Risers – Flexible Pipes and Umbilicals

Introduction and Global Analysis

Brasil – Japan Cooperative Courses

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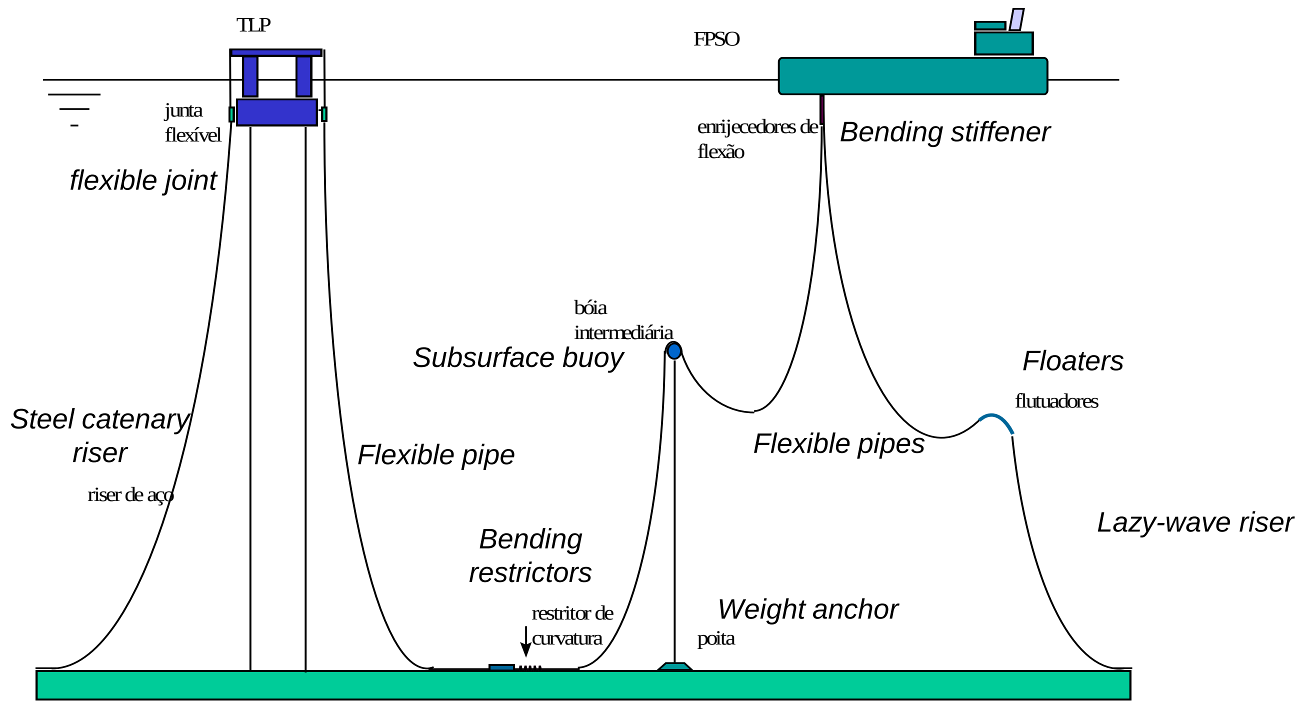
Risers



- ***Umbilical cables***: control signals, electrical power, fluid injection to the submarine equipment at the well head.

- ***Flexible pipes:*** conveying oil, gas, from the well head to the production floating system or to another storage and offloading vessel after processing.

Hystoric and trends

- ‘70s – fixed platforms:
- ‘80s – Semi-submersible platforms and TLP’s
- ‘90s: TLP’s, SPARS
- 2000s: FPSO’s, TLP’s, Mono Column, Semi-subs

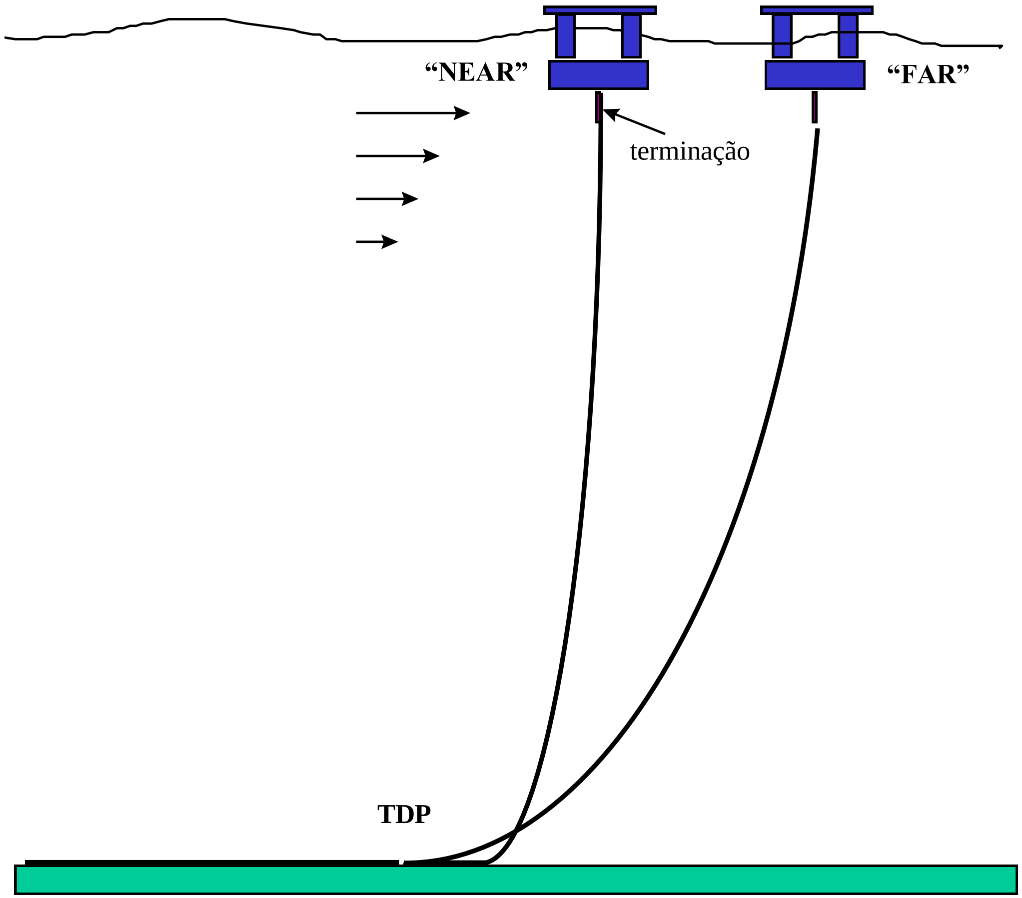
- Umbilicals and steel risers (static)
- Umbilicals and flexible pipes (dynamic)
- Umbilicals, flexible pipes and steel catenary risers (dynamic)
- Umbilicals, mixed systems, riser towers (dynamic)

Catenary Risers

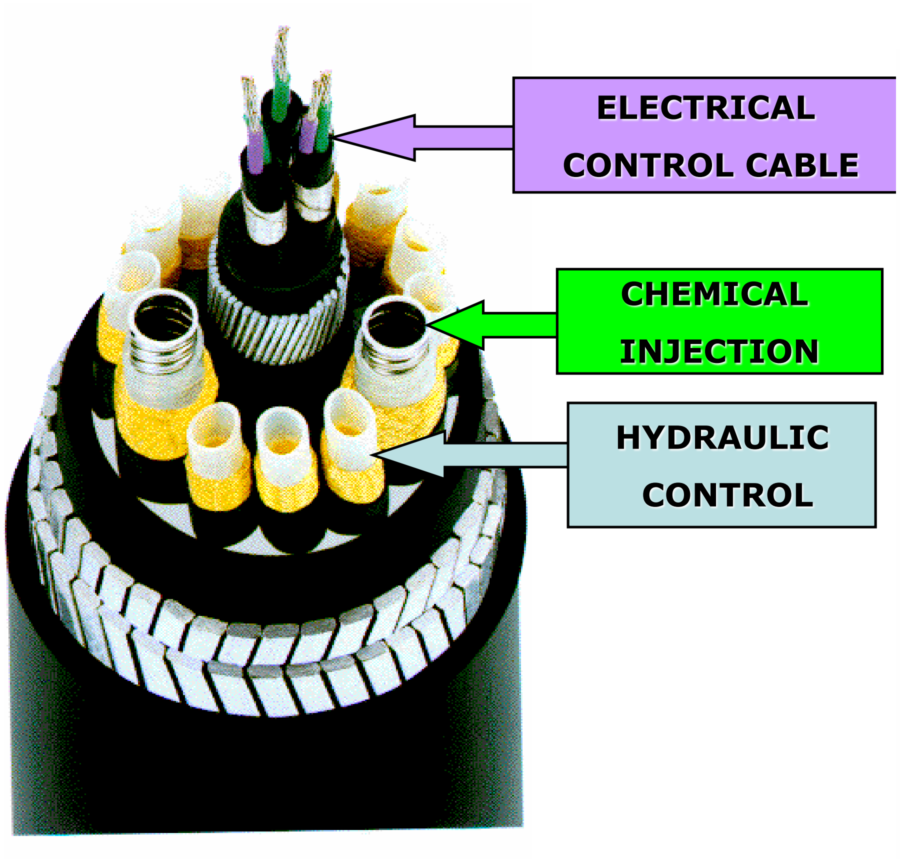
- ***Loading***: environmental action:
  - direct (current, waves) and
  - indirect, driven by the floating system.

- ***Mechanical failures:*** overloading, fatigue, localized damage (impact), collapse, corrosion, welding, flexible joints, bending stiffeners, connections, etc...

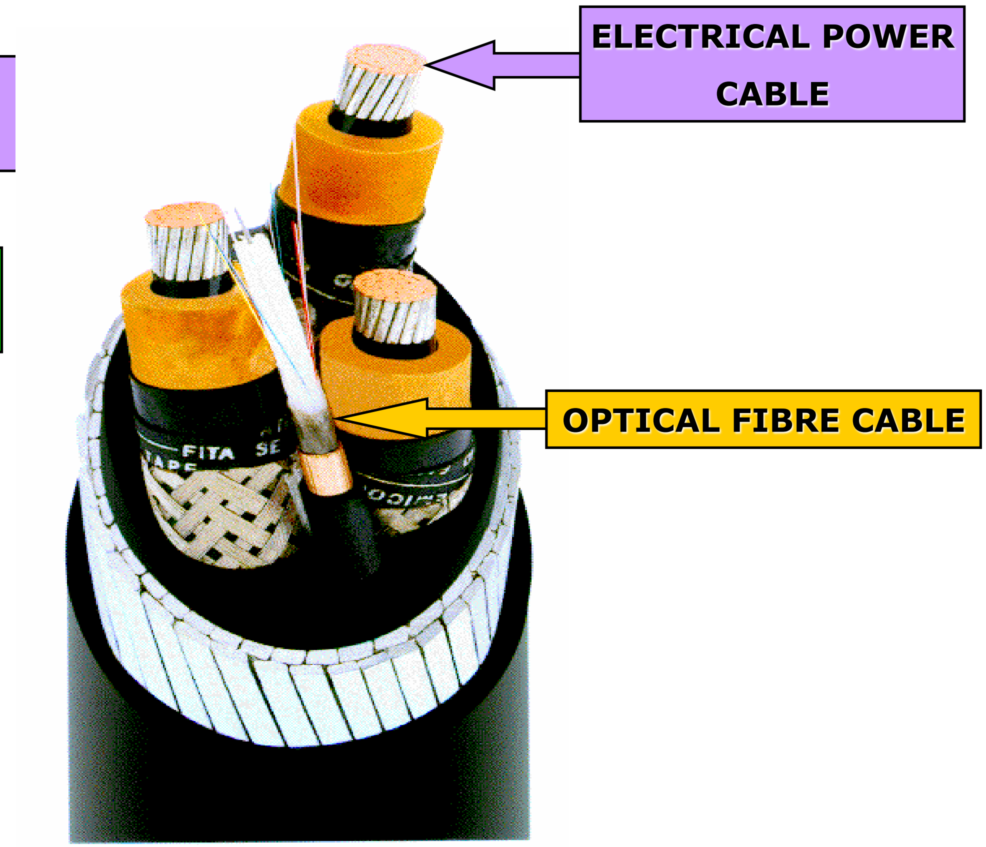
- ***Environmental action has a stochastic nature.***



Typical Umbilical Cables

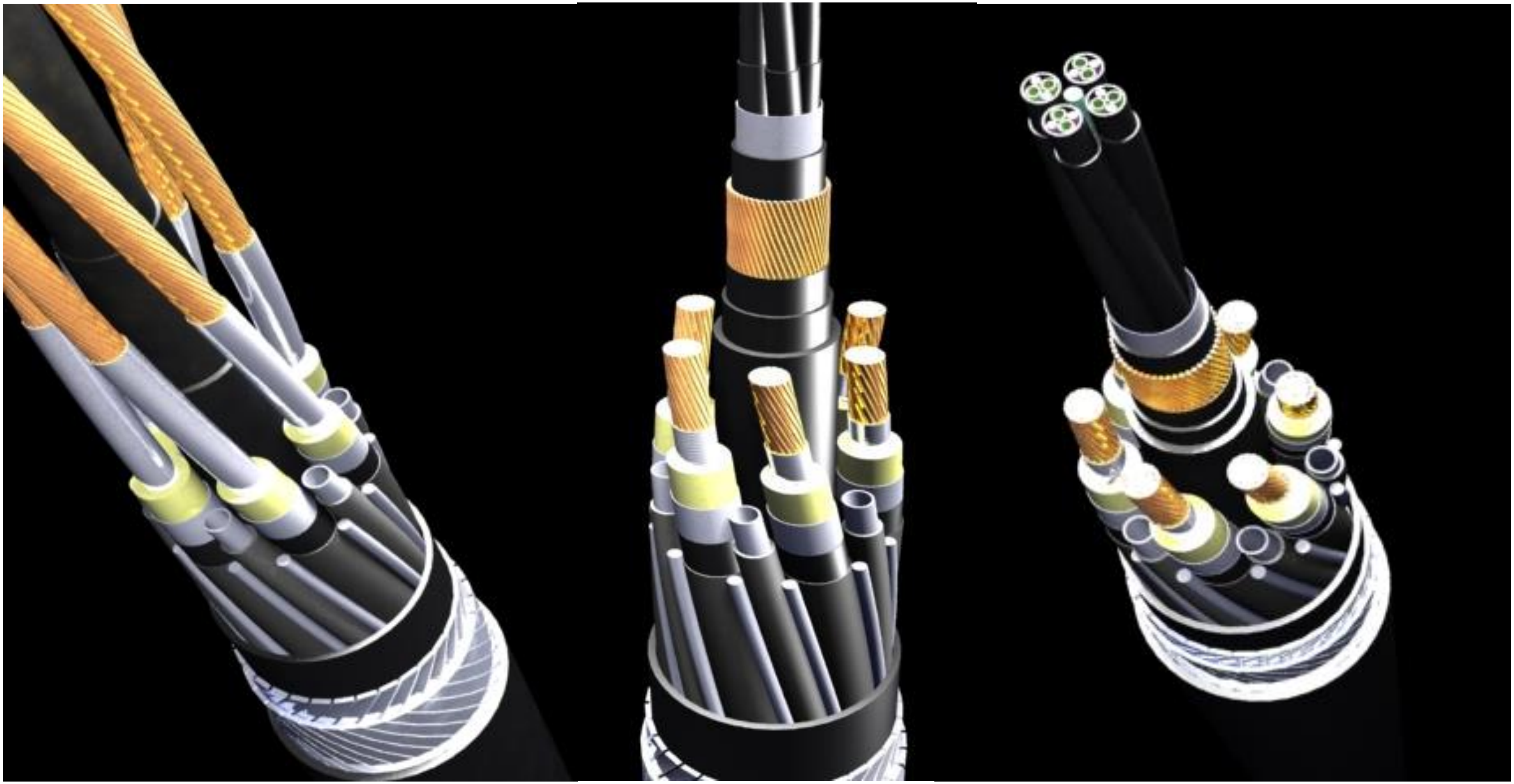


DYNAMIC ELECTRO-HYDRAULIC UMBILICAL

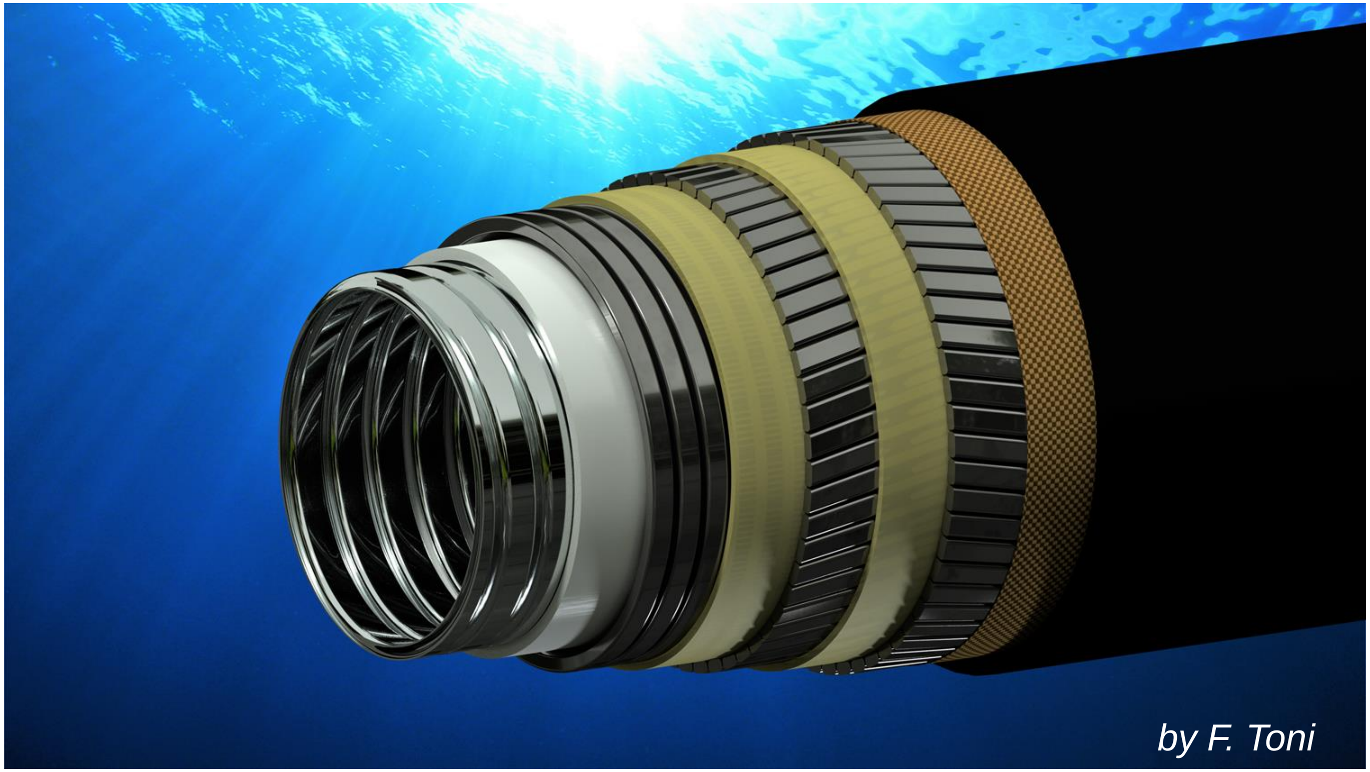


DYNAMIC POWER-OPTICAL UMBILICAL

Integrated Steel Tubed Umbilicals (STU)



Typical Flexible Pipe



Typical failure modes

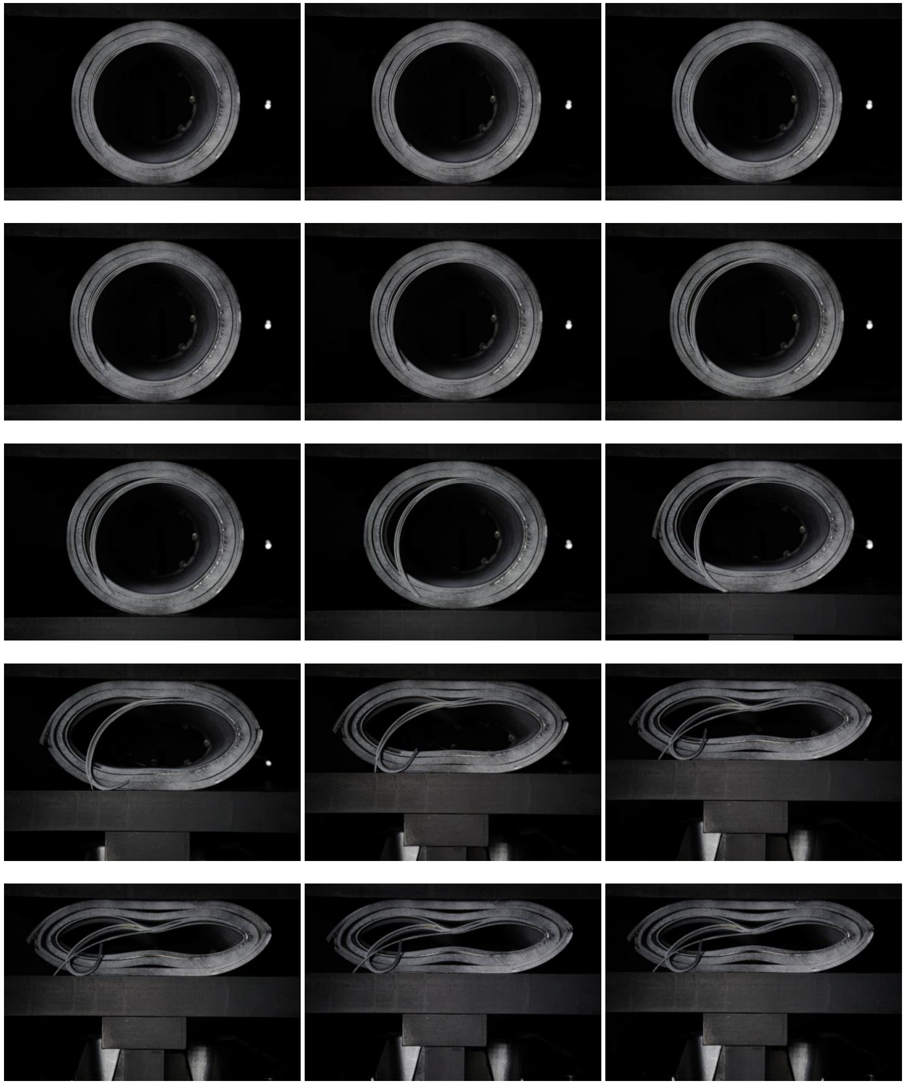
- Helical tendons rupture – under traction and internal pressure;
- Internal carcasses collapse – under external pressure, squeezing and crushing;
- Wear and fatigue of metallic components;
- Helical armour layers instabilities (birdcaging and lateral buckling)
- Leakage of plolymeric layers due to aging, chemical atack, degradation;
- Extreme bending efforts, caused by flexural-torcional instabilities (loops) during laying operations or during fabrication/storage;
- Thermal expansion and sudden variation of bending stiffness;
- Gas permeation in the anular region – corrosion.
- Creeping of polymeric layers;
- Hoses colapse; copper strands fatigue and kinking (umbilicals);
- Others....

Typical failure modes

Minimum Bending radius Tests

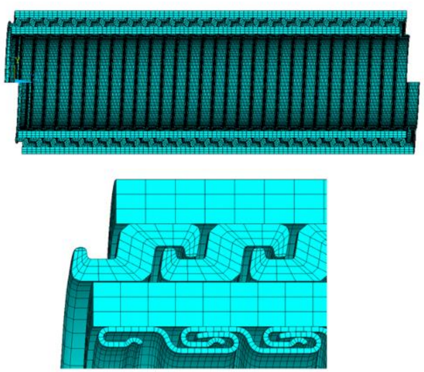
Bending on a wheel

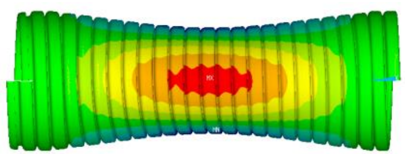
Typical failure modes

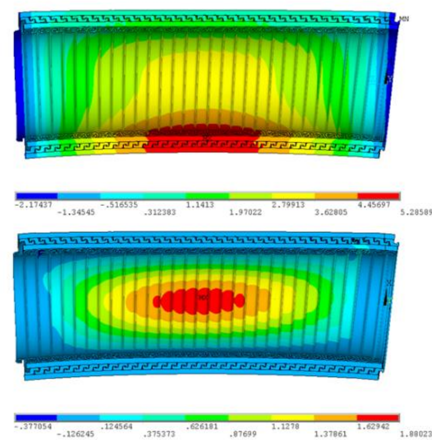


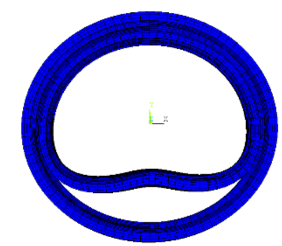
4'' flexible pipe: pressure armor and carcass under crushing tests

Typical failure modes





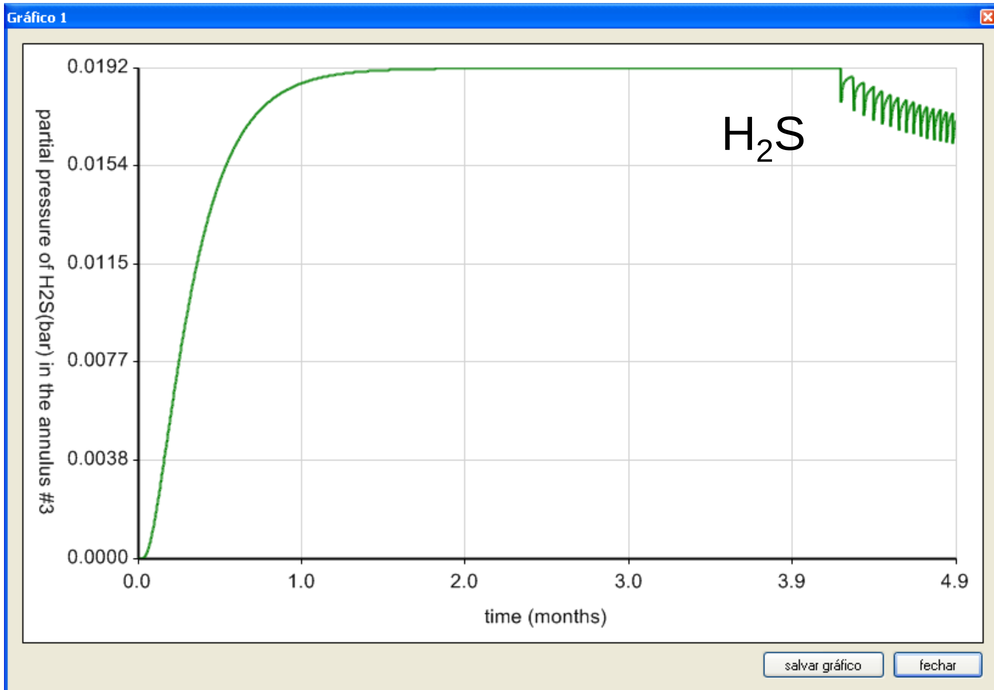


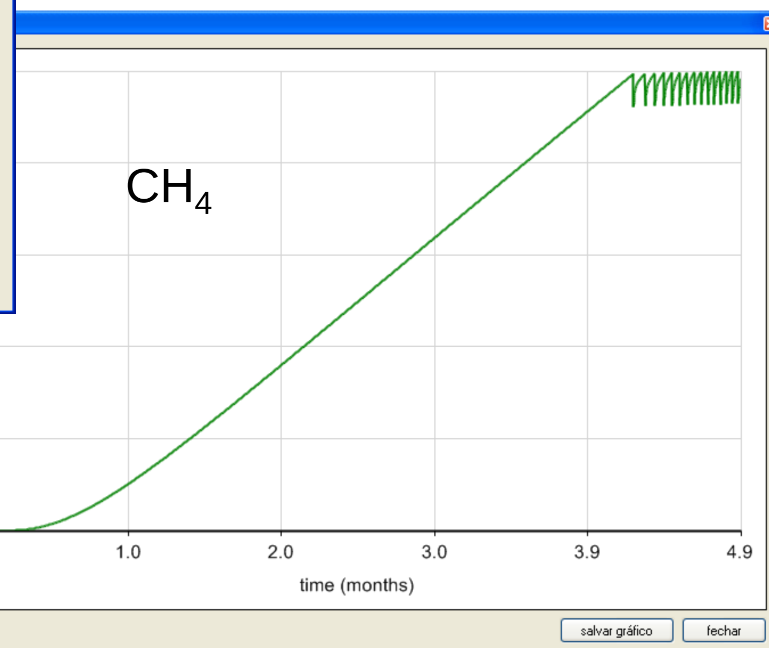


Flexible pipe collapse modes

external pressure, squeezing

Typical failure modes



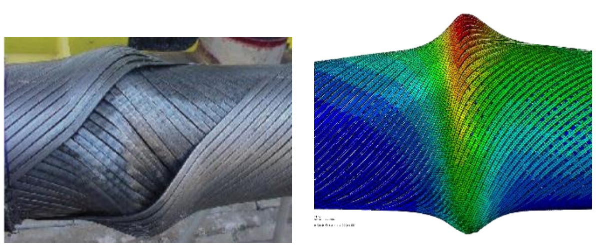


Corrosion due to annular gas permeation

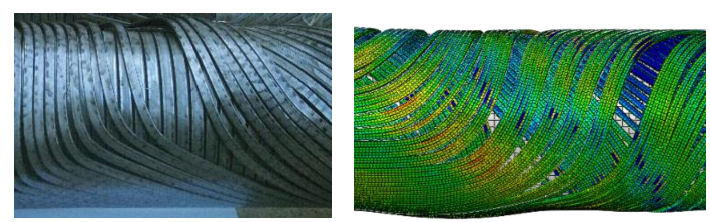
partial pressure with time in annulus #3

Typical failure modes

Instabilities of flexible pipes

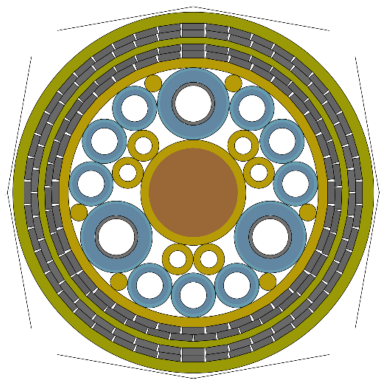


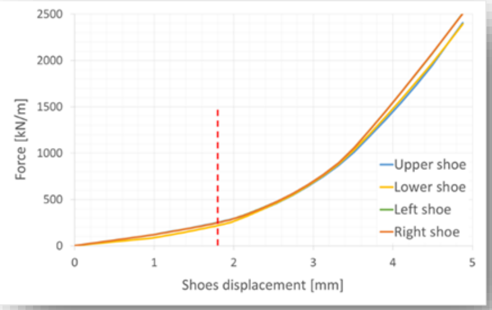
birdcaging

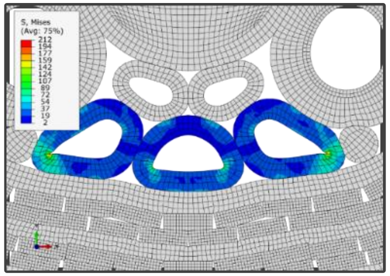


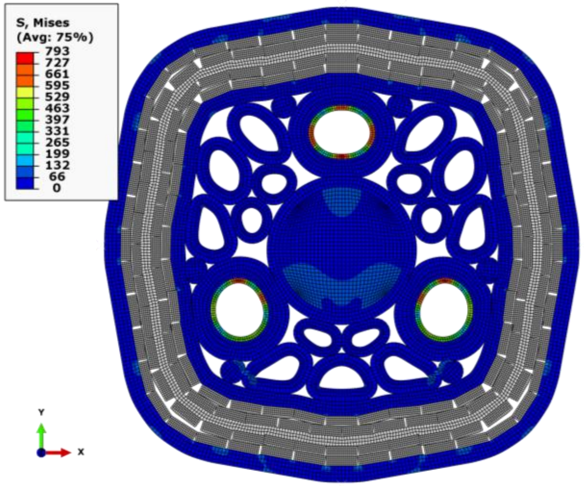
Lateral buckling

Typical failure modes









Umbilical crushing

Facts

- Long lengths and low tensioning:
  - Global mechanics dominated by geometric stiffness (tension);
- High axial rigidity and low bending stiffness:
  - Dynamic equations numerically rigid (several distinct frequencies coexisting);
- Geometrically nonlinear boundary conditions:
  - Local analysis necessary at hot spots (TDZ, Top, floaters)(;
- Dynamic perturbations:
  - Global dynamics can be linearized and end effects corrected a posteriori.

Global Analysis Approaches

- A complete design procedure deals with many (*inter-related*) aspects of the dynamic response caused by FPU motions and ocean currents, assessing their impact on ULS and FLS, as:
  - first-order wave motions and slow-drift motions (wave and wind);
  - VIV, wake-interference and clashing;
  - dynamic instabilities;
  - non-linear boundary conditions at:
    - TDA;
    - Hang-off.
- Design procedures rely on exhaustive mathematical modeling and demand a huge computational effort.
- Even though, many (*isolated*) fundamentals aspects are not yet fully understood.

Global Analysis Approaches

- There are at least three different time-scales in the catenary riser dynamic structural problem:
  - The first one is dominated by axial rigidity, giving rise to relatively small periods of oscillation.
  - The second one is related to the catenary or geometric rigidity.
  - The third one is of a local nature and is due to the local flexural rigidity effects.
- Such a diversity of time-scales can lead to serious limitations concerning numerical integration methods by rendering dynamic equations mathematically stiff.
- Even the starting problem, to determine the static configuration, can pose serious numerical difficulties, as the flexural rigidity effect is confined and dominant just inside small regions close to the ends, the TDP (touch-down point) and the upper end-fitting or close to other regions of high curvatures.

Global Analysis Approaches

Conventional

- Numerical integration of the nonlinear static equilibrium equations;
- Nonlinear dynamic analysis around the static equilibrium ***in time domain***;

Huge computational times.

Expedit

- Numerical integration of the nonlinear static equilibrium equations;
- Linear dynamic analysis around the static equilibrium ***in frequency domain***;
- Local nonlinear correction through boundary-layer techniques at hot spots.

Global Analysis Approaches

- Time Domain (TD) schemes are strongly recommended (API-2RD) for/as:
  - comprehensive treatment of the fully nonlinear hydro-elastic problem;
  - extreme environmental conditions, large displacements, tension coupling, nonlinear loading, foundation modelling;
  - transient events: *pull-in/pull-out/disconnecting operations, loss of FPU station-keeping ability, mooring-system failures*;
  - a reference for equivalent frequency-domain analysis.
- Frequency Domain (FD) schemes are used for speeding-up design procedures:
  - TDA nonlinear boundary condition should be considered consistently through asymptotic methods; Aranha et al (1997) and Pesce and Martins (2004).
  - ‘Equivalent’ linear spring modeling is not consistent and must be consciously exercised vs TD simulations.

Global Analysis Approaches

- Numerous numerical methods have been discussed and implemented in the last two decades; see, e.g., Leira and Remseth (1985), Larsen (1992) …. Silveira and Martins (2003).

	CDM	HBM	WTM	NWM
Initial Procedures	*	*	***	***
Stability	*	***	***	***
Accuracy	**	**	***	***
Flexibility	*	*	**	***
Speed	***	***	*	**

Numerical methods; a qualitative comparison.
(*****:** better evaluation); Silveira and Martins (2003)

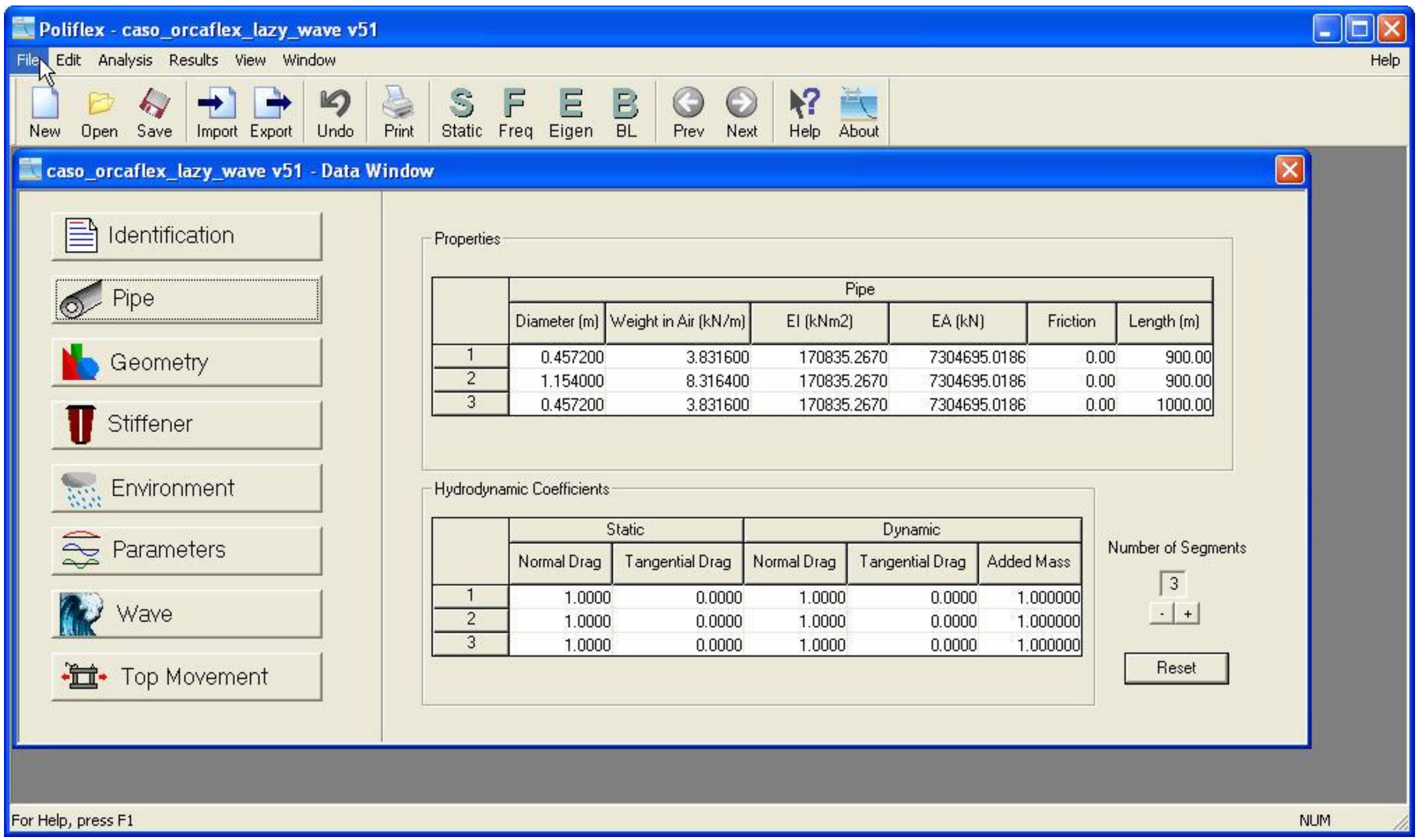
CDM: Central Difference method
HBM: Houlbolt
WTM: Wilson-Theta
NWM: Newmark

Global Analysis Approaches

Computational Codes

POLIFLEX 2D and 3D

Dynamics in FD

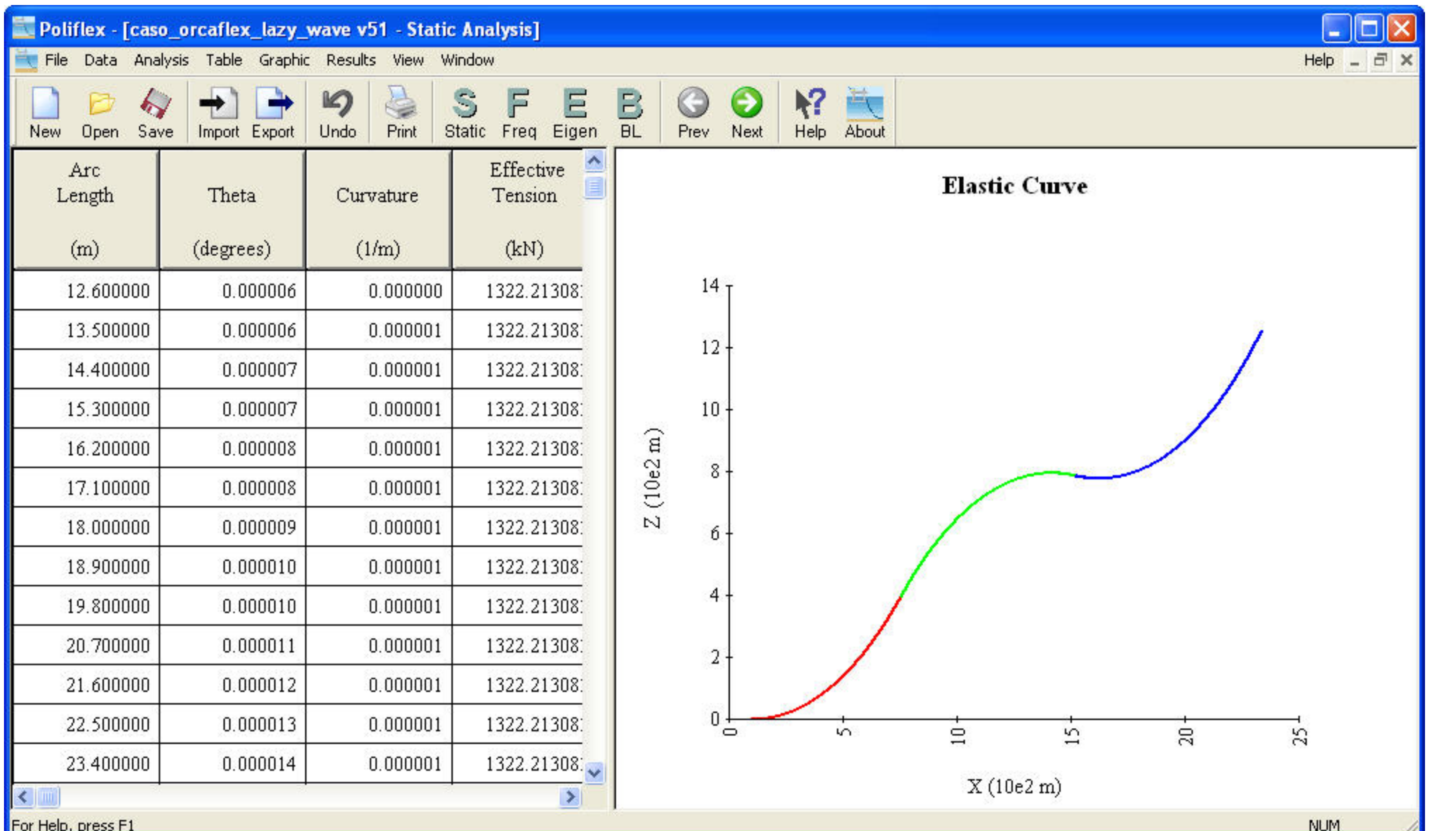


Global Analysis Approaches

Computational Codes

POLIFLEX 2D and 3D

Dynamics in FD



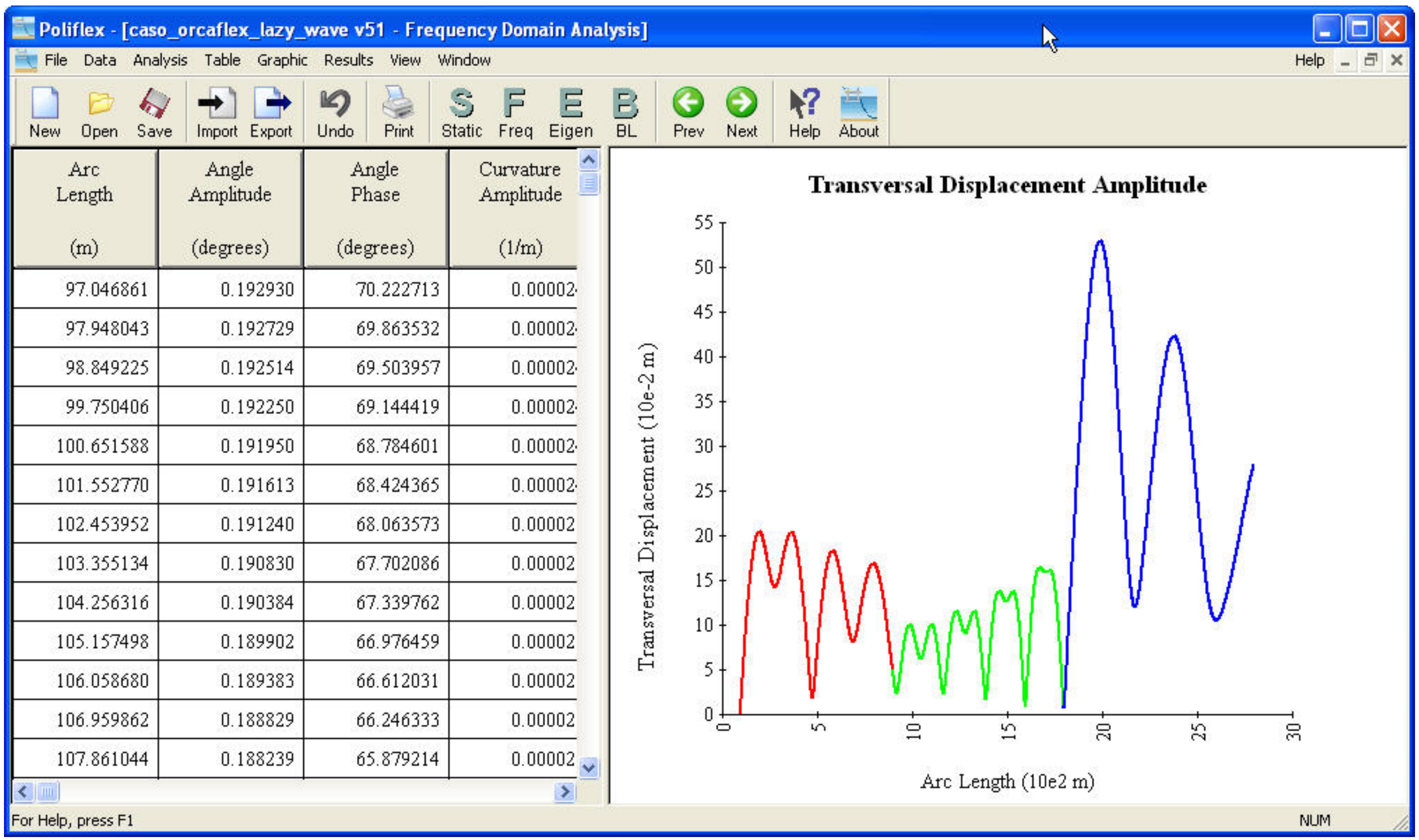
Arc Length (m)	Theta (degrees)	Curvature (1/m)	Effective Tension (kN)
12.600000	0.000006	0.000000	1322.21308
13.500000	0.000006	0.000001	1322.21308
14.400000	0.000007	0.000001	1322.21308
15.300000	0.000007	0.000001	1322.21308
16.200000	0.000008	0.000001	1322.21308
17.100000	0.000008	0.000001	1322.21308
18.000000	0.000009	0.000001	1322.21308
18.900000	0.000010	0.000001	1322.21308
19.800000	0.000010	0.000001	1322.21308
20.700000	0.000011	0.000001	1322.21308
21.600000	0.000012	0.000001	1322.21308
22.500000	0.000013	0.000001	1322.21308
23.400000	0.000014	0.000001	1322.21308

Global Analysis Approaches

Computational Codes

POLIFLEX 2D and 3D

Dynamics in FD



Arc Length (m)	Angle Amplitude (degrees)	Angle Phase (degrees)	Curvature Amplitude (1/m)
97.046861	0.192930	70.222713	0.00002
97.948043	0.192729	69.863532	0.00002
98.849225	0.192514	69.503957	0.00002
99.750406	0.192250	69.144419	0.00002
100.651588	0.191950	68.784601	0.00002
101.552770	0.191613	68.424365	0.00002
102.453952	0.191240	68.063573	0.00002
103.355134	0.190830	67.702086	0.00002
104.256316	0.190384	67.339762	0.00002
105.157498	0.189902	66.976459	0.00002
106.058680	0.189383	66.612031	0.00002
106.959862	0.188829	66.246333	0.00002
107.861044	0.188239	65.879214	0.00002

Environmental loading

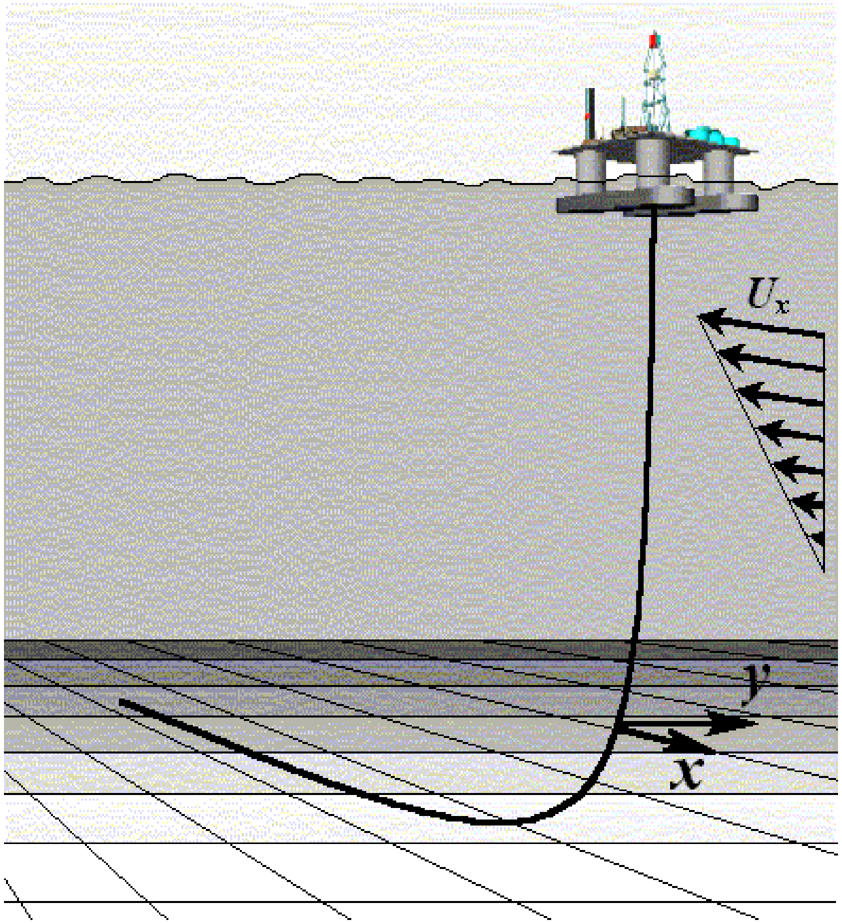
Direct

- Current:
  - Drag
  - VIV
- Waves:
  - Mean drag;
  - Dynamic loading

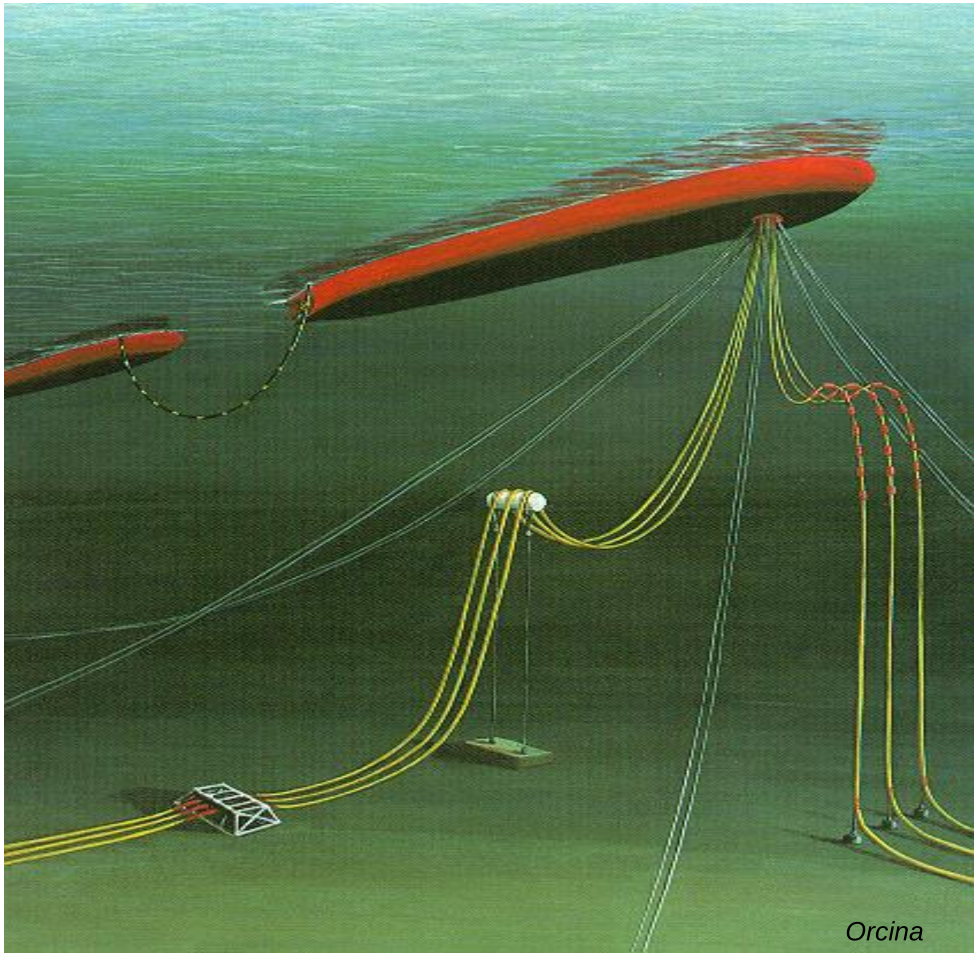
Indirect

- Motion imposed at top by FPU:
  - In the wave frequency range;
  - In low frequency range due to:
    - waves;
    - current;
    - wind;
    - DP systems.

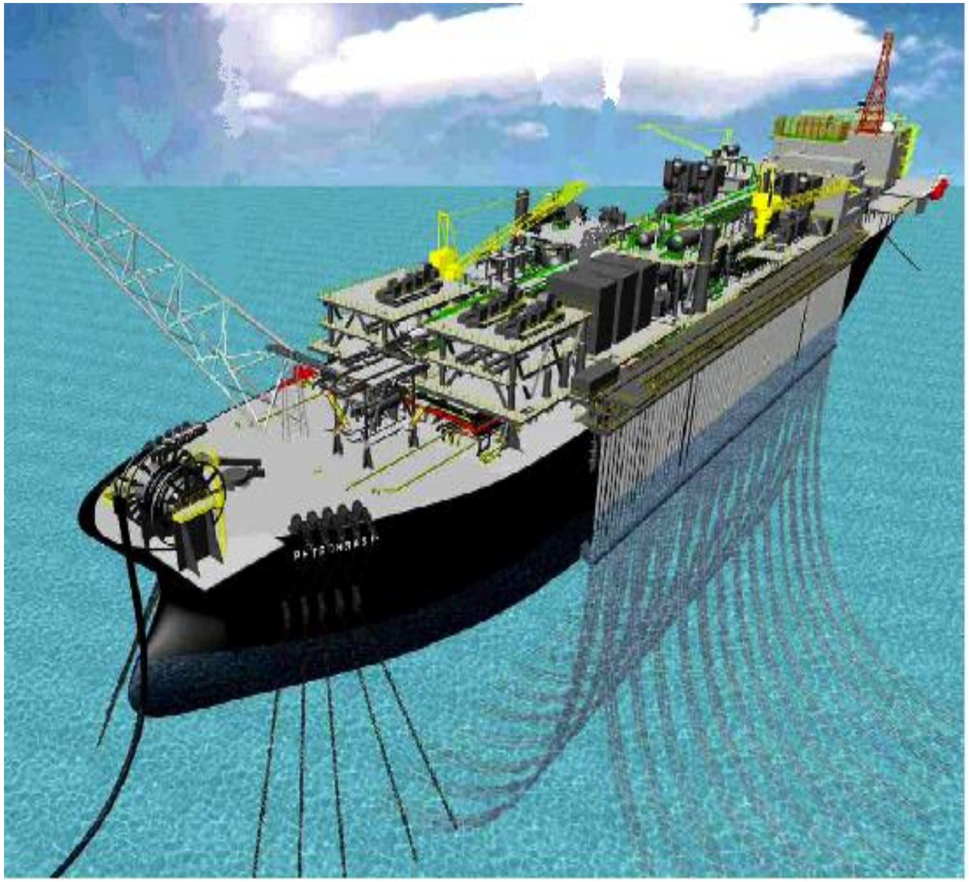
Interactions



Moored Semi-Submersible Production Platform



Turret-mooring FPSO

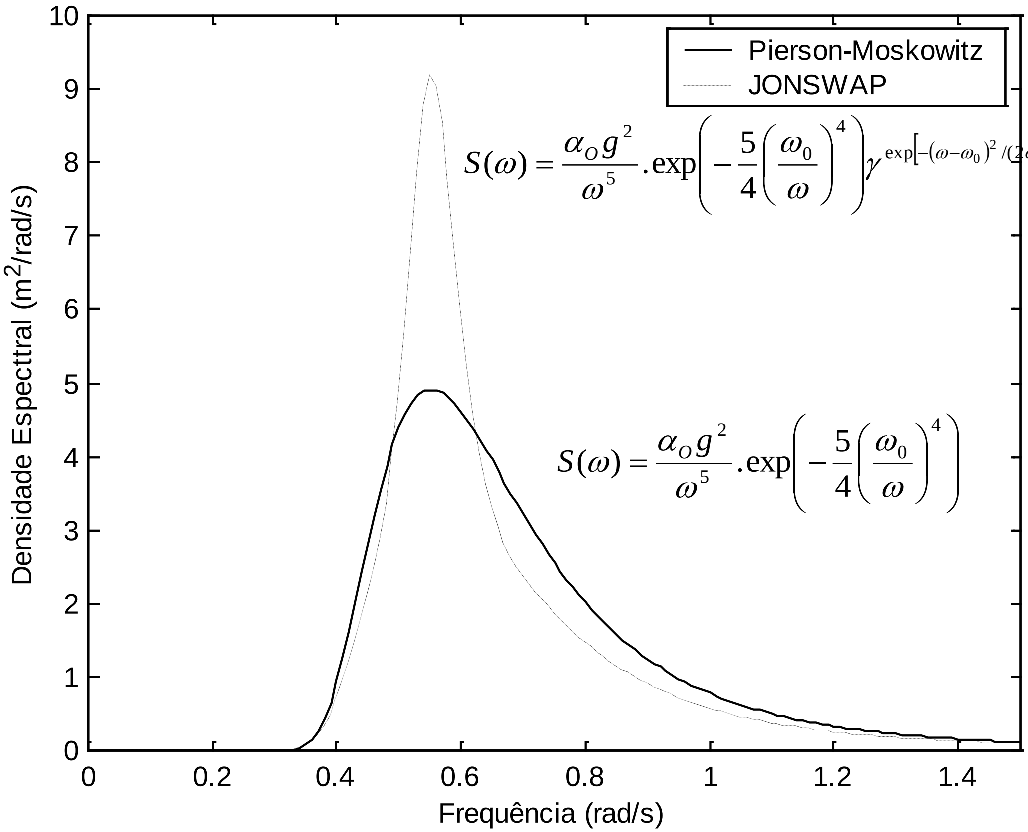


Spread-mooring FPSO

DP-FPSO

6 Azimuth Thrusters
2700kW
+459kN / -293kN

Wave Spectrum



$$\sigma = \begin{cases} 0{,}07 & \omega \le \omega_0 \\ 0{,}09 & \omega > \omega_0 \end{cases}$$

$$S(\omega) = \frac{\alpha_O g^2}{\omega^5}.\exp\left(-\frac{5}{4}\left(\frac{\omega_0}{\omega}\right)^4\right)\gamma^{\exp\left[-(\omega-\omega_0)^2/(2\sigma^2\omega_0^2)\right]}$$

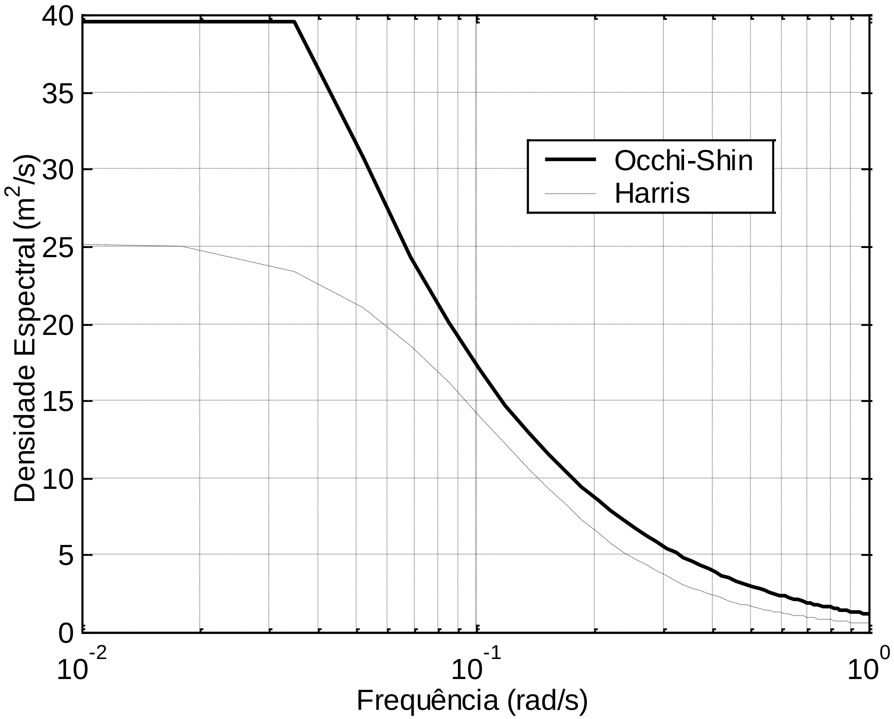
$$\alpha_O = \frac{5}{16.g^2} H_s{}^2 \omega_0{}^4 \left[1 - 0{,}287.\ln(\gamma)\right]$$

$$S(\omega) = \frac{\alpha_O g^2}{\omega^5}.\exp\left(-\frac{5}{4}\left(\frac{\omega_0}{\omega}\right)^4\right)$$

$$\alpha_O = \frac{5}{16 g^2} H_S^2 \omega_0^4$$

TP=11,4s e *HS*=5,5m

Wind spectrum



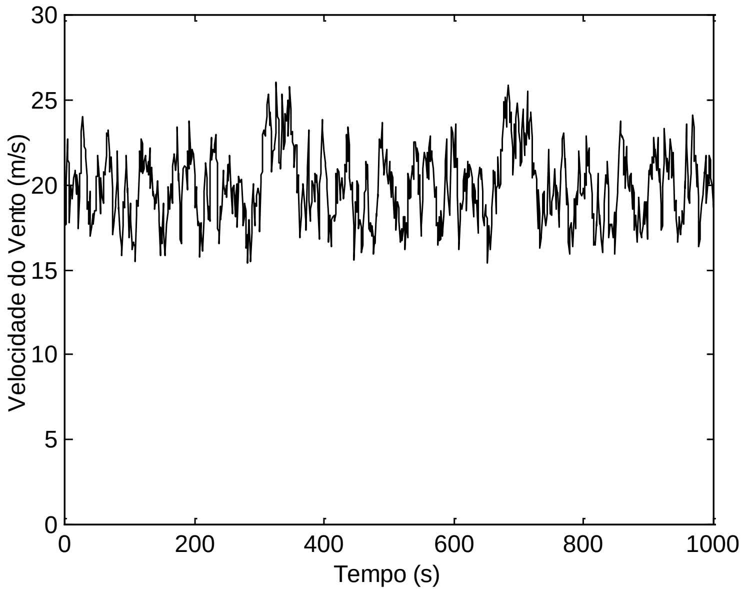
Occhi-Shin

$$S_V(\omega) = \frac{(750 + 69V).10^{-6} V^2 F_g}{\omega}$$

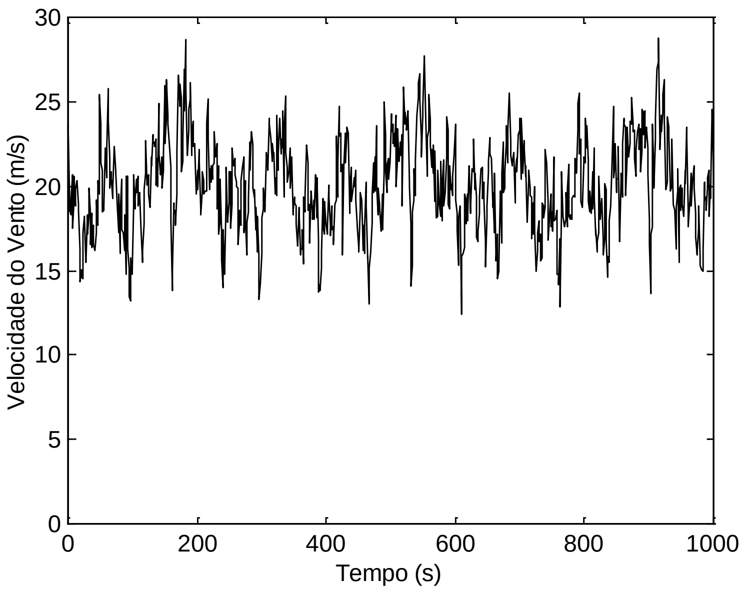
Harris

$$S_V(\omega) = 1146.C.V.\left[2 + \left(\frac{286\omega}{V}\right)^2\right]^{-\frac{5}{6}}$$

Wind speed sample

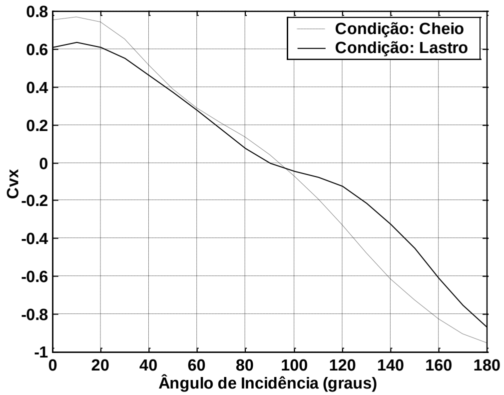


Harris

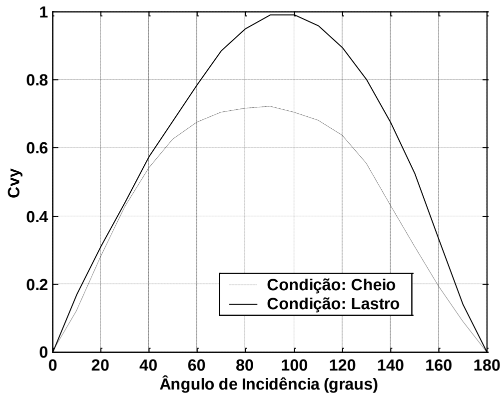


Occhi-Shin

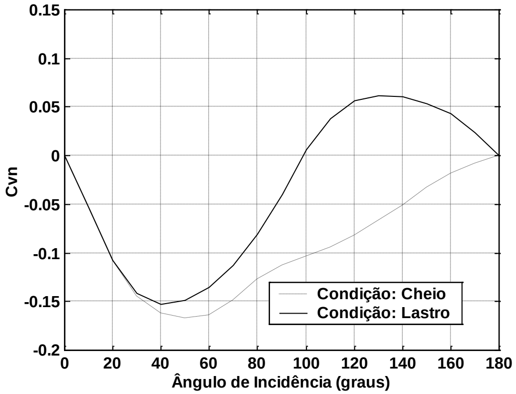
Wind force and moment coefficients (OCIMF)



lateral

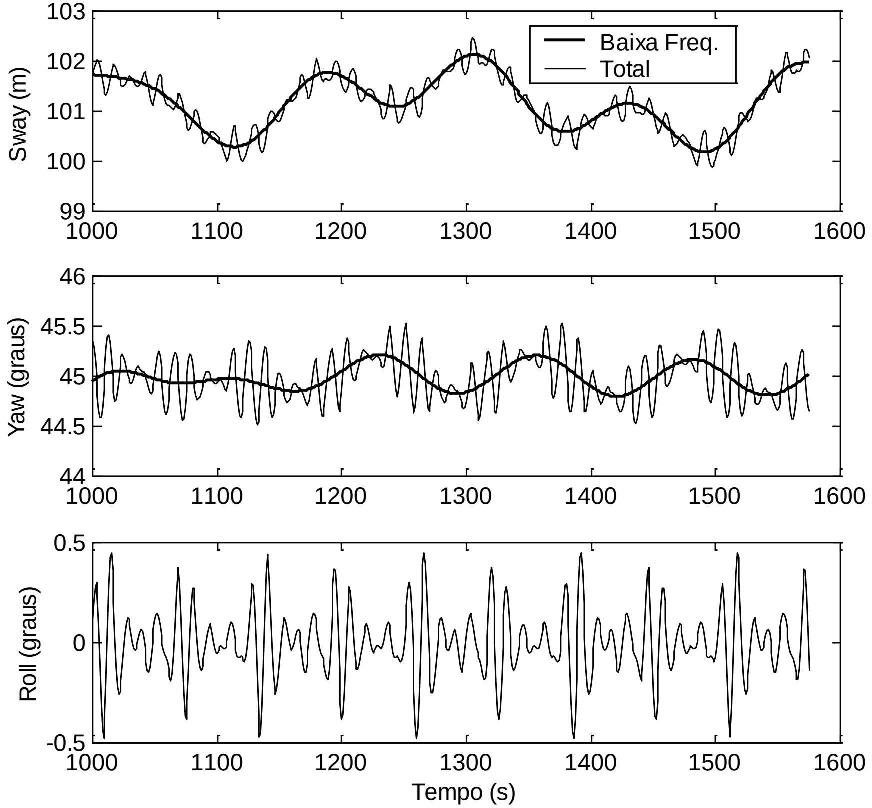


longitudinal



yaw

FPU Motions due to waves

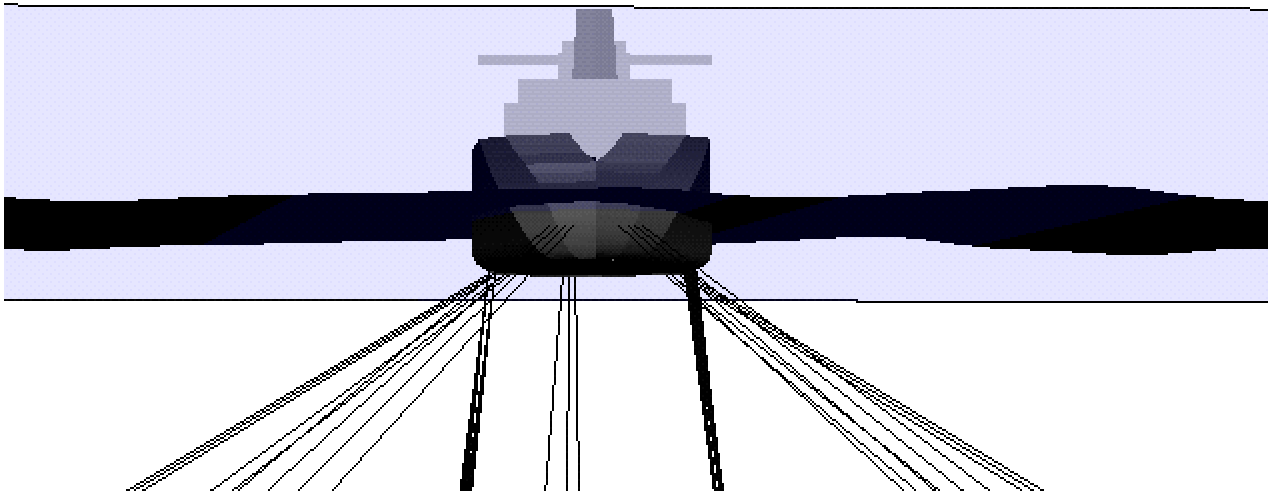


First and second-order wave forces

VLCC 100% loaded; Sea state: *Tp*=11,4s e *Hs*=5,5m

Low frequency motions caused by second order forces due to waves

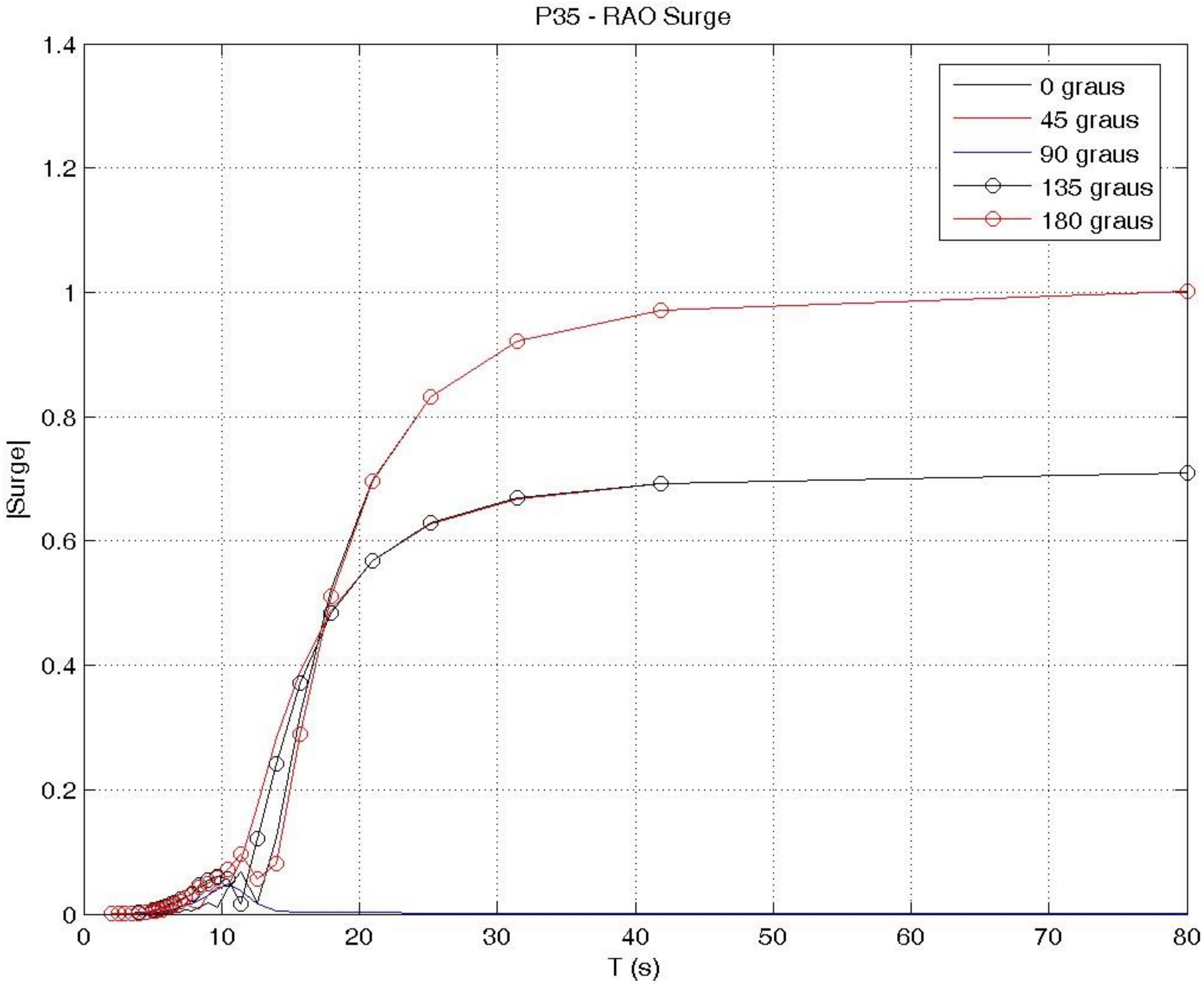
$$x_{jPO}(t,\beta_0)=\sum_{i=1}^{n}\sqrt{2S(\omega_i)RAO_j(\omega_i,\beta_0)^2\Delta\omega}\cos(\omega_i t+phase(RAO_j(\omega_i,\beta_0))+\phi_j)$$



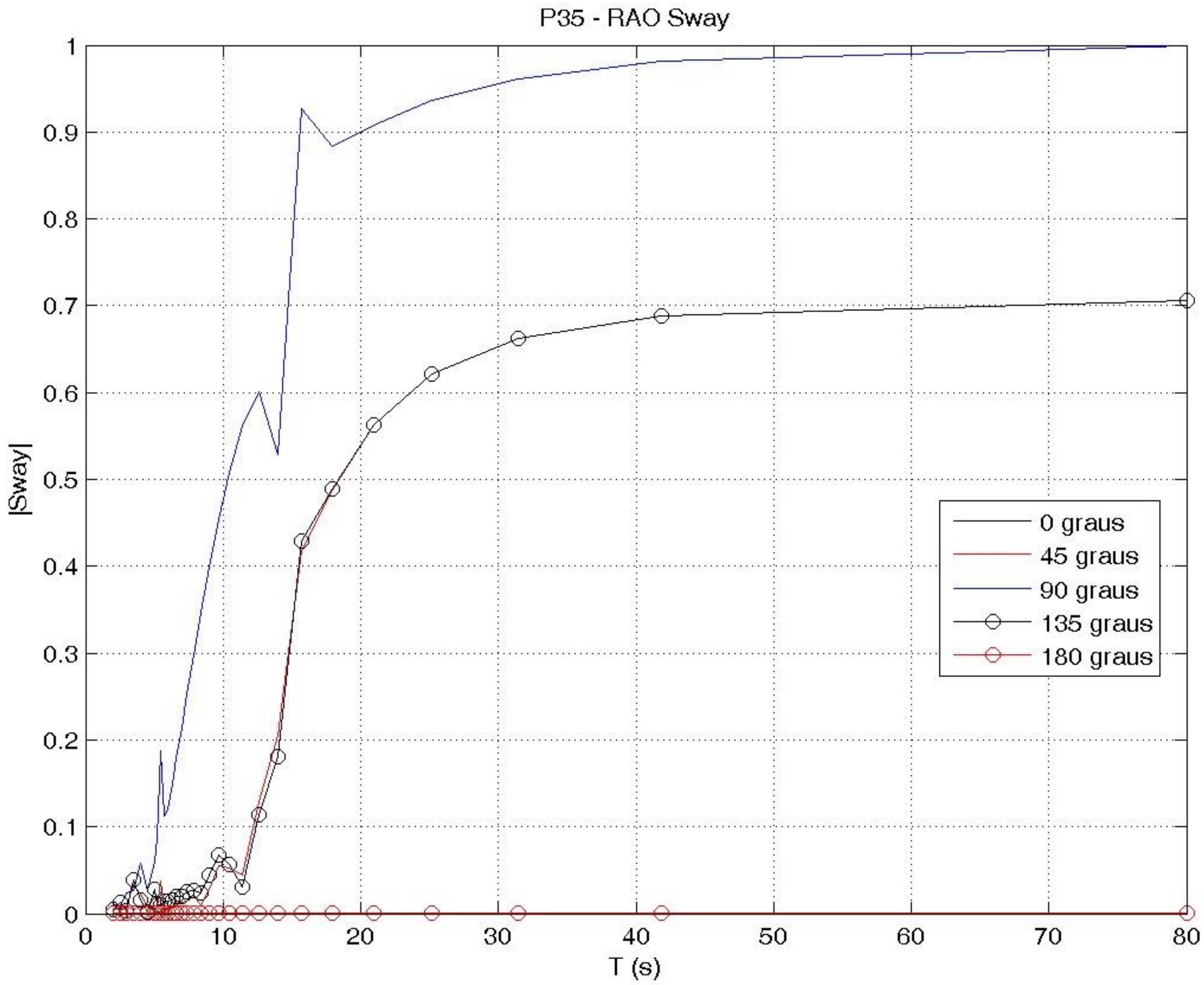
$$\left[x_{jPO}(t,\beta_0)\right]_{rms}=2\sqrt{\int_0^\infty S(\omega).RAO_j^{\,2}(\omega,\beta_0)d\omega}$$

$$\left[x_{jPO}(t,\beta_0)\right]_{\max}=1{,}866\times\left[x_{jPO}(t,\beta_0)\right]_{rms}$$

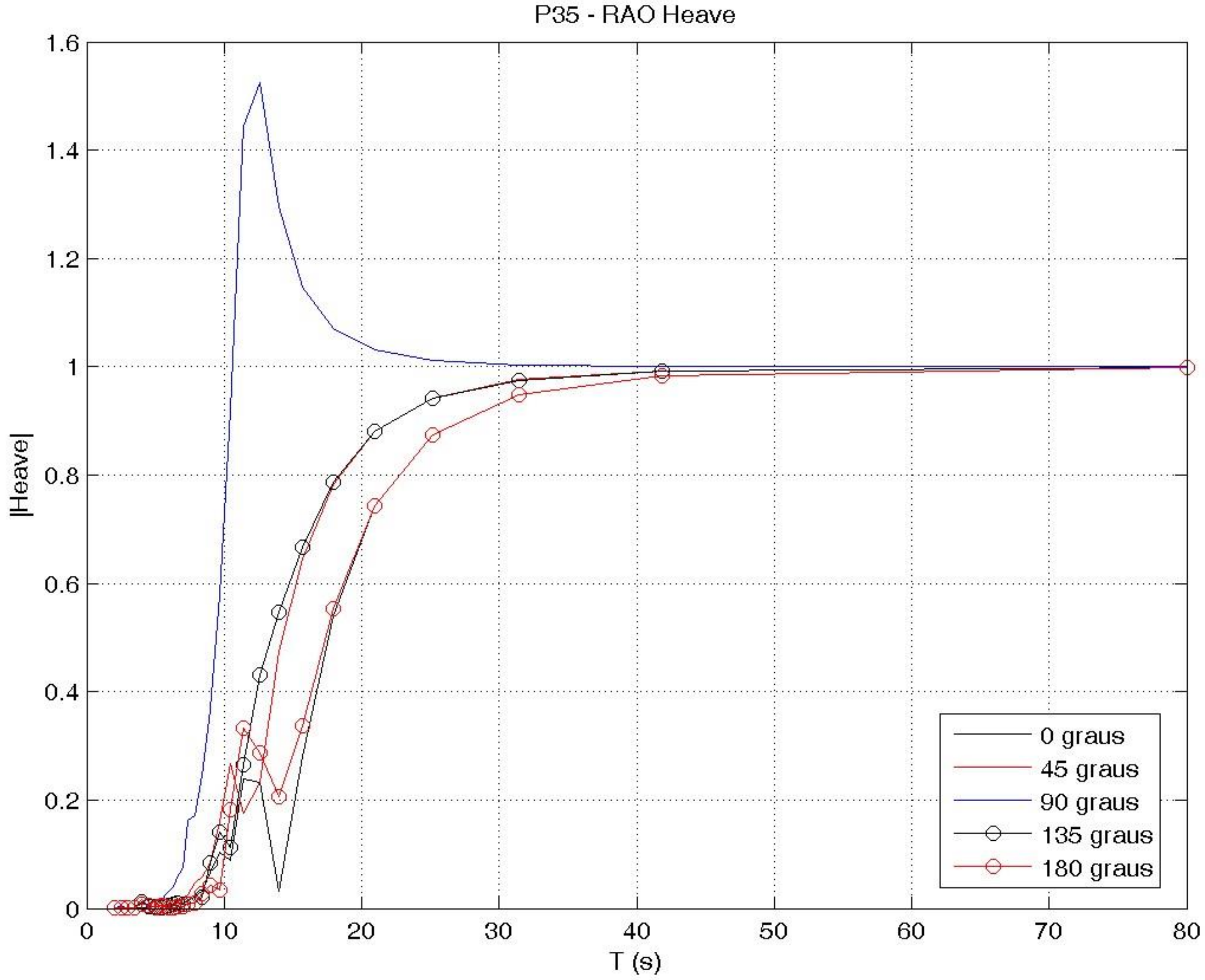
Typical RAO - Surge



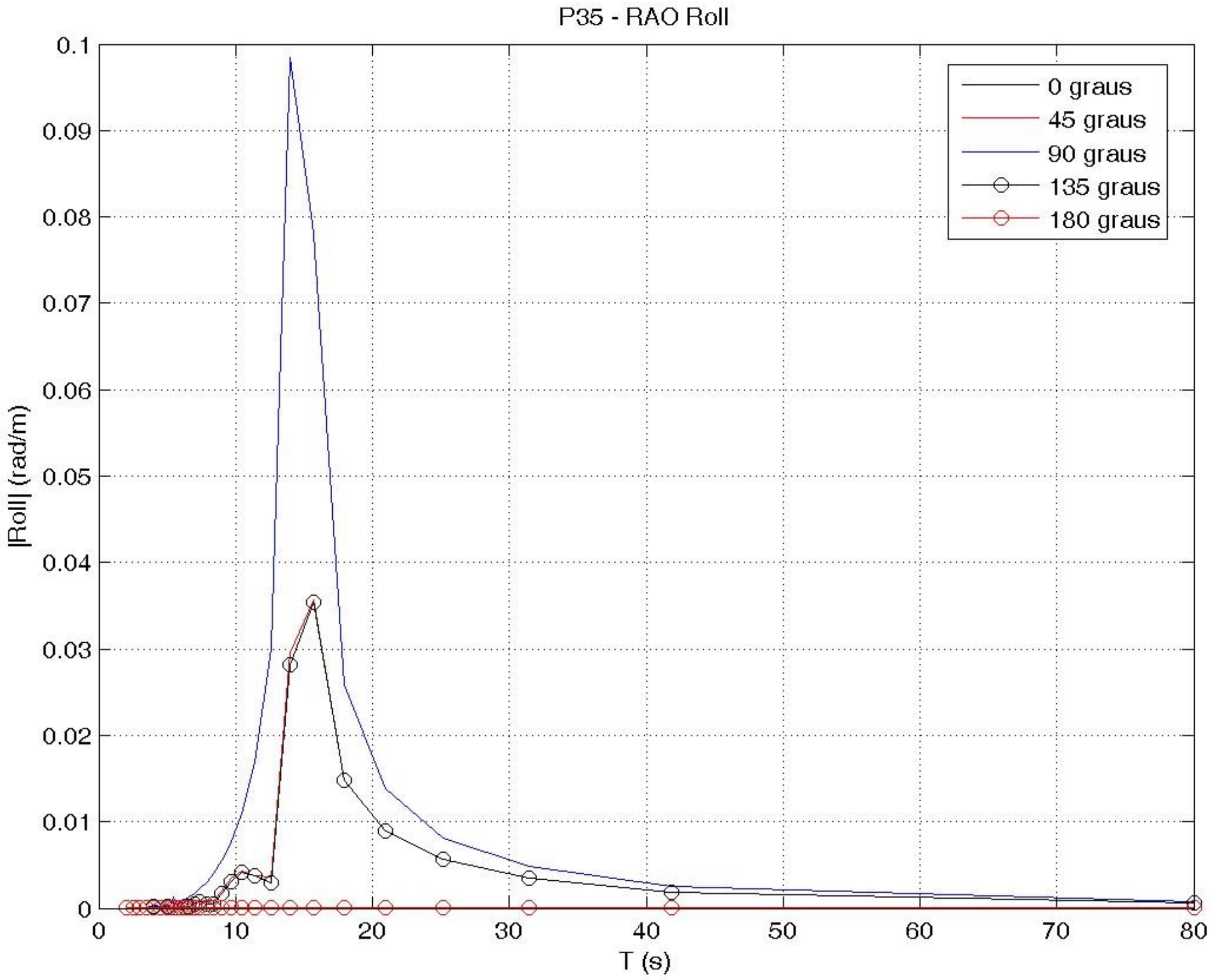
Typical RAO - Sway



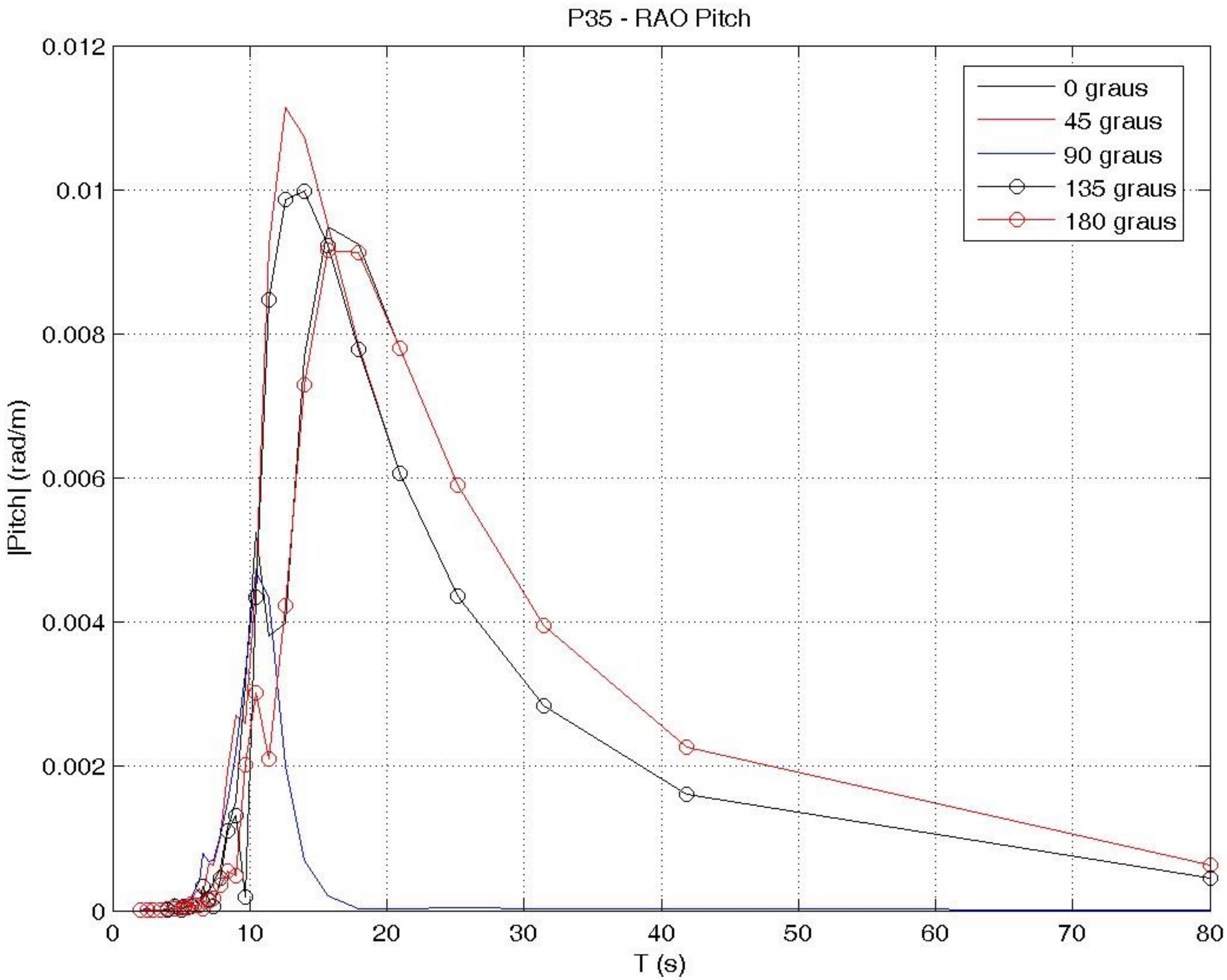
Typical RAO - Heave



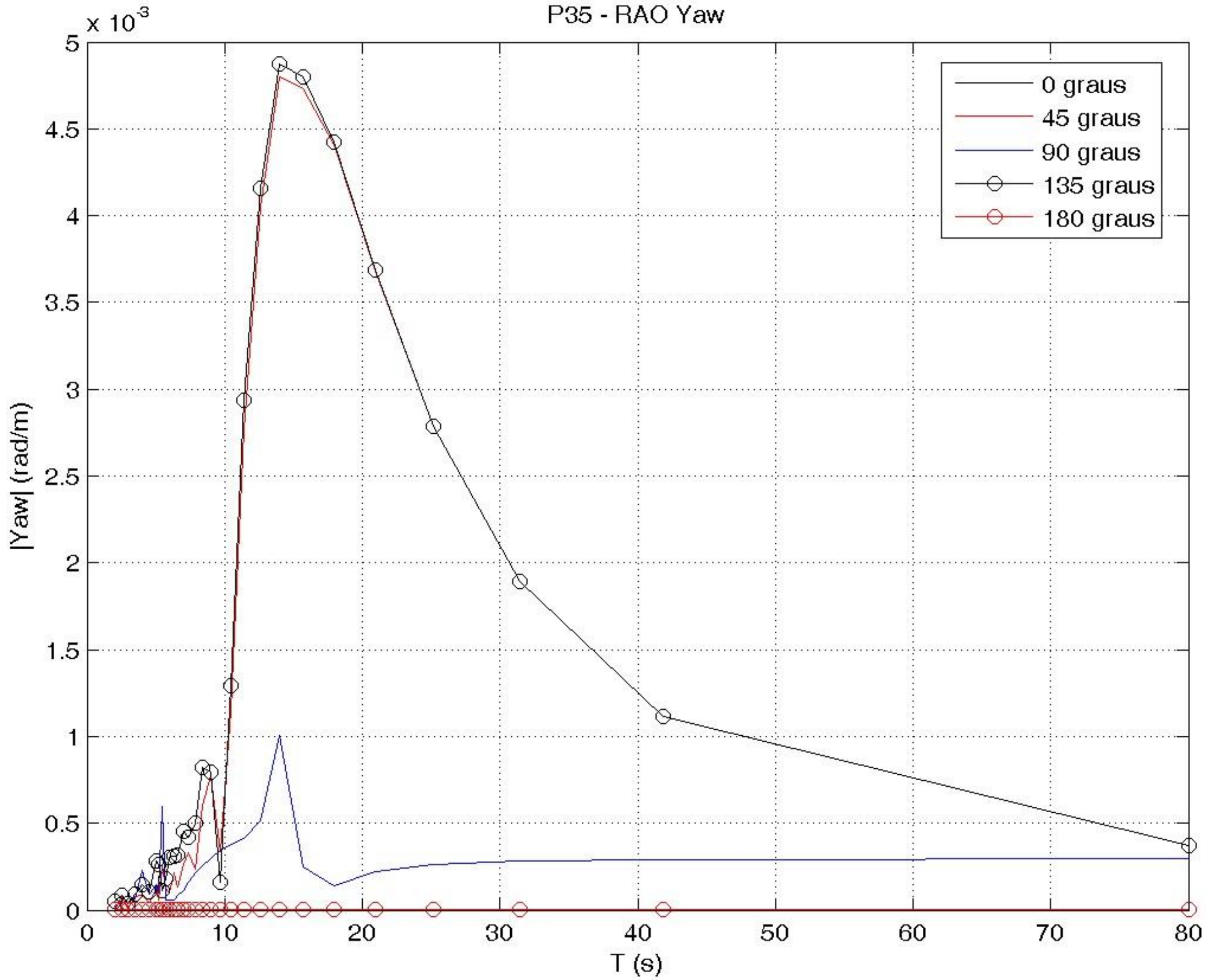
Typical RAO - Roll



Typical RAO - Pitch



Typical RAO - Yaw



Selection of Environmental Conditions

Facts

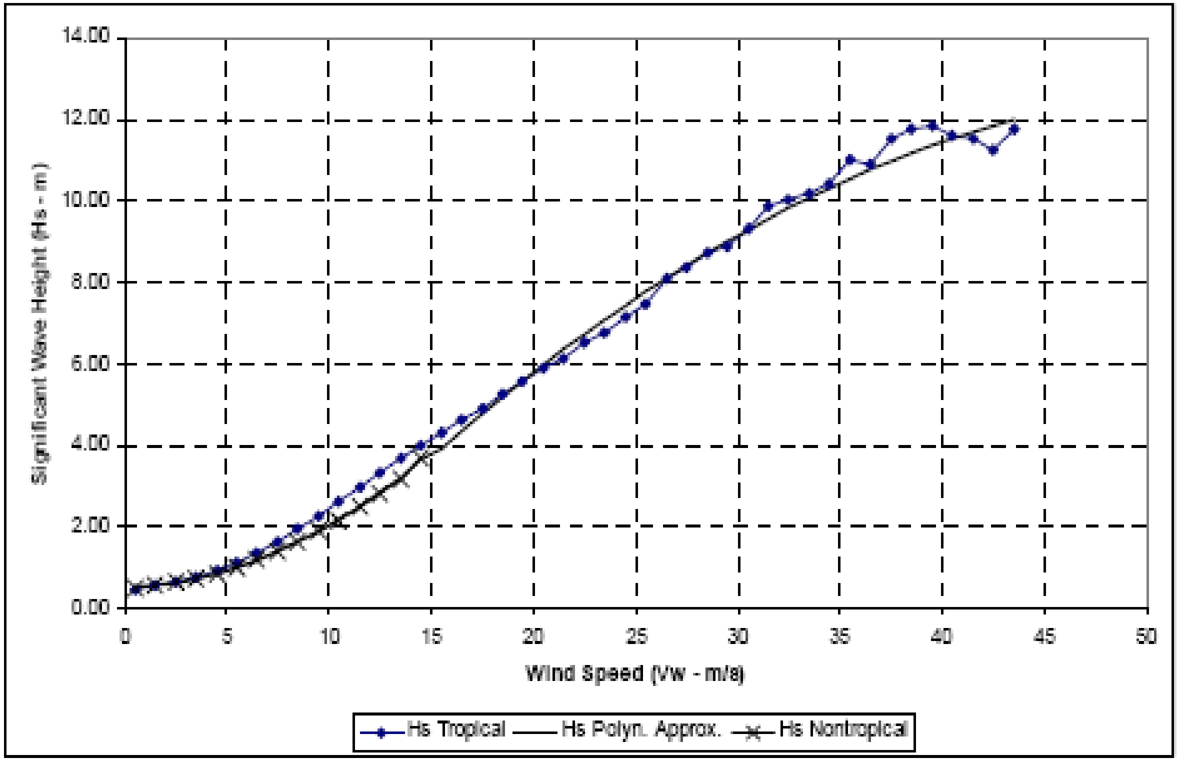
- Described by joint PDFs;
- Multi-directional seas;
- Huge number of combinations and incidences.

Enormous computational time, turning analysis procedures cumbersome

Approach

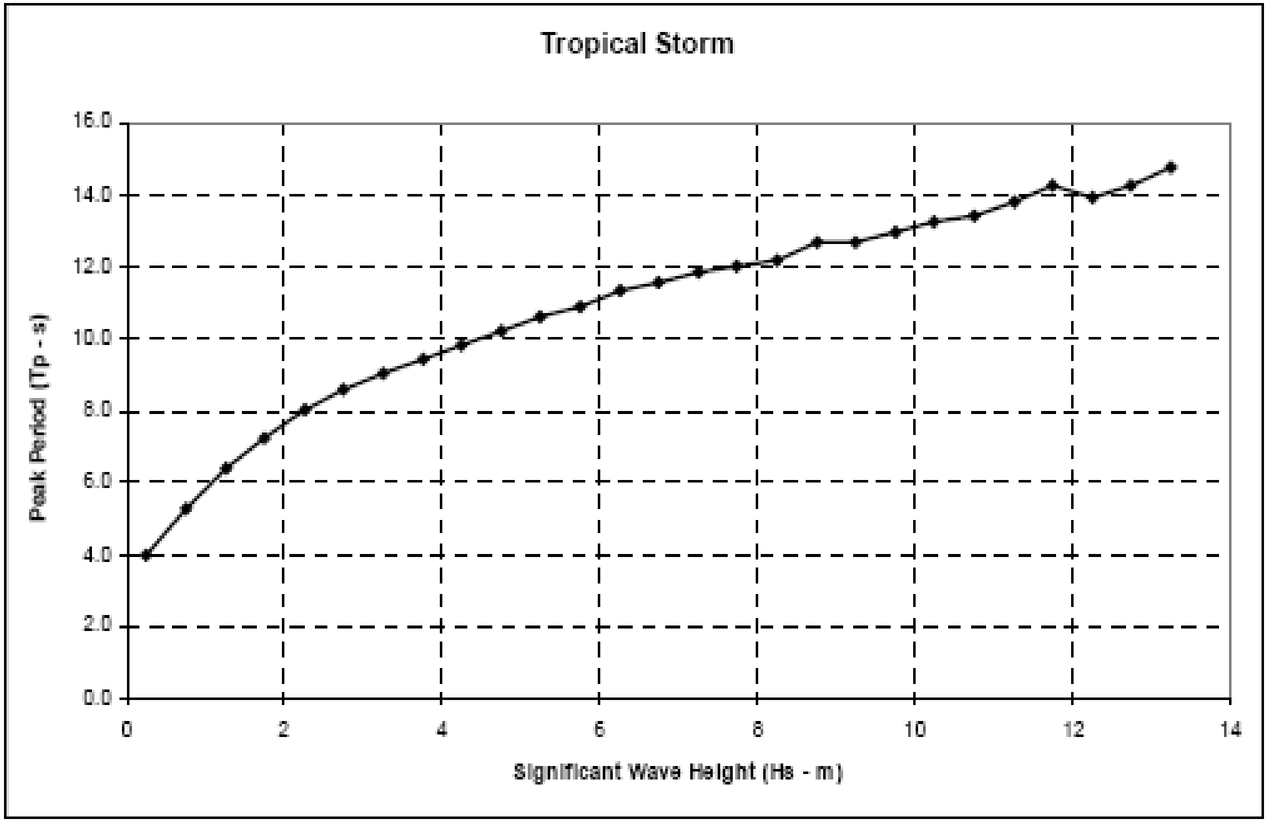
- Selection of a certain number of environmental combinations, related to the particular station keeping system (spread mooring, Turret, DP);
- Local sea – wind correlation;
- Prelimanry analysis in frequency domain
- Selected analysis cases in time domain.

Selection of Environmental Conditions



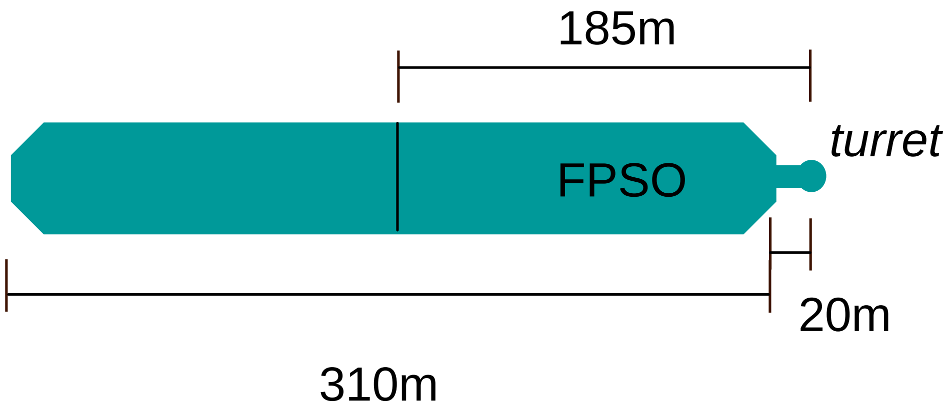
Relation between Significant Wave Height and Wind Speed

Selection of Environmental Conditions



Relation between peak period and significant wave height

Selection of Environmental Conditions



Depth: 1200m

100 year Storm:

Hs=7.2m

Hmax=13.9m

Tp=14.2s

100 year Current

V=1,95m/s at surface level

profile according to table 4

Shell-BC10

Sea States

Table 1. Independent Extreme Values for Wind and Wave

Preliminary analysis

Return Period	1 Year	5 Year	10 Year	100 Year
Hs (m)	4.1	5.4	5.8	7.2
Swell (m)	3.2	4.7	5.3	7.1
Seas (m)	3.2	4.6	5.1	6.6
Hmax (m)	7.7	10.3	11.2	13.9
Wind Speed (m/s) 10m, 1-hour	13.0	15.9	16.8	19.1

Table 2. Global Response Test Sea States

Lazy-wave extreme conditions analysis

Parameter	100 Year Sea	100 Year Swell	100 Year Current
Swell Hs (m)	5.3	7.1	5.3
Swell Tp (sec)	15	17.2	15
Sea Hs (m)	6.6	5.1	5.1
Sea Tp (sec)	13.5	11.2	11.2
Full Hs (m)	7.2	7.2	5.8
Full Tp (sec)	14.2	14.2	13.4
Wind Speed (m/s) 10m, 1- hour	19	16.8	16.8
Current (m/s)	10 Year	10 Year	100 Year
JONSWAP Gamma	2.5	1.6	2

Current Profile

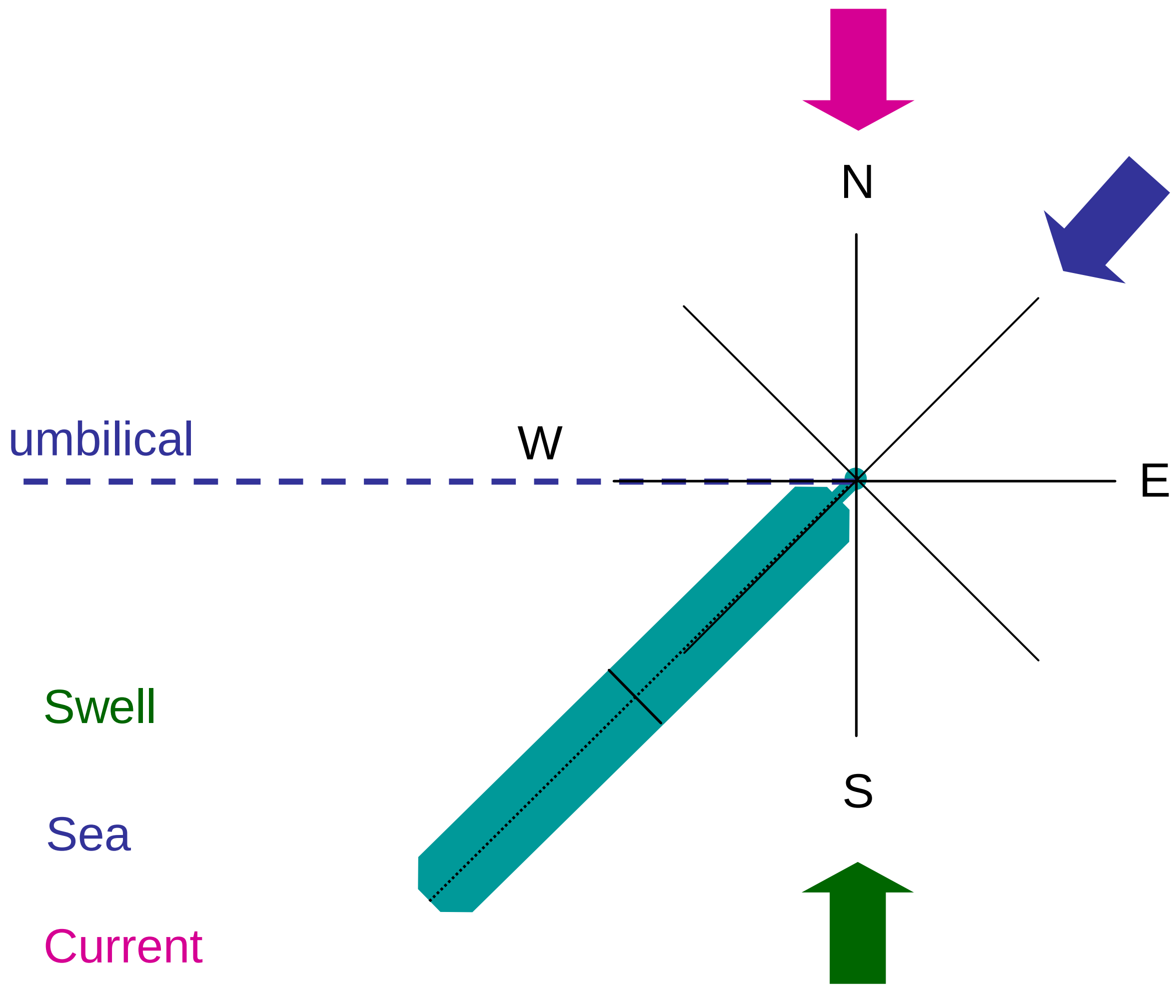
Table 3. Extreme Current Profiles for 90°-225°

	Return Period Profiles for Directions 90°-225°									
	95%		1-year		5-year		10-year		100-year	
Depth (m)	v_{il} (m/s)	v_{ol} (m/s)	v_{il} (m/s)	v_{ol} (m/s)	v_{il} (m/s)	v_{ol} (m/s)	v_{il} (m/s)	v_{ol} (m/s)	v_{il} (m/s)	v_{ol} (m/s)
0	0.81	0.00	1.28	0.00	1.52	0.00	1.62	0.00	1.95	0.00
20	0.80	0.00	1.26	0.00	1.50	0.00	1.60	0.00	1.92	0.00
40	0.78	0.00	1.23	0.00	1.47	0.00	1.57	0.00	1.88	0.00
60	0.77	0.00	1.21	0.00	1.44	0.00	1.54	0.00	1.85	0.00
80	0.74	0.00	1.17	0.00	1.39	0.00	1.48	0.00	1.78	0.00
100	0.70	0.00	1.10	0.00	1.31	0.00	1.40	0.00	1.68	0.00
150	0.40	0.03	0.63	0.05	0.75	0.05	0.80	0.06	0.96	0.07
200	0.24	0.05	0.37	0.08	0.44	0.09	0.47	0.10	0.57	0.12
300	0.12	0.05	0.20	0.08	0.23	0.09	0.25	0.10	0.30	0.12
400	-0.03	0.12	-0.03	0.12	-0.03	0.12	-0.03	0.12	-0.03	0.12
500	-0.07	0.20	-0.07	0.20	-0.07	0.20	-0.07	0.20	-0.07	0.20
600	-0.25	0.18	-0.25	0.18	-0.25	0.18	-0.25	0.18	-0.25	0.18
1200	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.15	-0.10	-0.20	-0.10

Table 4. Extreme Current Profiles for 0°-90°

	Return Period Profiles for Directions 0°-90°									
	95%		1-year		5-year		10-year		100-year	
Depth (m)	v_{il} (m/s)	v_{ol} (m/s)	v_{il} (m/s)	v_{ol} (m/s)	v_{il} (m/s)	v_{ol} (m/s)	v_{il} (m/s)	v_{ol} (m/s)	v_{il} (m/s)	v_{ol} (m/s)
0	0.30	0.00	1.16	0.00	1.52	0.00	1.62	0.00	1.95	0.00
20	0.30	0.00	1.14	0.00	1.50	0.00	1.60	0.00	1.92	0.00
40	0.30	0.00	1.12	0.00	1.47	0.00	1.57	0.00	1.88	0.00
60	0.30	0.00	1.10	0.00	1.44	0.00	1.54	0.00	1.85	0.00
80	0.30	0.00	1.06	0.00	1.39	0.00	1.48	0.00	1.78	0.00
100	0.30	0.00	1.00	0.00	1.31	0.00	1.40	0.00	1.68	0.00
150	0.30	0.00	0.83	0.00	1.08	0.00	1.16	0.00	1.39	0.00
200	0.30	-0.06	0.65	-0.12	0.86	-0.16	0.92	-0.17	1.10	-0.20
400	0.30	0.08	0.37	0.08	0.48	0.10	0.52	0.11	0.62	0.13
525	0.30	0.13	0.30	0.13	0.30	0.13	0.30	0.13	0.30	0.13
1200	0.10	0.10	0.10	0.10	0.10	0.10	0.15	0.10	0.20	0.10

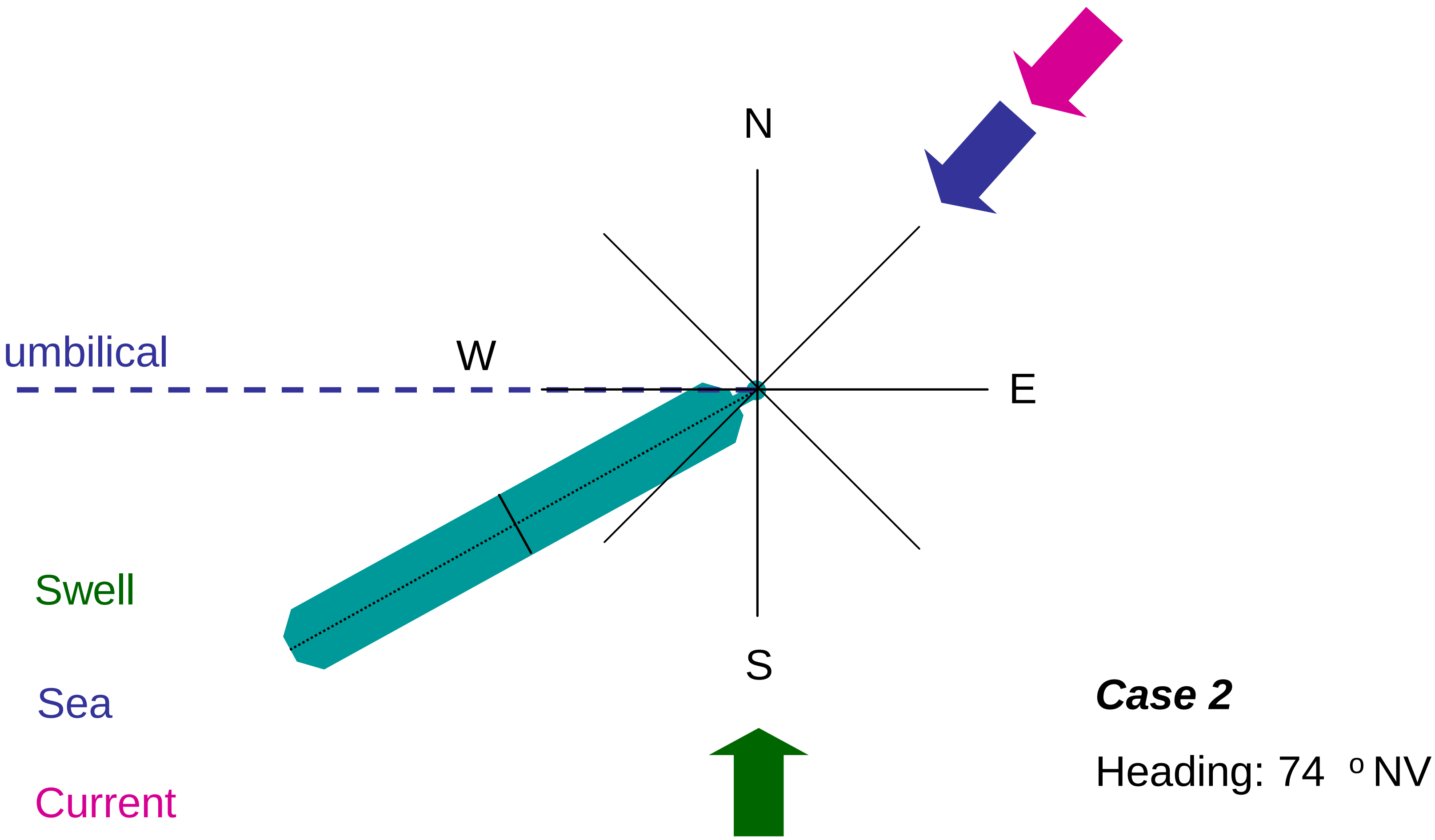
Preliminary Study: 60 Cases



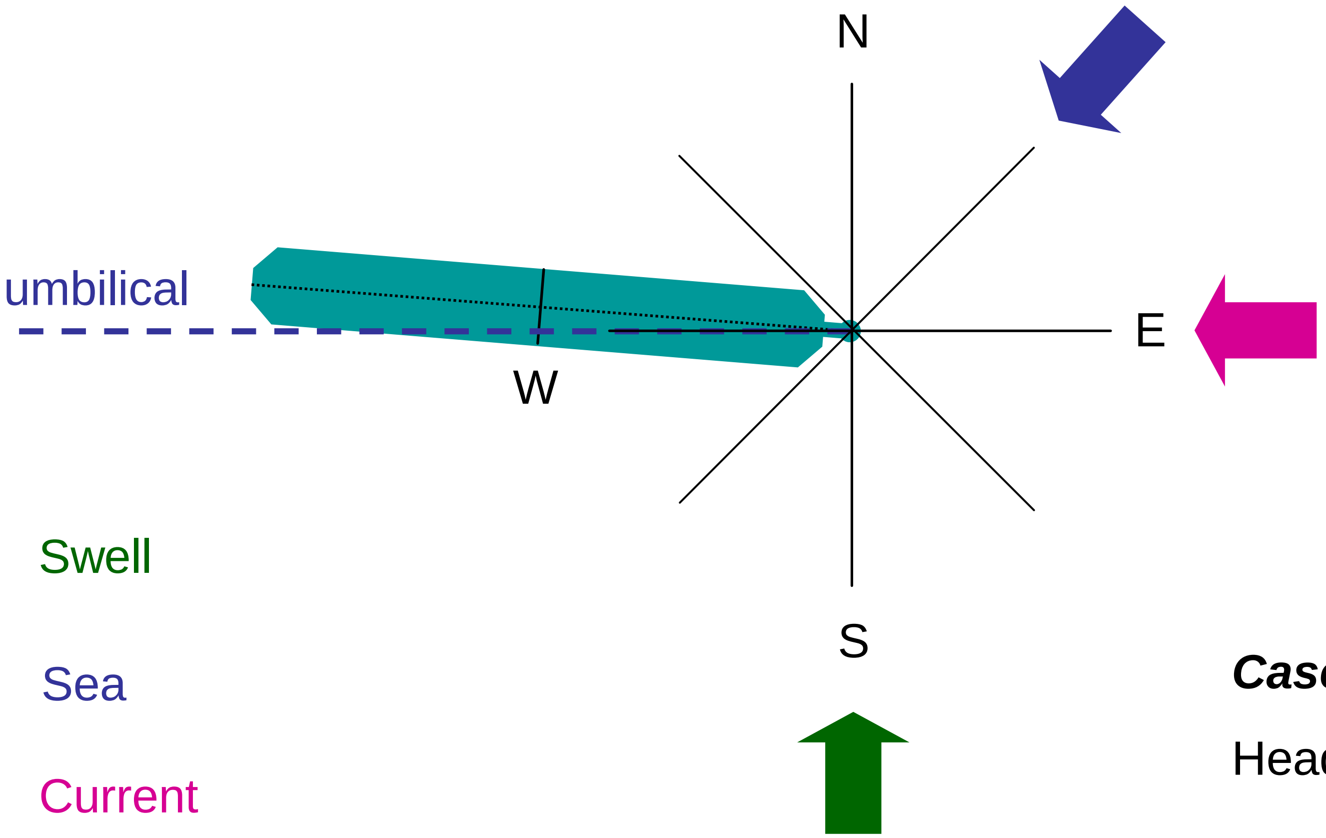
Case 1

Heading: 45^{o} NV

Preliminary Study: 20 Cases



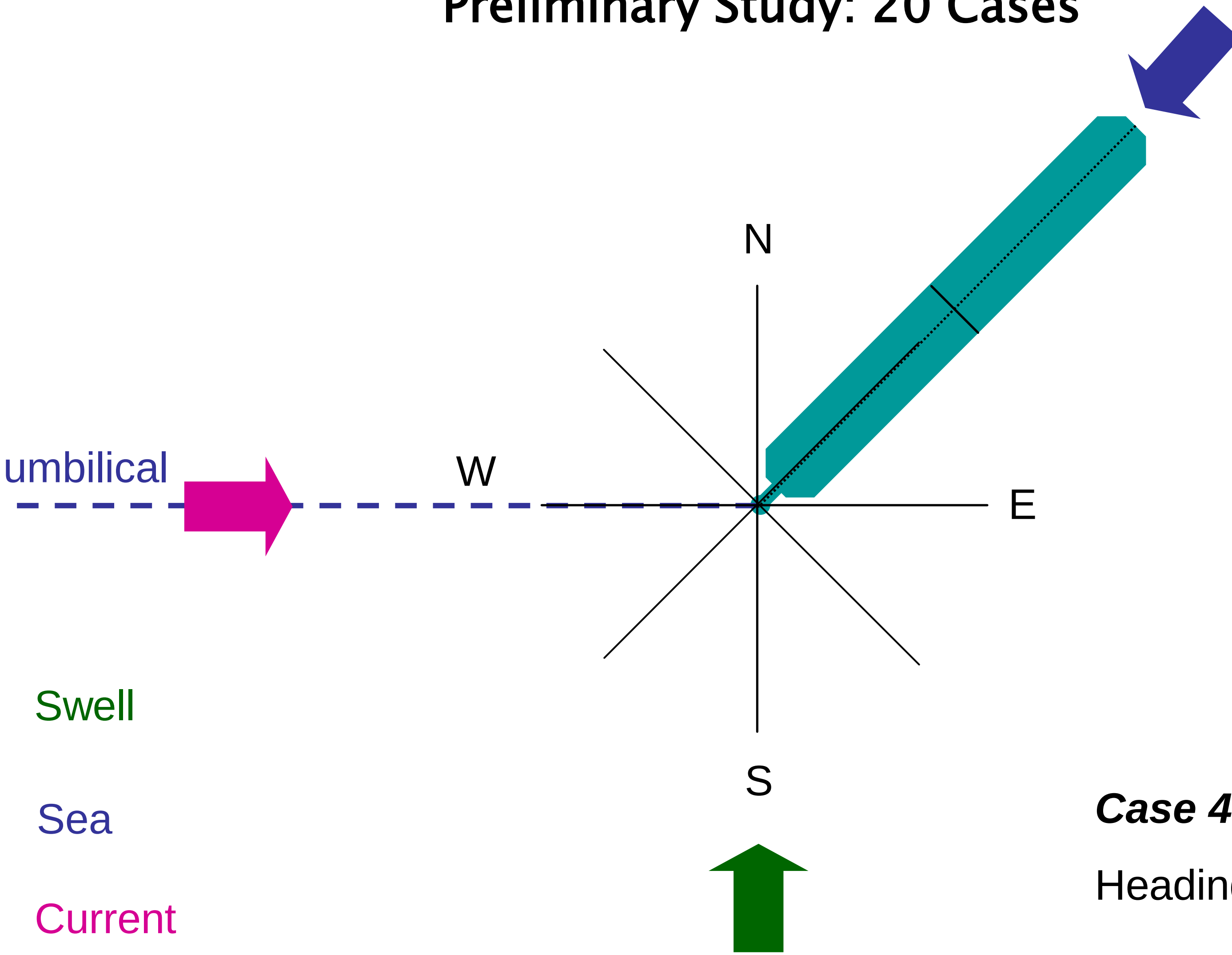
Preliminary Study: 20 Cases



Case 3

Heading: 100º NV

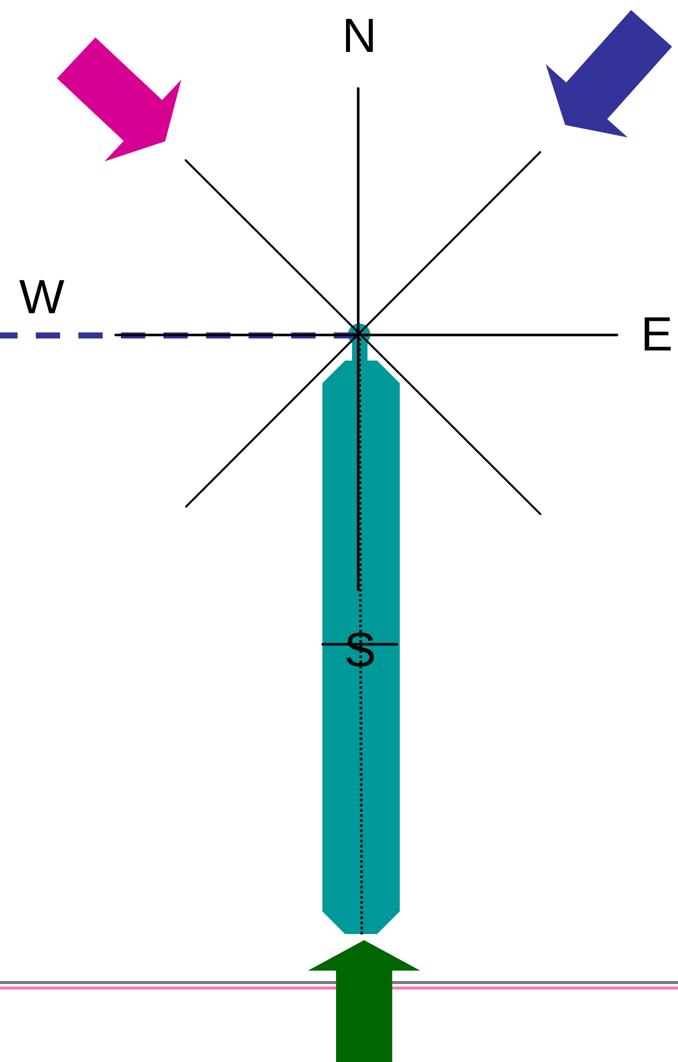
Preliminary Study: 20 Cases



Case 4

Heading: 225º NV

Preliminary Study: 20 Cases



umbilical

Swell

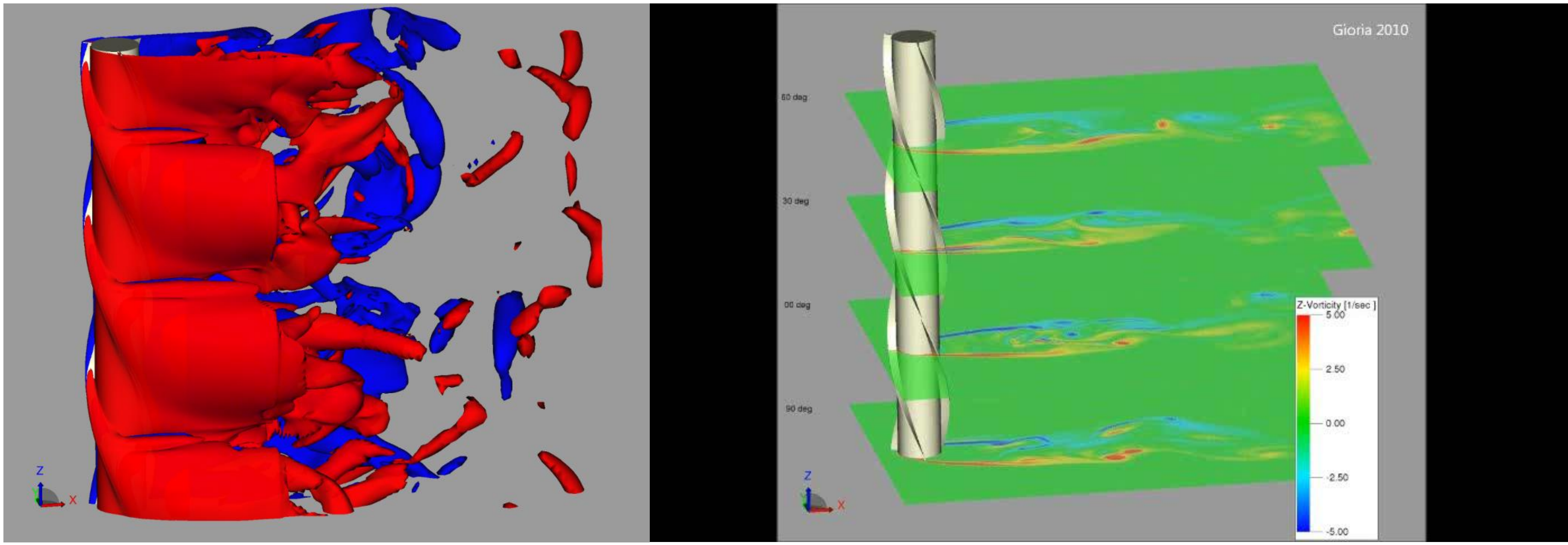
Sea

Current

Case 5

Heading: 0 º NV

VIV



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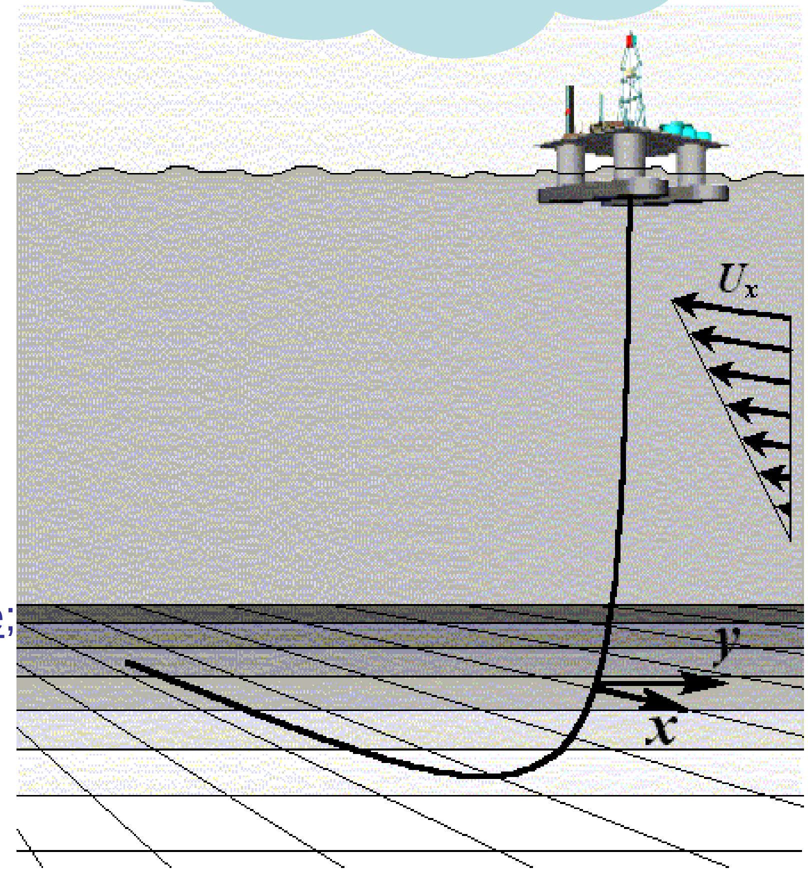
VIV

Less important to flexible pipes and umbilical, due to high structural damping

- Fundamental findings and their impact in riser dynamics:
  - Reynolds number dependence;
  - mass ratio dependence;
  - effect of coupled stream and cross-wise vibrations and bifurcations of shedding patterns;
  - persistent vibration at high reduced velocities at very low mass ratio.
- Still challenging riser dynamics:
  - multi-modal (in and out-of-plane) simultaneous excitation in sheared flow.
  - curvature effects;
  - stream and cross-wise sub-harmonic resonance;
  - coupling of VIV with dynamics in other time-scales;
  - VSIV – VIV induced by FPU motions
  - supressors and hydrodynamic loading.



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