Time-domain Nonlinear Coupled Analyses Covering Typical Mooring and Riser Configurations for FPSOs

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DNV GL - Software

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  - Tandem offloading
  - Side-by-side offloading
  - Catenary Anchor Leg Mooring (CALM) terminal
- Examples

Analysis for the design of FPSO mooring, riser and offloading system

Mooring alternatives

Spread mooring (MPM)

- Mooring and riser
  - SCR
  - Bending stiffener and jumper
- FPSO coupled with TLP

Single Point mooring (SPM)

- Riser alternatives
  - SCR
  - TLR
  - SHLR
- Accidental analysis
- Detachable turret
- SPM with DP

Offloading

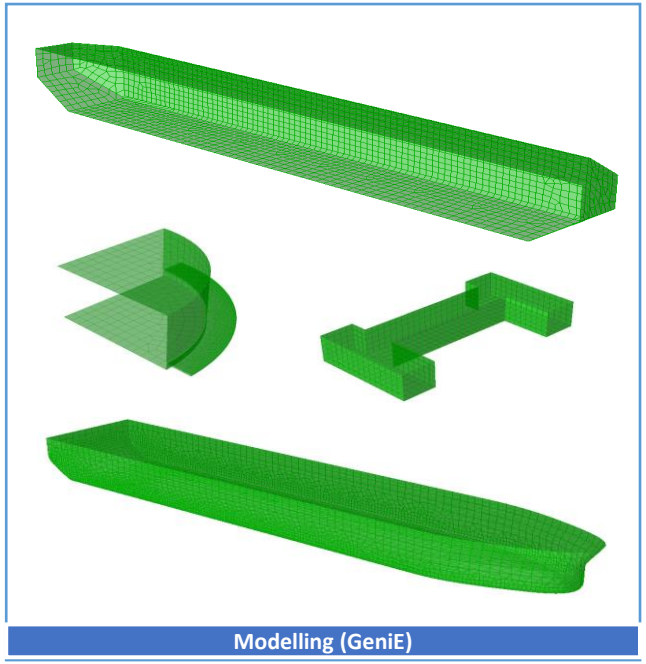
Tandem

Side-by-side

CALM buoy

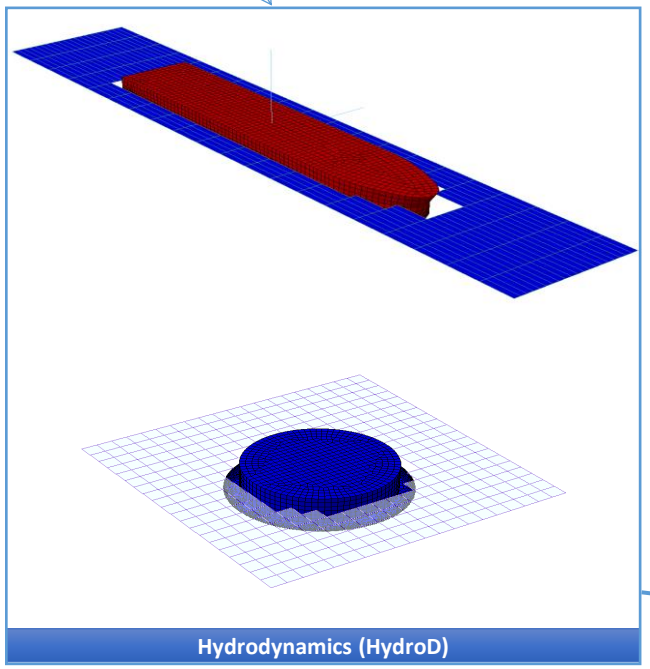
- CALM buoy with shuttle tanker
- CALM buoy with FTB and shuttle tanker

Typical workflow

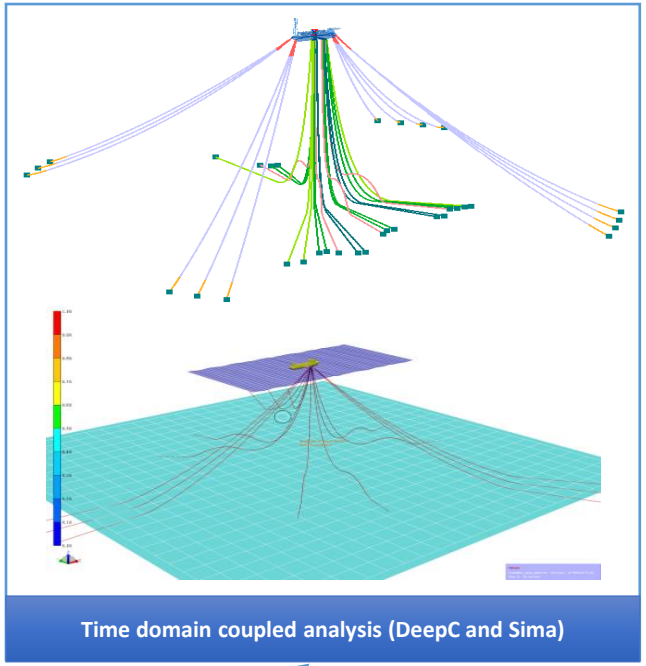


Modelling (GeniE)

FEM models



Hydrodynamics (HydroD)



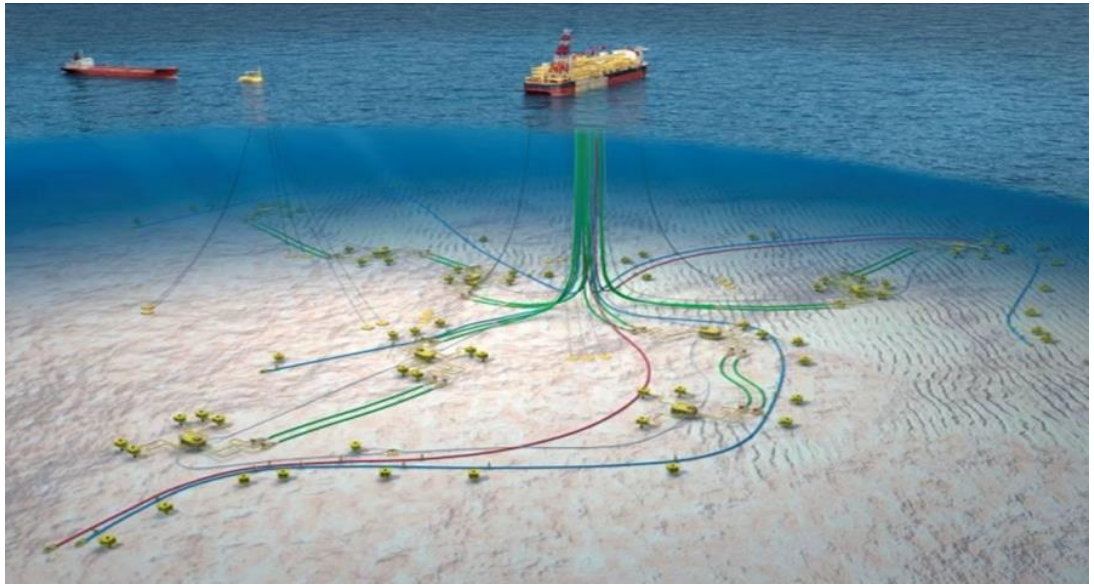
Time domain coupled analysis (DeepC and Sima)

Hydrodynamic coeff.

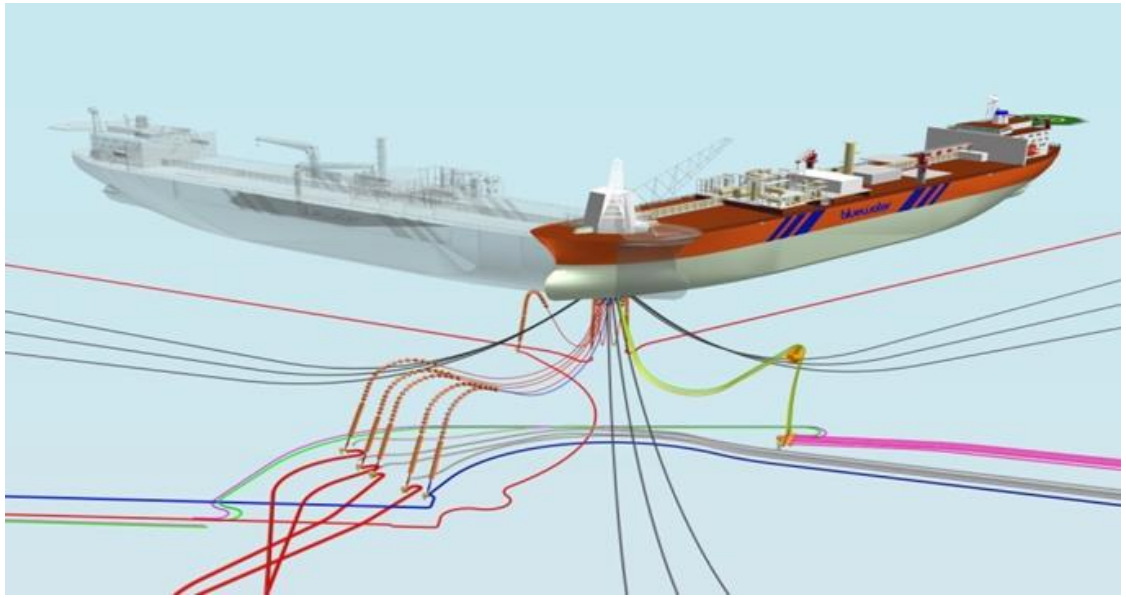
- Added Mass and Damping
- 1st and 2nd wave forces
- Wave drift damping
- Etc.

Mooring Types

Spread Mooring

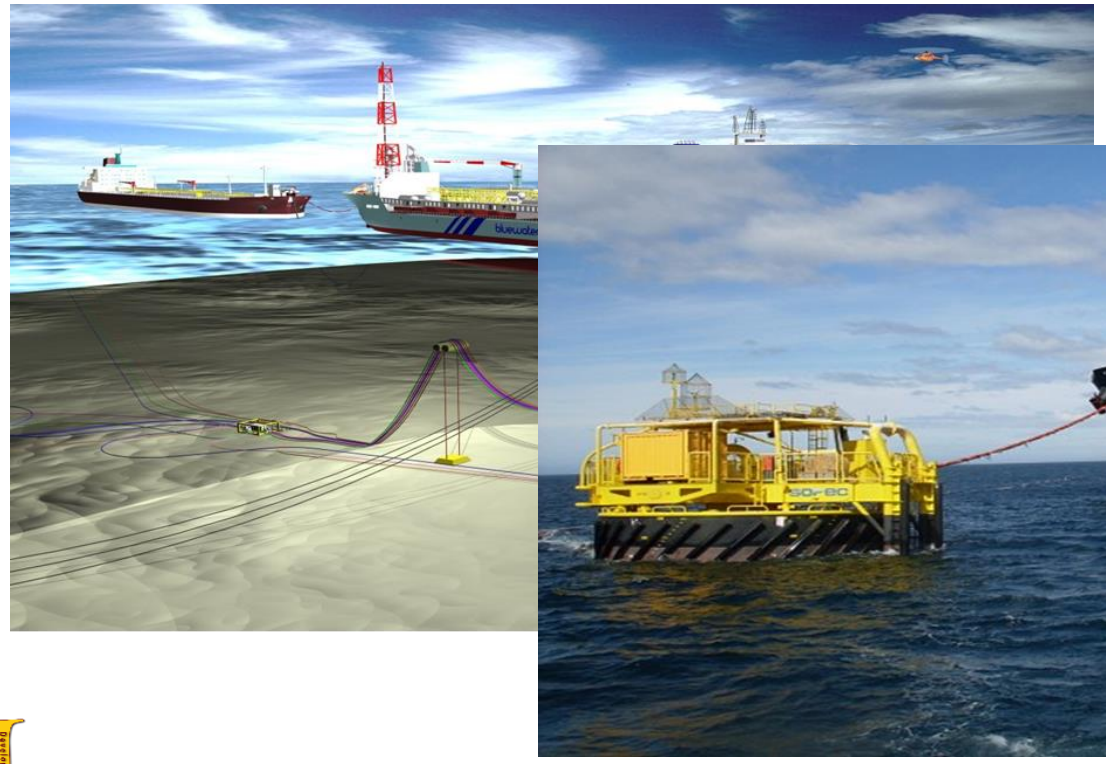


Turret Mooring



Offloading alternatives

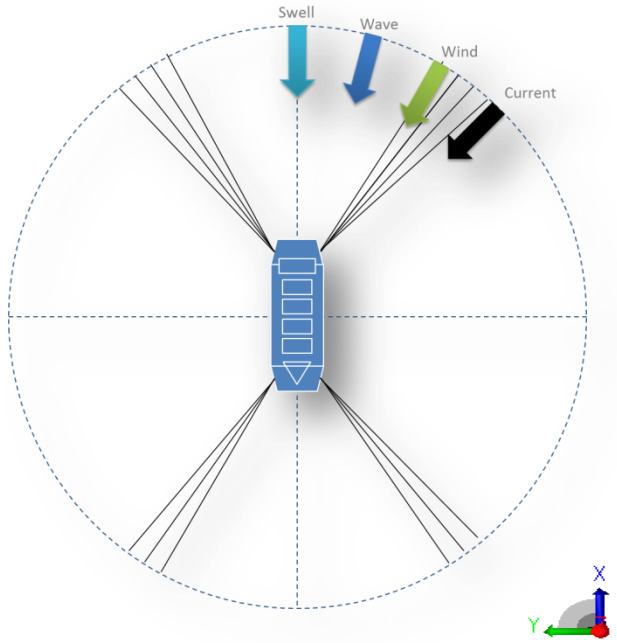
Tandem



Side-by-side

Mooring system

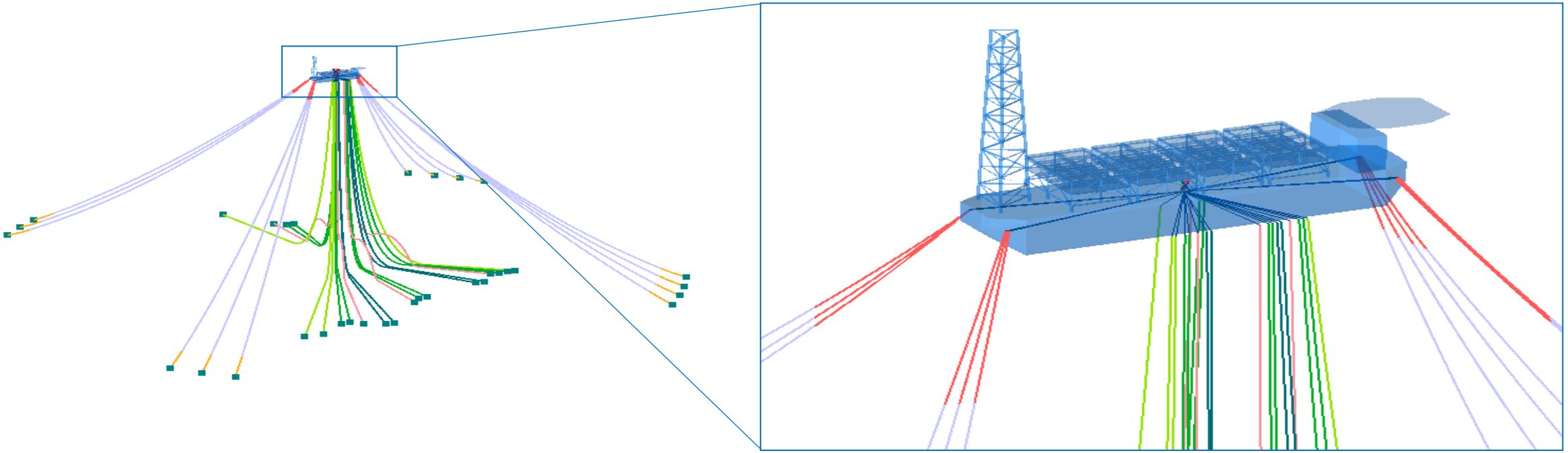
- Water depth 1,400 m
- 14 mooring lines
- Non-collinear environment



Environment Condition - West Africa - 100 Years Return Period (Ref. DNV-OS-E301, DNV-RP-C205)												
	Wave (Wind)			Dir	Swell			Dir	Wind	Dir	Current	Dir
	Hs (m)	Tp (s)	γ	(deg)	Hs (m)	Tp (s)	γ	(deg)	(m/s)	(deg)	(m/s)	(deg)
Cabon	2.5	8.0	2.0	180	4.0	15.2	6.0	185	21.1	210	1.36	225

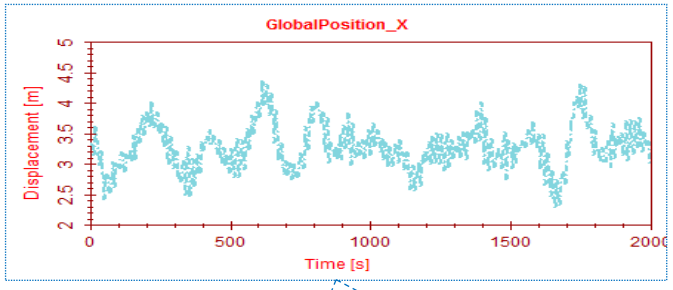
MPM FPSO Mooring lines										
		Length	Nominal D	Drag Coefficients		Added Mass		Mass in air	Axial Stiffness	Min Breaking Load
		(m)	(mm)	Cdy	Cdx	Cay	Cax	(kg/m)	(N)	(N)
Top Chain	R4 studless	150	119	2.4	1.15	1	0.08	281.8	1.209E+09	1.34E+07
Center wire	SPR 2 unsheathed	2000	119	1.2	0.008	1	0	56.0	5.721E+09	8.97E+06
Bottom Chain	R4 studless	150	114	2.4	1.15	1	0.08	258.6	1.110E+09	1.24E+07

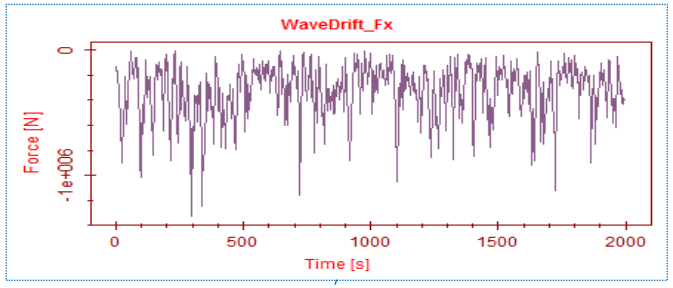
Spread mooring with risers and umbilicals

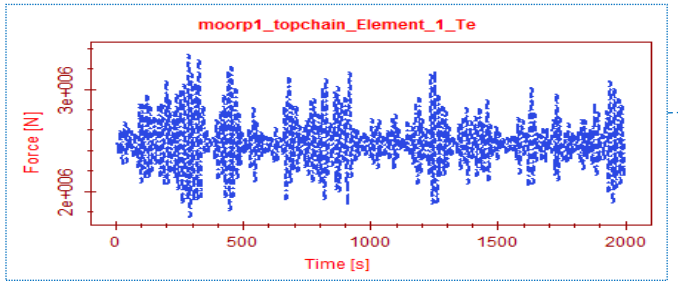


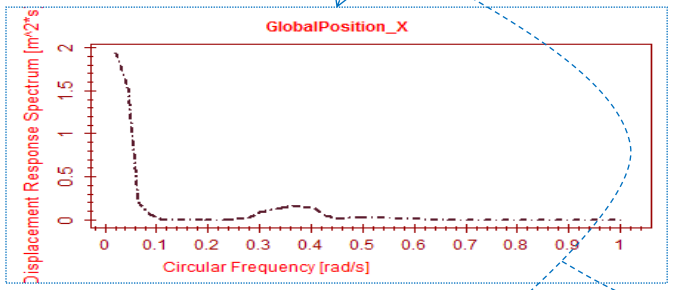
14 mooring lines, 8 production risers, 4 gas injection riser,
4 water injection risers, 4 umbilicals

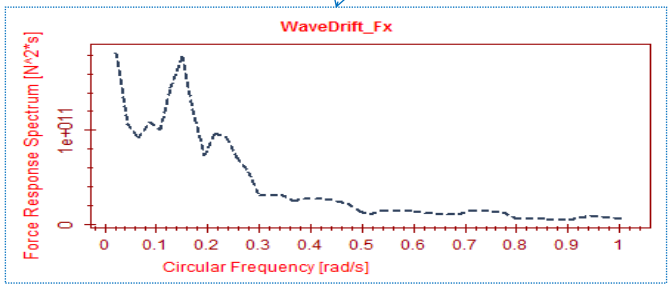
Results and post-processing

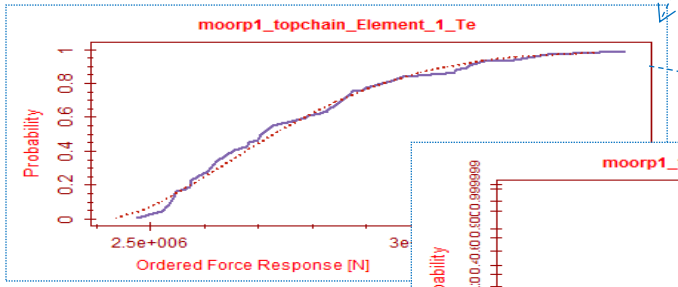


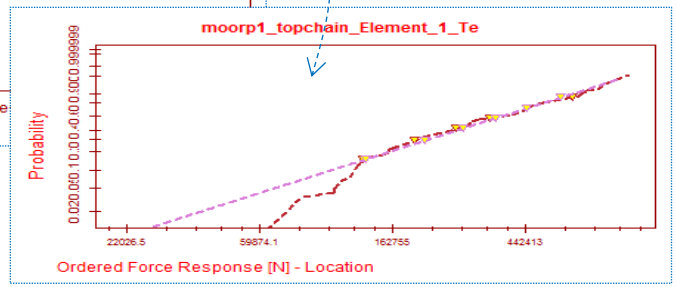


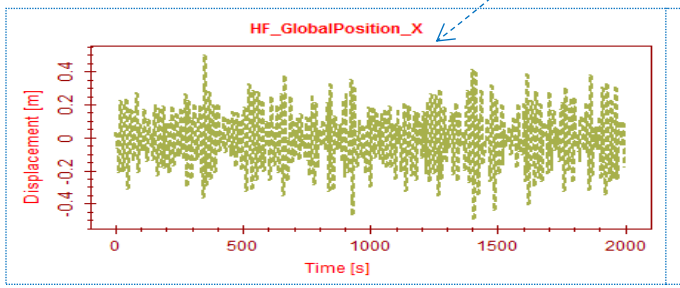


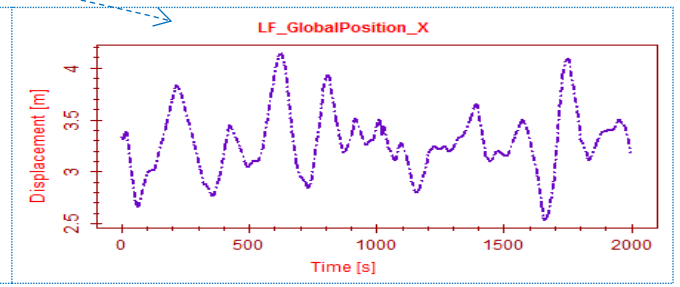


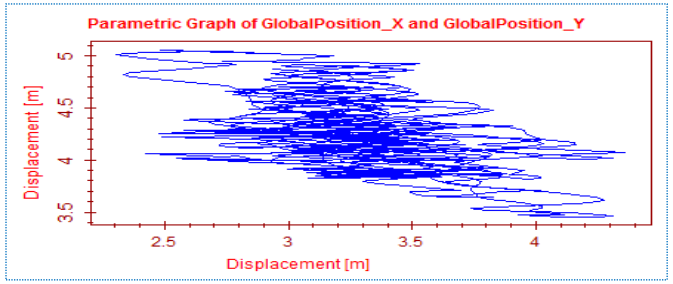




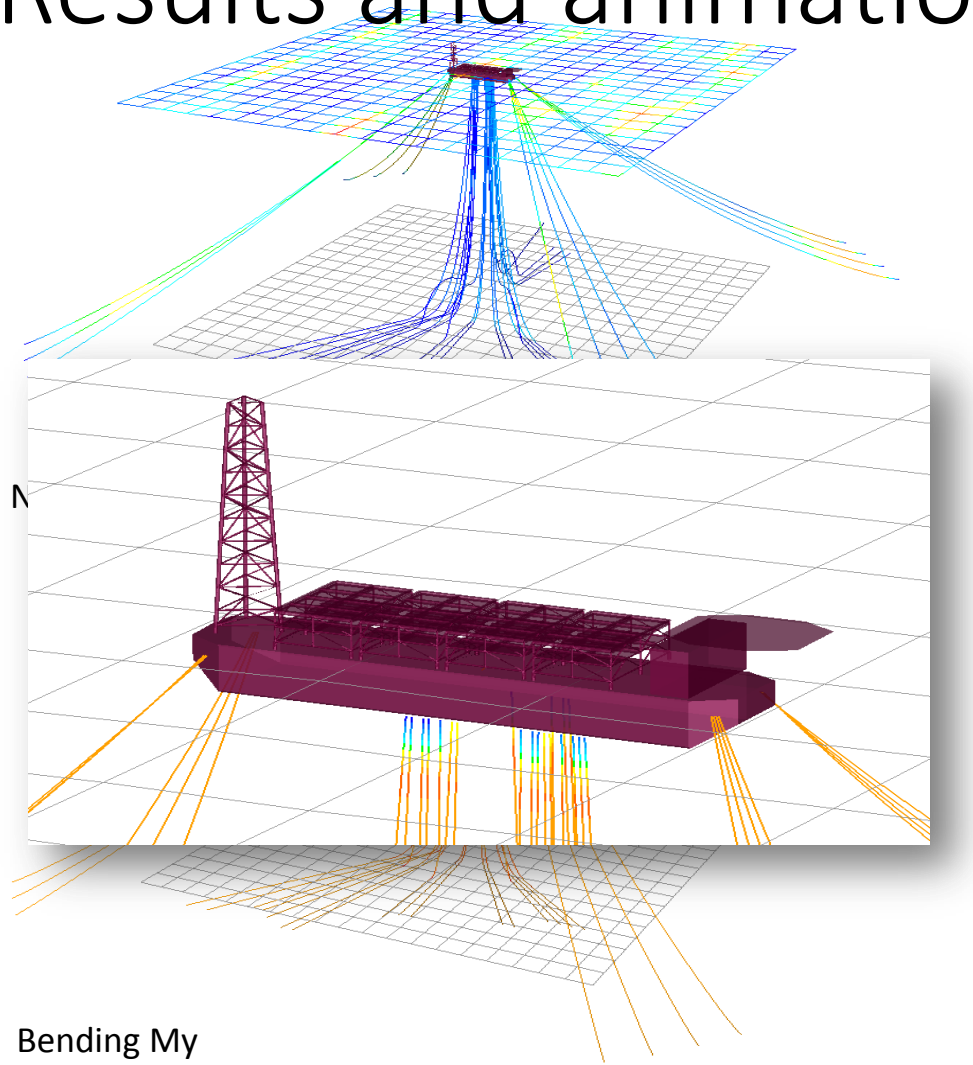




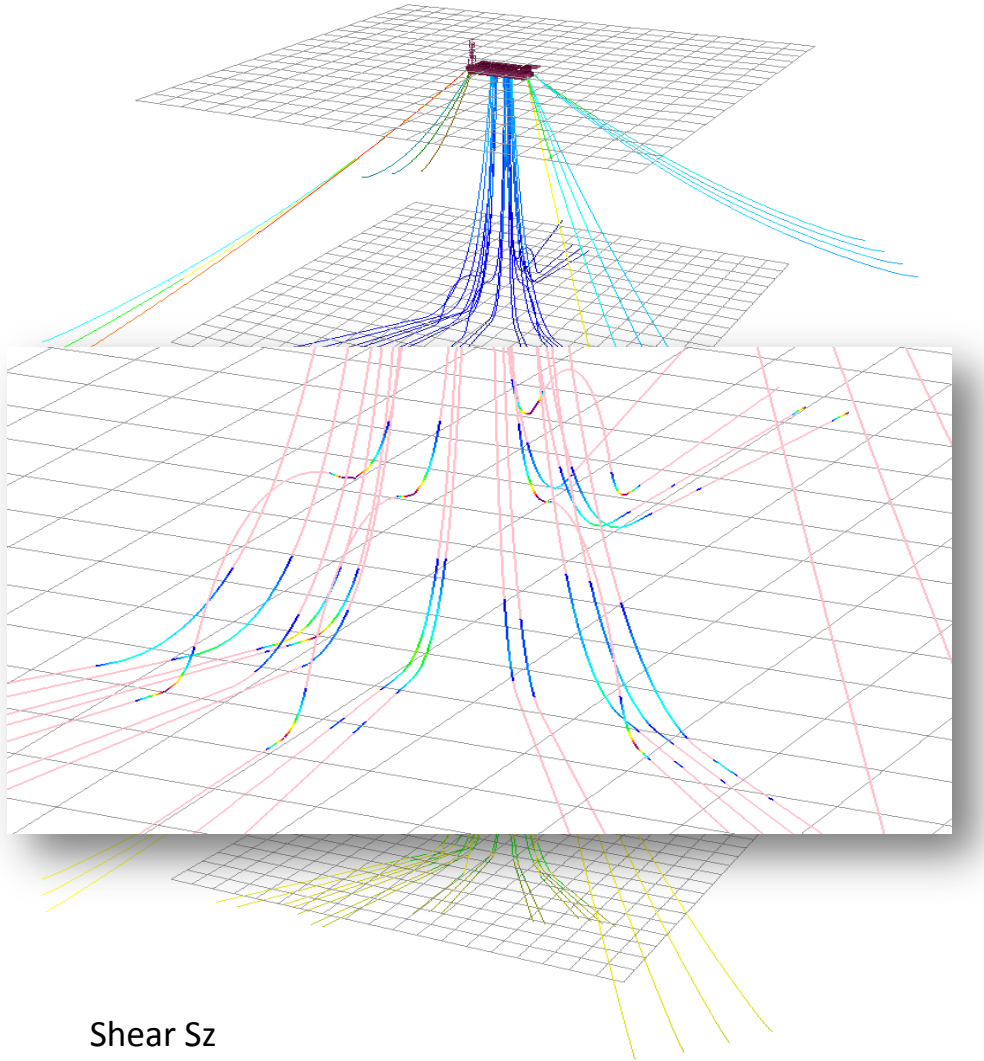




Results and animation



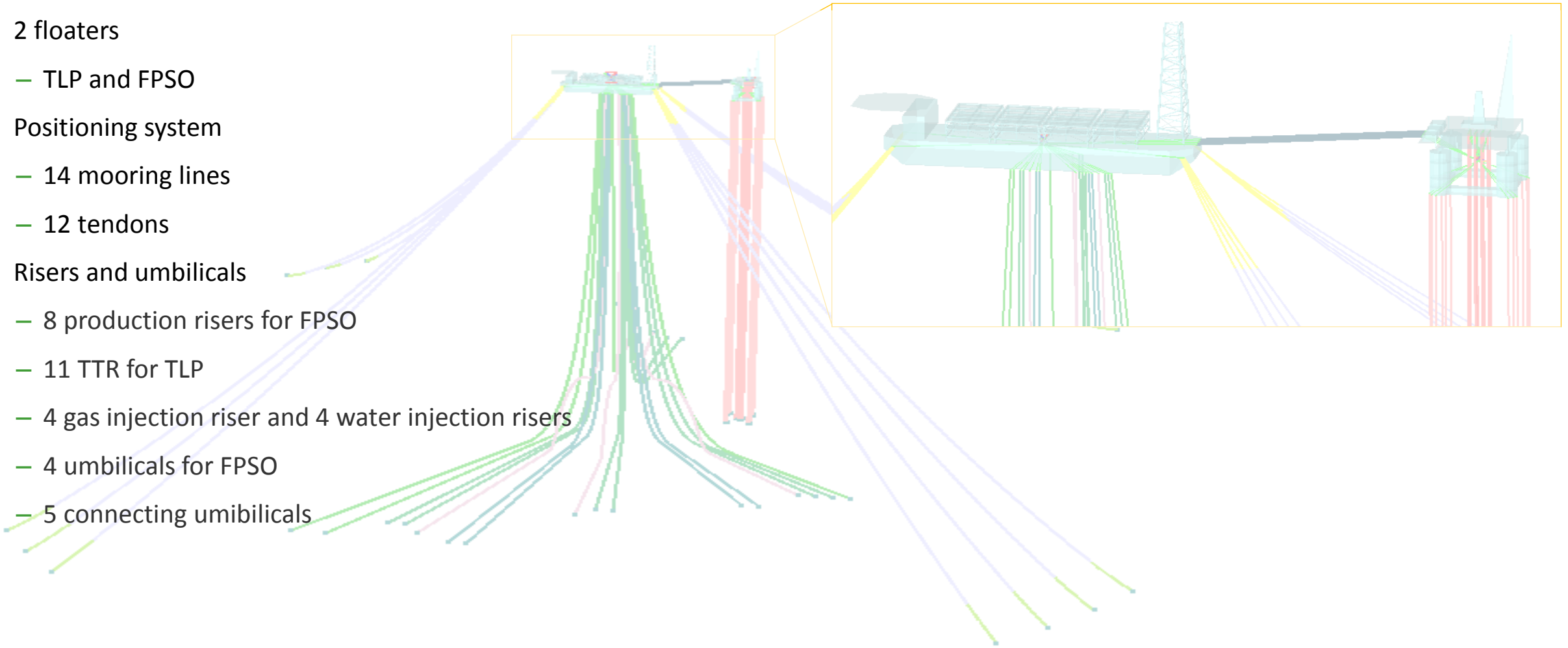
Bending My



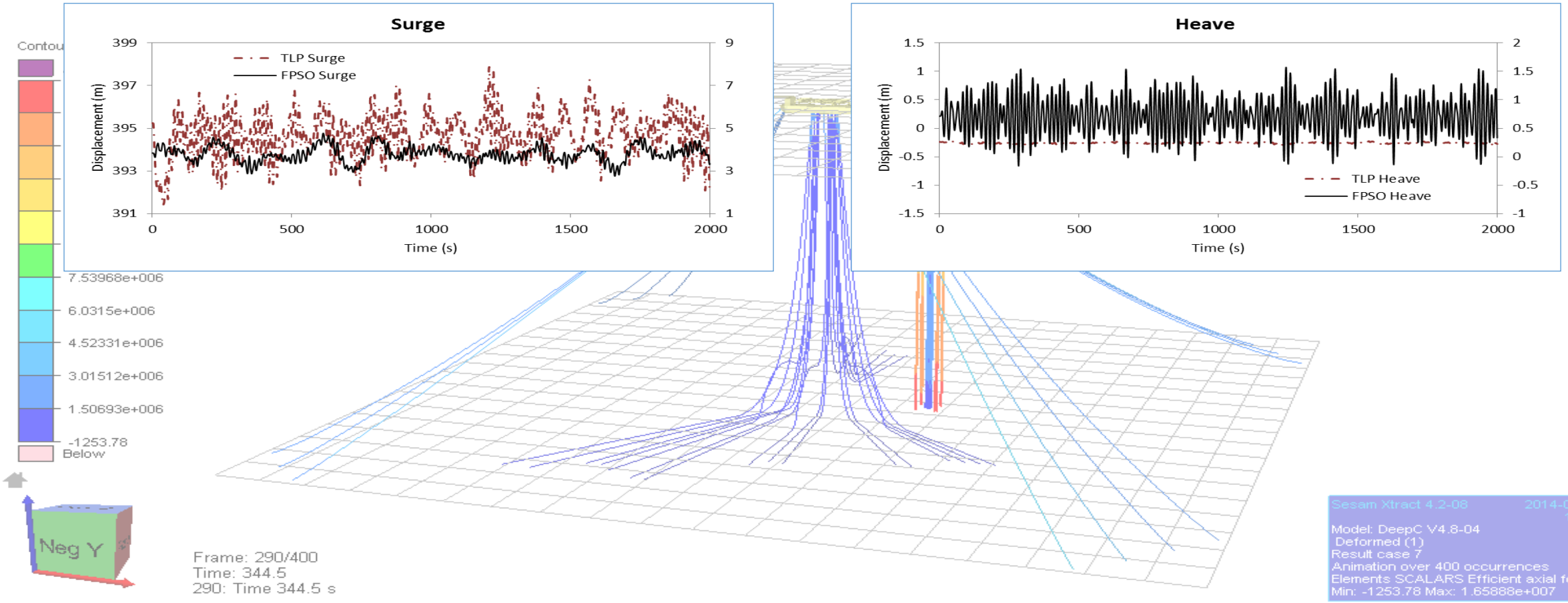
Shear Sz

With TLP

- 2 floaters
  - TLP and FPSO
- Positioning system
  - 14 mooring lines
  - 12 tendons
- Risers and umbilicals
  - 8 production risers for FPSO
  - 11 TTR for TLP
  - 4 gas injection riser and 4 water injection risers
  - 4 umbilicals for FPSO
  - 5 connecting umibilicals

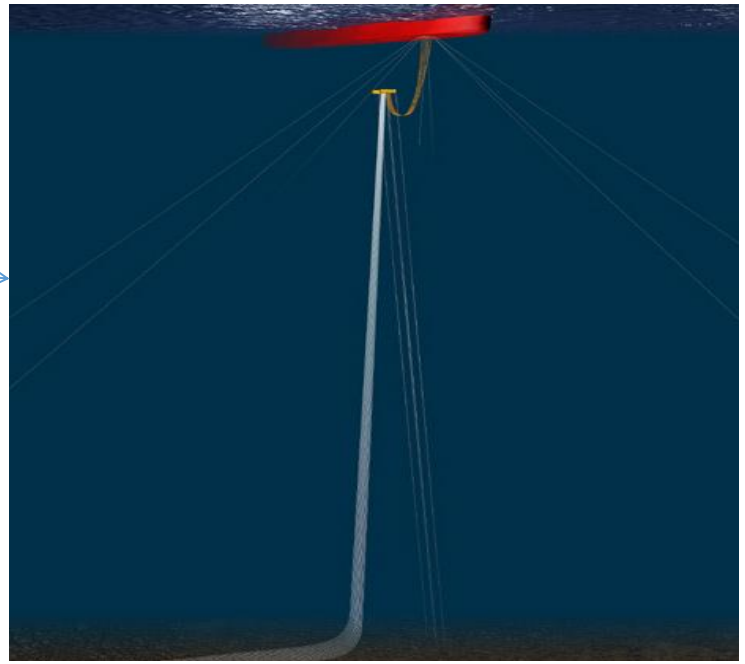


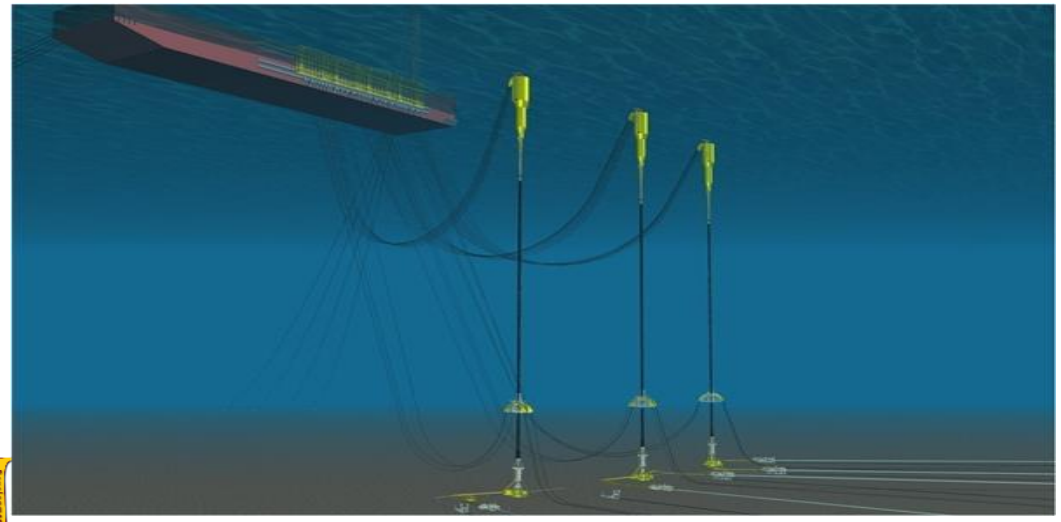
Results


Surge
TLP Surge
FPSO Surge
Displacement (m)
Time (s)
Heave
TLP Heave
FPSO Heave
Displacement (m)
Time (s)
Contou
7.53968e+006
6.0315e+006
4.52331e+006
3.01512e+006
1.50693e+006
-1253.78
Below
Neg Y
Frame: 290/400
Time: 344.5
290: Time 344.5 s
Sesam Xtract 4.2-08
2014-09-22
15:05
Model: DeepC V4.8-04
Deformed (1)
Result case 7
Animation over 400 occurrences
Elements SCALARS Efficient axial force
Min: -1253.78 Max: 1.65888e+007

Turret mooring and riser analysis

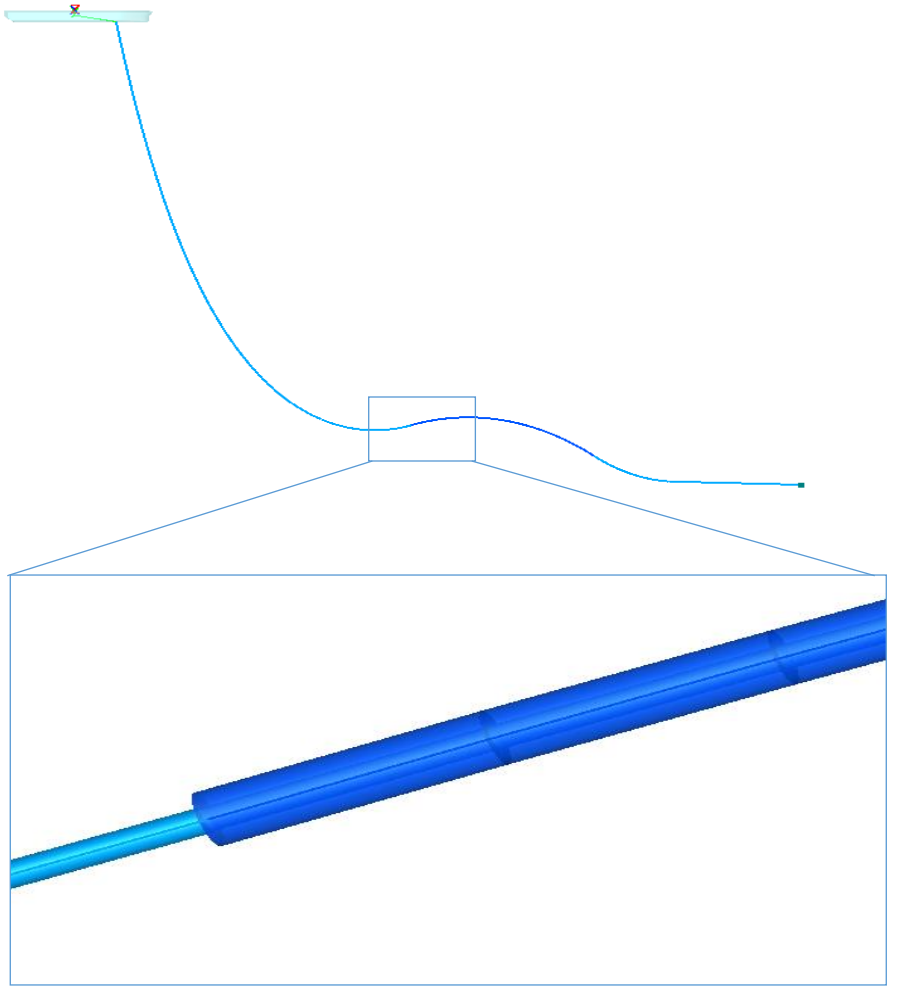
- Mooring analysis
- Riser configurations[4]
  - Steel Lazy Wave Riser (SLWR)
  - Tension Leg Riser (TLR)
  - Single Line Hybrid Riser (SLHR)



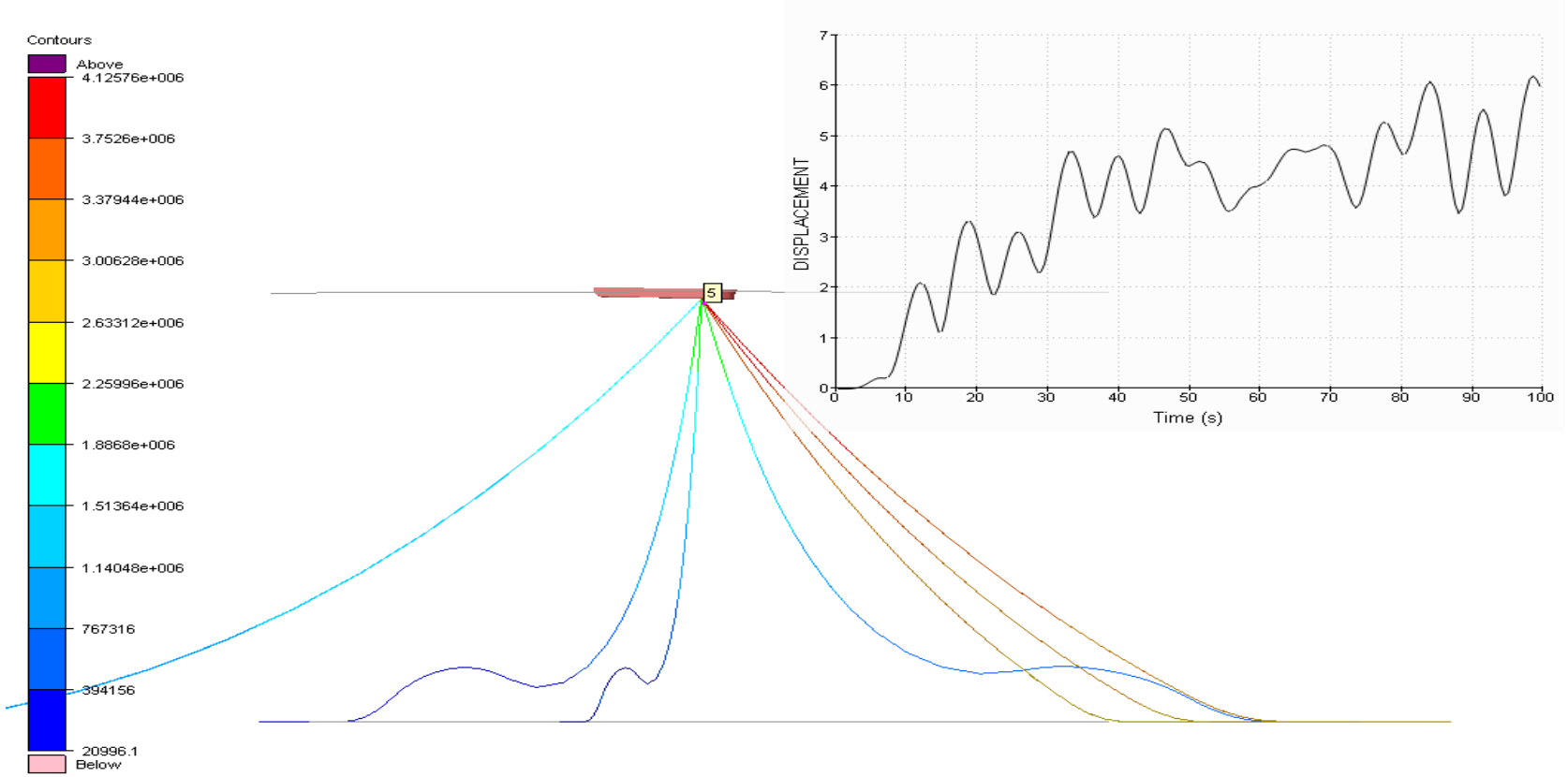


SLWR

- Compliant riser system
  - An alternative to SCR
- Lower stress and fatigue damage near the touch down point (TDP)
  - Maximum vertical motion at the riser hang off point is high in 100-year hurricane
- Optimized by
  - Examining riser performance in extreme sea states
  - Minimizing mount of buoyancy
- Parameters of interests
  - Max and min effective tensions
  - Max Von Mises stresses



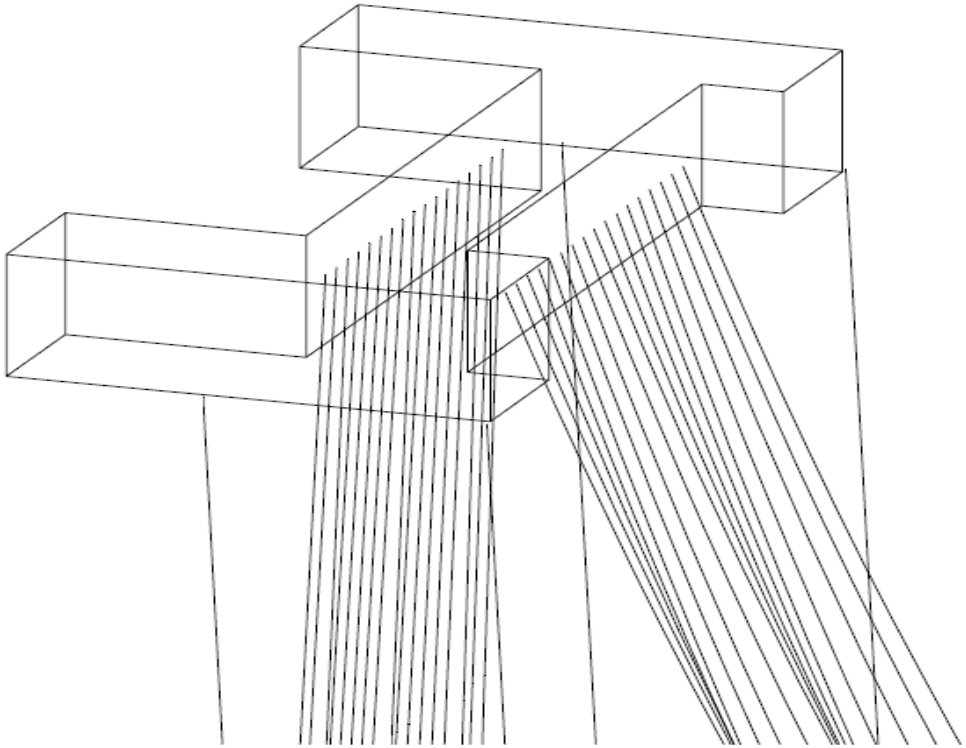
Results

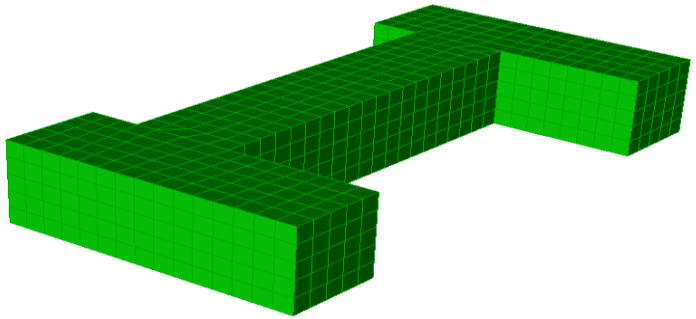


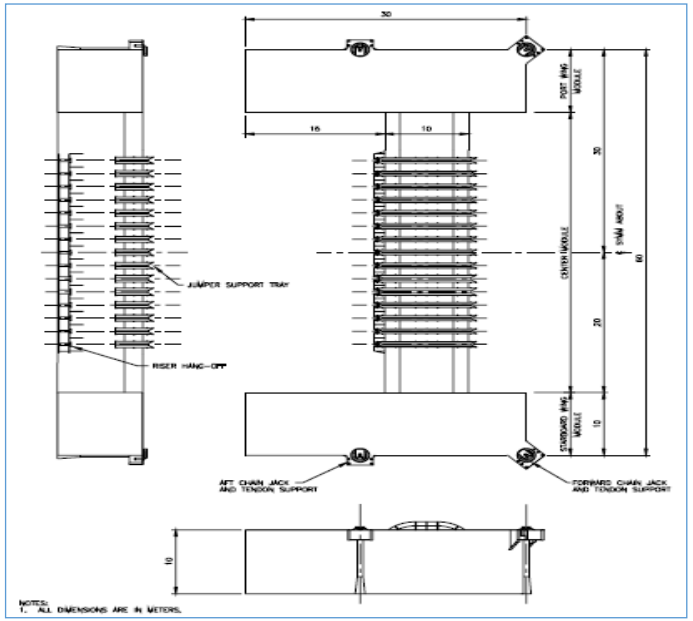
Preferable to [4]

- Place the “wave” as close as possible to the seabed
- Have enough buoyancy to maintain the “wave” shape up to the extreme far position

Tension Leg Riser (TLR)[5]

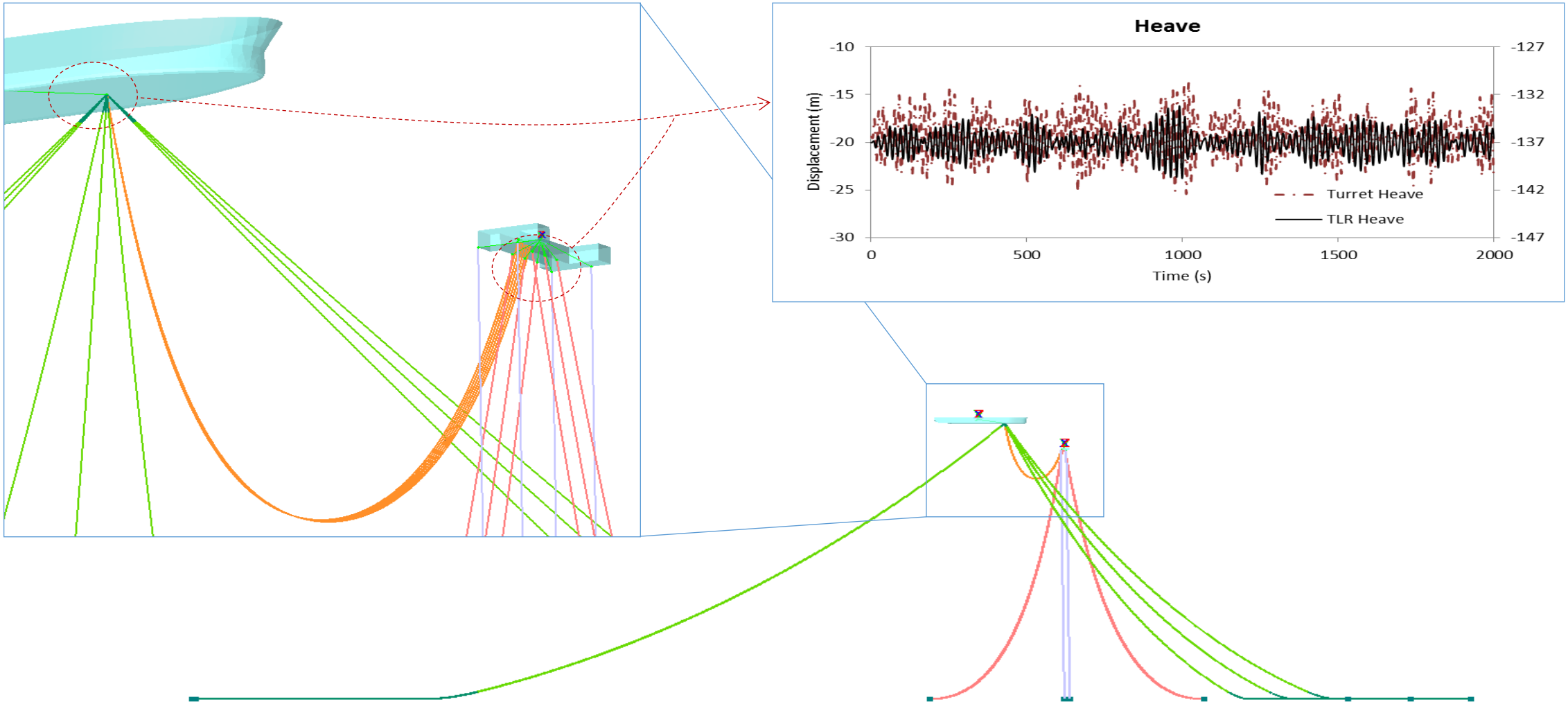






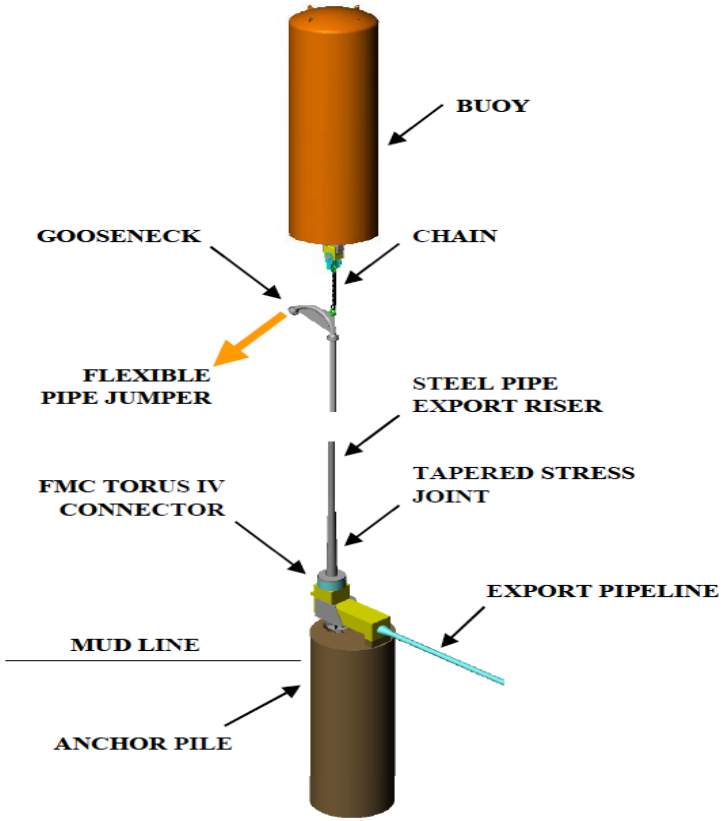
In the case study, 6 SCR was used, departing on each side of the buoy.

Decoupling motions of FPSO

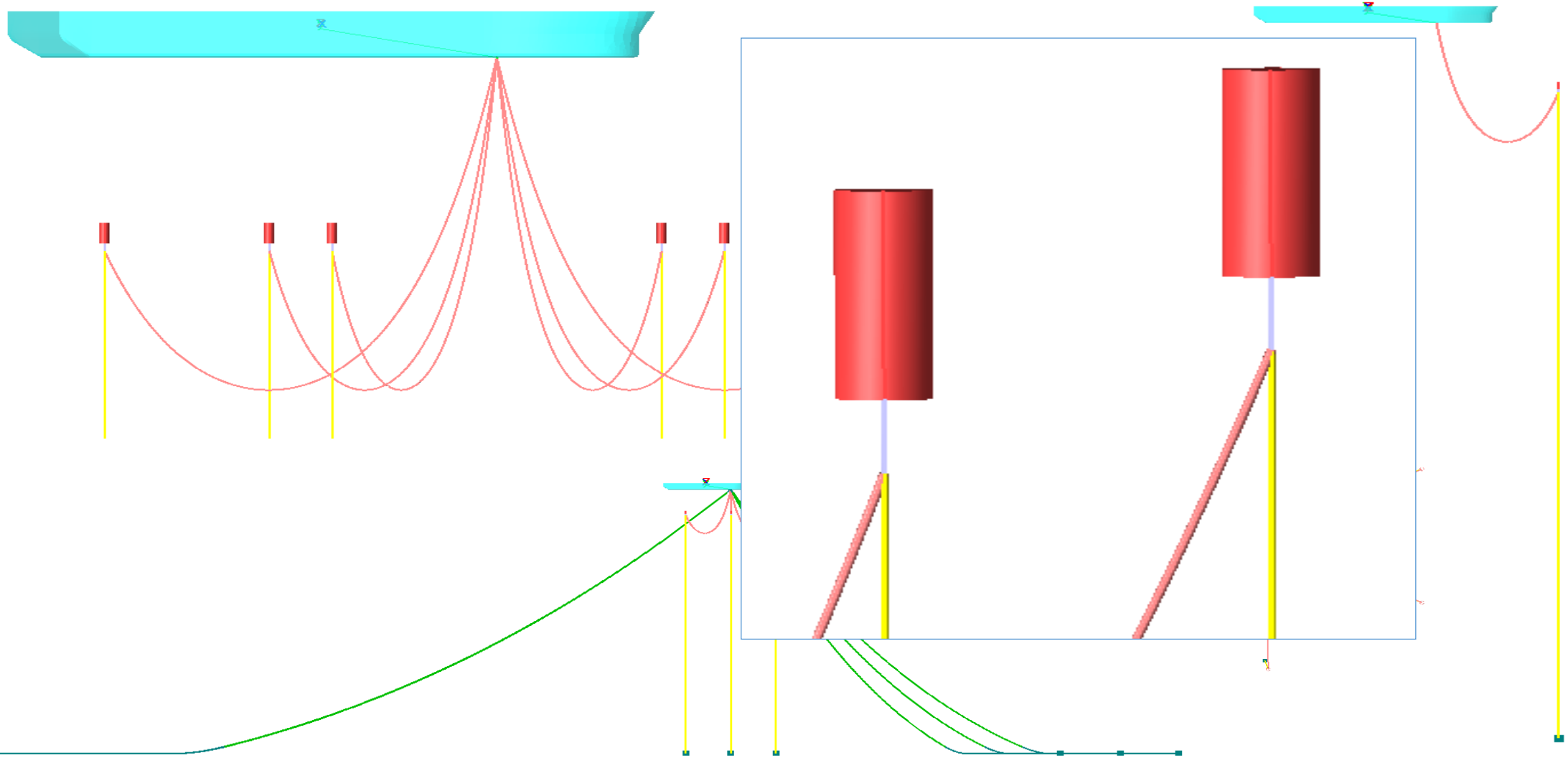


Single Line Hybrid Riser (SLHR)[5]

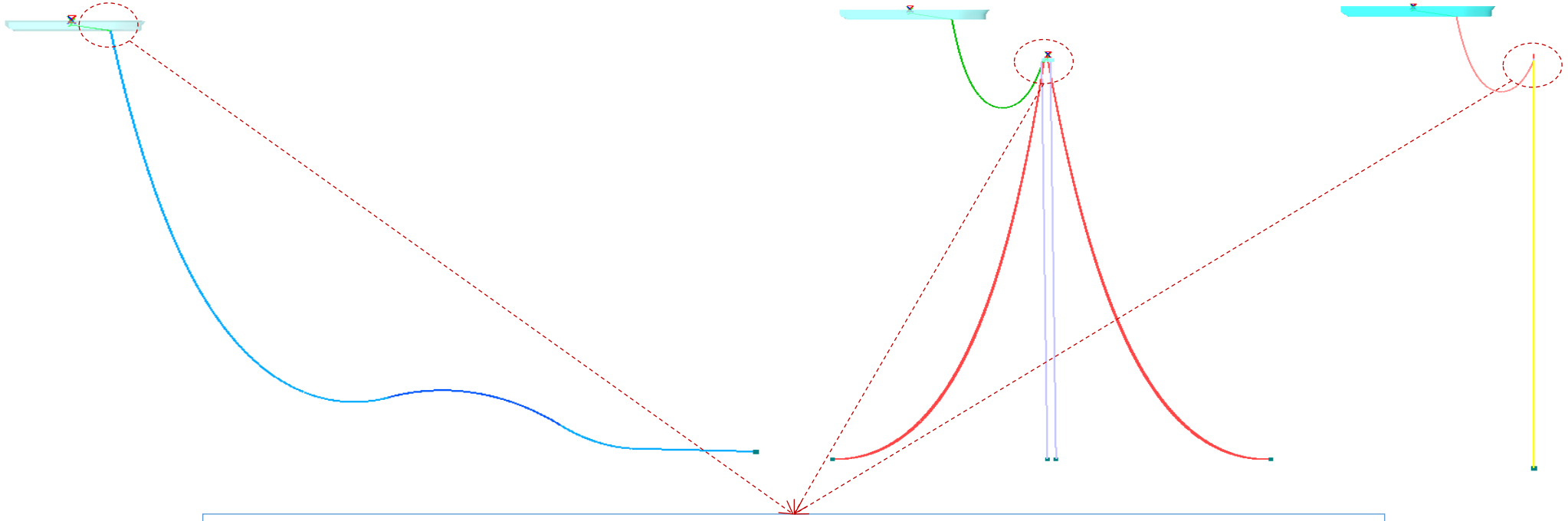
- A hybrid decoupled riser system
  - Decoupled from motions of FPSO
- SLHR composed of
  - Vertical rigid pipe
  - Stress joint and suction pile
  - Gooseneck connecting riser and flexible jumpers

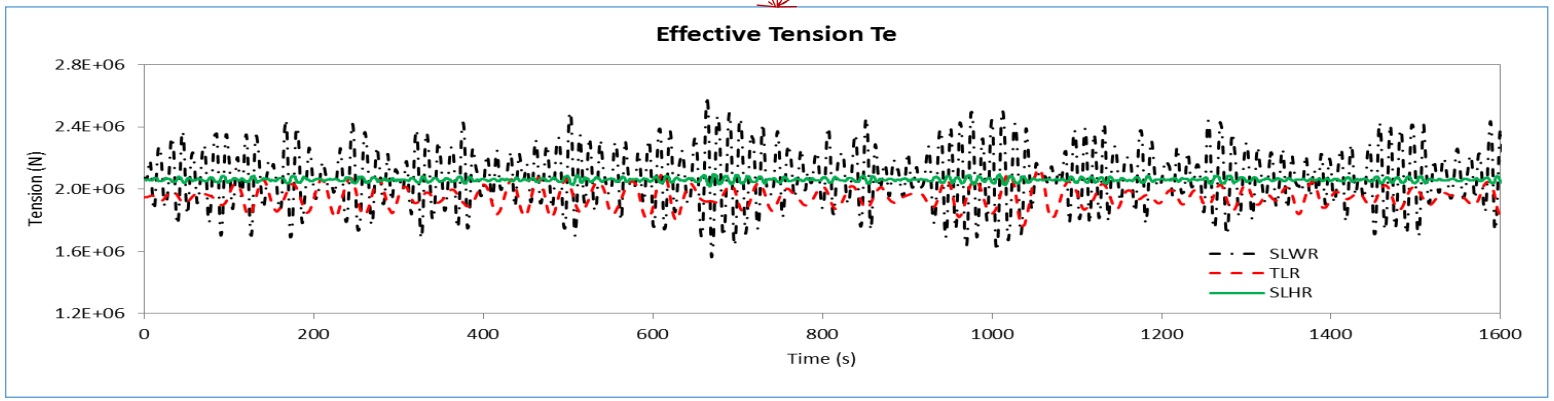


Modelling

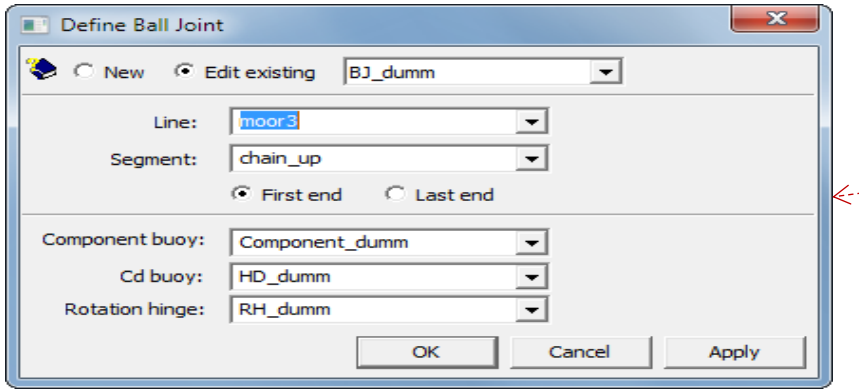


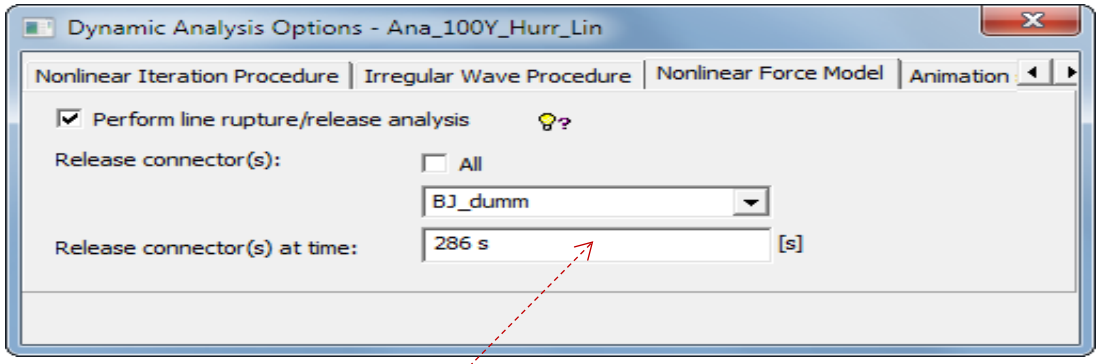
Brief comparison

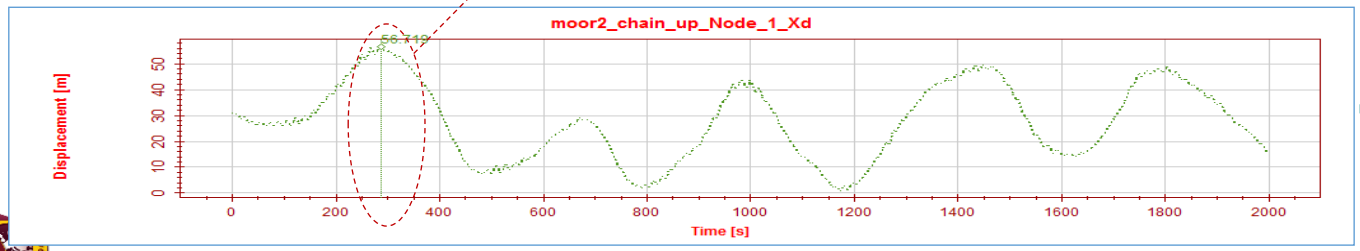


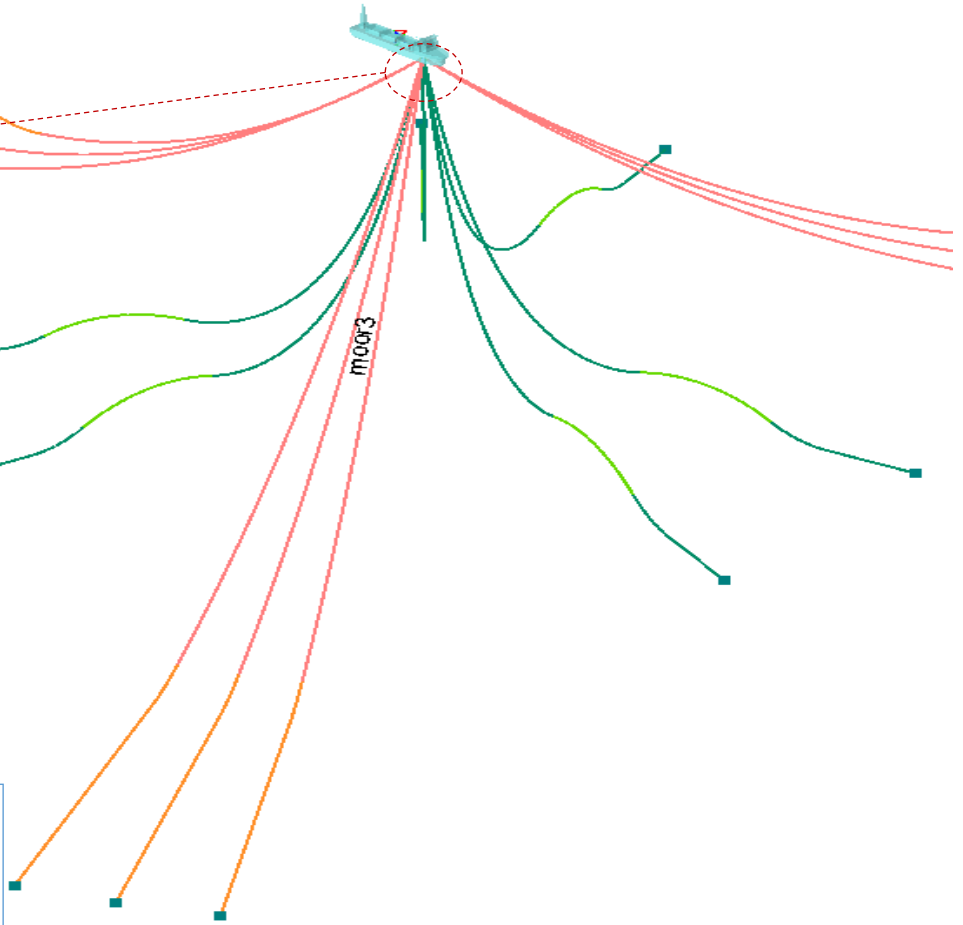


Breaking line transient analysis

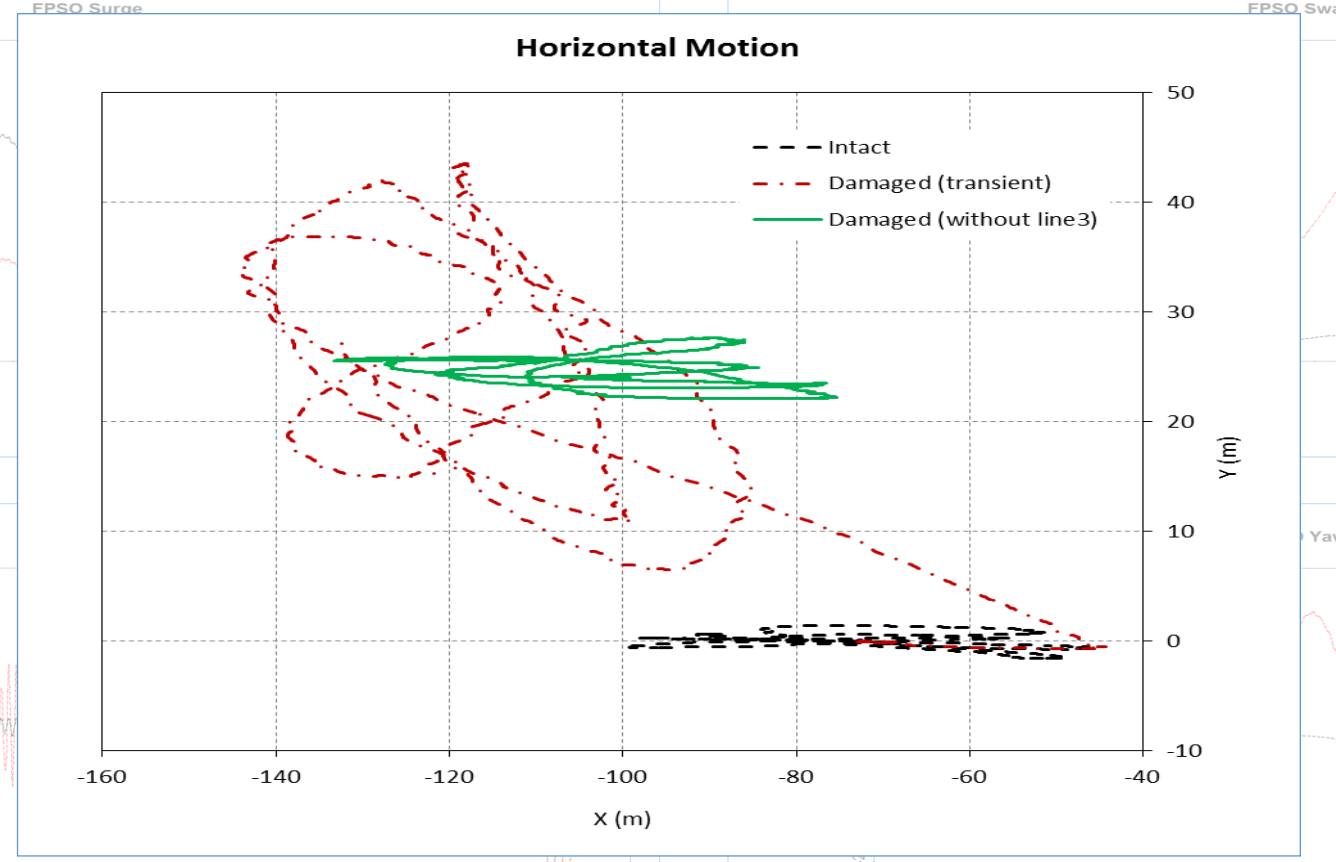






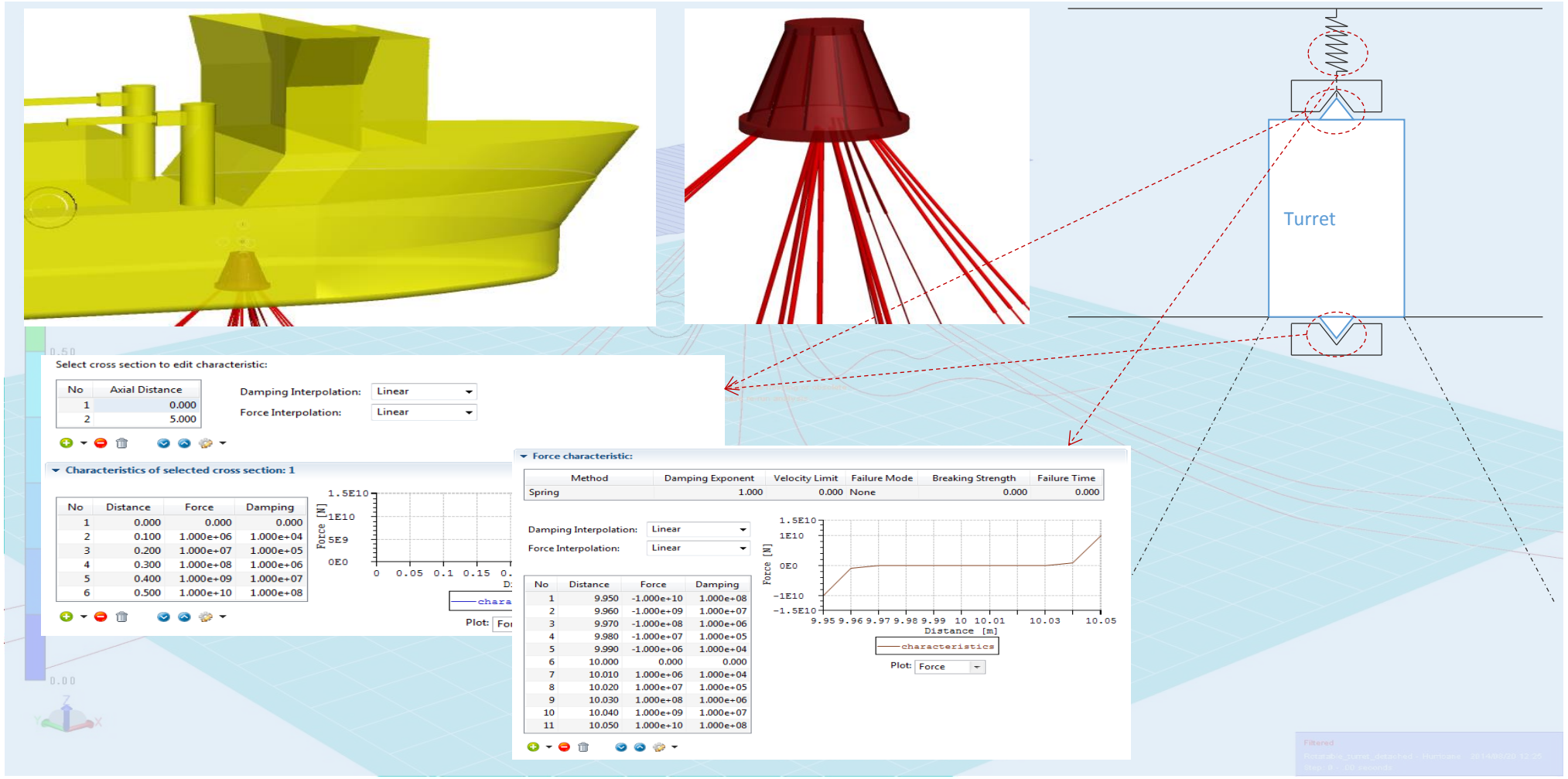


Comparison – Intact and damaged, motions

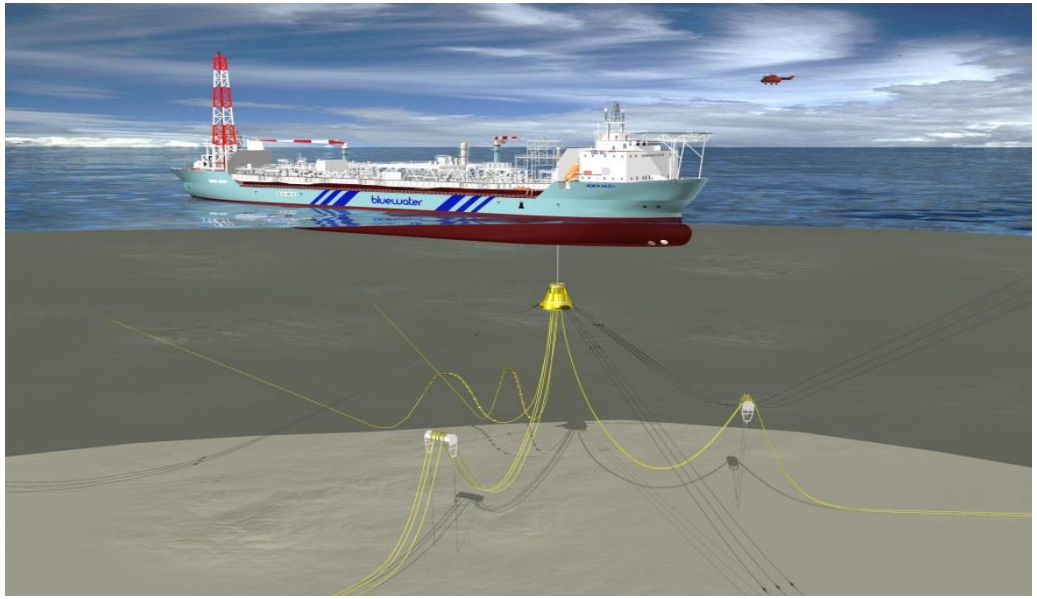


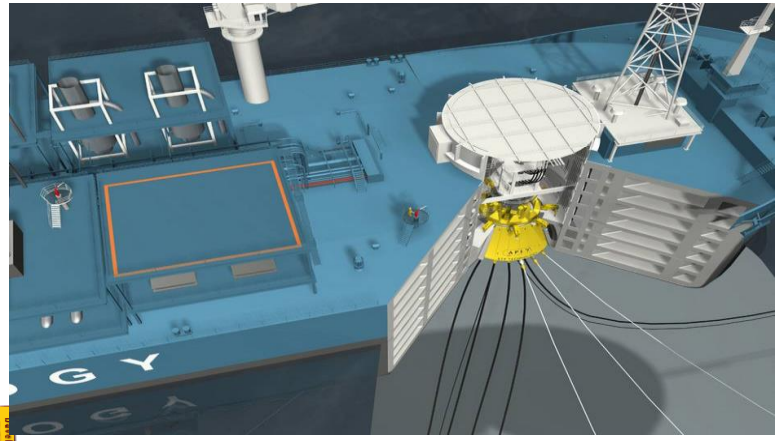
10% water depth: 137.4m (100m) 14% water depth: 191.8m (145m)

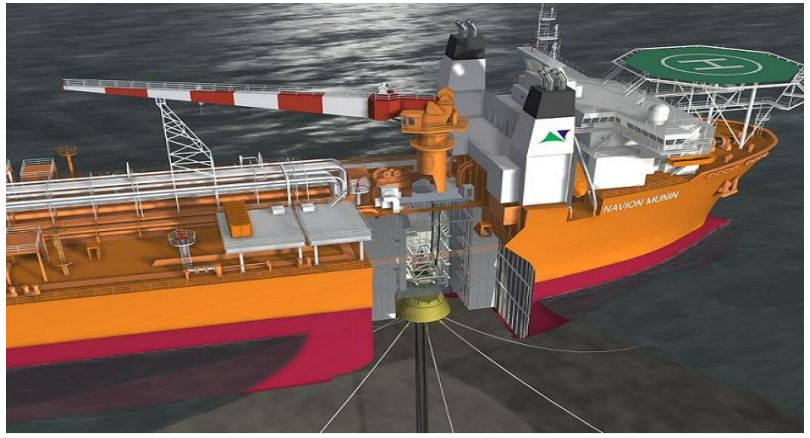
SPM FPSO with rotatable turret model

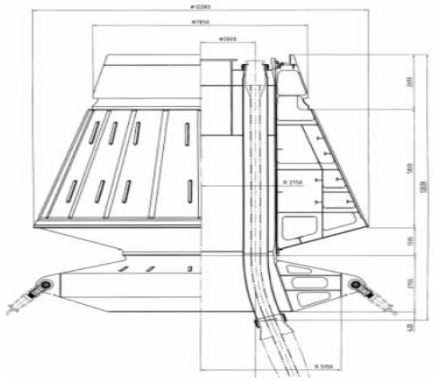


Detachable turret (e.g. MUNIN FPSO)

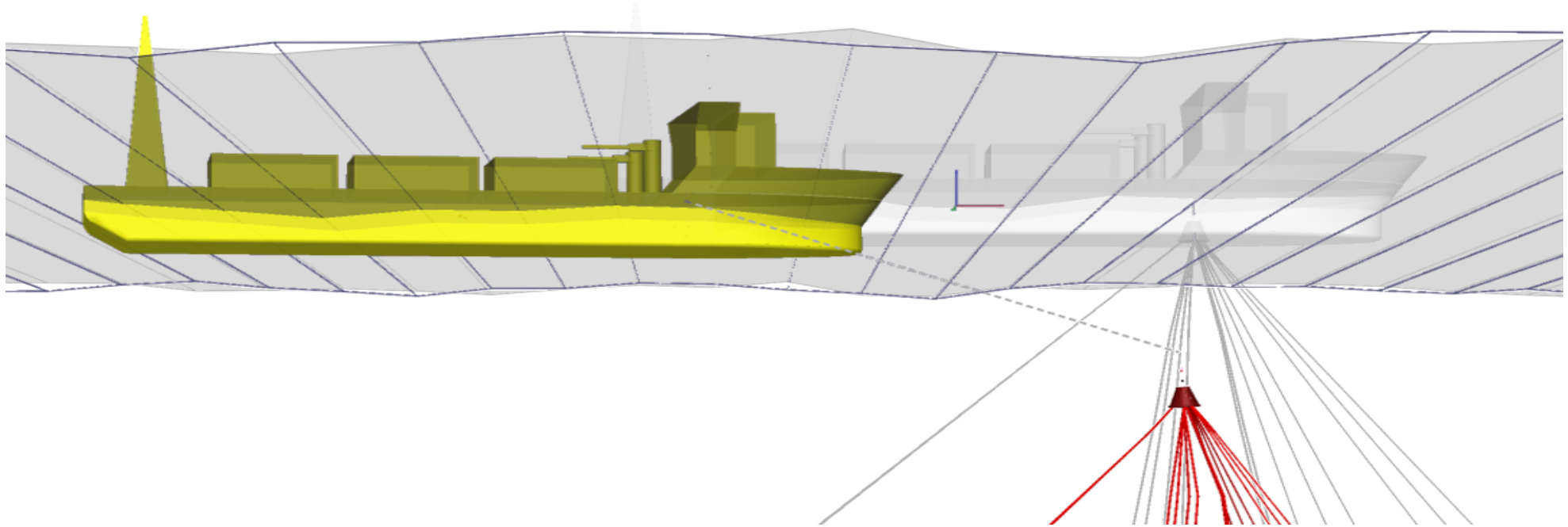


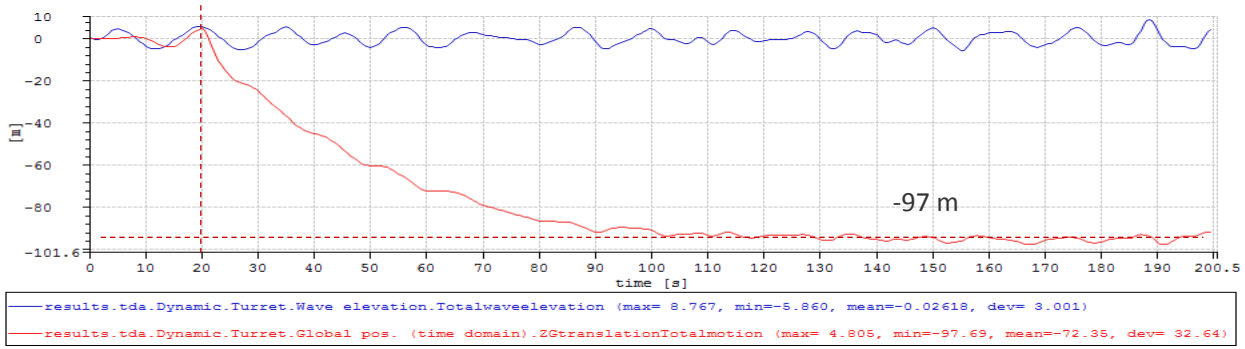


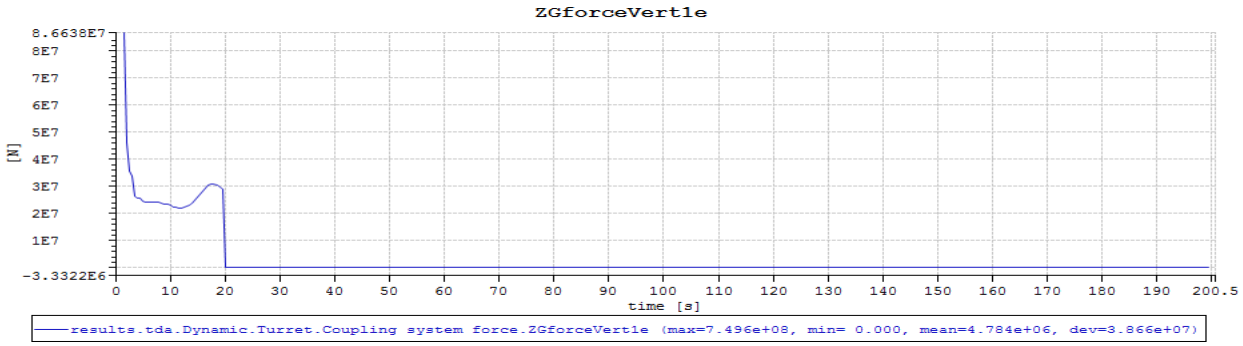




Turret motions



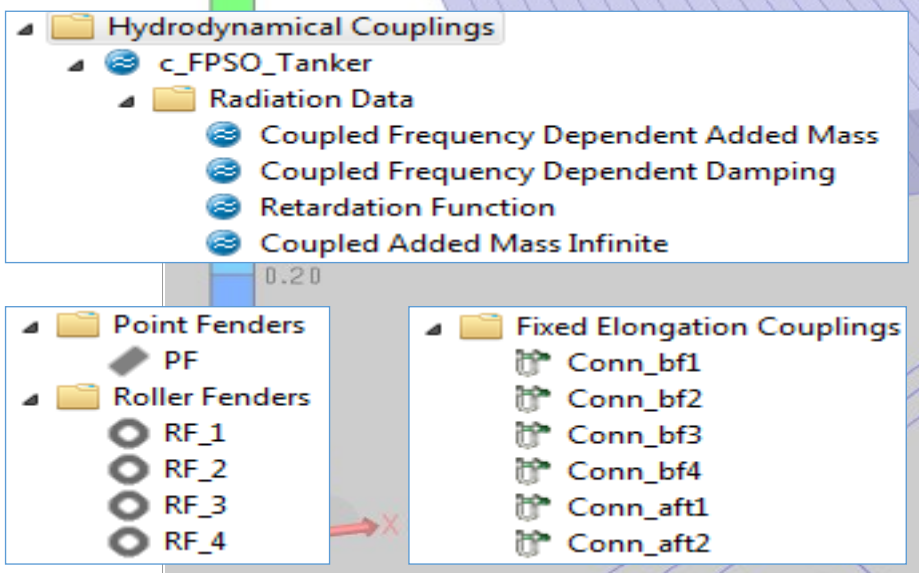


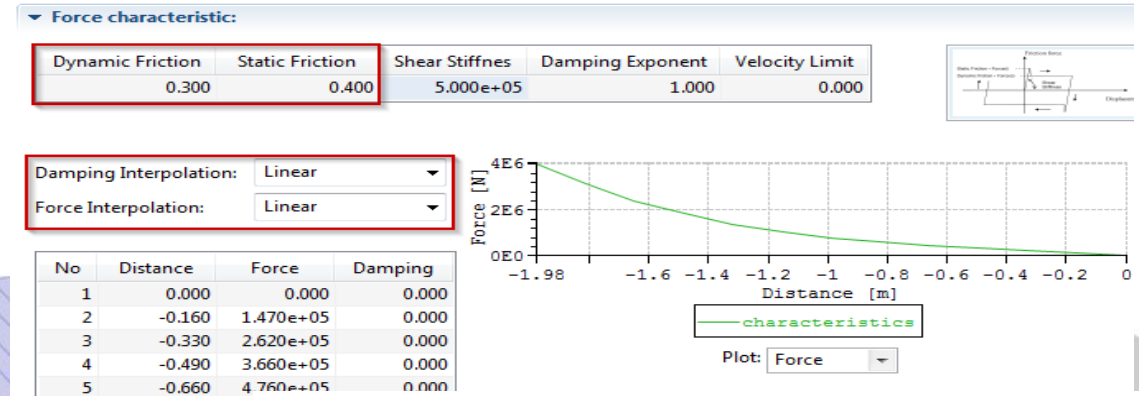


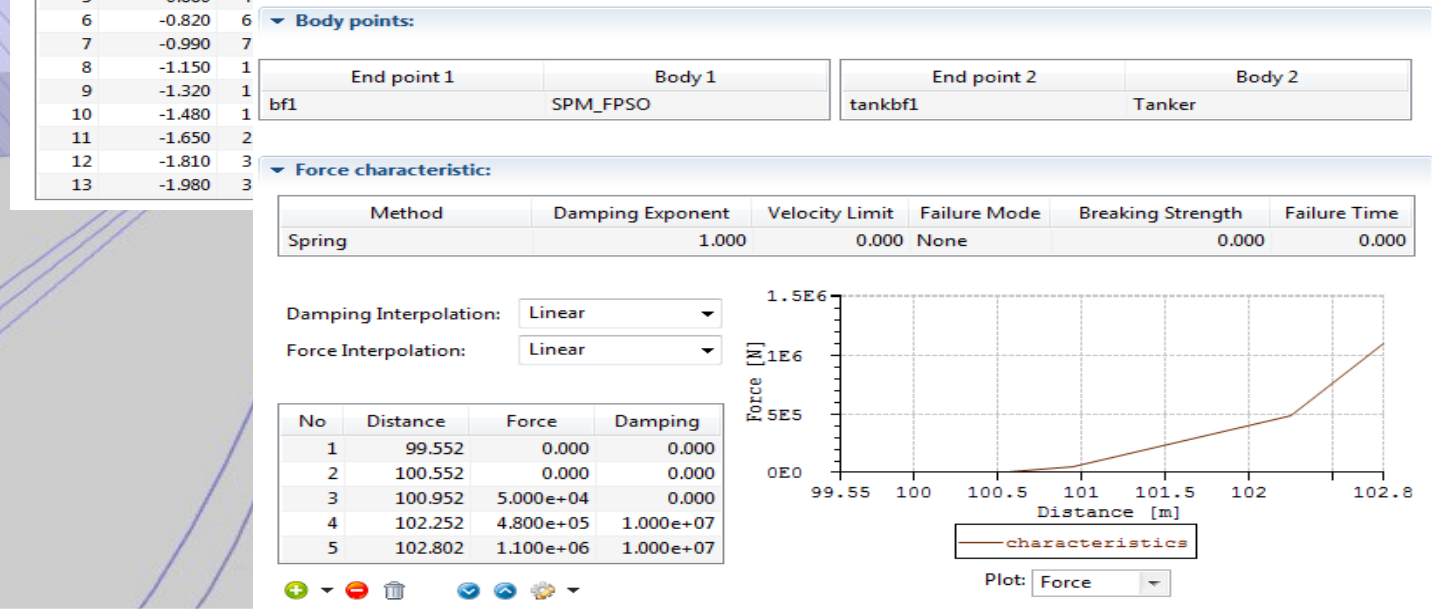
Side-by-side offloading with SPM FPSO

Multi-body coupling

- Hydrodynamic coupling
- Fenders
- Connecting lines
- Etc.

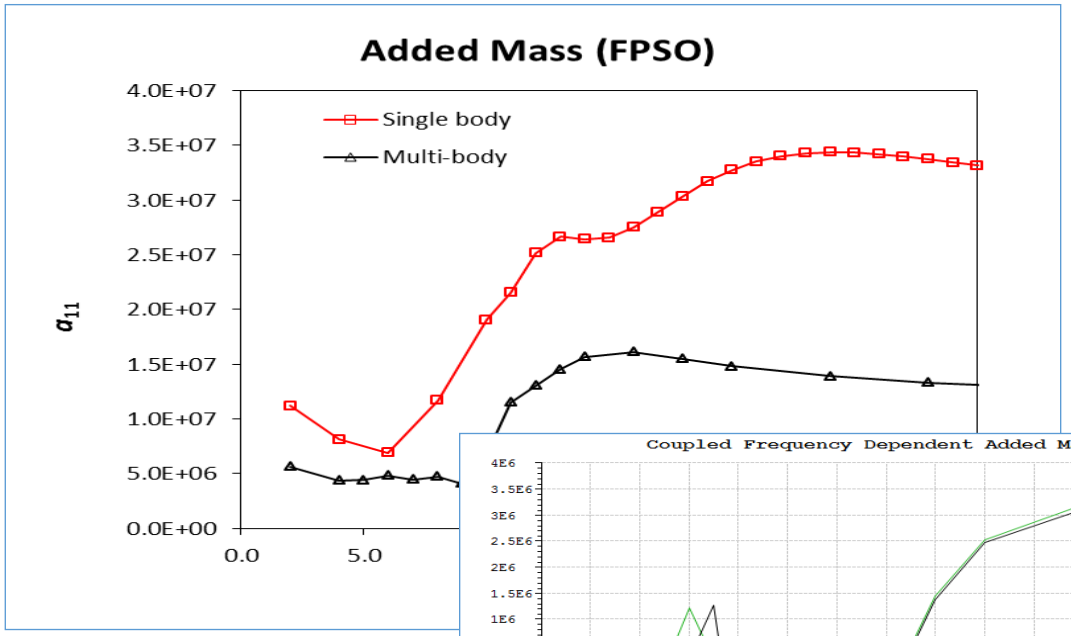


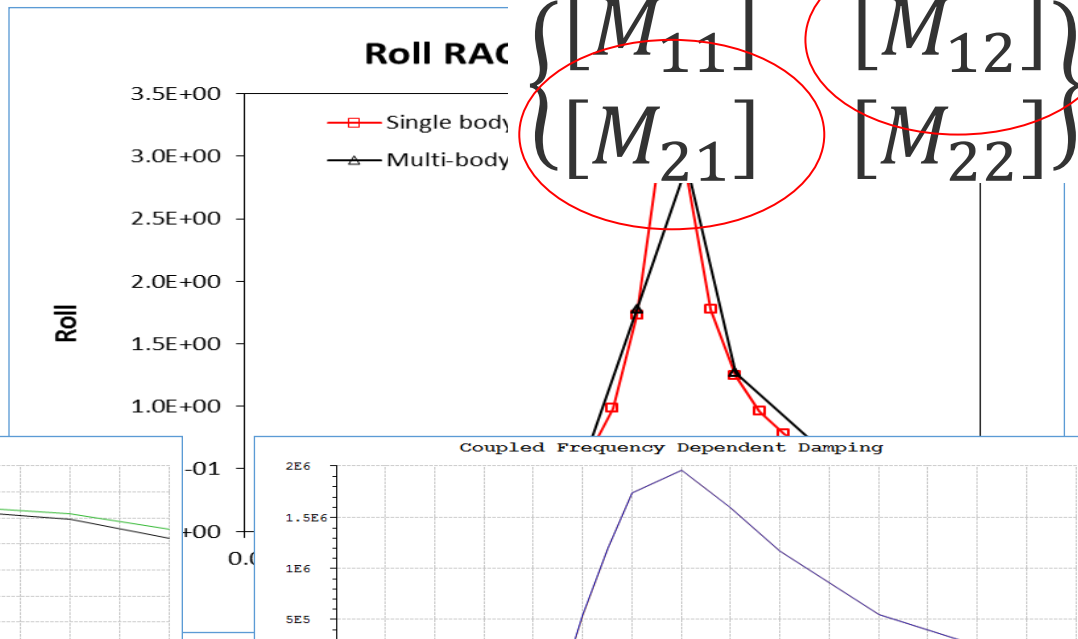


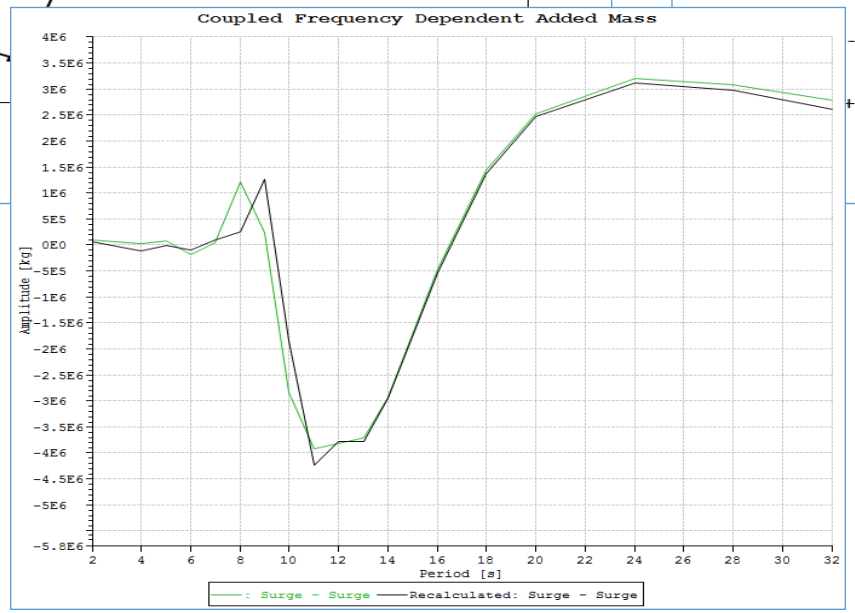


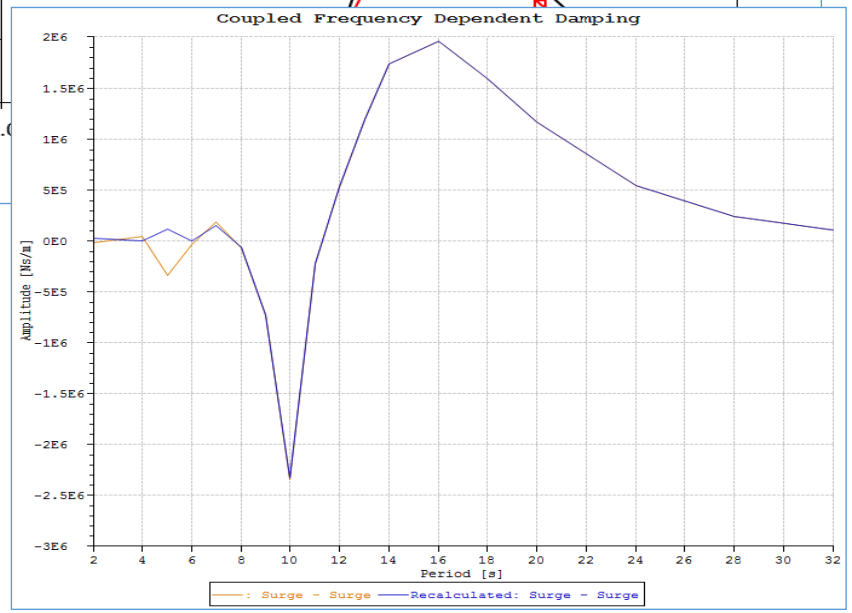
Hydrodynamic coupling calculation in Wadam

$$\begin{Bmatrix} [M_{11}] & [M_{12}] \\ [M_{21}] & [M_{22}] \end{Bmatrix}$$

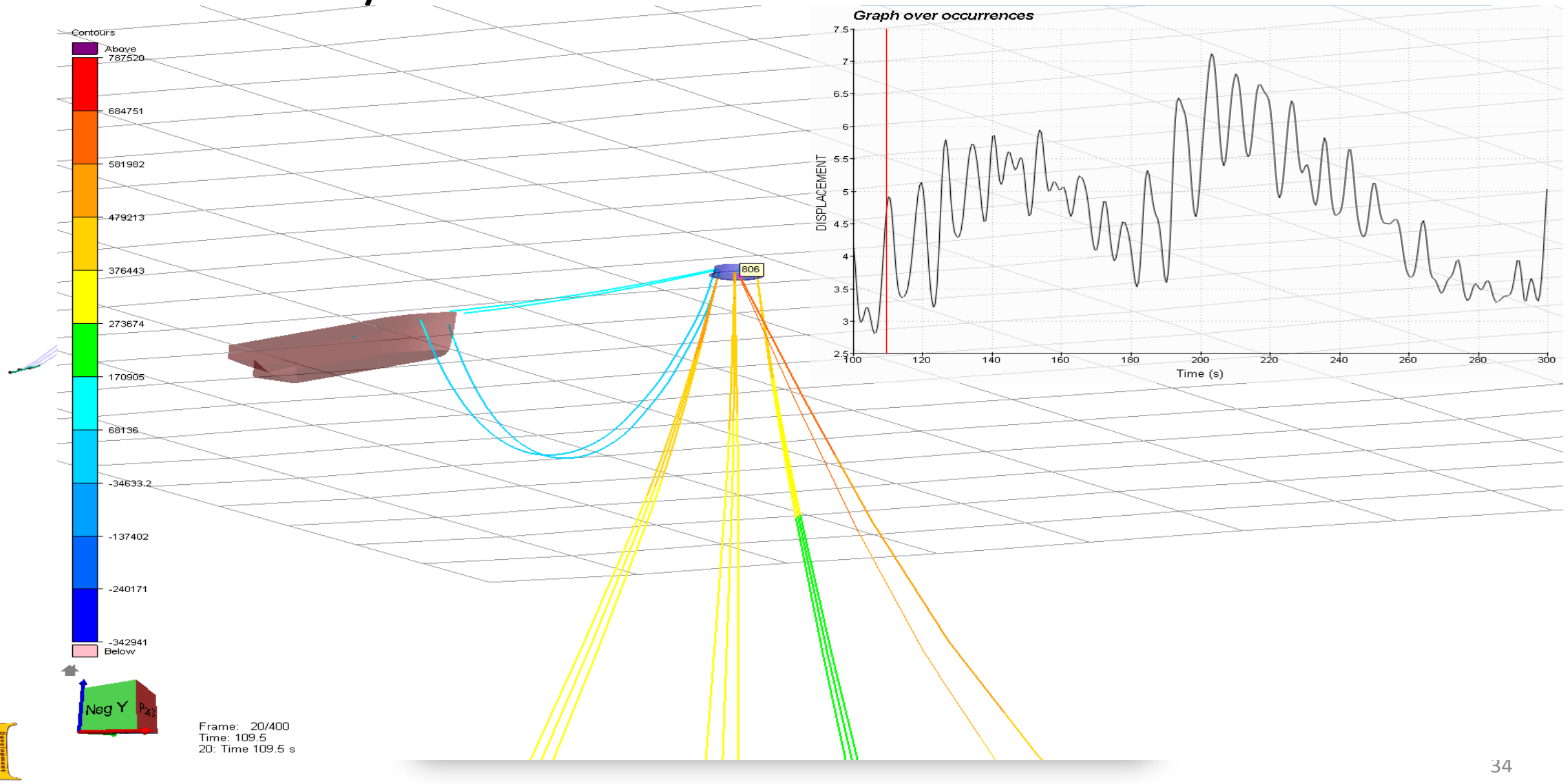




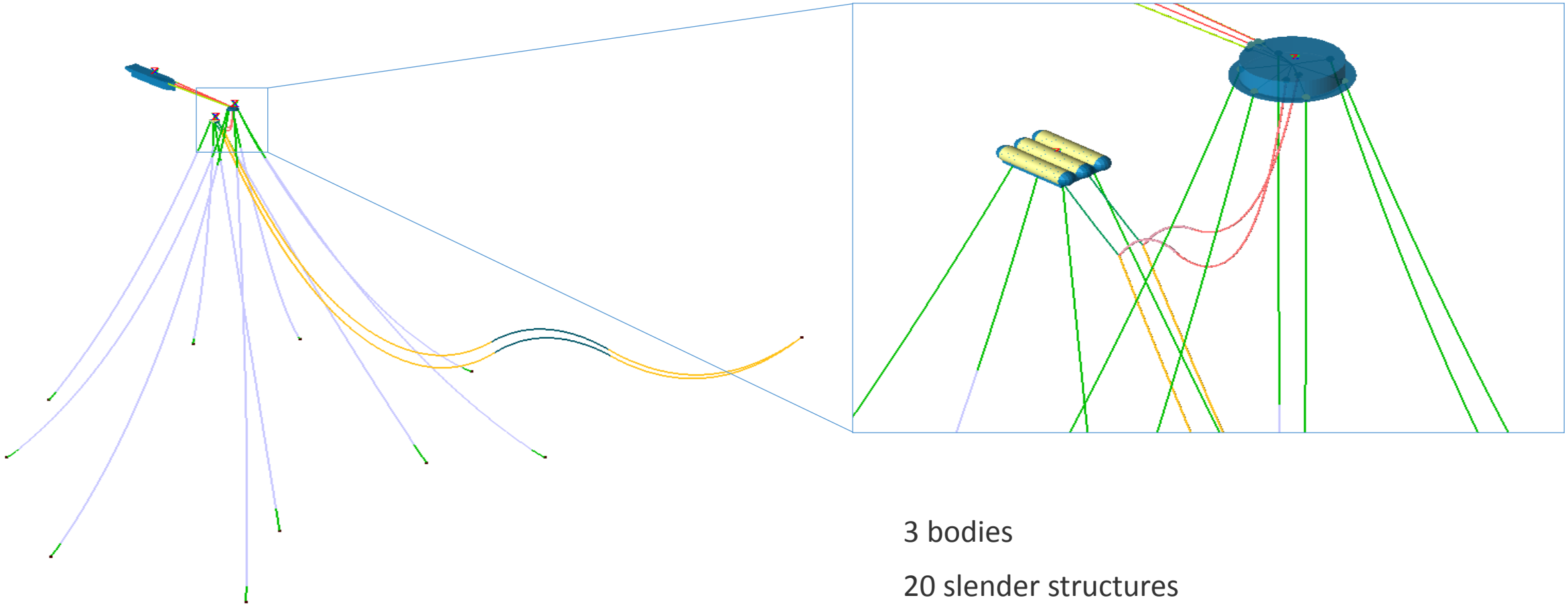




CALM buoy


Contours
Above
787520
684751
581982
479213
376443
273674
170905
68136
-34633.2
-137402
-240171
-342941
Below
Neg Y
Pos X
Frame: 20/400
Time: 109.5
20: Time 109.5 s
806
Graph over occurrences
DISPLACEMENT
Time (s)
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
100
120
140
160
180
200
220
240
260
280
300

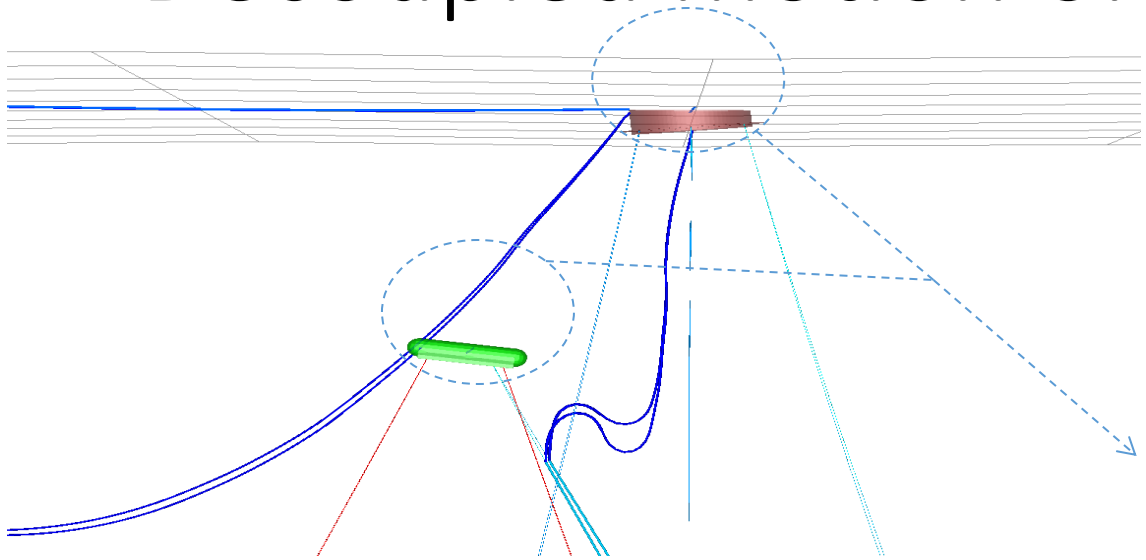
More complex setting

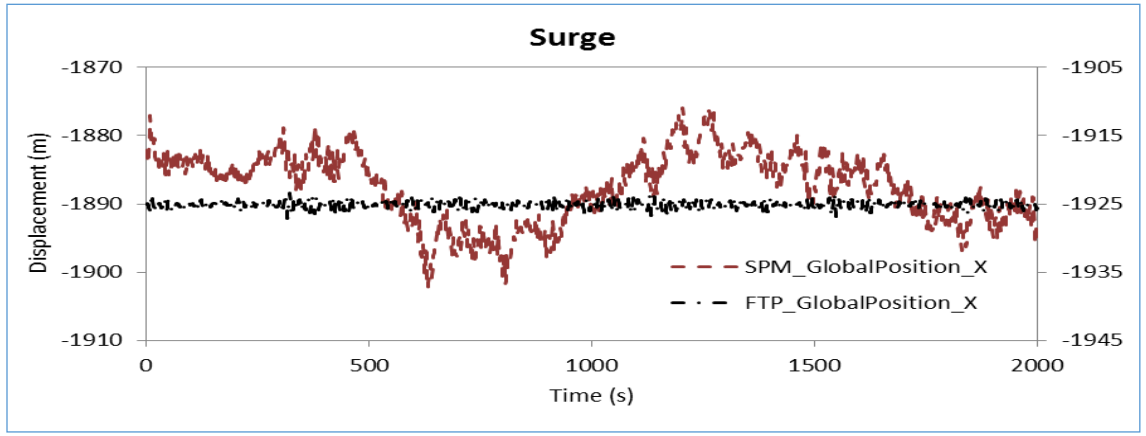


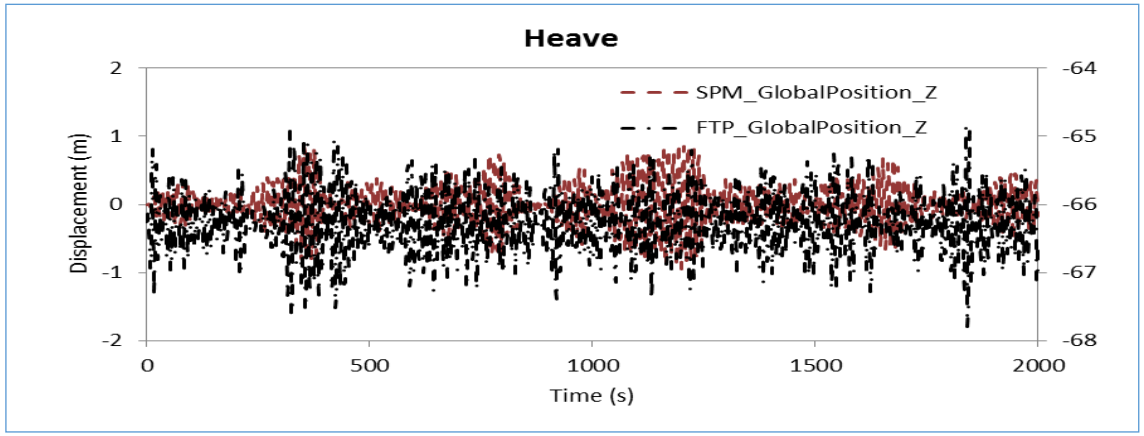
3 bodies

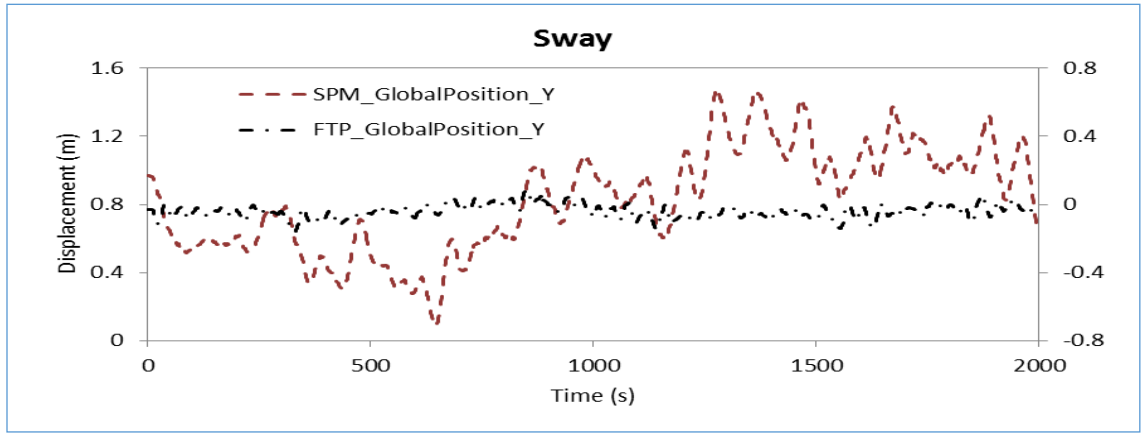
20 slender structures

Decoupled motion of SPM and FTB

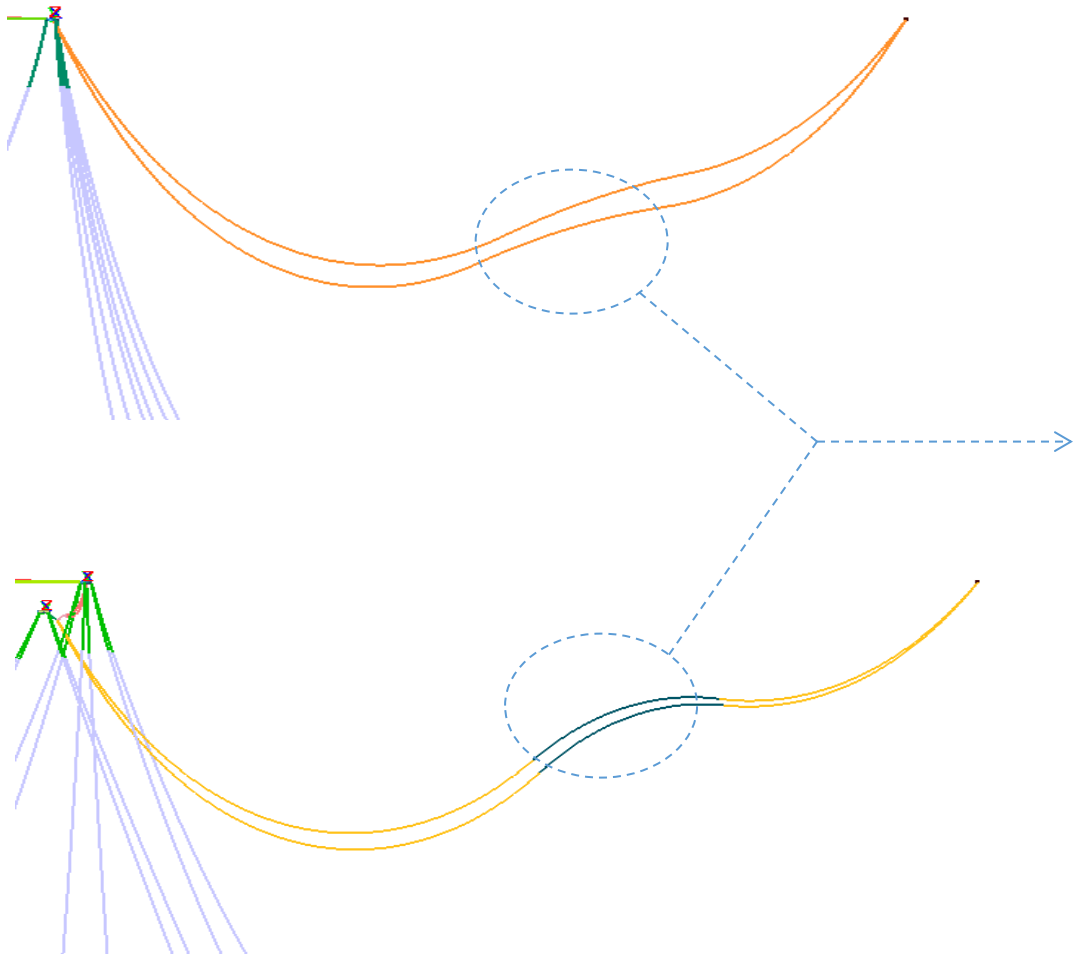


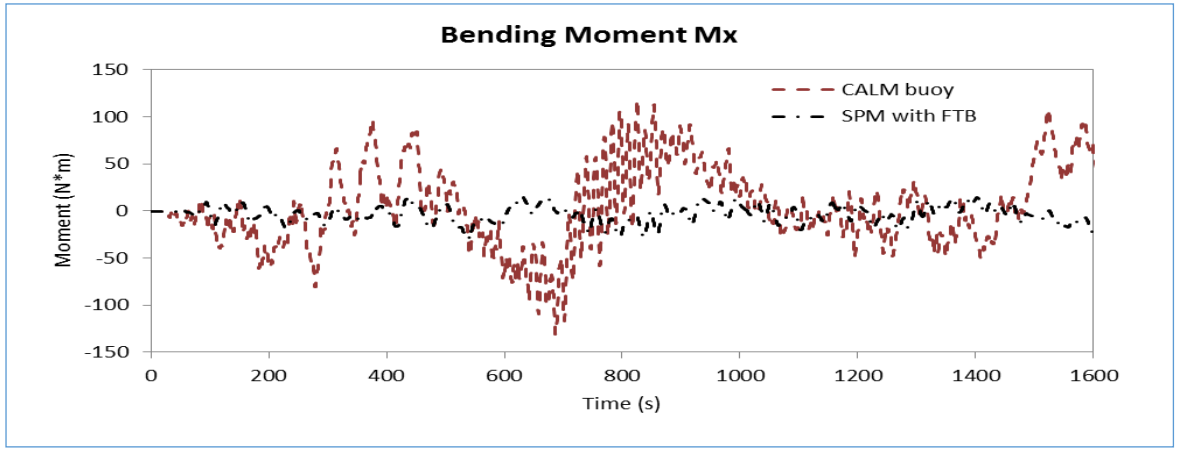


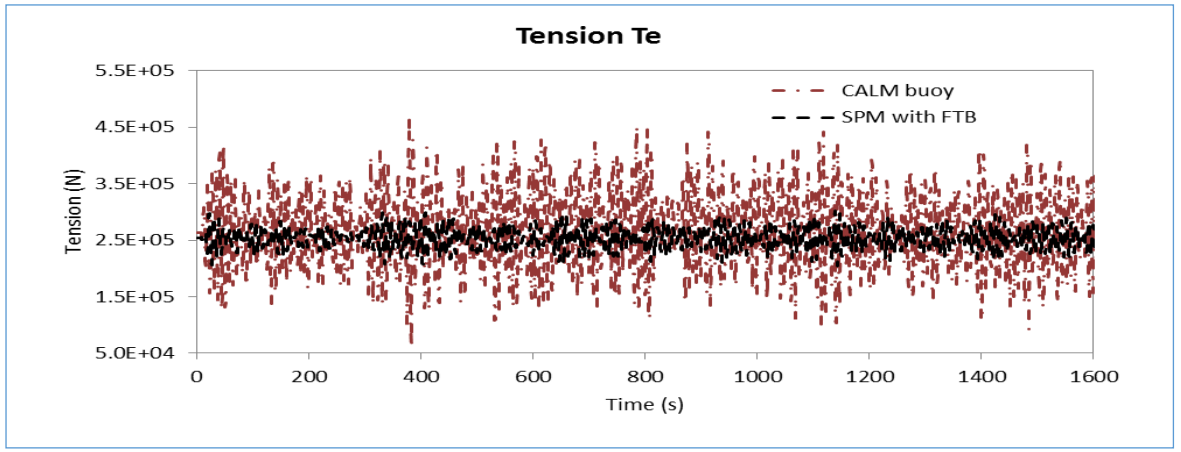




Dynamic loading on the flowlines reduced







Summary

- Sesam from DNV GL covers comprehensive analysis of FPSO mooring and offloading alternatives including
  - Spread mooring and turret mooring
  - Turret mooring with thrusters
  - SCR, FTB, Hybrid, etc.
- Global and local analysis easily simulated
  - Bellmouth and jumper analysis
  - Local turret analysis
- Mooring (riser) disengaged transient analysis provides more confidence
- Detachable turret analysis

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2. O. Ihonde, J. Mattinson, L.T. England, (2002) “FPSO mooring & offloading system alternatives for deepwater West Africa”, 6th Annual Offshore West Africa Conference.
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4. C.A. Zimmermann, D. Petruska, A.S. Duggal, (2002) “Effective Riser Solutions for a Deepwater FPSO”, OMAE 2002.
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