies
- Need for lighter materials led to the need for composites
- Composites have high strength and light weight properties that can be harnessed in the offshore industry;
- Composite materials can be modeled using softwares and codes -ANSYS ACP;
- Composite Materials have advantages which could be utilised in the offshore riser application to improve riser technology;
- Research on Composite Risers have been on for about 27 years;
- Companies like Airborne and Magma have successful applications of composite pipes and composite risers;
- More collaboration needed- industry, academia, stakeholders

Sketch of risers on SPAR design

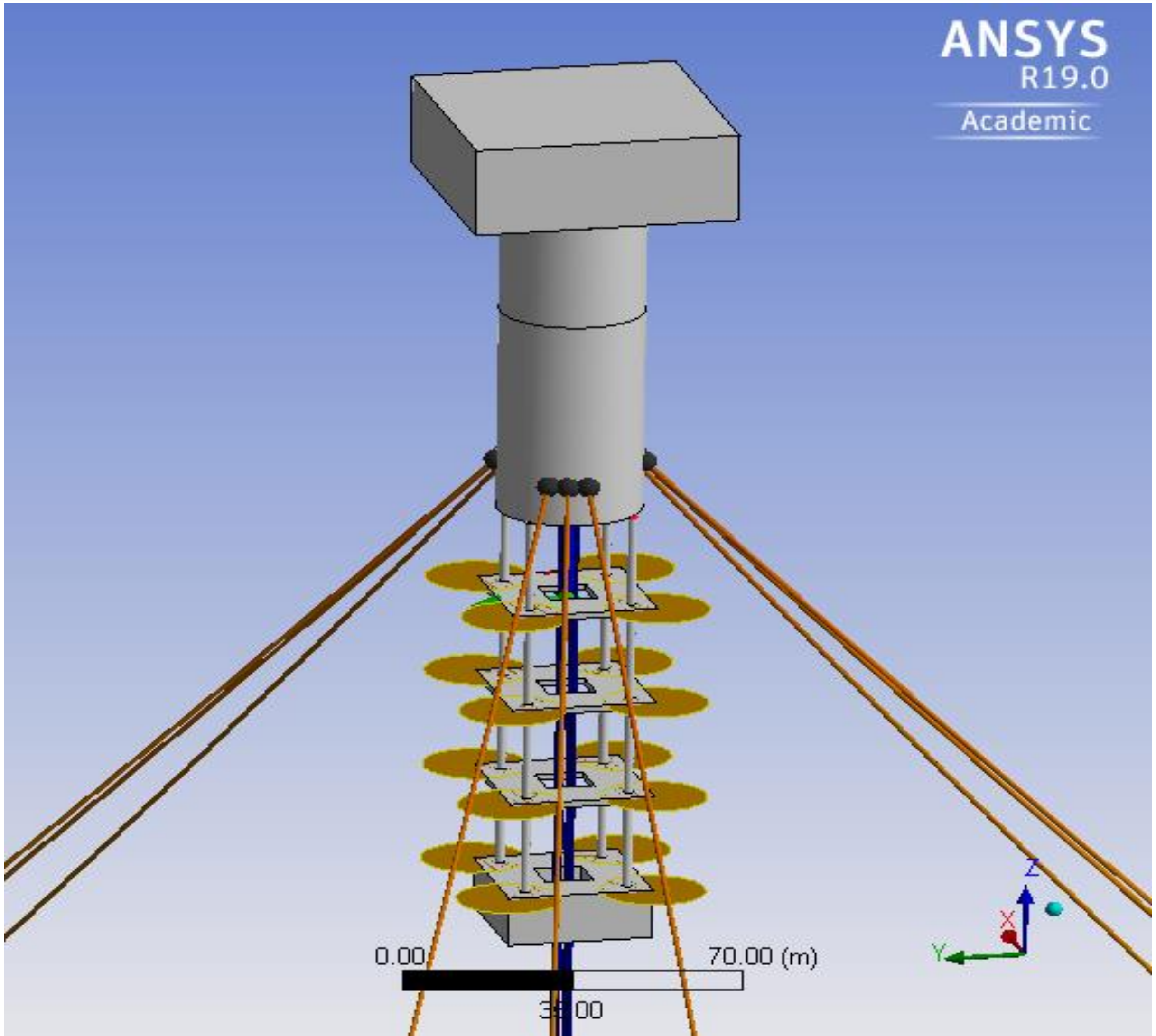




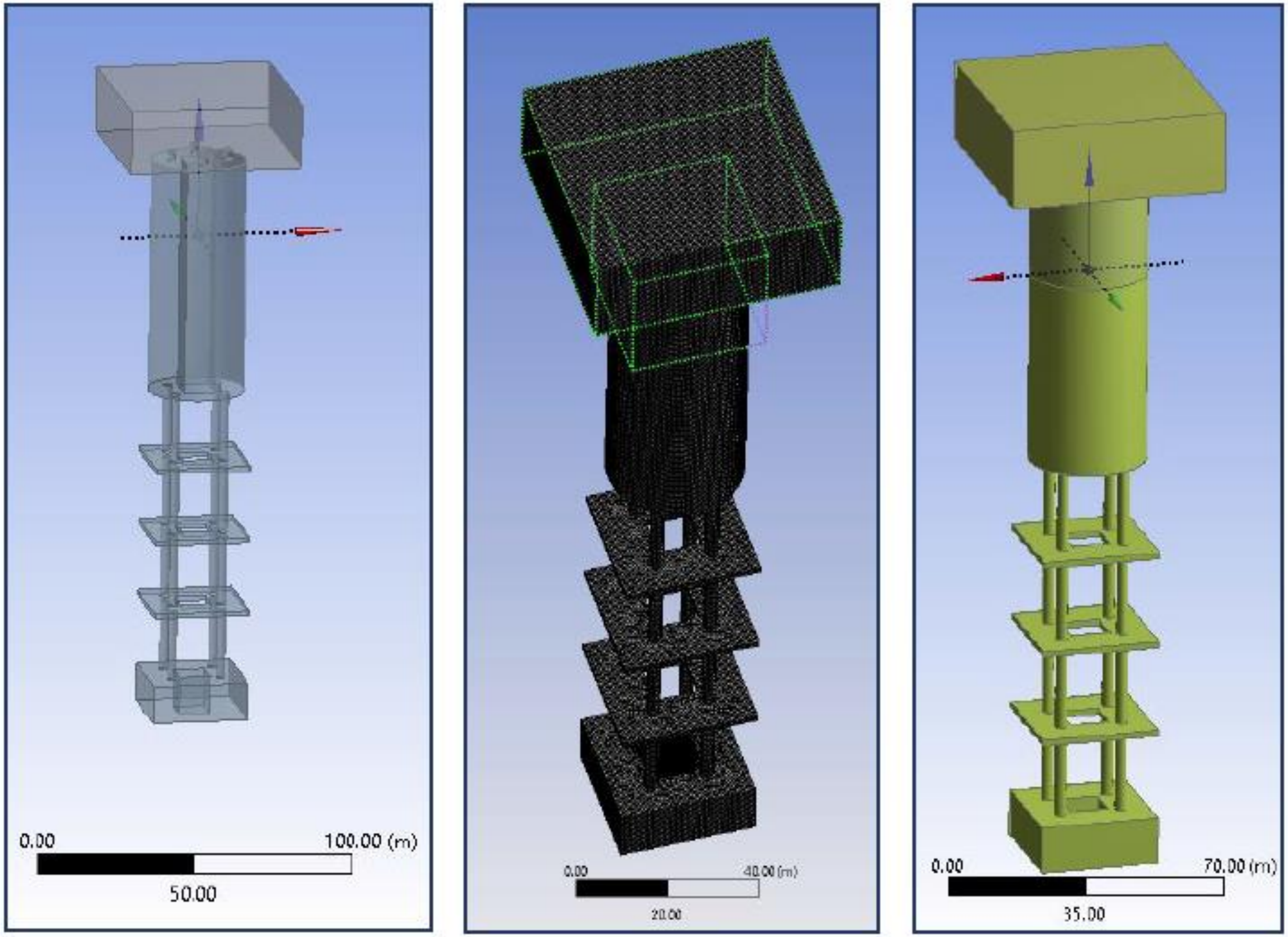
$$DAF_{Hose} = \frac{\text{Dynamic Response Amplitude(With hydrodynamic loads on Hose)}}{\text{Static Response Amplitude (Without hydrodynamic loads on Hose)}}$$

Catenary Equation $y = H/w[\cosh\left(\frac{wx}{H}\right) - 1]$

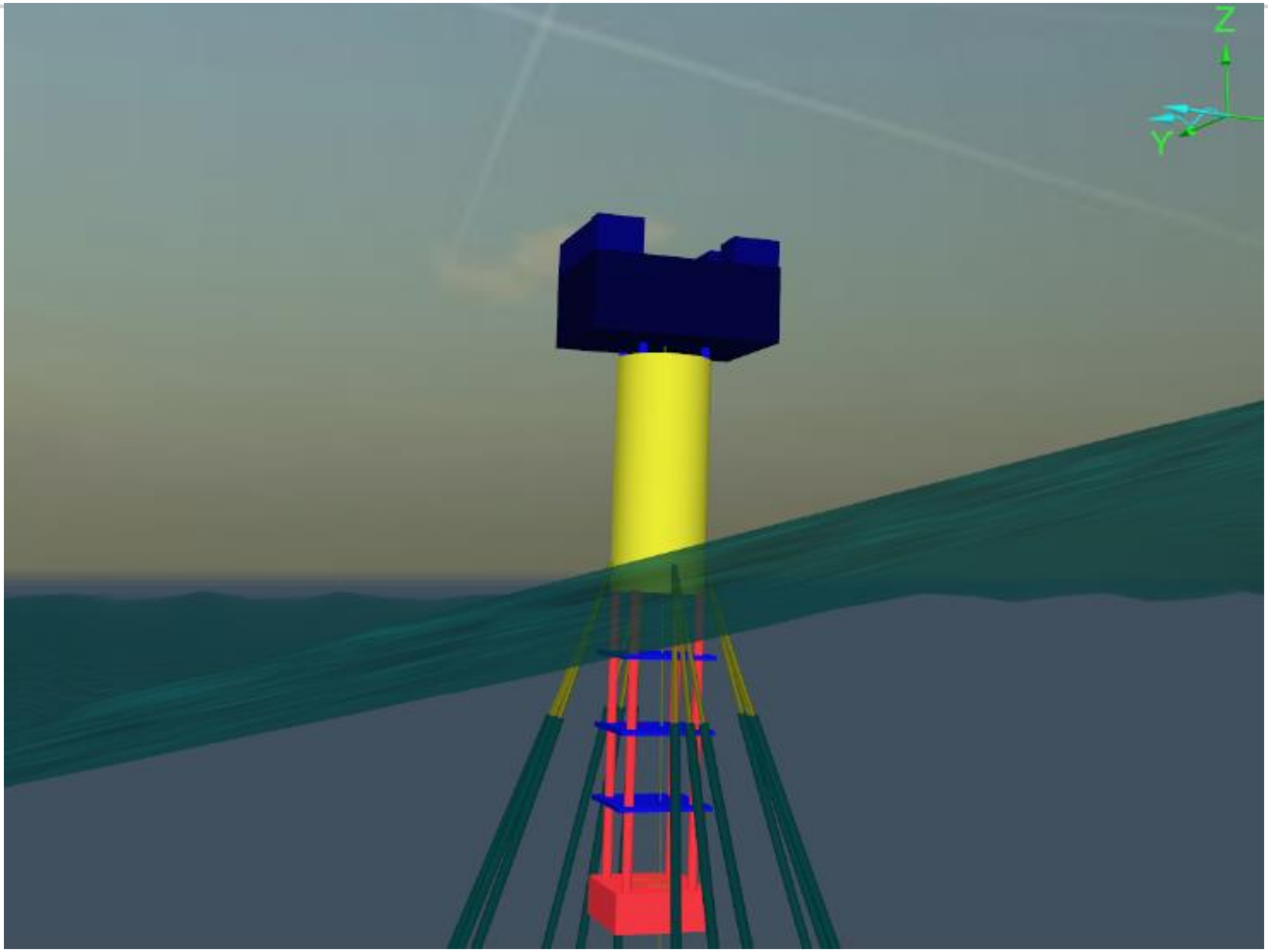
Truss SPAR, Mooring lines, and risers in ANSYS AQWA



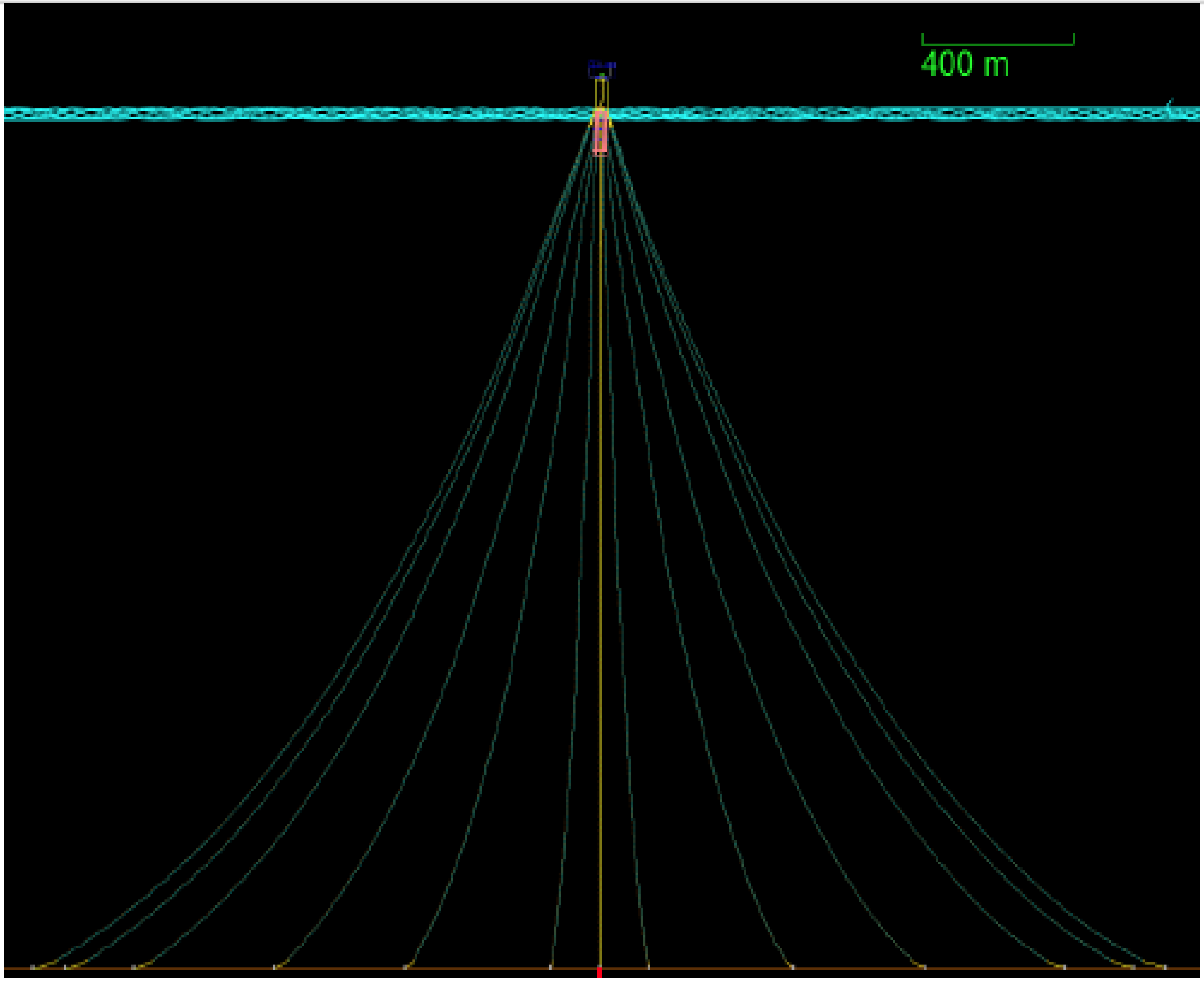
SPAR models showing shell model, hydrodynamic panel and solid model



Global Design on SPAR in Orcaflex



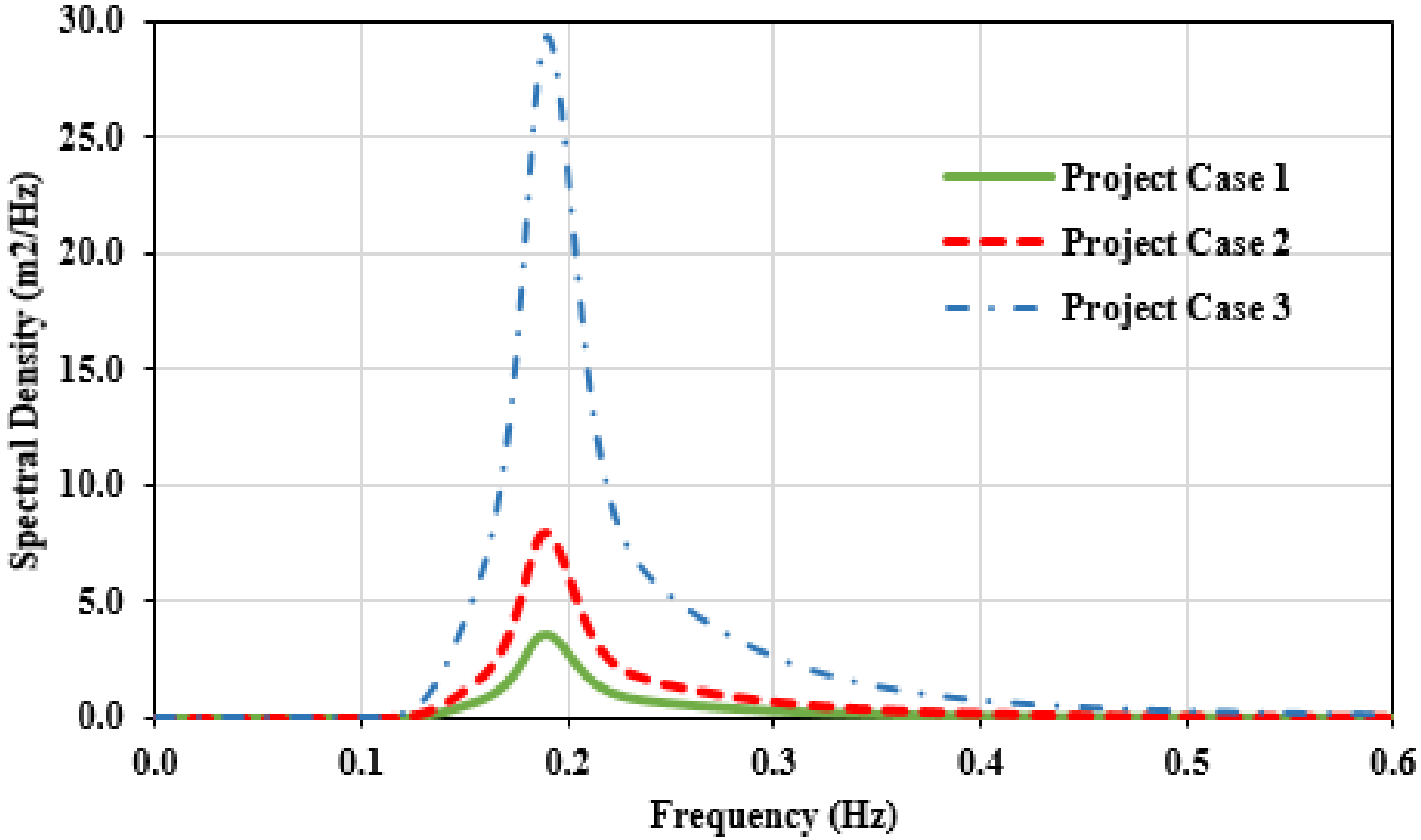
OrcaFlex model illustrating the riser and mooring lines



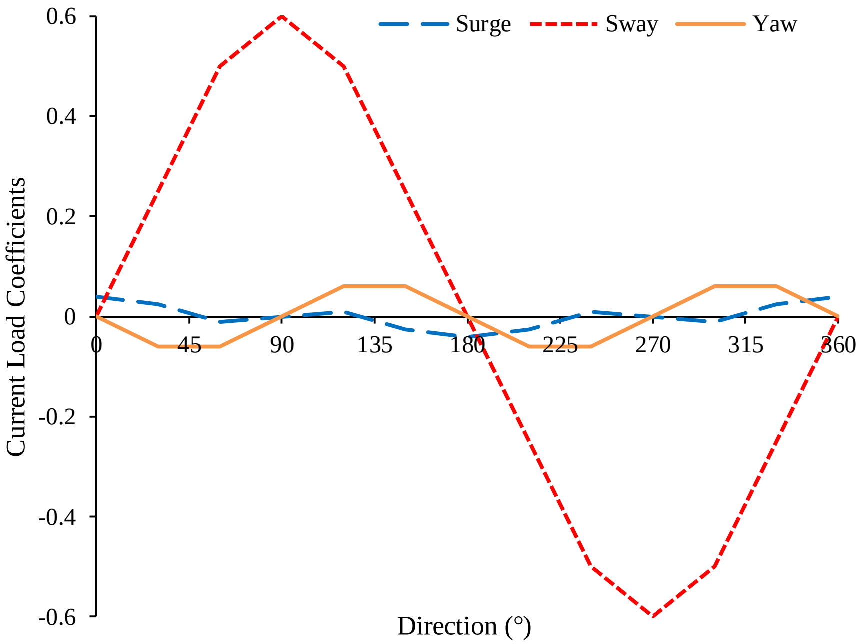
Comparison of Spar and TLP Natural Periods

Platform Type	Spar	TLP
Surge Period (s)	>100	>100
Sway Period (s)	>100	>100
Yaw Period (s)	>100	>100
Roll Period (s)	<5	50-90
Pitch Period (s)	<5	50-90
Heave Period (s)	<5	20-35

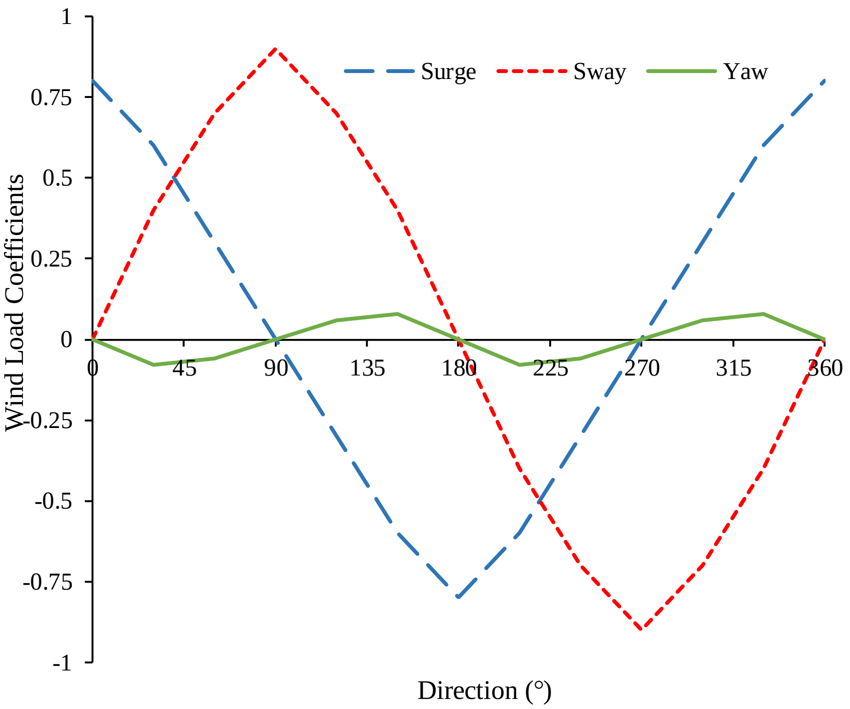
JONSWAP Spectrum for the 3 Environmental Project Cases



Current and Wind



Current Load Coefficient



Wind Load Coefficient

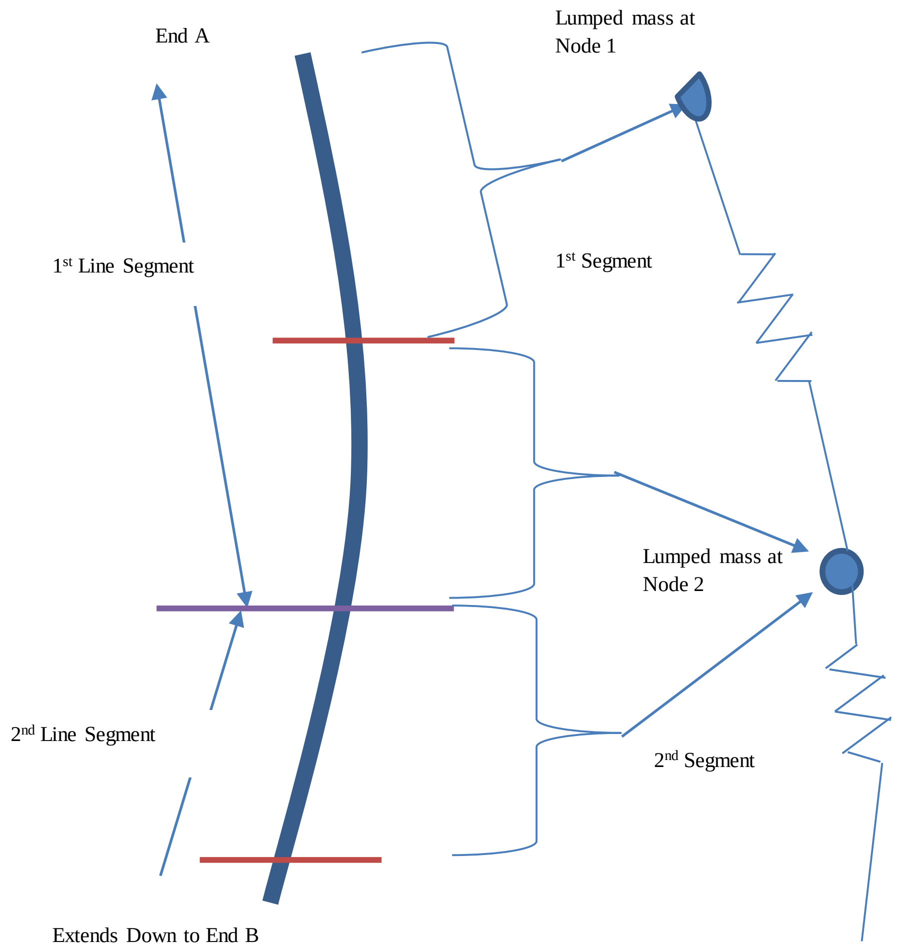
Strength of submarine hoses in Chinese-lantern configuration from hydrodynamic loads on CALM buoy, Ocean Engineering,

Volume 171, 2019, Pages 429-442, ISSN 0029-8018, https://doi.org/10.1016/j.oceaneng.2018.11.010.

Wave Forces on Offshore Structures

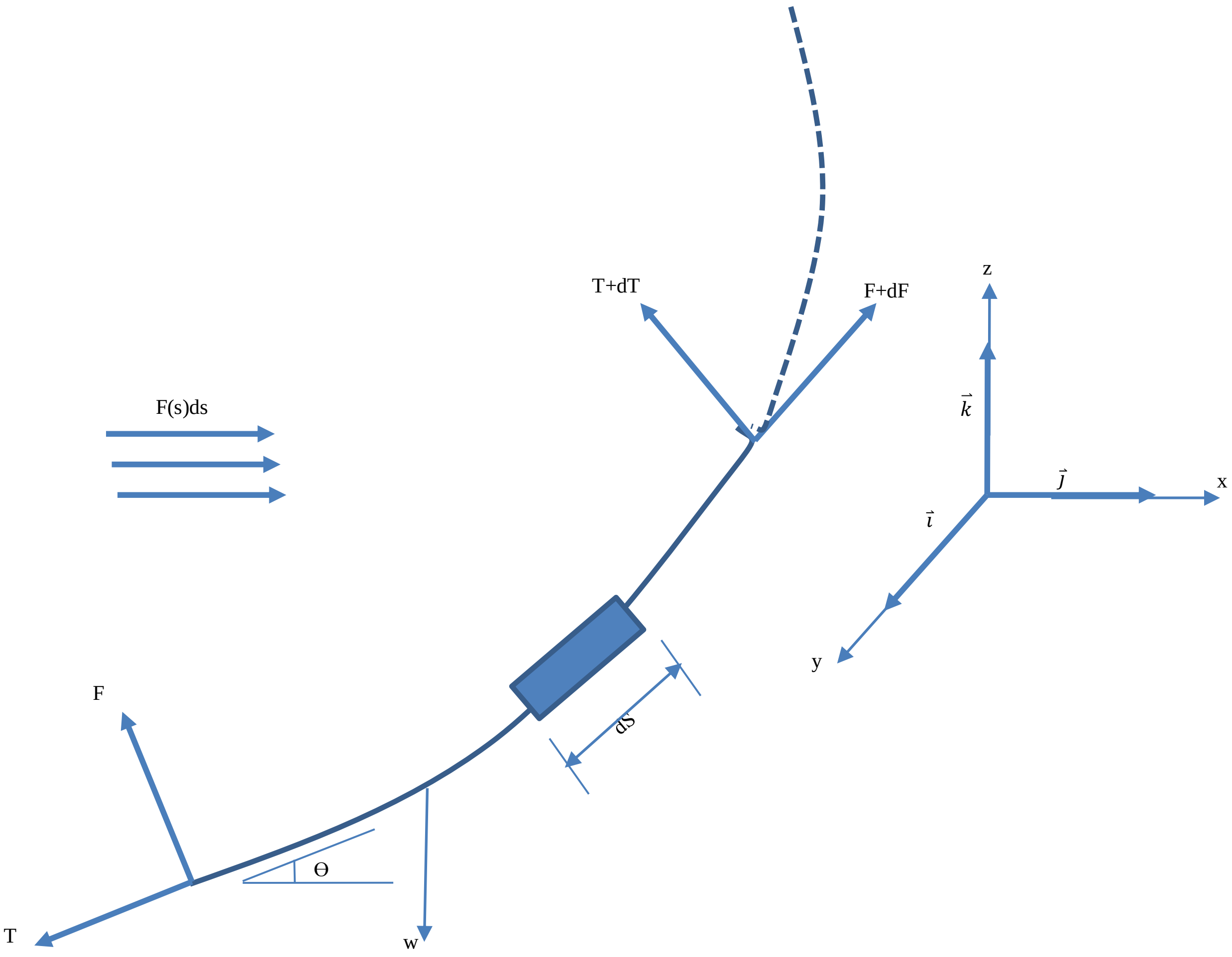
- Offshore structures are subject to various loads. These loads include the wave forces, currents forces, tension forces, etc.
- The behaviour of an offshore structure is subject to diffraction forces. This leads to hydrodynamics study. The principle of this originates from Morison's Equation.
- Waves can either be Regular or Irregular. An example of Regular waves is Dean Stream Wave; For Irregular wave is JONSWAP.
- Different wave theories can be applied, depending on the ocean condition. They have different properties too.
- An example is the Linear Wave Theory. This is used in Froude-Kyrov forces, which assumes that pressure field is undisturbed and is applied for diffraction analysis of offshore structures.

Orcaflex Line Model (courtesy: Orcina, 2014)

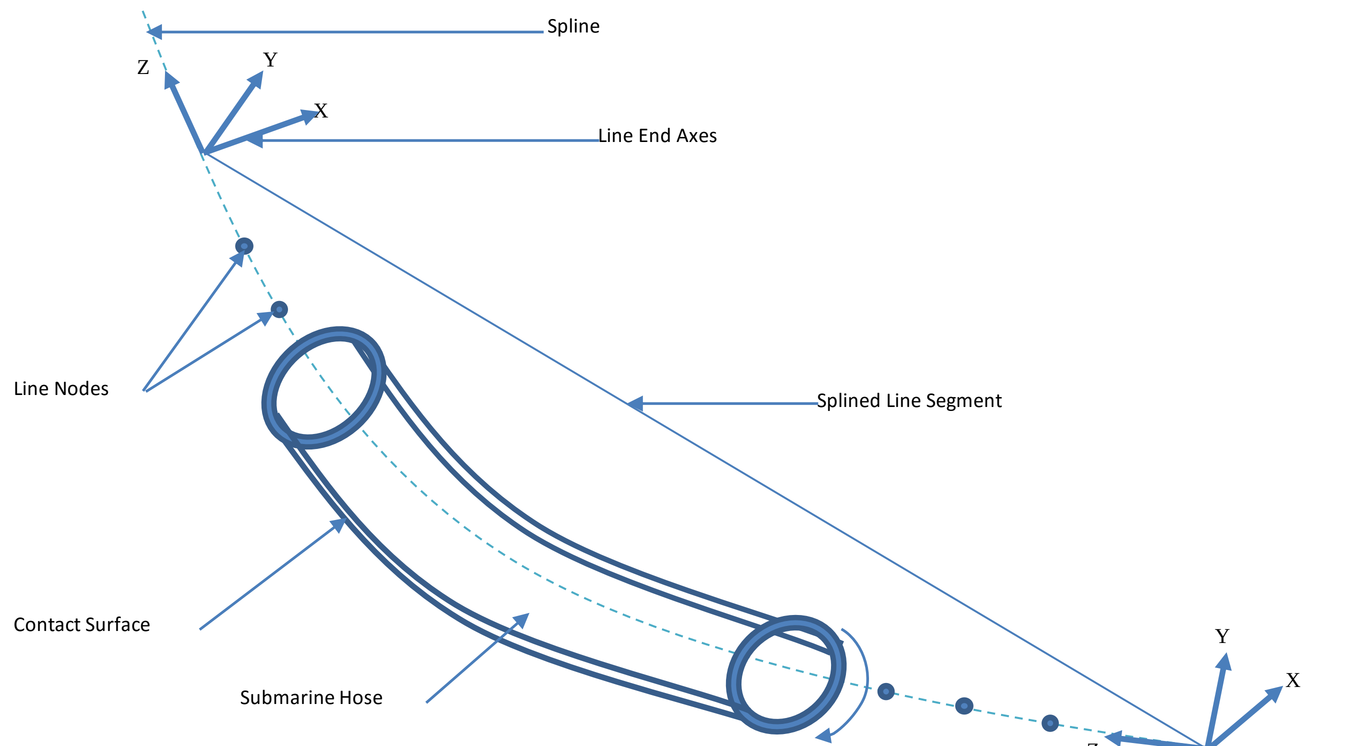


(a) The Main Line (b) The Discretized Model

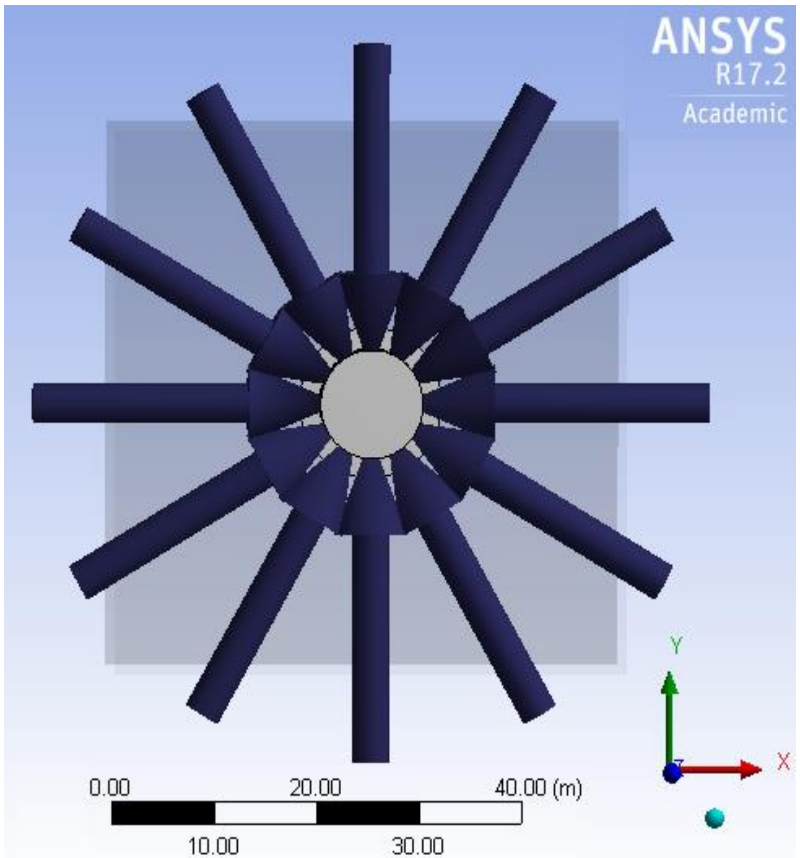
Forces on line element

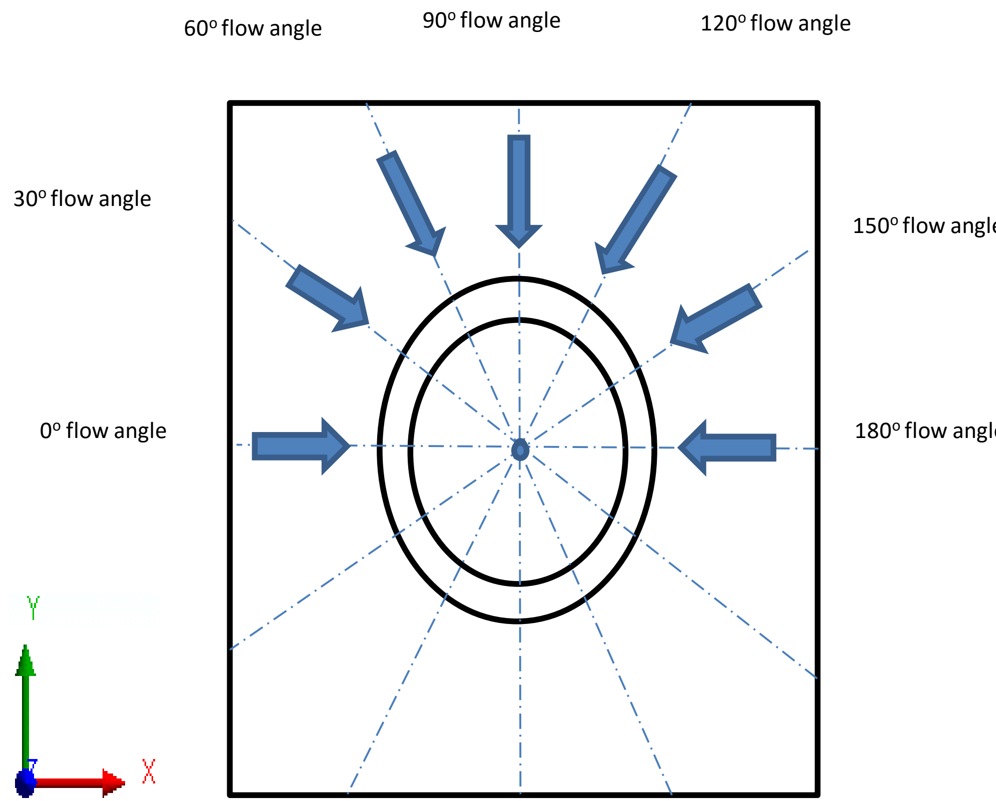


Spline Segment



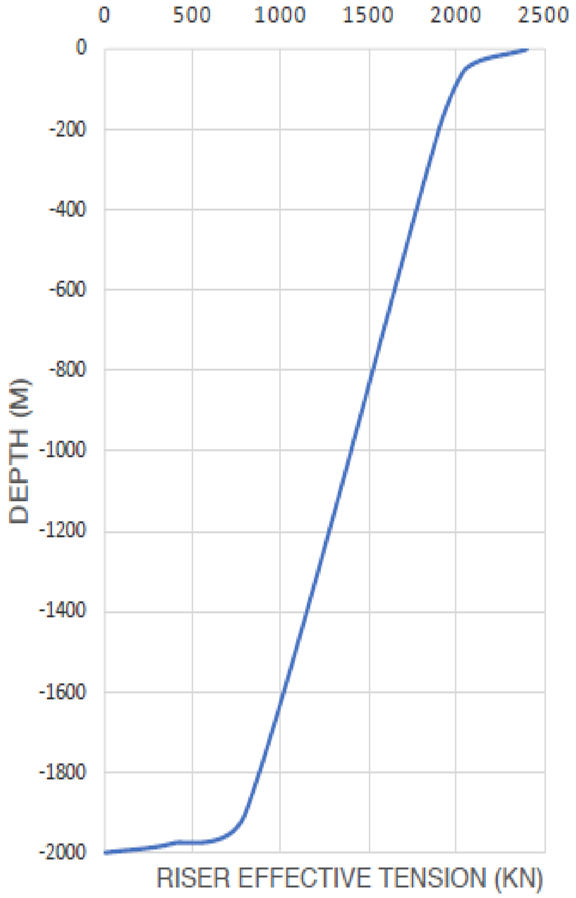
Wave Angles & Flow Angles

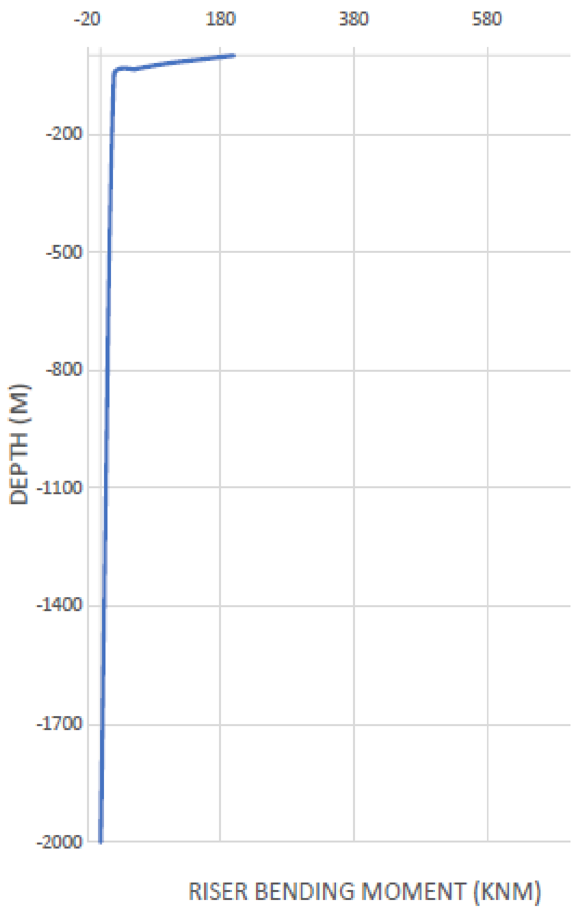


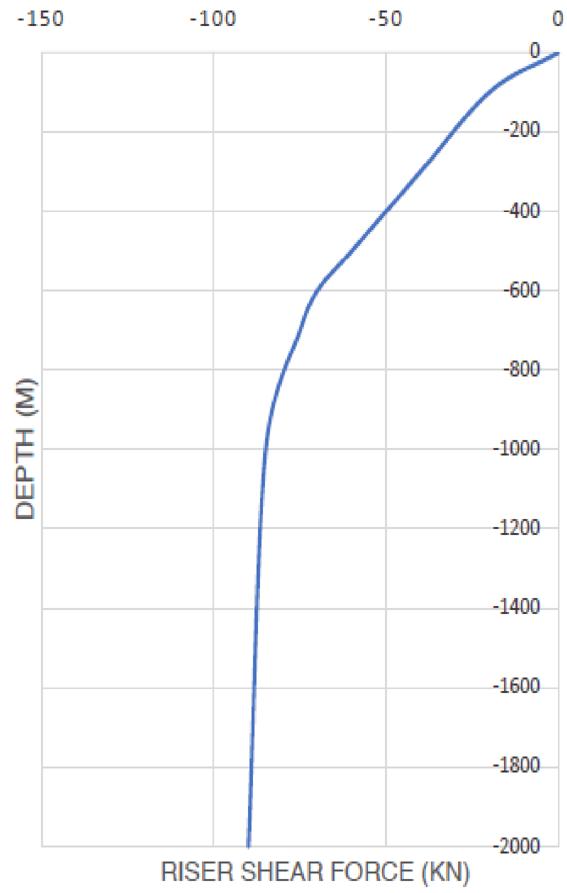


Not drawn to scale

Reduction in riser length with water depth







Conclusion

- The dynamic models on the CALM buoy with hose in Lazy-S configuration were established by first inputting the RAOs, with other principal environmental, geometric and material properties. The model was validated using existing models.
- Then, a set of sensitivity studies are carried out by varying the wave heights, flow angle and soil stiffness. Effects of the wave angle and hose hydrodynamic loads on the structural response of the hose are studied in terms of the bending moment, effective tension and curvature.
- The models with 0° flow angle generally predicted greater curvatures, bending moments, and effective tension than those with 90° flow angle. The effects of the hose hydromantic loads on the structural response of the hose are associated with flow angles.

Further Research Work

- Further investigation on this is ongoing to ascertain the design suitability of the composite risers on both offshore structures considered. Numerical simulations to investigate the Vortex-Induced Vibration (VIV) of the riser and the Fluid Structure Interaction (FSI) understanding for the riser using ANSYS Fluent.
- The parameters investigated are the strength estimation, hydrodynamics and mechanics of the hoses. Some experimental work has been carried out on the Lancaster University Wave Tank using a CALM buoy model, with and without hose connections. Some investigation on the composite riser end-fittings is been carried out both experimentally and numerically using FRP pipe sections.
- Further work on FEM and experiment is ongoing.

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Thank You