SÃO PAULO SCHOOL OF ADVANCED SCIENCES ON
NONLINEAR DYNAMICS
São Paulo, July 29th - August 9th, 2019

A REDUCED ORDER MODEL IN OCEAN ENGINEERING DYNAMICS

Module 28

Professor Celso P. Pesce

ceppesce@usp.br

University of São Paulo

with collaboration of

Dr. Guilherme R. Franzini, Associate Prof.

Dr. Renato M.M. Orsino, Assistant Prof.

ESCOLA POLITÉCNICA DA UNIVERSIDADE DE SÃO PAULO

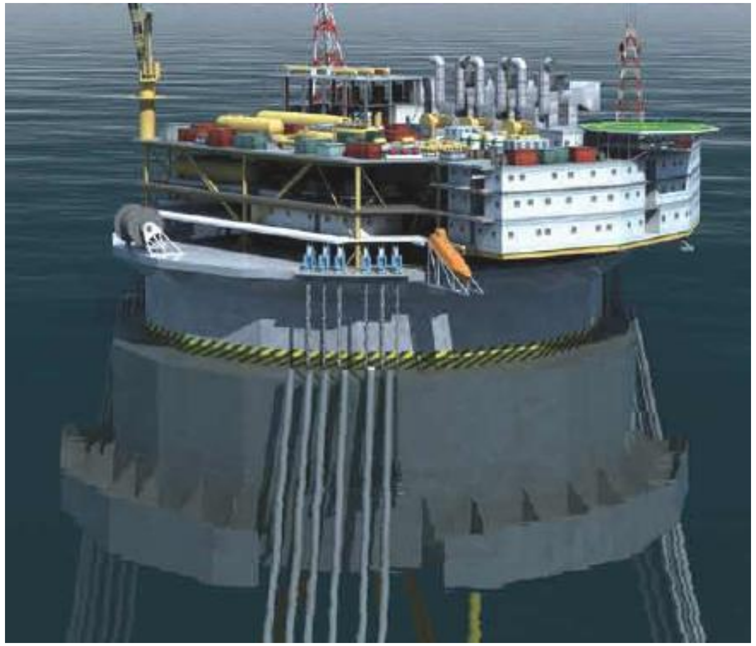
FAPESP

SUMMARY

1. Analytical Model for Mooring forces on the Horizontal Plane

2. Current Induced Motions of a moored mono-column platform

MONOCOLUMN PLATFORMS



MonoBR-GoM
with a moon-pool
(Nishimoto et al, 2010)

Sevan Marine Co.
Up: FPSO Sevan Hummingbird.
Bottom: FPSO Sevan Piranema
(Gonçalves et al, 2010b)

MONOBR – TRAJECTORIES AND DYNAMIC RESPONSE

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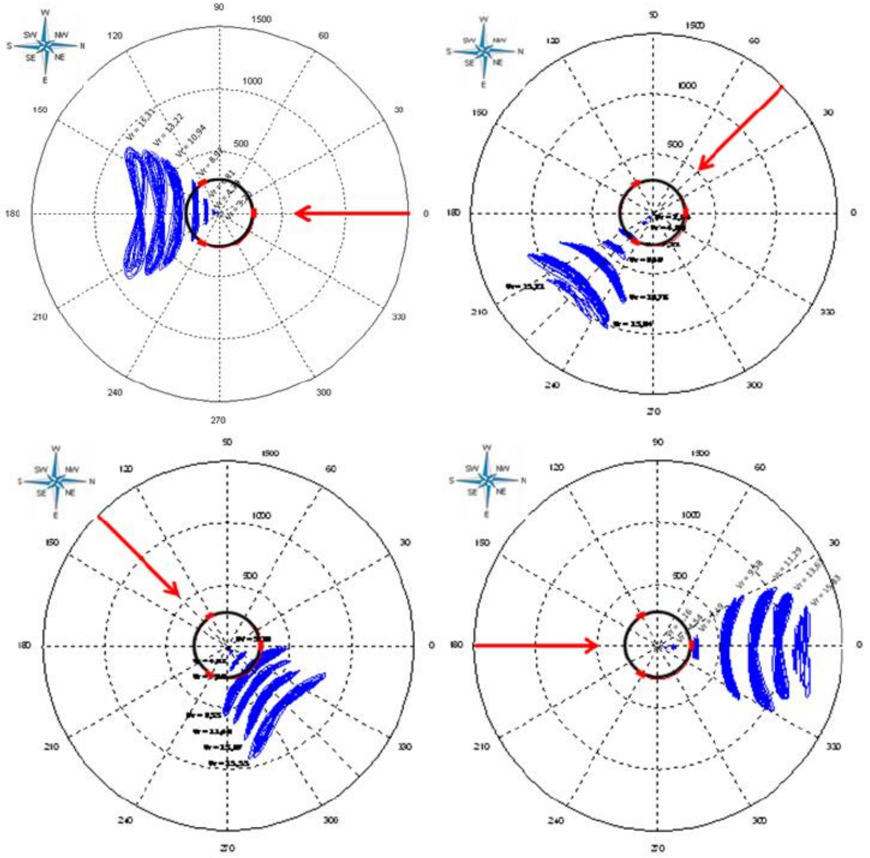
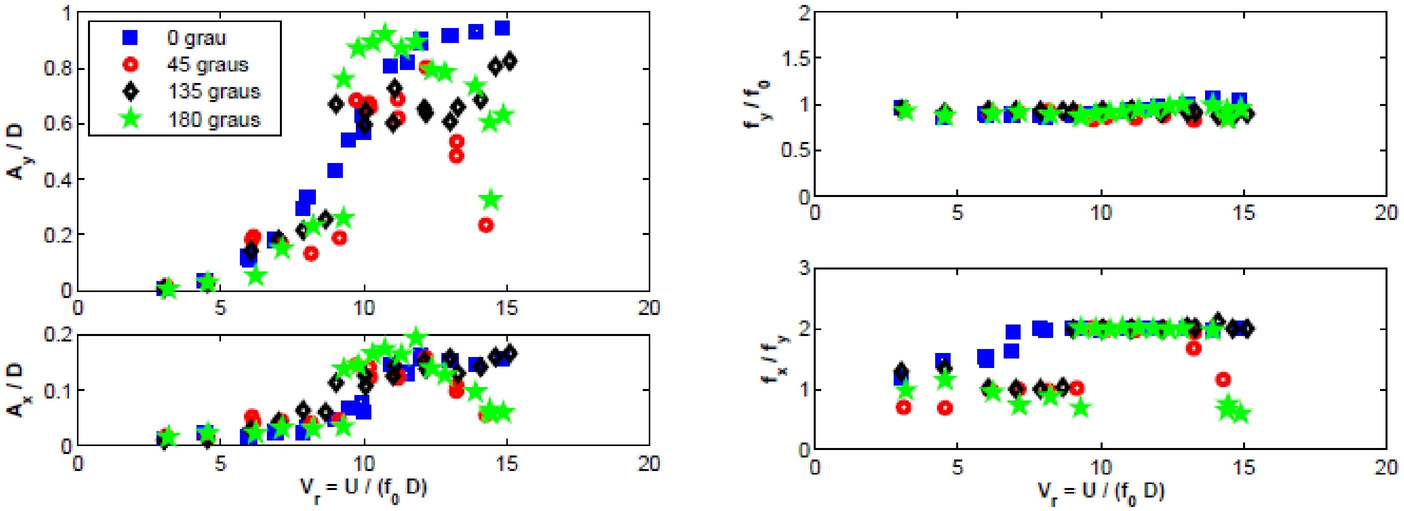
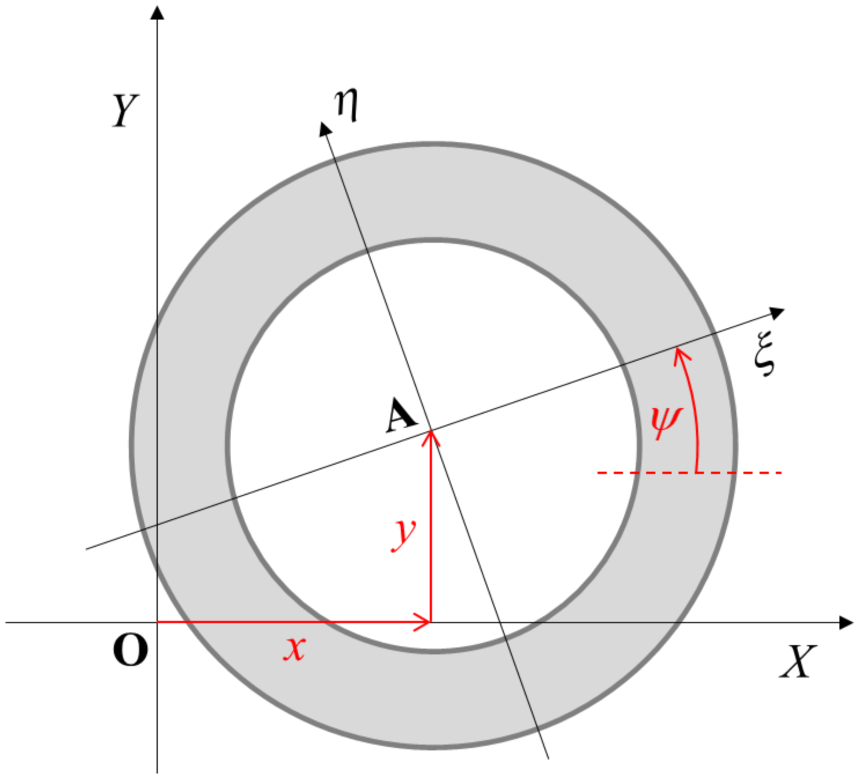




MonoBR, Experimental data
Gonçalves, R.T., PhD Thesis, 2013;
Gonçalves et al 2010, J Offshore Mech and Arctic Engineering

REDUCED ORDER MODEL ON THE HORIZONTAL PLANE



$$A \equiv G$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\mathbf{q}}}\right) - \frac{\partial T}{\partial \mathbf{q}} = \mathbf{Q}^m + \mathbf{Q}^v$$ Usual Lagrange Equations

$$\mathbf{q} = \begin{bmatrix} x & y & \psi \end{bmatrix}^T$$ Generalized coordinates

$$\mathbf{Q}^m = \left[Q_j^m \right]$$ Mooring system generalized forces

$$\mathbf{Q}^v = \left[Q_j^v \right]; \quad j = 1,2,3$$ Generalized viscous hydrodynamic forces due to the incident current

EQUATIONS OF MOTION

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$$T = \frac{1}{2}\dot{\mathbf{q}}^T \mathbf{M}\dot{\mathbf{q}}$$

In the general case, the mass matrix is a full matrix, such that the generalized coordinates couple inertially. In this case, however,

$$\mathbf{M} = \mathbf{M}_p + \mathbf{M}_a = \begin{bmatrix} M_p & 0 & 0 \\ 0 & M_p & 0 \\ 0 & 0 & I_p \end{bmatrix} + \begin{bmatrix} M_a & 0 & 0 \\ 0 & M_a & 0 \\ 0 & 0 & I_a \end{bmatrix}$$

Assuming the body axisymmetric with respect to a vertical axis, Gz, so that $\boldsymbol{M}$ is invariant w.r.t. the rotation ψ

$$M_a = C_a\left(\rho\frac{\pi D^2}{4}H\right) + M_{mp}; \quad I_a = 0$$

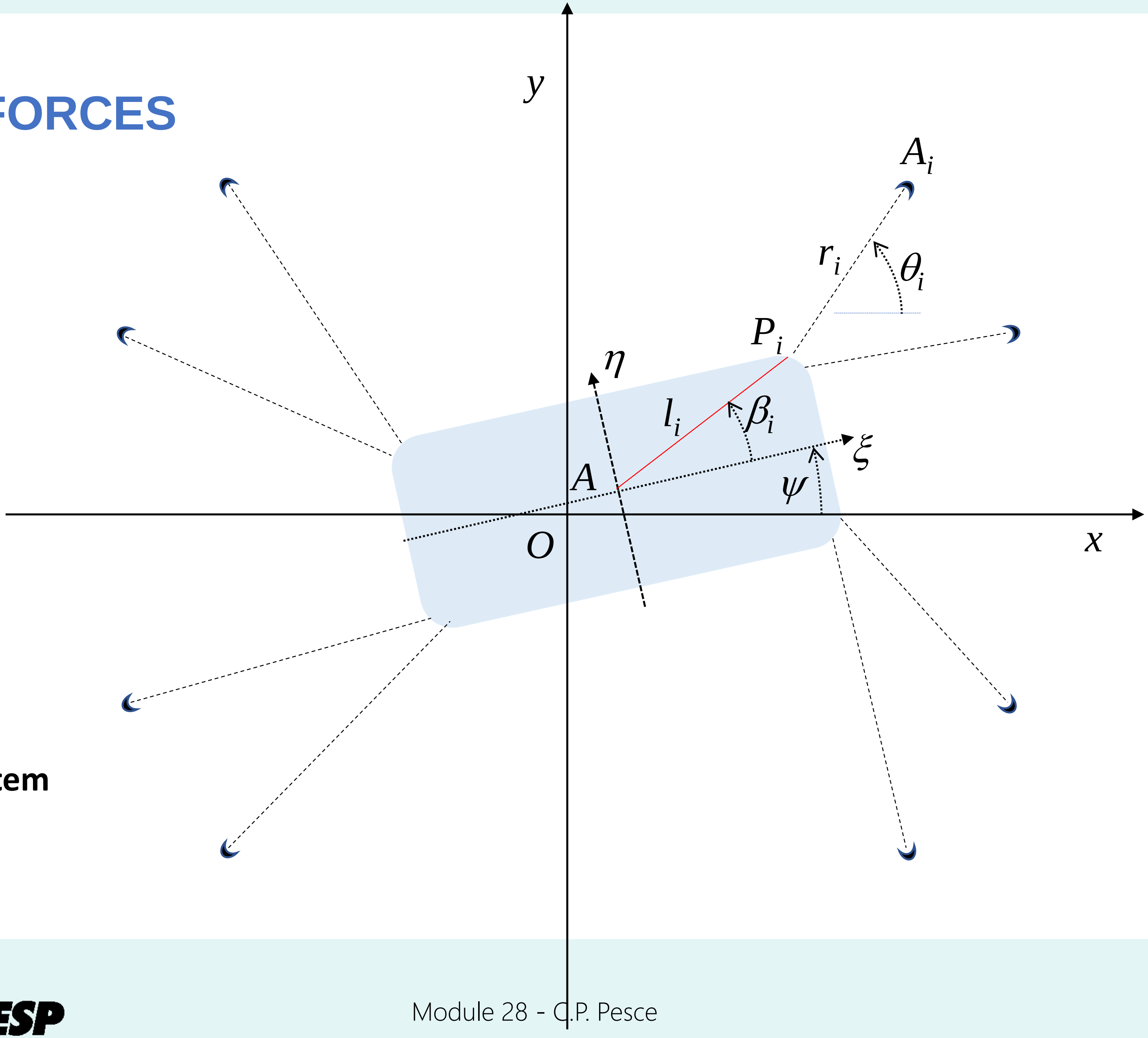
Added mass coefficients at very low frequencies

M_{mp} Mass of water inside the moon-pool is **considered constant**

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\mathbf{q}}}\right) - \frac{\partial T}{\partial \mathbf{q}} = \mathbf{Q}^m + \mathbf{Q}^v \quad \Rightarrow \quad \boxed{\mathbf{M}\ddot{\mathbf{q}} = \mathbf{Q}^m + \mathbf{Q}^v}$$

Neglecting second-order inertial terms

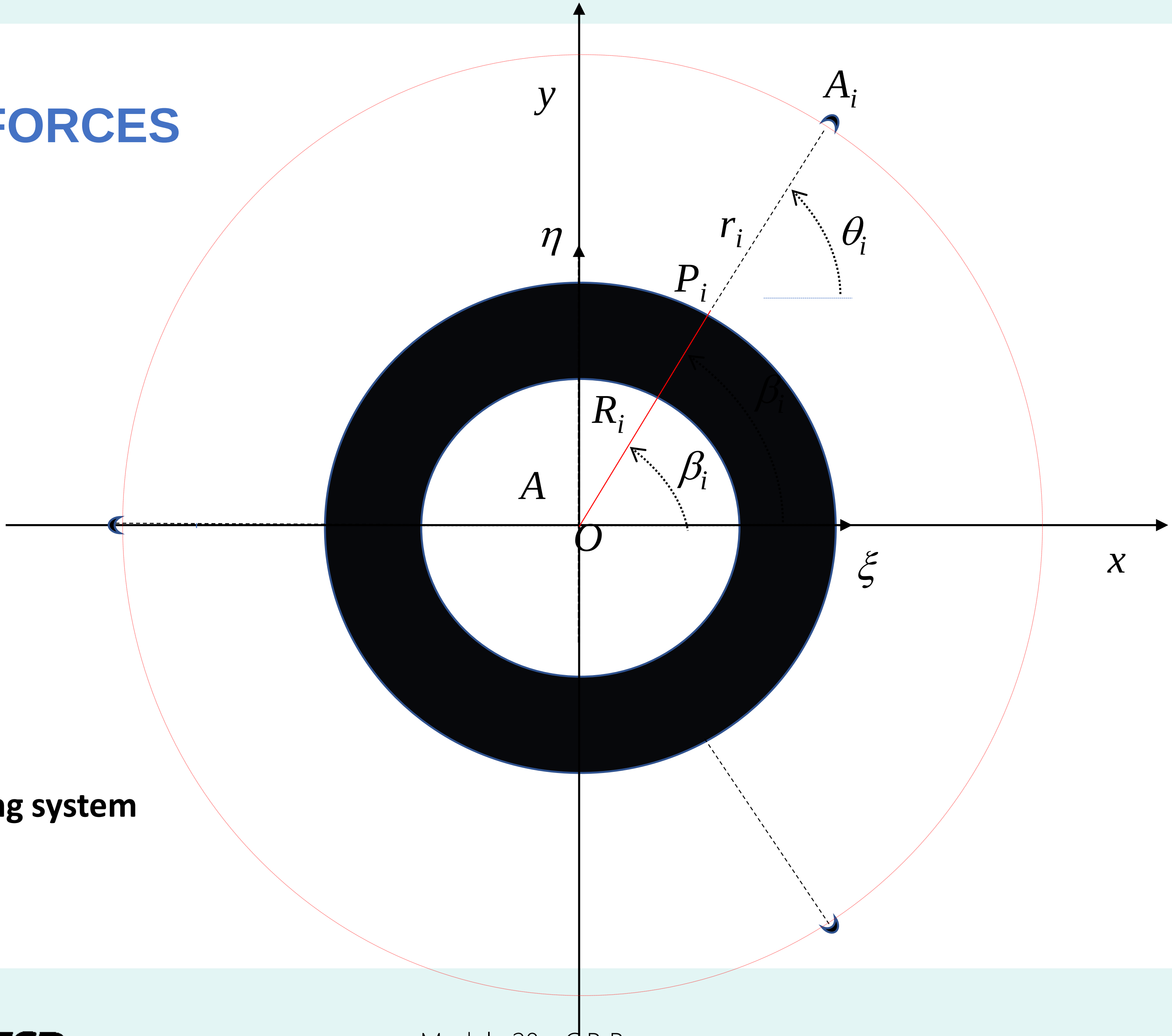
MOORING FORCES



Generic mooring system

MOORING FORCES

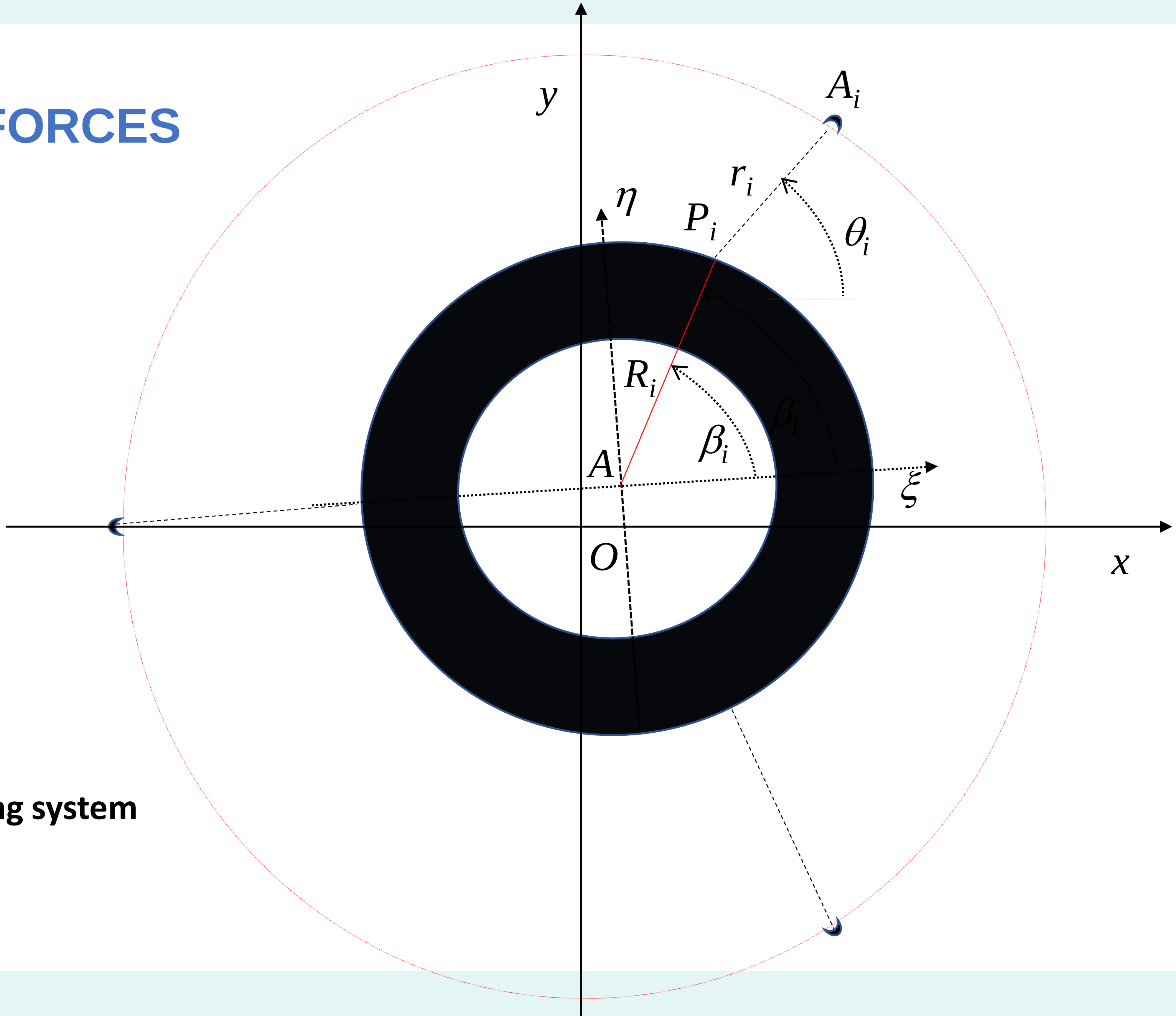
Horizontal plane projection



Monocolumn mooring system

MOORING FORCES

Horizontal plane projection



Monocolumn mooring system

GENERALIZED NONLINEAR MOORING FORCES ON THE HORIZONTAL PLANE

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$$Q_j^m = \sum_{i=1}^{N} \mathbf{F}_i^T \frac{\partial \mathbf{P}_i}{\partial q_j} = \sum_{i=1}^{N} f_i(r_i)\mathbf{e}_i^T \frac{\partial \mathbf{P}_i}{\partial q_j}; \quad j = 1,2,3; \quad i = 1,..,N$$

$$\mathbf{F}_i = \mathbf{F}_i(r_i) = f_i(r_i)\mathbf{e}_i; \quad i = 1,..,N$$

Horizontal mooring line force function

$$\mathbf{e}_i = \frac{(\mathbf{A}_i - \mathbf{P}_i)}{|\mathbf{A}_i - \mathbf{P}_i|} = \frac{(\mathbf{A}_i - \mathbf{P}_i)}{r_i} = [\cos\theta_i \quad \sin\theta_i]^T; \quad i = 1,..,N$$

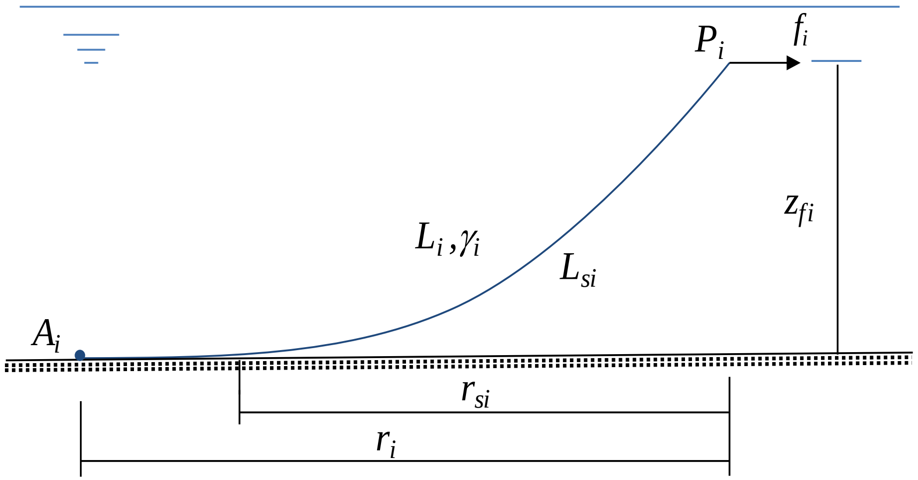
Mooring line unit director vector

$$\mathbf{P}_i = [x + R_i \cos(\psi + \beta_i) \quad y + R_i \,\mathrm{sen}(\psi + \beta_i)]^T$$

Fairlead position, for each mooring line

CATENARY MOORING LINES ON A FRICTIONLESS SEABED

$$\frac{r_i(f_i)}{L_i} = 1 - \frac{f_i}{\gamma_i L_i}\left[\left(\frac{1+2\,f_i/\gamma_i z_{fi}}{\left(f_i/\gamma_i z_{fi}\right)^2}\right)^{\frac{1}{2}} - \ln\left(1 + \frac{\gamma_i z_{fi}}{f_i} + \left(\frac{1+2\,f_i/\gamma_i z_{fi}}{\left(f_i/\gamma_i z_{fi}\right)^2}\right)^{\frac{1}{2}}\right)\right]$$



γ_i Mooring line linear immersed weight

L_i Mooring line total length

z_{fi} Distance from fairlead to sea bottom

GENERALIZED LINEAR MOORING FORCES: LOCAL STIFFNESS MATRIX

$$\mathbf{Q}^m = \mathbf{Q}^m(\mathbf{q};\Pi)$$ Generalized mooring forces

$$\mathbf{q} = \begin{bmatrix} x & y & \psi \end{bmatrix}^T$$ Generalized coordinates

$$\Pi = \left\{ \begin{pmatrix} \mathbf{A}_i & R_i & \beta_i \end{pmatrix}; i = 1,..,N \right\}$$ Geometric parameters

LOCAL STIFFNESS MATRIX

$$\mathbf{K}(\mathbf{q};\Pi,\bar{\mathbf{q}}) = -\left[\frac{\partial Q_j}{\partial q_k}\right]_{\mathbf{q}=\bar{\mathbf{q}}}$$

$$\Rightarrow$$

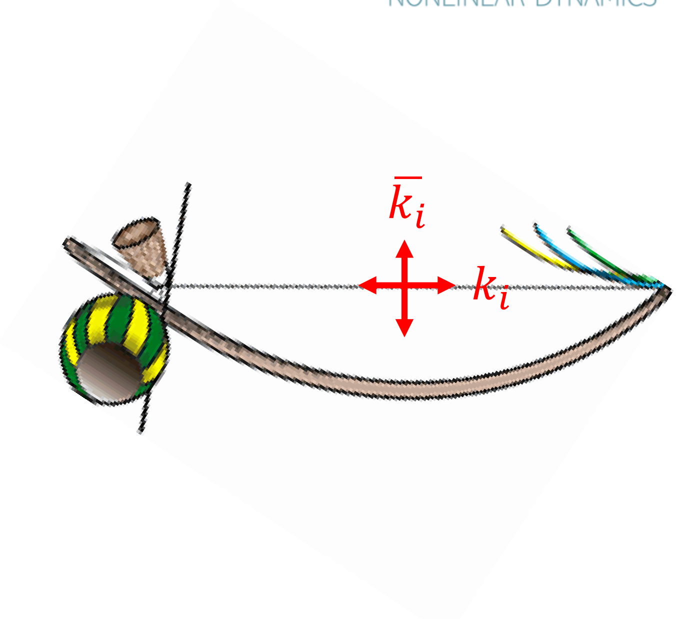
$$\mathbf{K}(\mathbf{q};\Pi,\bar{\mathbf{q}}) = \begin{bmatrix} k_{xx} & k_{xy} & k_{x\psi} \\ k_{xy} & k_{yy} & k_{y\psi} \\ k_{x\psi} & k_{y\psi} & k_{\psi\psi} \end{bmatrix}_{(\bar{x},\bar{y},\bar{\psi})}$$

GENERALIZED LINEAR MOORING FORCES: LOCAL STIFFNESS MATRIX

$$K_{jk} = -\frac{\partial}{\partial q_k}\sum_{i=1}^{N} f_i(r_i)\vec{e}_i \cdot \frac{\partial P_i}{\partial q_j} =$$

$$= -\sum_{i=1}^{N} \frac{\partial f_i}{\partial q_k}\vec{e}_i \cdot \frac{\partial P_i}{\partial q_j} - \sum_{i=1}^{N} f_i \frac{\partial}{\partial q_k}\left(\vec{e}_i \cdot \frac{\partial P_i}{\partial q_j}\right) =$$

$$= -\sum_{i=1}^{N} f_i' \frac{\partial r_i}{\partial q_k}\vec{e}_i \cdot \frac{\partial P_i}{\partial q_j} - \sum_{i=1}^{N} f_i \left(\frac{\partial \vec{e}_i}{\partial q_k} \cdot \frac{\partial P_i}{\partial q_j} + \vec{e}_i \cdot \frac{\partial^2 P_i}{\partial q_k \partial q_j}\right)$$



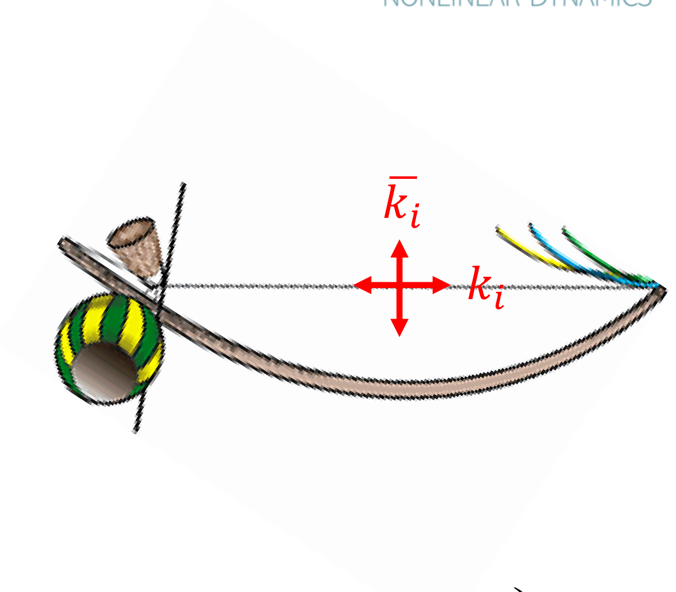
Mooring line tangent stiffness

$$f_i' = df_i / dr_i \equiv k_i(r_i)$$

Mooring line string stiffness

$$f_i(r_i)/r_i \equiv \bar{k}_i(r_i)$$

GENERALIZED LINEAR MOORING FORCES: LOCAL STIFFNESS MATRIX



$$k_{xx} = \sum_{i=1}^{N} \left(k_i \cos^2(\theta_i) + \bar{k}_i \operatorname{sen}^2(\theta_i) \right)$$

$$k_{yy} = \sum_{i=1}^{N} \left(k_i \operatorname{sen}^2(\theta_i) + \bar{k}_i \cos^2(\theta_i) \right)$$

$$k_{\psi\psi} = \sum_{i=1}^{N} \left(k_i R_i^2 \operatorname{sen}^2(\psi + \beta_i - \theta_i) \right) + \sum_{i=1}^{N} \bar{k}_i R_i^2 \left(\cos^2(\psi + \beta_i - \theta_i) + \frac{r_i}{R_i} \cos(\psi + \beta_i - \theta_i) \right)$$

GENERALIZED LINEAR MOORING FORCES: LOCAL STIFFNESS MATRIX

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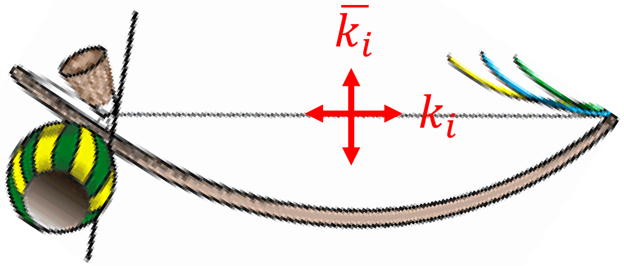
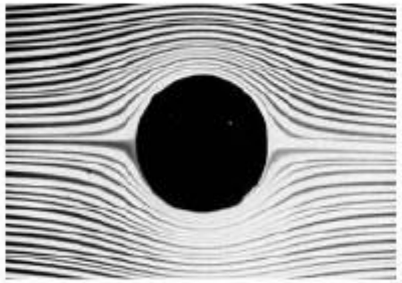
$$k_{xy}=k_{yx}=\sum_{i=1}^{N}\left(k_i-\bar{k}_i\right)\mathrm{sen}\left(\theta_i\right)\cos\left(\theta_i\right)$$

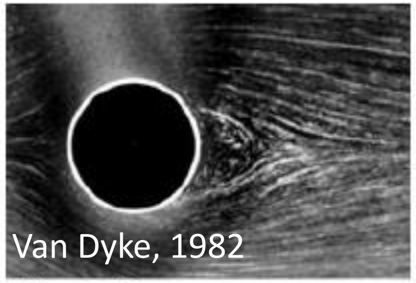


$$k_{x\psi}=k_{\psi x}=-\sum_{i=1}^{N}\left(k_iR_i\cos\left(\theta_i\right)\mathrm{sen}\left(\psi+\beta_i-\theta_i\right)\right)-\sum_{i=1}^{N}\left(\bar{k}_iR_i\,\mathrm{sen}\left(\theta_i\right)\cos\left(\psi\right.\right.$$

$$k_{y\psi}=k_{\psi y}=-\sum_{i=1}^{N}\left(k_iR_i\,\mathrm{sen}\left(\theta_i\right)\mathrm{sen}\left(\psi+\beta_i-\theta_i\right)\right)+\sum_{i=1}^{N}\left(\bar{k}_iR_i\cos\left(\theta_i\right)\cos\left(\psi+\beta_i-\theta_i\right)\right)$$

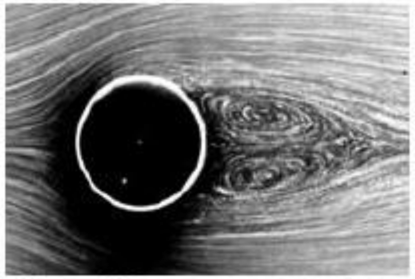
BASICS ON CLASSIC VIV


Sem separação

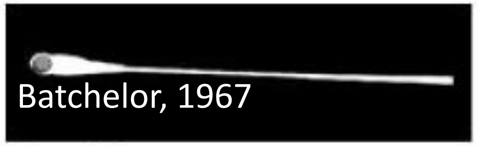


Re = 13


Re = 9,6


Re = 26

Meneghini et al, 2010

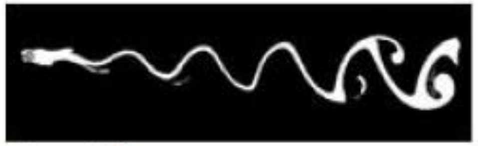


Re = 32


Re = 73

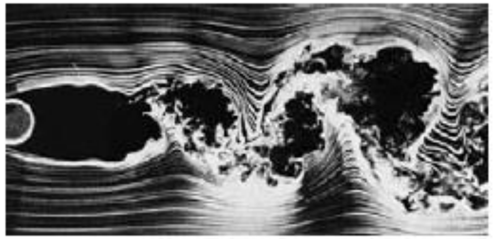

Re = 55


Re = 102


Re = 65


Re = 161

Re=140


$Re=10^4$

CLASSICAL VIV

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Vortex-wake dynamics could be represented through van der Pol or Rayleigh oscillators

Vortex shedding:

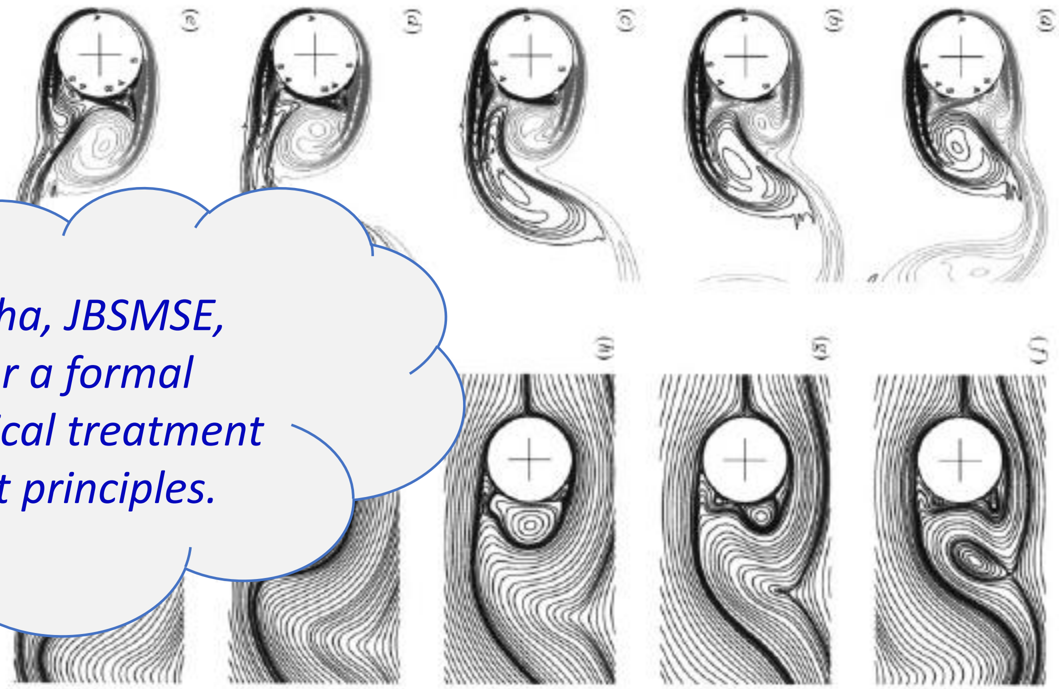
- ✓ Flow pasting bluff-bodies
- ✓ Comes from the inherent instability and interaction between shear layers
- ✓ Is a self-regulated and stable phenomenon: **Hopf bifurcation** with onset at Re~50
- ✓ Important dimensionless parame s:

$\mathrm{Re} = UD/\nu$	Reynolds num
$St = f_s D/U$	Strouhal numbe

- ✓ Reynolds number: ratio between inertial a forces
- ✓ Strouhal number: depends on the body shape and regulates the shedding frequency

See Aranha, JBSMSE, 2004 for a formal mathematical treatment from first principles.

Vorticity contours



Generation and vortex shedding at Re=500. Half-cycle.
Blackburn & Henderson, 1999

CLASSICAL VIV

Vortex Induced Vibrations:

- ✓ Nonlinear fluid-structure interaction resonant phenomenon
- ✓ Self-regulated
- ✓ Important dimensionless parameters:

$U^* = V_r = U/f_n D$	Reduced velocity
$f_s^* = f_s/f_n = StU^*$	Shedding frequency
$f^* = f/f_n$	Response frequency
$m^* = m/m_d$	Mass ratio (specific density)
$C_a = m_a/m_d$	Added mass coefficient
$\zeta = c/2m\omega_n = c/4\pi m f_n$	Structural damping

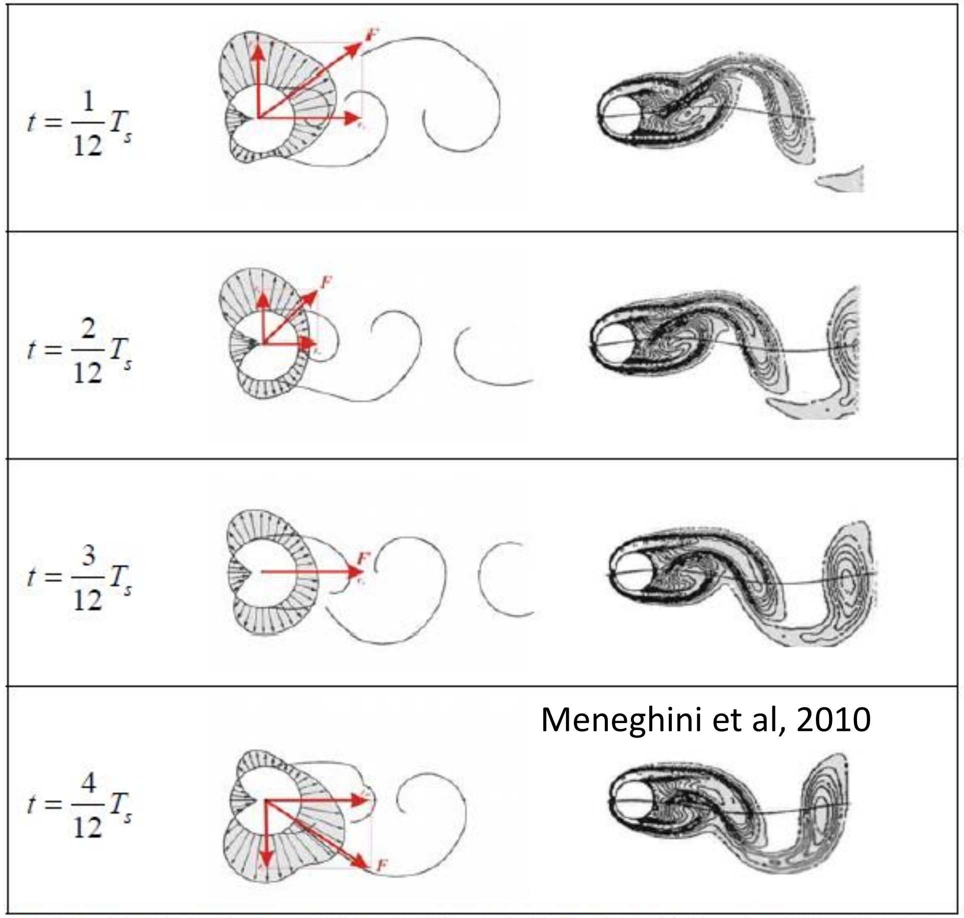
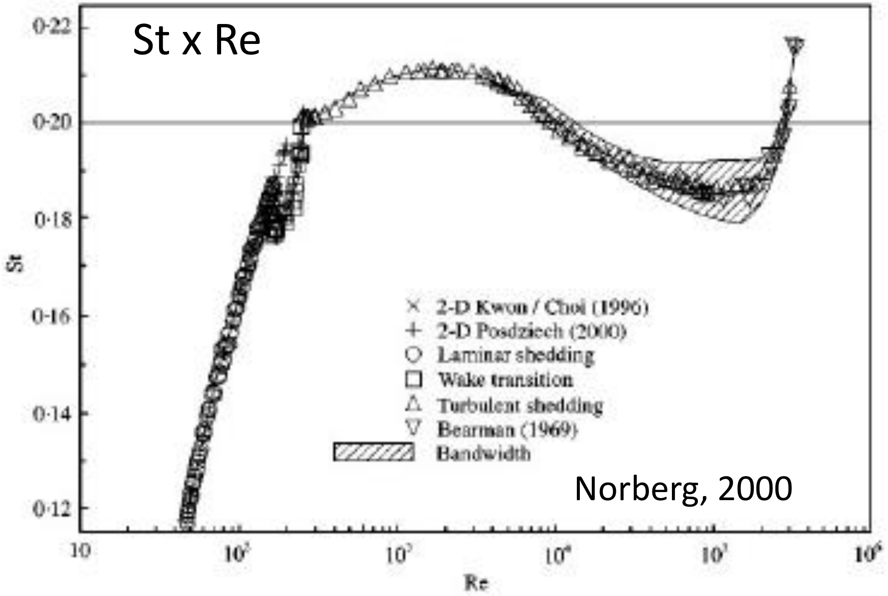
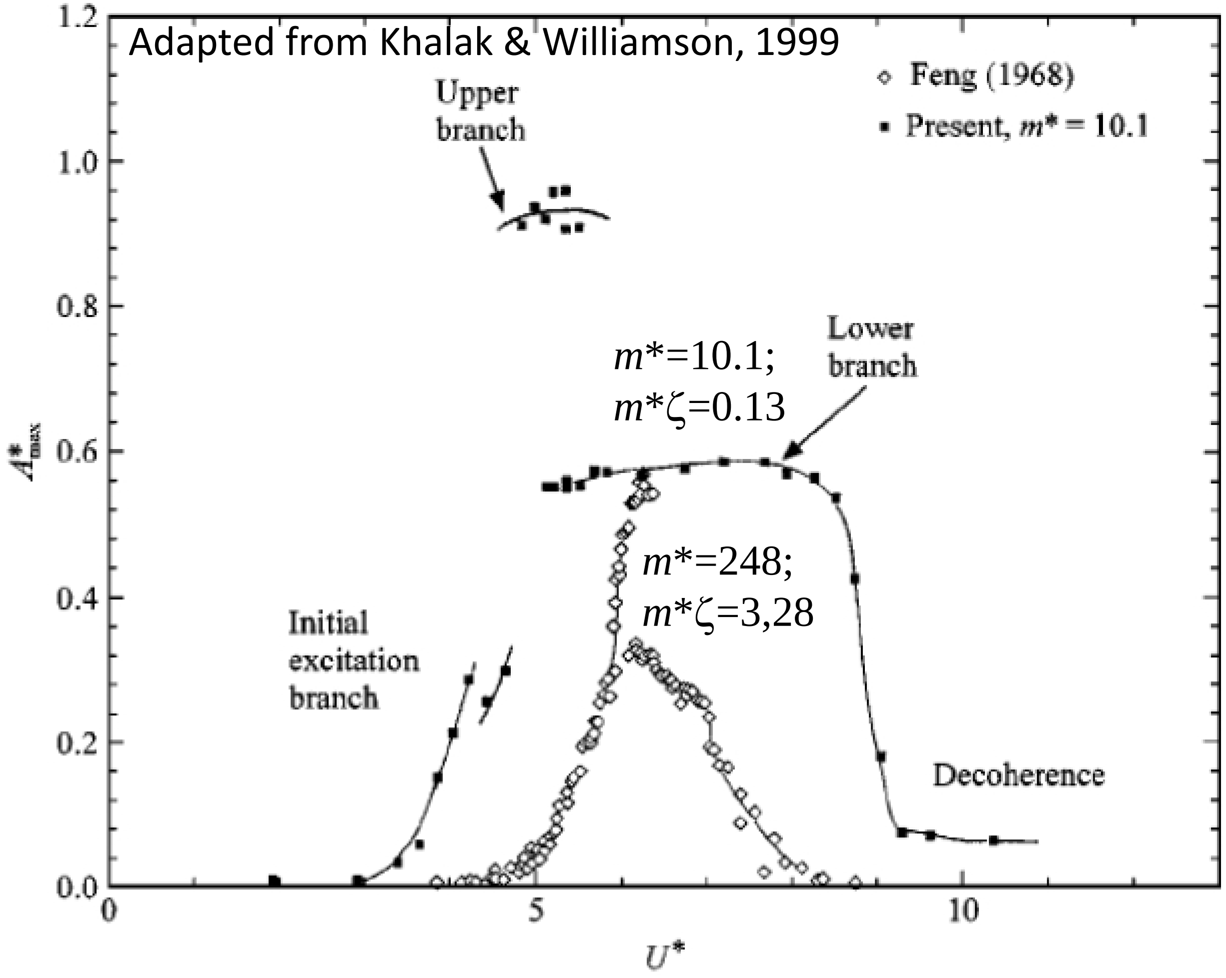


Figura 35: Variação do campo de pressão na parede para aproximadamente um terço do ciclo de emissão de vórtices. Adaptado de Blevins (1990) e Meneghini (1993).

CLASSICAL VIV





CLASSICAL VIV

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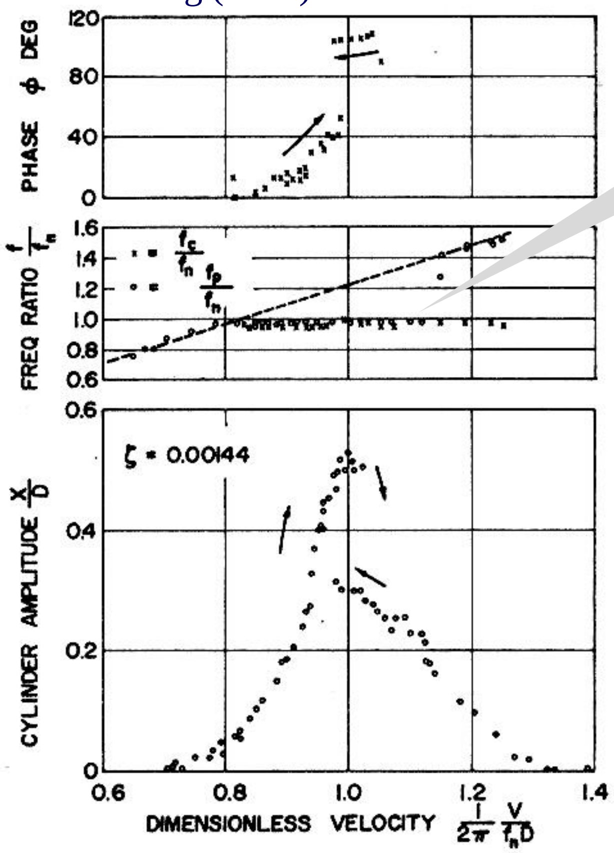
Feng (1968)



Lock-in

Lock-in:

$$f_s^* = f_s / f_n = StU^* \cong 1$$

and

$$f^* = f / f_n \cong 1$$

if $St \approx 0.2$ resonance peaks at $U^* \cong 5$

$$\frac{yo}{D} \propto \frac{C_Y \sin\phi}{(m^* + C_a)\zeta}$$

Wake-oscillator model for 1DOF VIV considering **Added Mass** as function of reduced velocity and a stall term

Fujarra, 2002 (PhD thesis) and Fujarra & Pesce (ASME-FSI, 2002)

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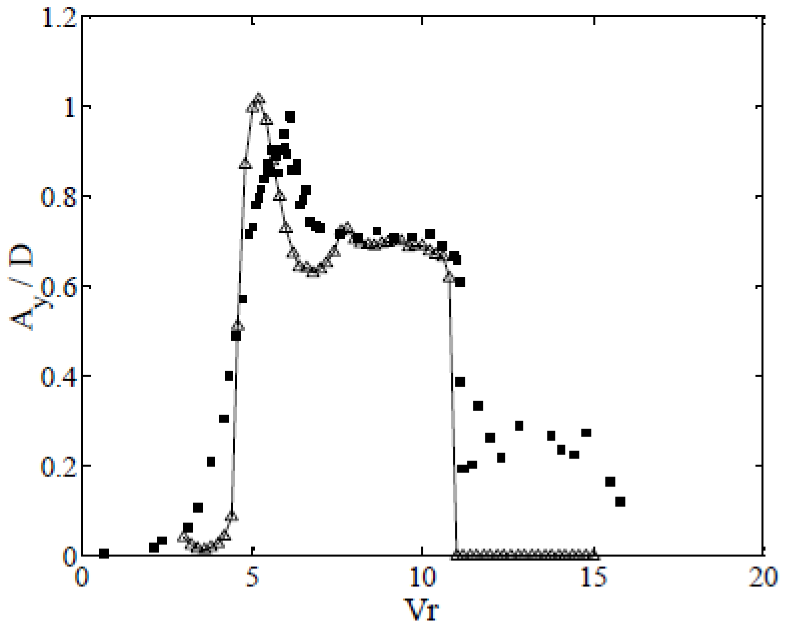

Figure 11. Non-dimensional amplitude prediction for Experiment (I) (Flexible Cantilever). Analytical Model modified by introducing added mass variability with reduced velocity, extracted from Experiment (II) (Elastically Mounted Rigid Cantilever, Figure 4). Lift-coefficient variability $C_L = C_L(V_r)$, adjusted according to Figure 10, after Willden and Grahan (2001).

2DOF VIV

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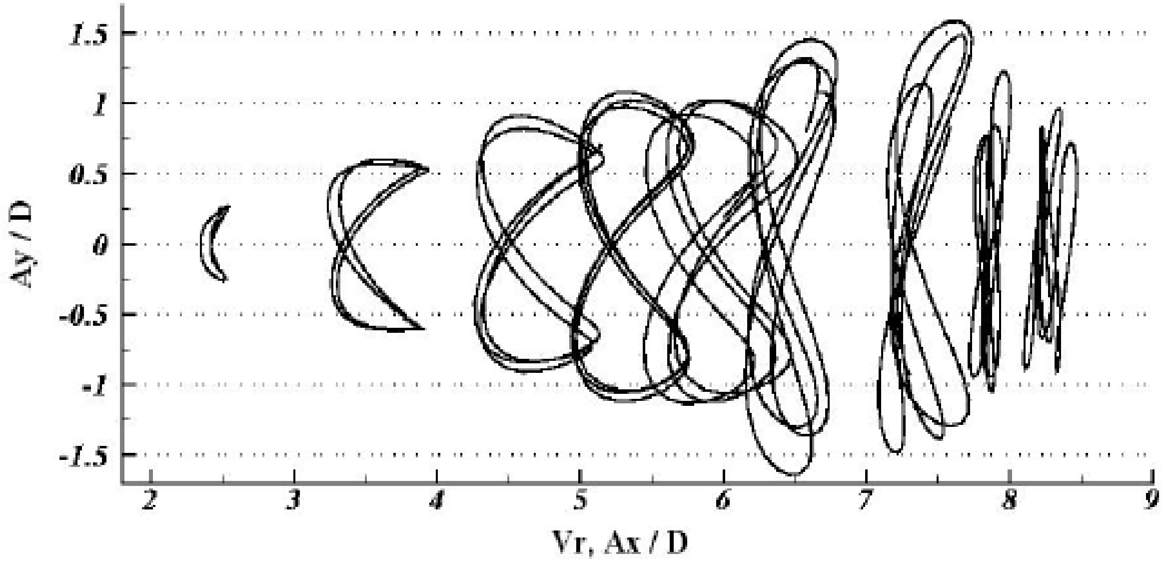
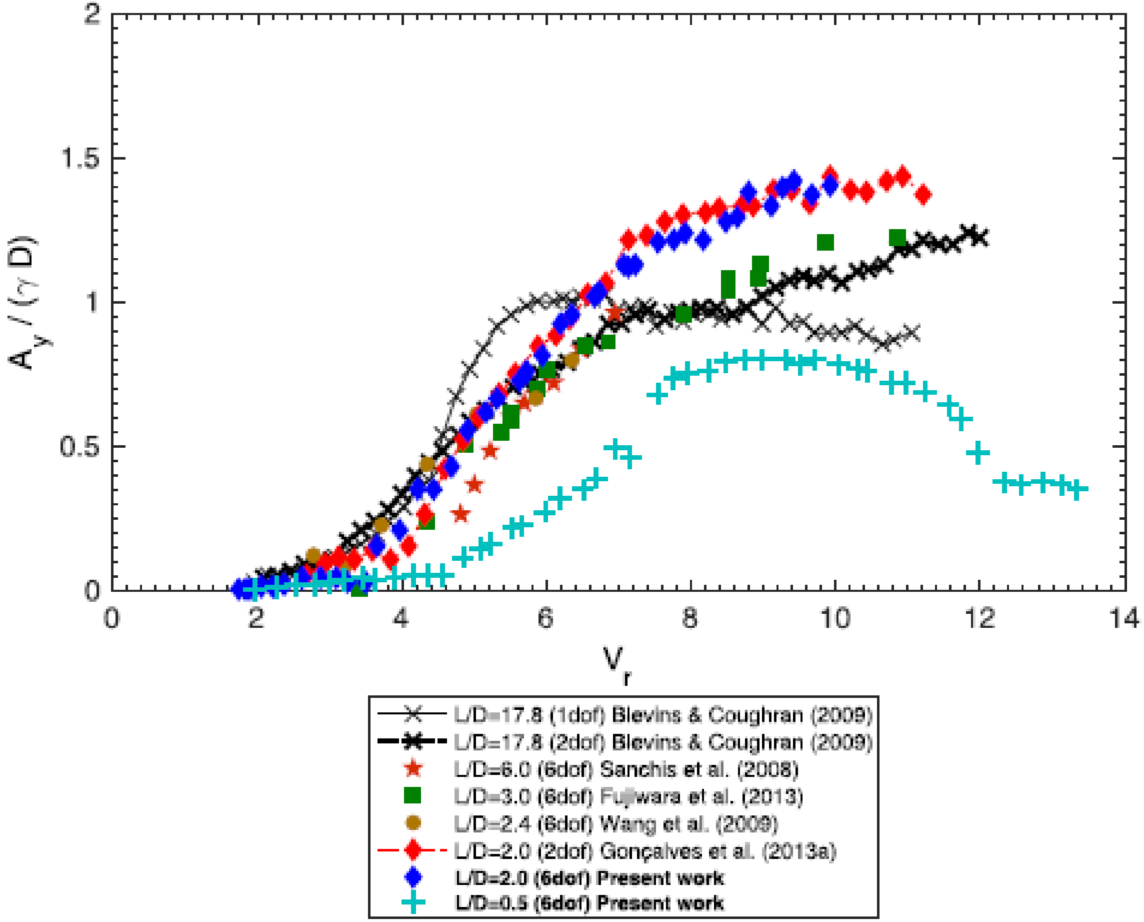
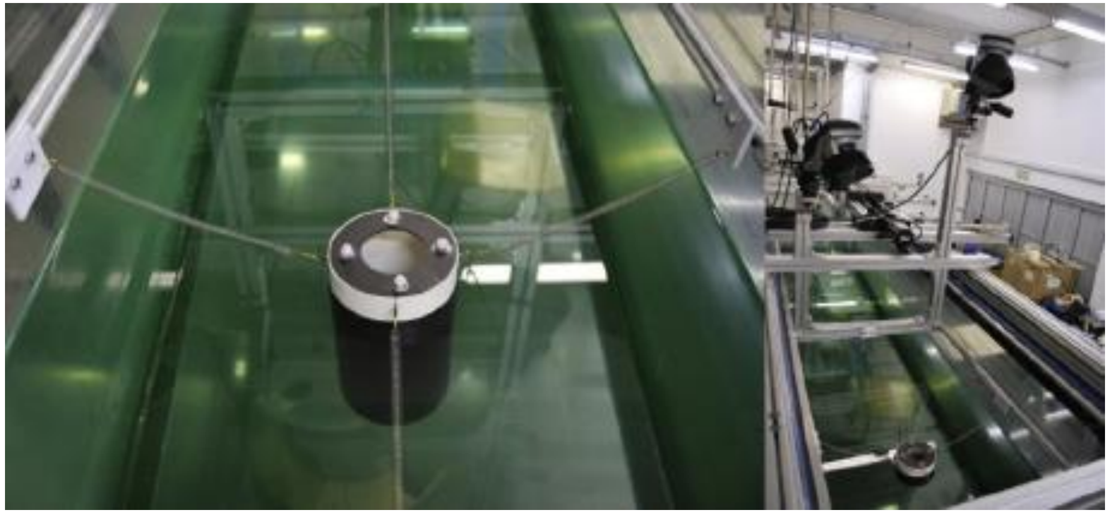


Eight-shaped trajectories: dual resonance

CURRENT INDUCED MOTIONS ON LOW ASPECT RATIO CYLINDERS

São Paulo School of Advanced Sciences on
NONLINEAR DYNAMICS





Gonçalves et al., Ocean Engineering 2018

CURRENT INDUCED MOTIONS ON LOW ASPECT RATIO CYLINDERS

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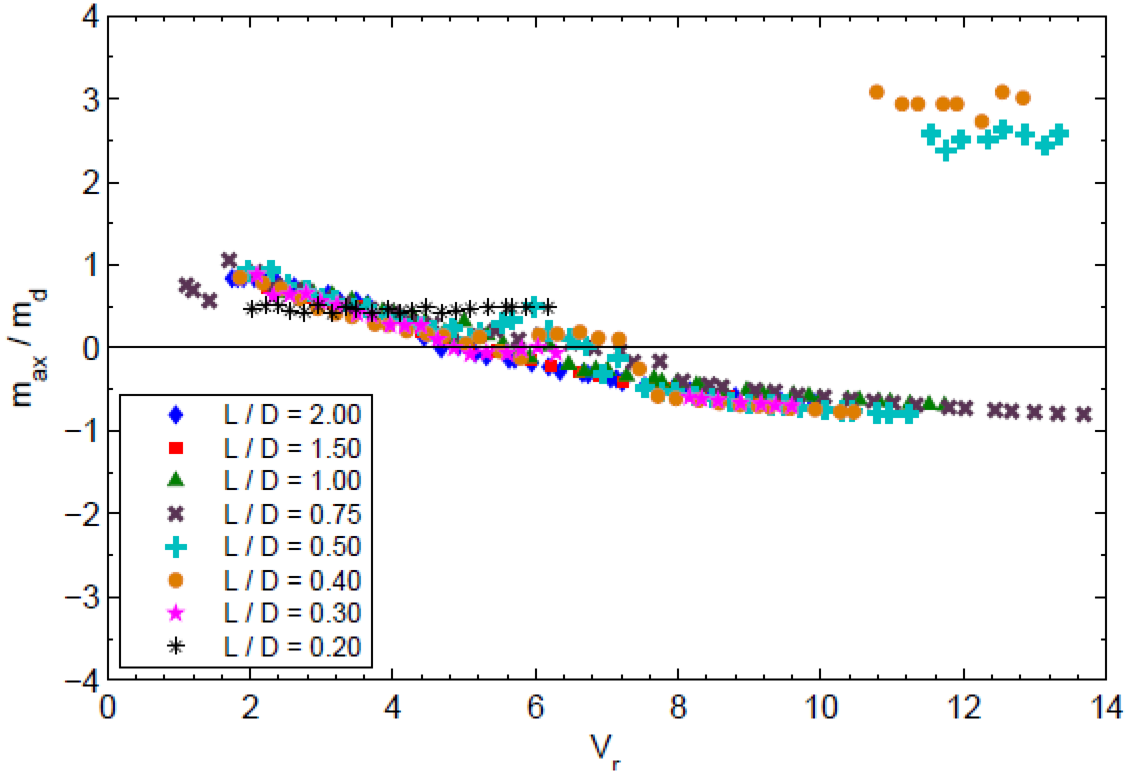
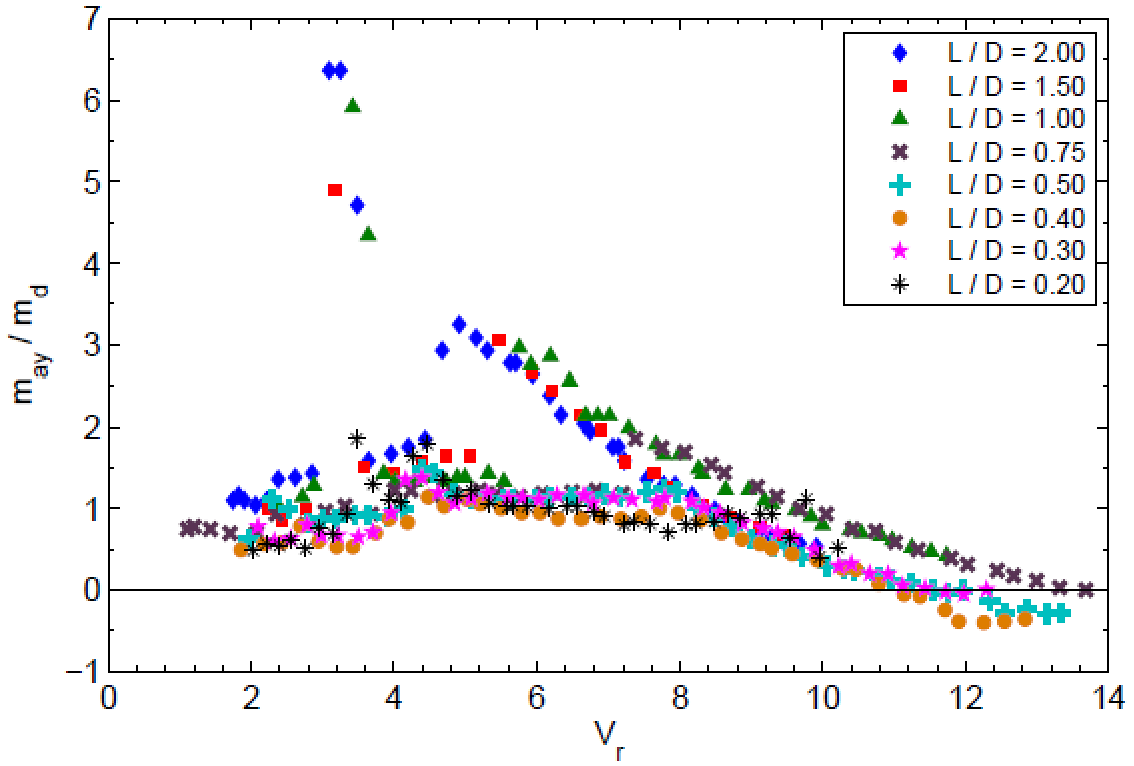
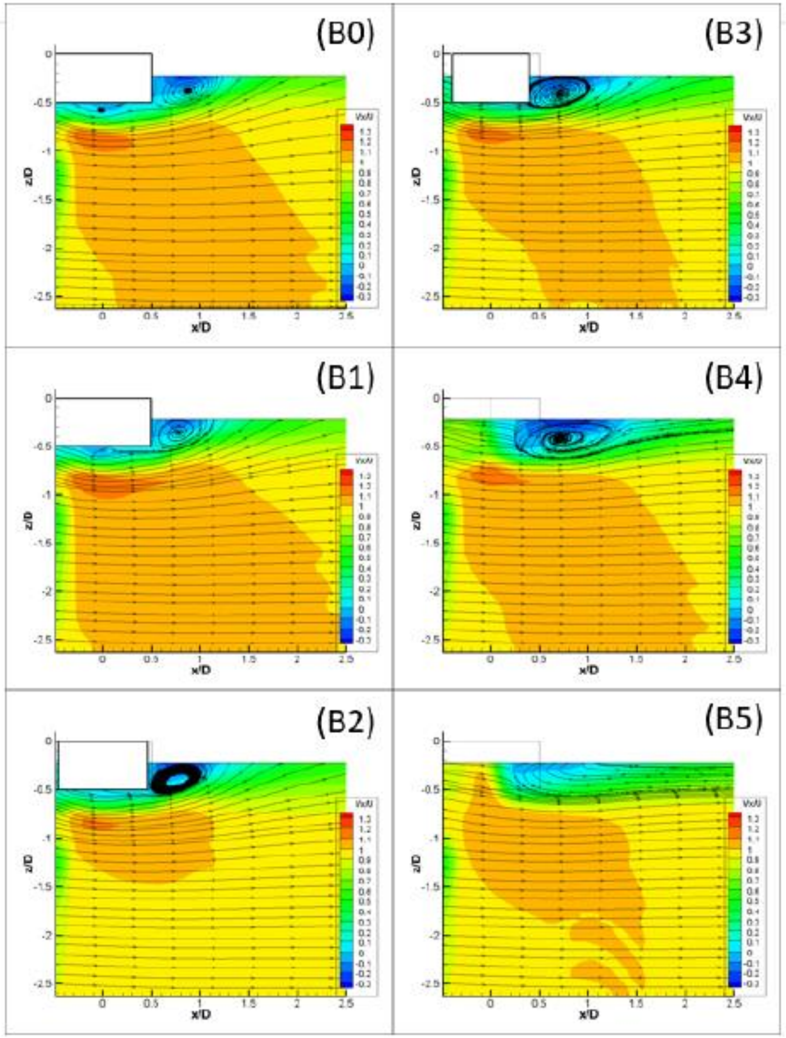
NONLINEAR DYNAMICS



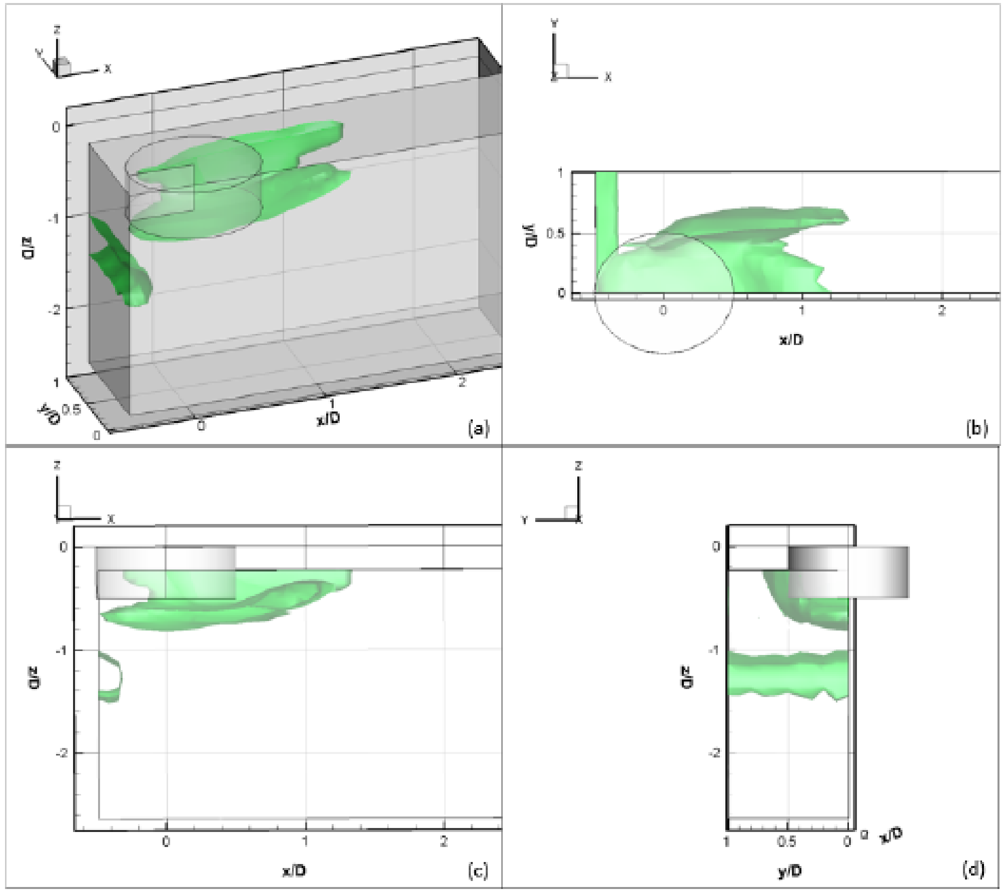


Added Mass in VIV
Gonçalves, R.T., PhD Thesis, 2013

FLOW AROUND A LOW-ASPECT RATIO CYLINDER (L/D=0.5)



V_x/U, Re=43000



Gonçalves et al, 2018

Vorticity isosurface
Re=43000

CURRENT INDUCED FORCES

(Inspired in Ogink and Metrikine, 2010 and Franzini & Bunzel, 2018)

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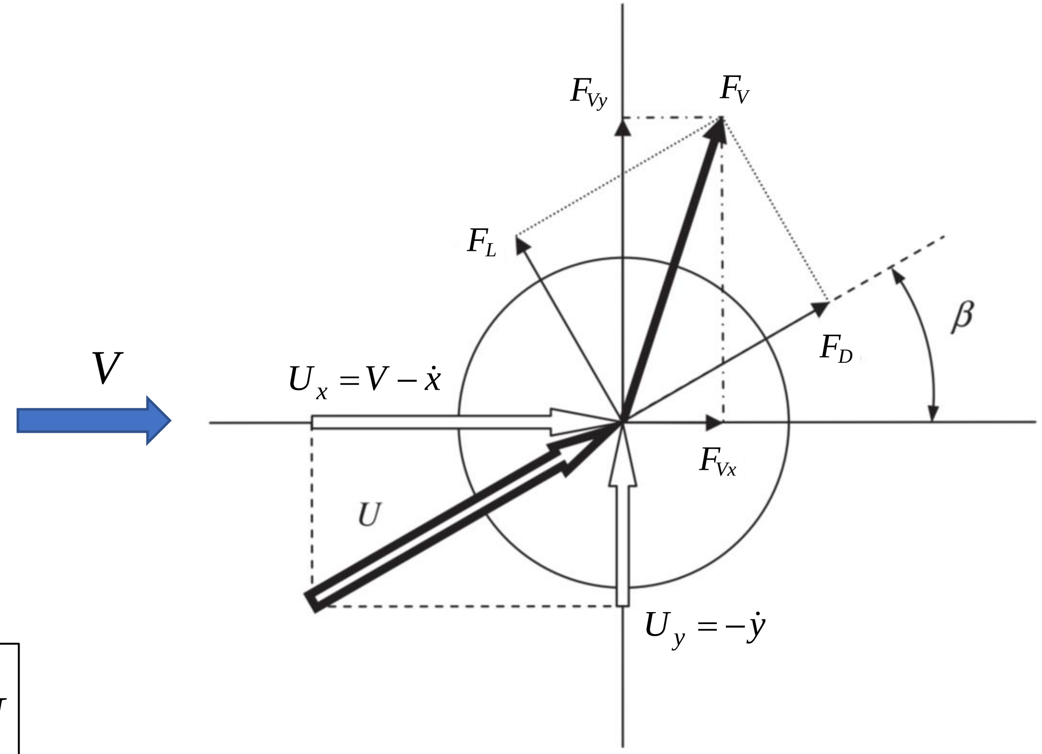
$$F_{Vx} = \frac{1}{2}\rho D L C_x V^2; \quad F_{Vy} = \frac{1}{2}\rho D L C_y V^2$$

$$C_x = \left(C_D U_x - C_L U_y\right)\frac{U}{V^2}; \quad C_y = \left(C_D U_y + C_L U_x\right)\frac{U}{V^2}$$

$$U_x = V - \dot{x}; \quad U_y = -\dot{y}; \quad U = \sqrt{U_x^2 + U_y^2}$$

$$F_{Vx} = F_D \cos\beta - F_L \sin\beta; \quad F_{Vy} = F_D \sin\beta + F_L \cos\beta$$

$$\cos\beta = U_x / U; \quad \sin\beta = U_y / U$$



$$F_{Vx} = \frac{1}{2}\rho D H \left(C_D U_x - C_L U_y\right)U; \quad F_{Vy} = \frac{1}{2}\rho D H \left(C_D U_y + C_L U_x\right)U$$

$$\mathbf{Q}^v = \frac{1}{2}\rho D H U\left[\left(C_D U_x - C_L U_y\right) \quad \left(C_D U_x - C_L U_y\right) \quad 0\right]^T$$

PHENOMENOLOGICAL MODEL AND HYDRODYNAMIC FORCES

2 dof wake-oscillators of the van der Pol type:

Enforced dual resonance

Inertial coupling

Shedding frequency

$$\ddot{w}_x + \varepsilon_x \omega_s \left(w_x^2 - 1\right)\dot{w}_x + 4\omega_s^2 w_x = \frac{A_x}{D}\ddot{x}$$

$$\omega_s = 2\pi S_t \left(V / D\right)$$

$$\ddot{w}_y + \varepsilon_y \omega_s \left(w_y^2 - 1\right)\dot{w}_y + \omega_s^2 \dot{w}_y = \frac{A_y}{D}\ddot{y}$$

governing two new generalized coordinates, related to the *wake dynamics*:

$$\mathbf{w} = \begin{bmatrix} w_x & w_y \end{bmatrix}^T$$

$(\varepsilon_x, \varepsilon_y)$ and (A_x, A_y) **Empirical parameters to be adjusted**

PHENOMENOLOGICAL MODEL AND HYDRODYNAMIC FORCES

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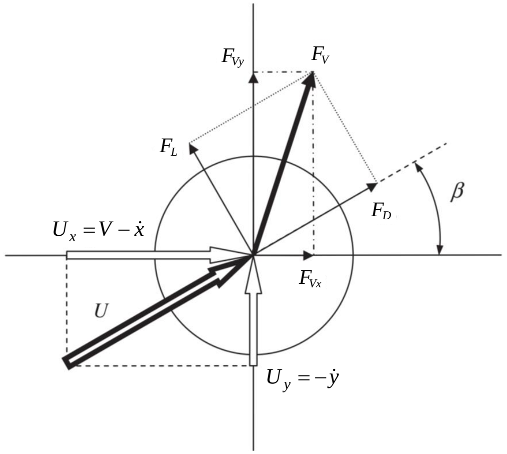
$$C_L = \frac{C_{L0}}{2} w_y$$

$$C_D = C_{D0}\left(1 + K w_y^2\right) + \frac{C_{D0}^f}{2} w_x$$

$$\mathbf{Q}^v = \frac{1}{2}\rho D H U \left[\left(C_D U_x - C_L U_y\right) \quad \left(C_D U_x - C_L U_y\right) \quad 0 \right]^T$$

C_{L0} and C_{D0} are the lift and drag coefficients for a fixed cylinder

V



C_{D0}^f is a weighting coefficient for the oscillation amplitude of the drag

K is an experimental constant

(Rosetti et al, 2009)

THE 5-DOF REDUCED ORDER MODEL

$$\tilde{\mathbf{M}}\ddot{\tilde{\mathbf{q}}} = \tilde{\mathbf{Q}}_c + \tilde{\mathbf{Q}}_{nc}$$

$$\tilde{\mathbf{M}} \in \Re^{5x5};\ \tilde{\mathbf{q}} \in \Re^{5}$$

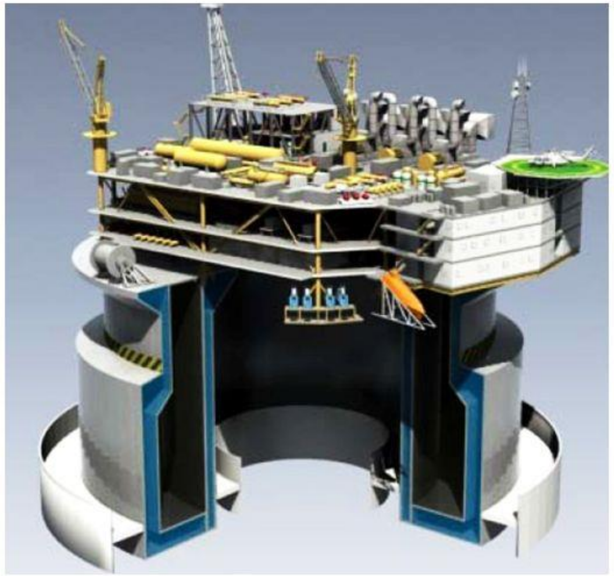
$$\tilde{\mathbf{M}} = \begin{bmatrix} M+M_a & 0 & 0 & 0 & 0 \\ 0 & M+M_a & 0 & 0 & 0 \\ 0 & 0 & I & 0 & 0 \\ -\frac{A_x}{D} & 0 & 0 & 1 & 0 \\ -\frac{A_y}{D} & 0 & 0 & 0 & 1 \end{bmatrix};\ \tilde{\mathbf{q}} = \begin{bmatrix} \mathbf{q} \\ \mathbf{w} \end{bmatrix} = \begin{bmatrix} x \\ y \\ \psi \\ w_x \\ w_y \end{bmatrix};\ \tilde{\mathbf{Q}}_c = \begin{bmatrix} \mathbf{Q}^m \\ -4\omega_s^2 w_x \\ -\omega_s^2 w_y \end{bmatrix};\ \tilde{\mathbf{Q}}_{nc} = \begin{bmatrix} \mathbf{Q}^v \\ -\varepsilon_x \omega_s \left(w_x^2 - 1\right)\dot{w}_x \\ -\varepsilon_y \omega_s \left(w_y^2 - 1\right)\dot{w}_y \end{bmatrix}$$

CASE STUDY - A MONOCOLUM PLATFORM (L/D=0.4)

Plataformas de Petróleo e Gás

Monocoluna - Moonpool

- MonoBR



- Completação Seca

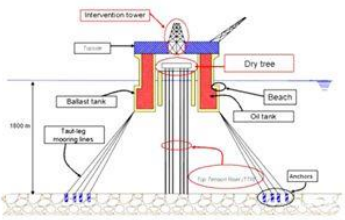


Table 1 – MonoBr-GoM main particulars and general parameters.

Draught, H (m)	39.50
Diameter, D (m)	100.0
Mass, M (t)	262000.0
Added mass coefficient, C_a	1.0
Mass of water in moon-pool, M_{mp} (t)	67447.0
Density of water, $\rho\left(\text{t/m}^3\right)$	1.025

Table 3 – Wake-oscillators parameters; Rosetti et al (2009), Gonçalves et al (2010).

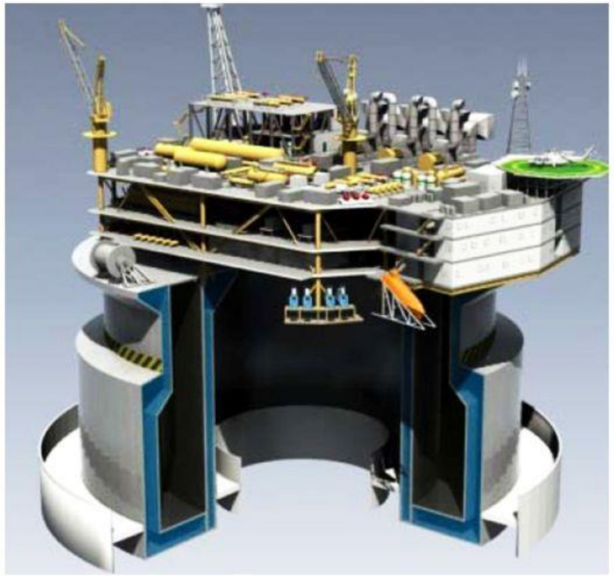
$[A_x; A_y]$	[12; 6]
$[\varepsilon_x; \varepsilon_y]$	[0.30; 0.15]
$[C_{D0}; C_{L0}; C^f_{D0}; K]$	[0.70; 0.30; 0.10; 0.05]
Strouhal number, S_t	0.078

MONOCOLUMN MOORING SYSTEM

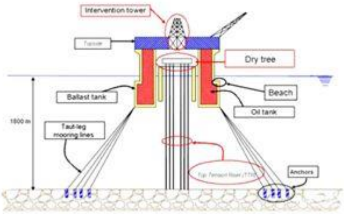
Plataformas de Petróleo e Gás

Monocoluna - Moonpool

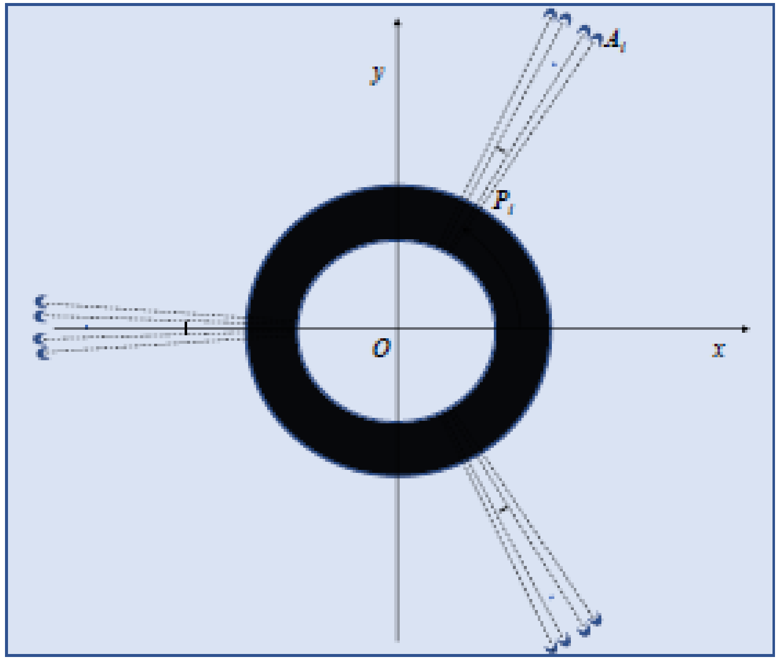
- MonoBR



- Completação Seca



$\alpha = 0$



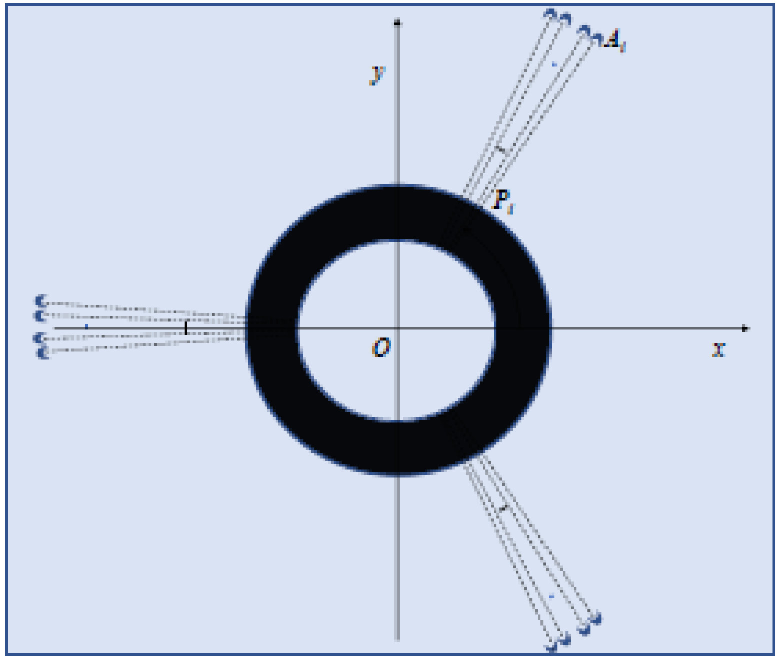
$\alpha = \pi$

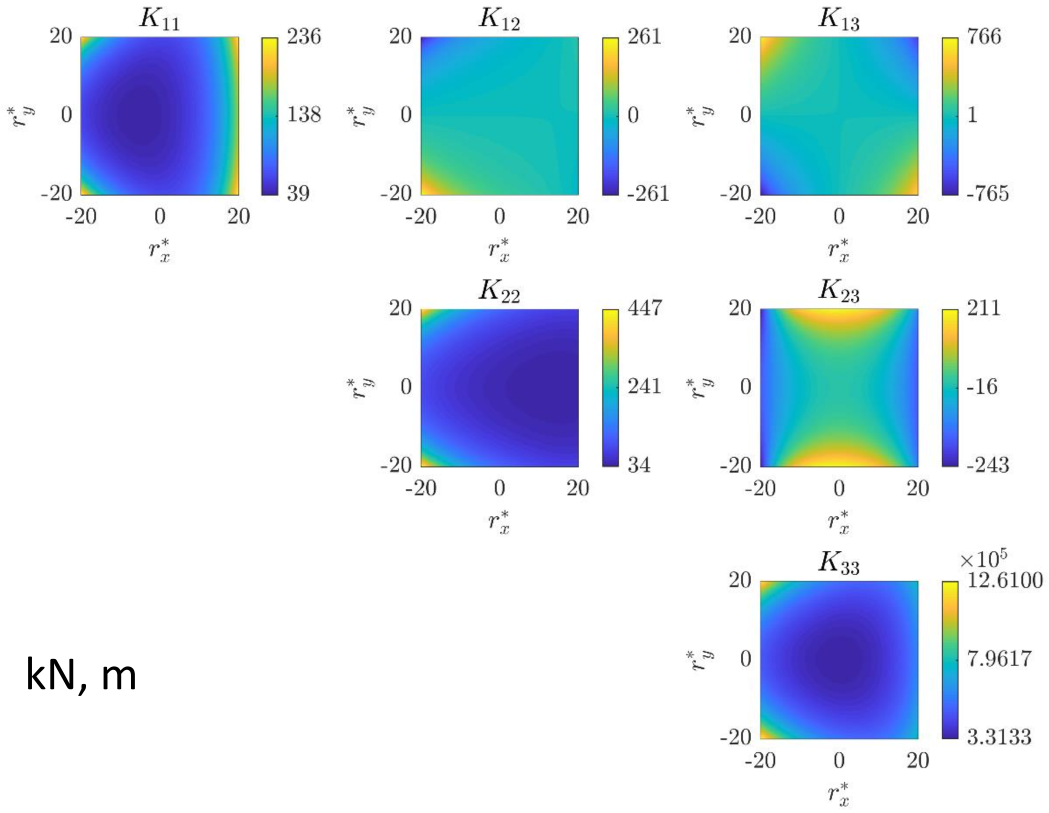
Table 2 – Mooring system: parameters and arrangement at neutral position, $\mathbf{q} = 0$. Catenary chains. Depth 500m.

Immersed weight, γ (kN/m)	1.07
Total length, L (m)	1525.0
Distance of fairlead from anchor, $r(f_0)$ (m)	1317.0
Horizontal component of pretension, f_0 (kN)	532.83
Number of mooring lines, N	12
Angles of mooring lines in the body frame, β (rad)	[(0.79, 0.96, 1.13, 1.31); (2.88, 3.05, 3.22, 3.40); (-0.79, -0.96, -1.13; -1.31)]

CASE STUDY - A MONOCOLUM PLATFORM (L/D=0.4)

SÃO PAULO SCHOOL OF ADVANCED SCIENCES ON NONLINEAR DYNAMICS





kN, m

Local mooring stiffness matrix as function of platform offset (% depth)

at yaw angle $\Psi = 0^o$

CASE STUDY - A MONOCOLUM PLATFORM (L/D=0.4)

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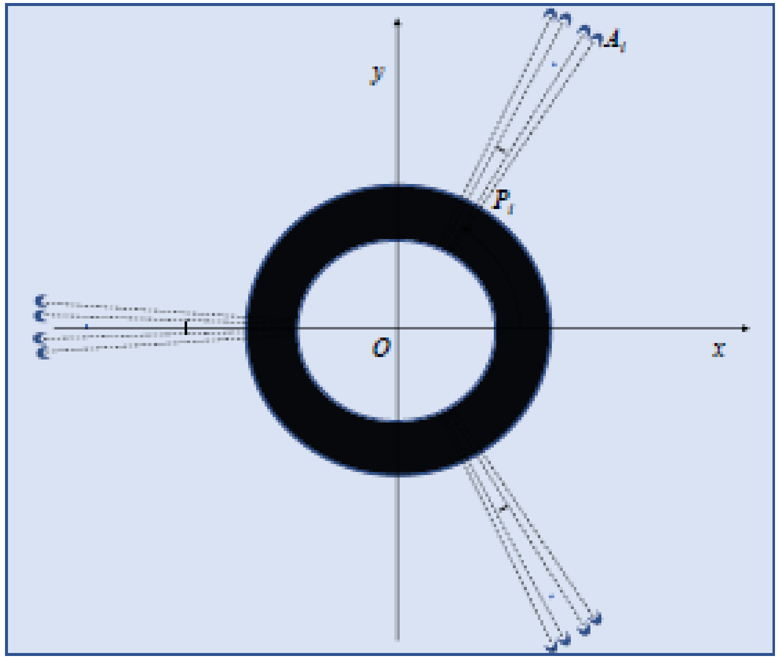
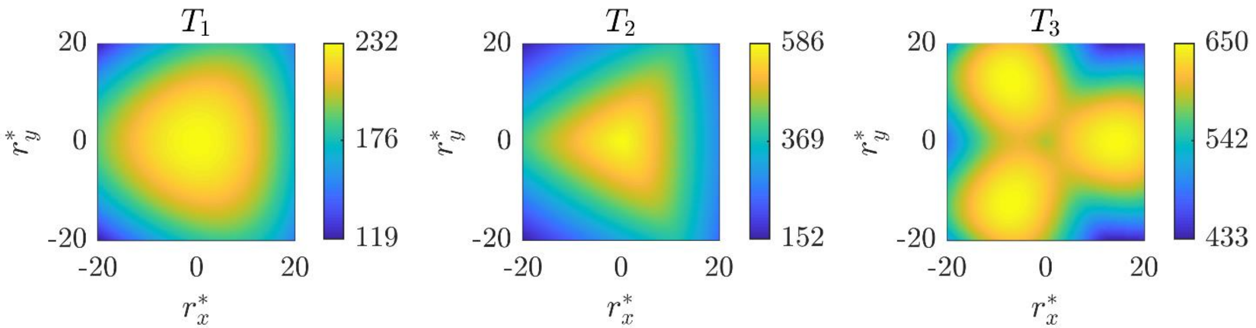
NONLINEAR DYNAMICS

Perfectly symmetric mooring arrangement





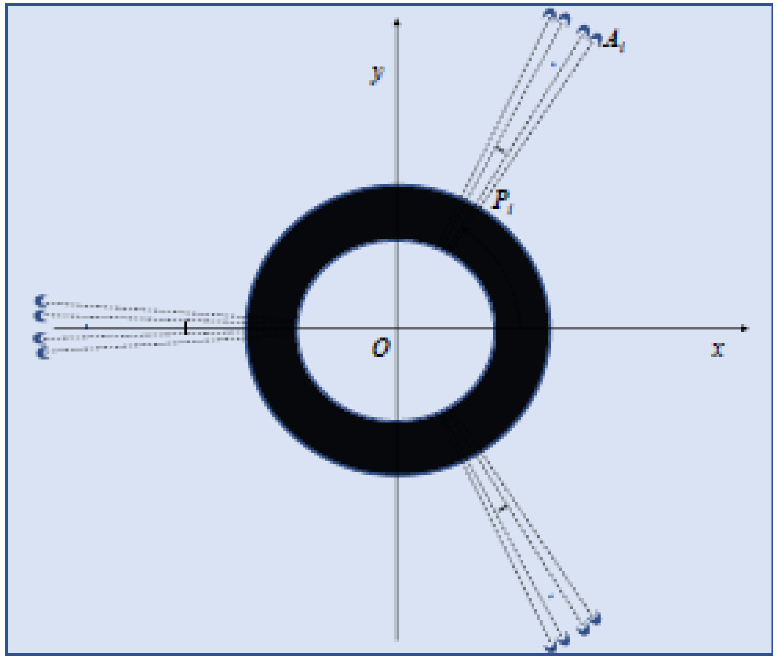
Natural periods as function of platform offset (% depth)
at yaw angle $\Psi = 0^o$

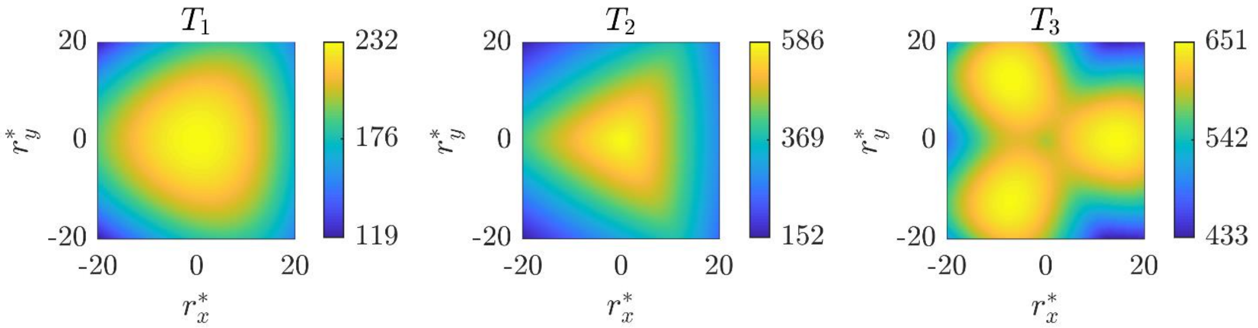
CASE STUDY - A MONOCOLUM PLATFORM (L/D=0.4)

SÃO PAULO SCHOOL OF ADVANCED SCIENCES ON NONLINEAR DYNAMICS

Small changes in symmetric mooring arrangement

179.76 º



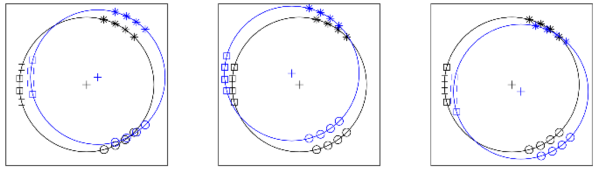


Natural periods as function of platform offset (% depth)

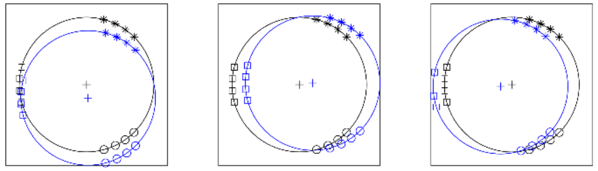
at yaw angle $\Psi = 0^o$

CASE STUDY - A MONOCOLUM PLATFORM (L/D=0.4)

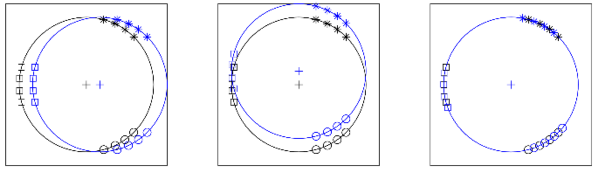
Perfectly symmetric mooring arrangement



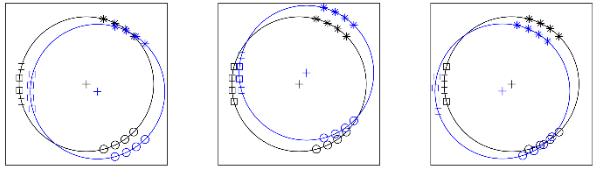
(-100,100)



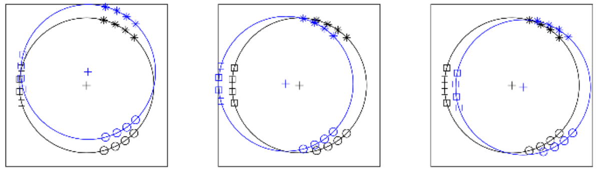
(100,100)



(0,0)



(-100,-100)



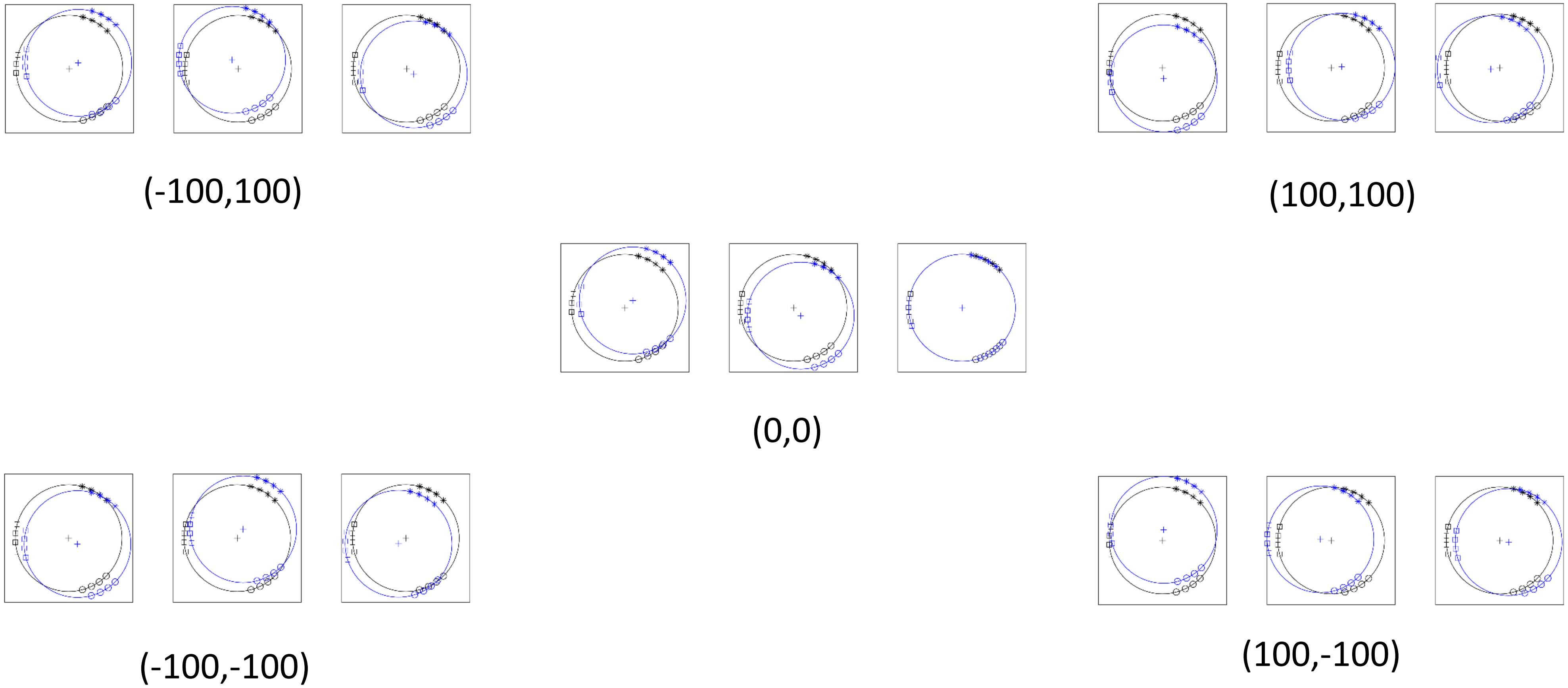
(100,-100)

Oscillation modes for five offsets (m).

CASE STUDY - A MONOCOLUM PLATFORM (L/D=0.4)

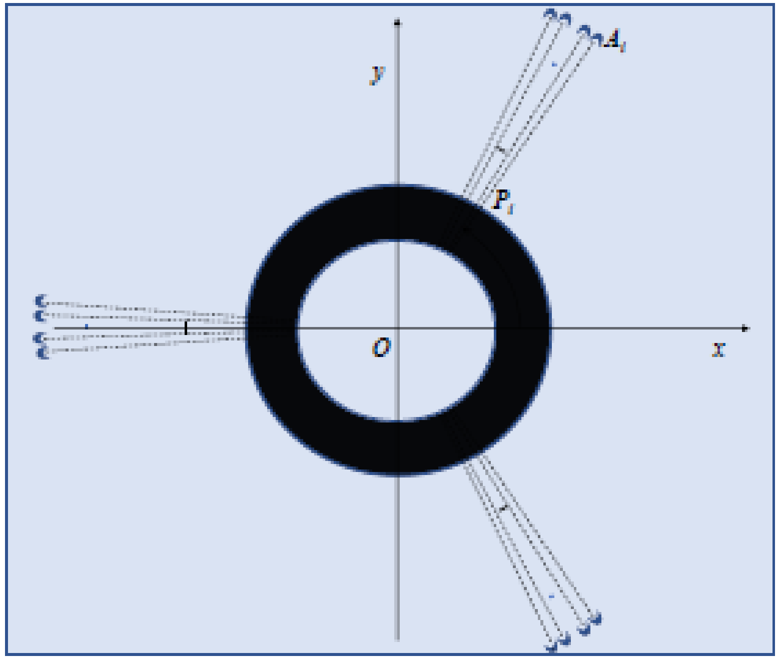
Small changes in symmetric mooring arrangement

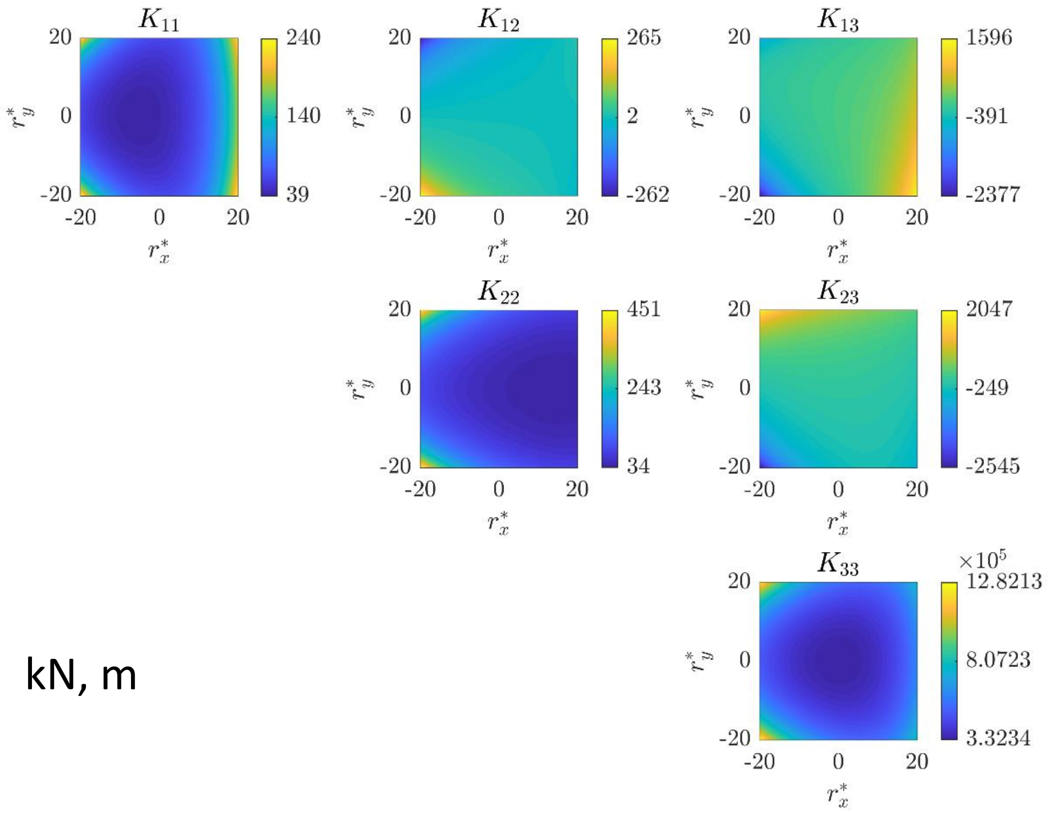
179.76 º



Oscillation modes for five offsets (m).

CASE STUDY - A MONOCOLUM PLATFORM (L/D=0.4)





kN, m

Local mooring stiffness matrix as function of platform offset (% depth)
at yaw angle $\Psi = 5^o$

CASE STUDY - A MONOCOLUM PLATFORM (L/D=0.4)

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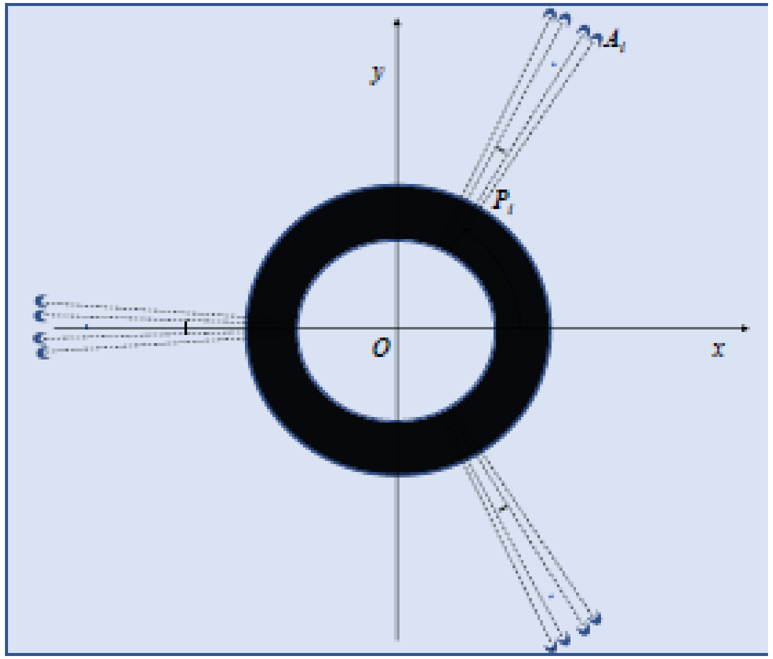
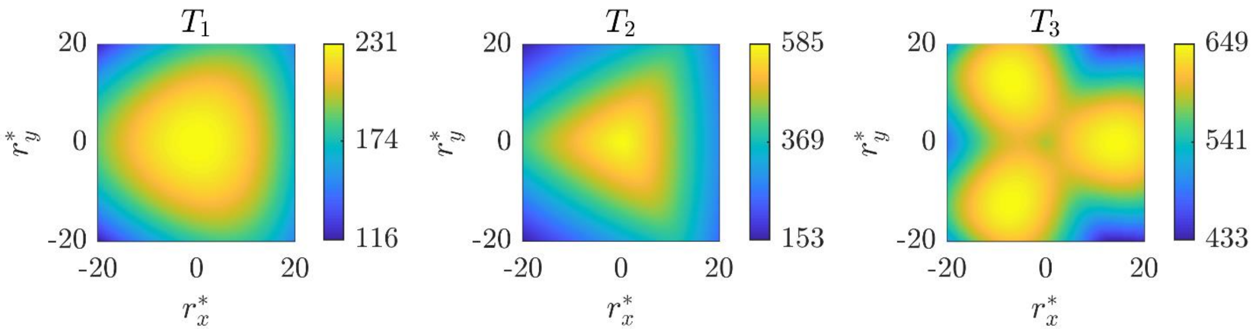
Small changes in symmetric mooring arrangement





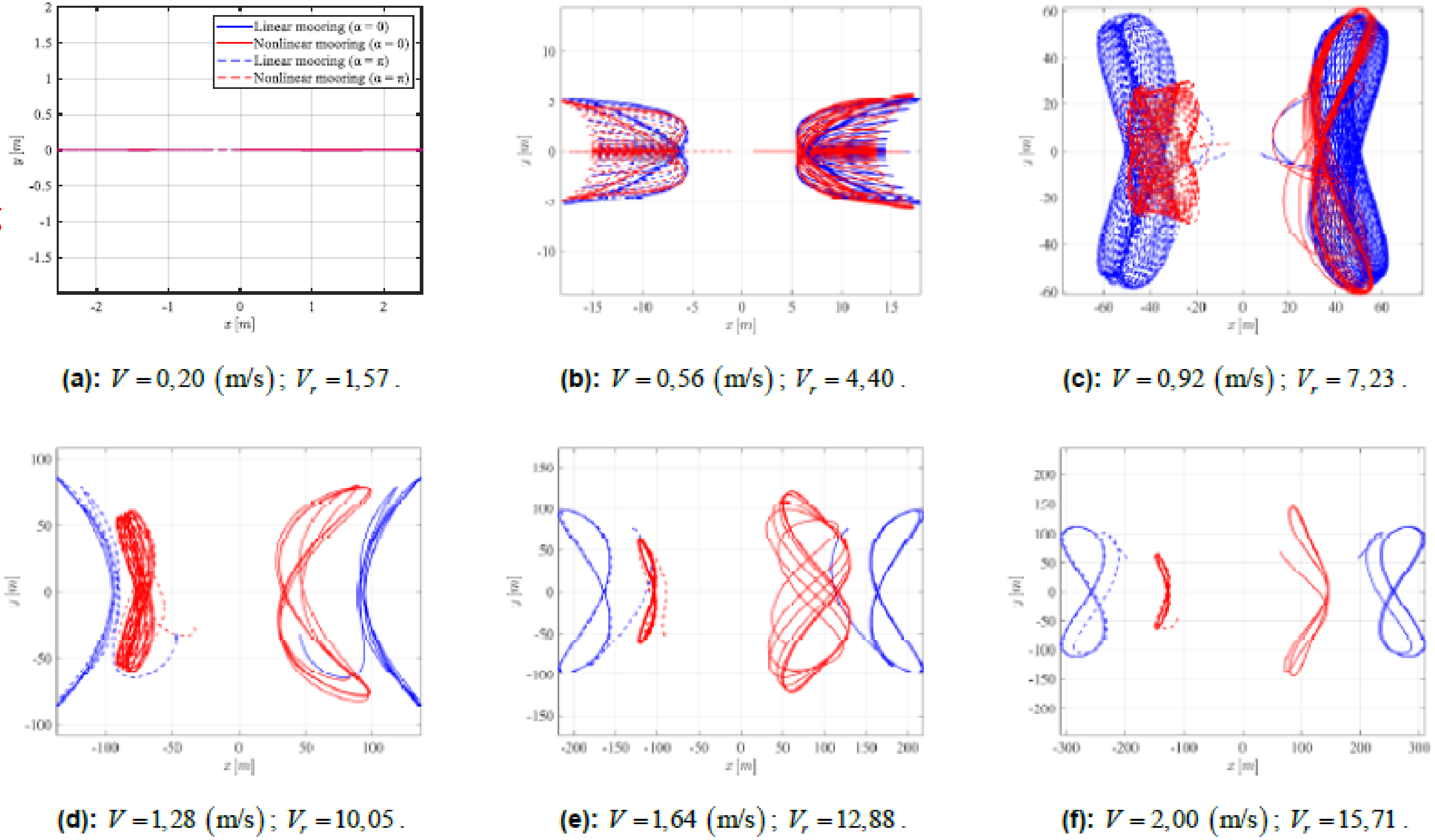
Natural periods as function of platform offset (% depth)

at yaw angle $\Psi = 0^o$

CASE STUDY - A MONOCOLUM PLATFORM (L/D=0.4)

Nonlinear mooring
$\alpha = 0$

Linear mooring
$\alpha = 0$

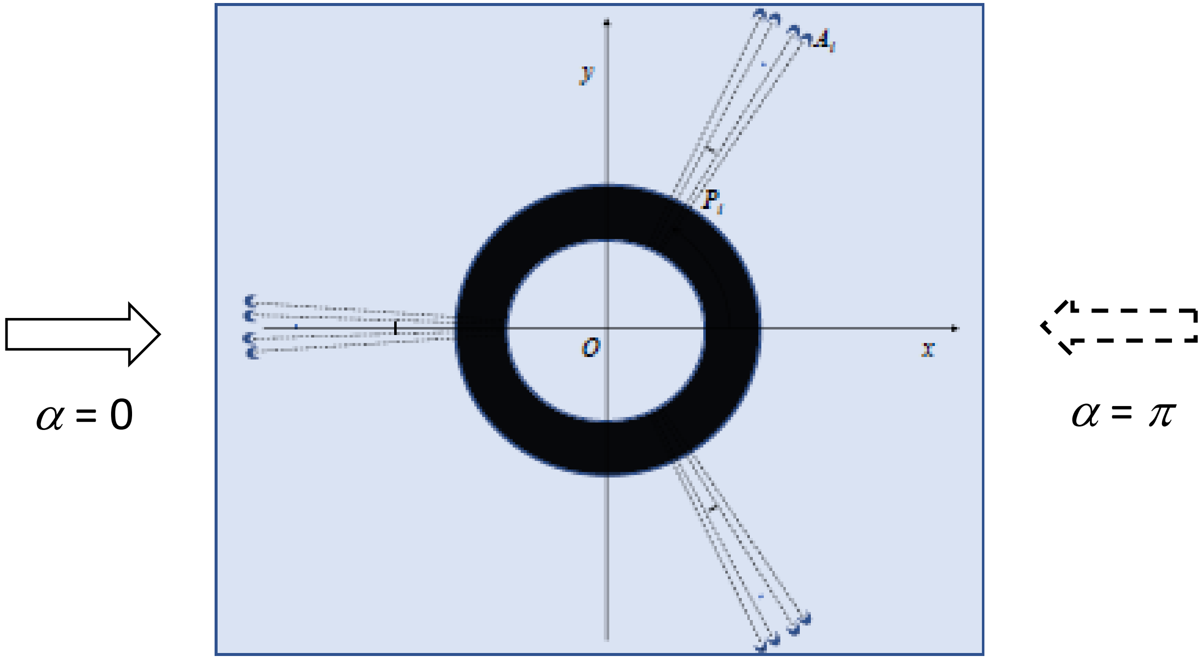


Nonlinear mooring
$\alpha = \pi$

Linear mooring
$\alpha = \pi$

Figure 6 – Center of mass trajectories on the horizontal plane. Current direction: (i) from left to right, α = 0 and (ii) from right to left, α = π. The terms 'linear' and 'nonlinear' in the legend refer only to the mooring system.

CASE STUDY - A MONOCOLUM PLATFORM (L/D=0.4)



CASE STUDY - A MONOCOLUM PLATFORM (L/D=0.4)

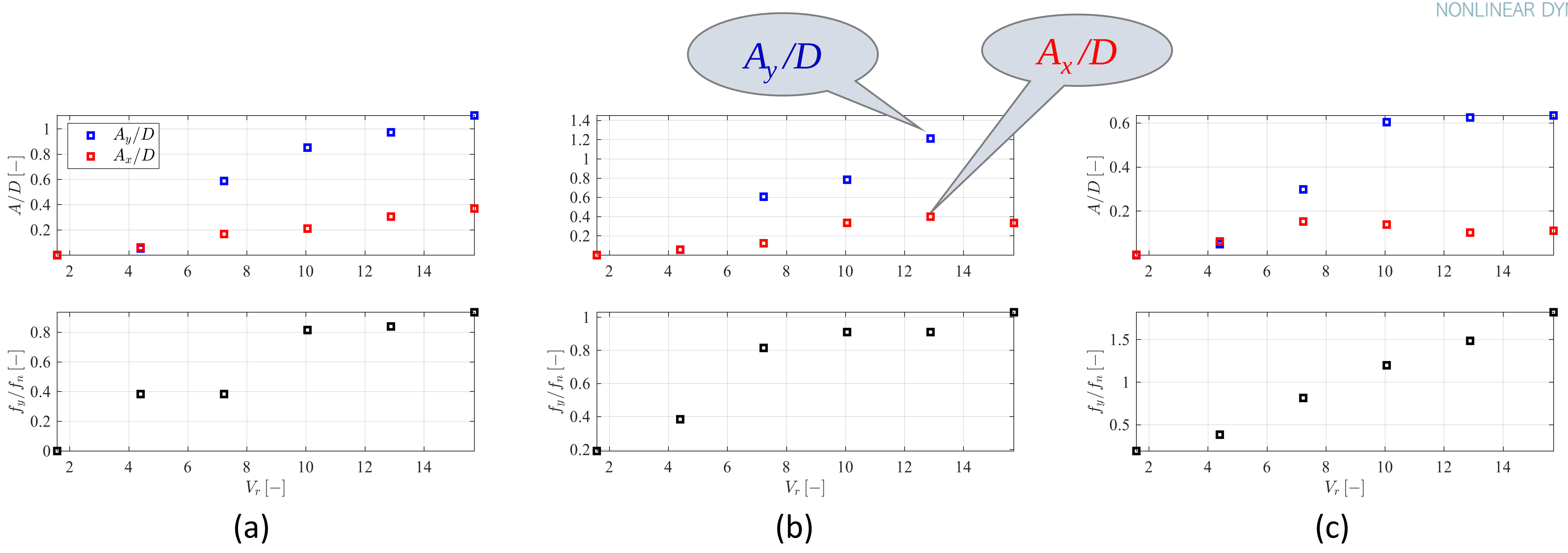
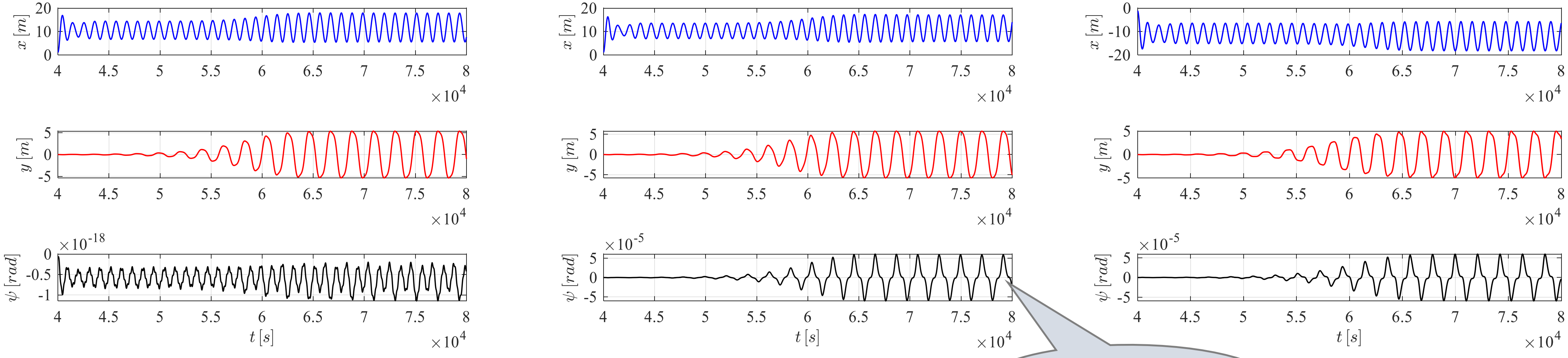


Figure 7 – Normalized amplitudes and oscillation frequencies, as a function of the reduced velocity. (a): linear mooring model, α = 0, π; (b): nonlinear mooring model, α = 0; (c): nonlinear mooring model, α = π.

$$St = 0.078 \Rightarrow \text{resonance peak expected at } V_r = 1/St \simeq 12.8$$

CASE STUDY - A MONOCOLUM PLATFORM (L/D=0.4)

Small oscillations



Yaw neglectable

(a) (b) (c)

Figure 8. Surge, sway and yaw motions. V=0.56m/s; V_r=4.4.
(a): linear mooring model, α **= 0,** π**; (b): nonlinear mooring model,** α **= 0; (c): nonlinear mooring model,** α **=** π**.**

CASE STUDY - A MONOCOLUM PLATFORM (L/D=0.4)

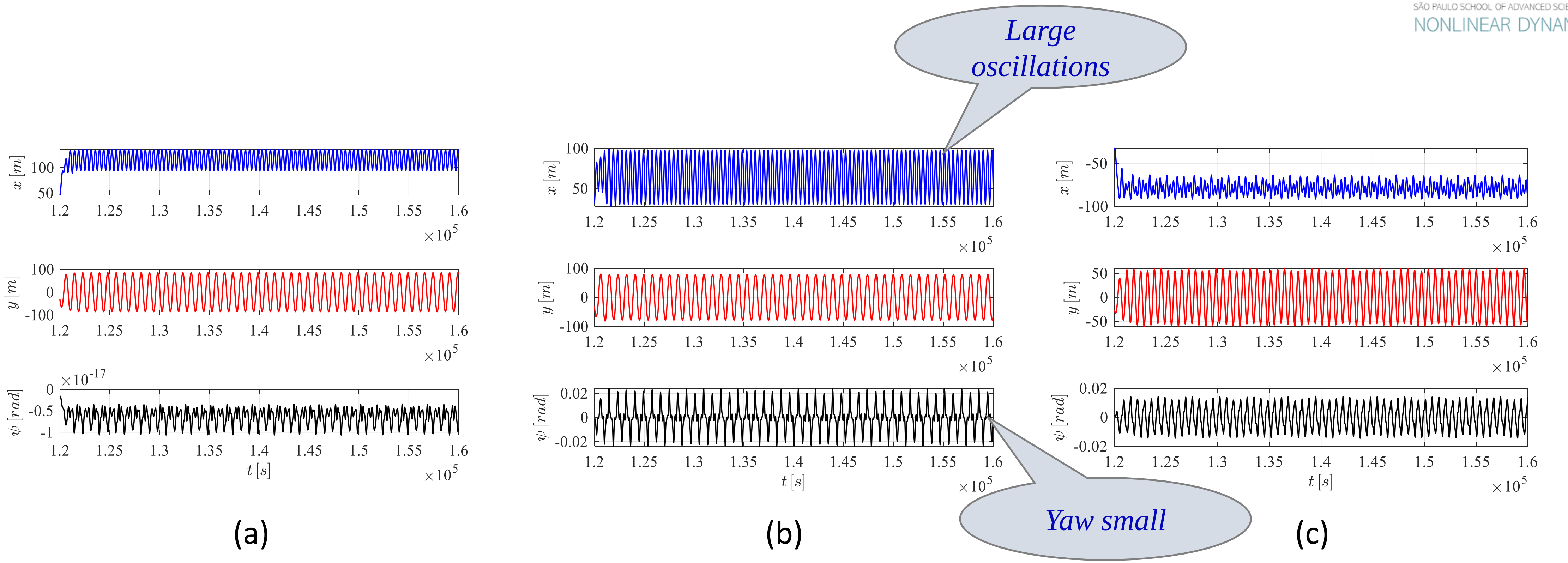


Figure 8. Surge, sway and yaw motions. V=1.28m/s; V_r=10.0.
(a): linear mooring model, α = 0, π; (b): nonlinear mooring model, α = 0; (c): nonlinear mooring model, α = π.

CASE STUDY - A MONOCOLUM PLATFORM (L/D=0.4)

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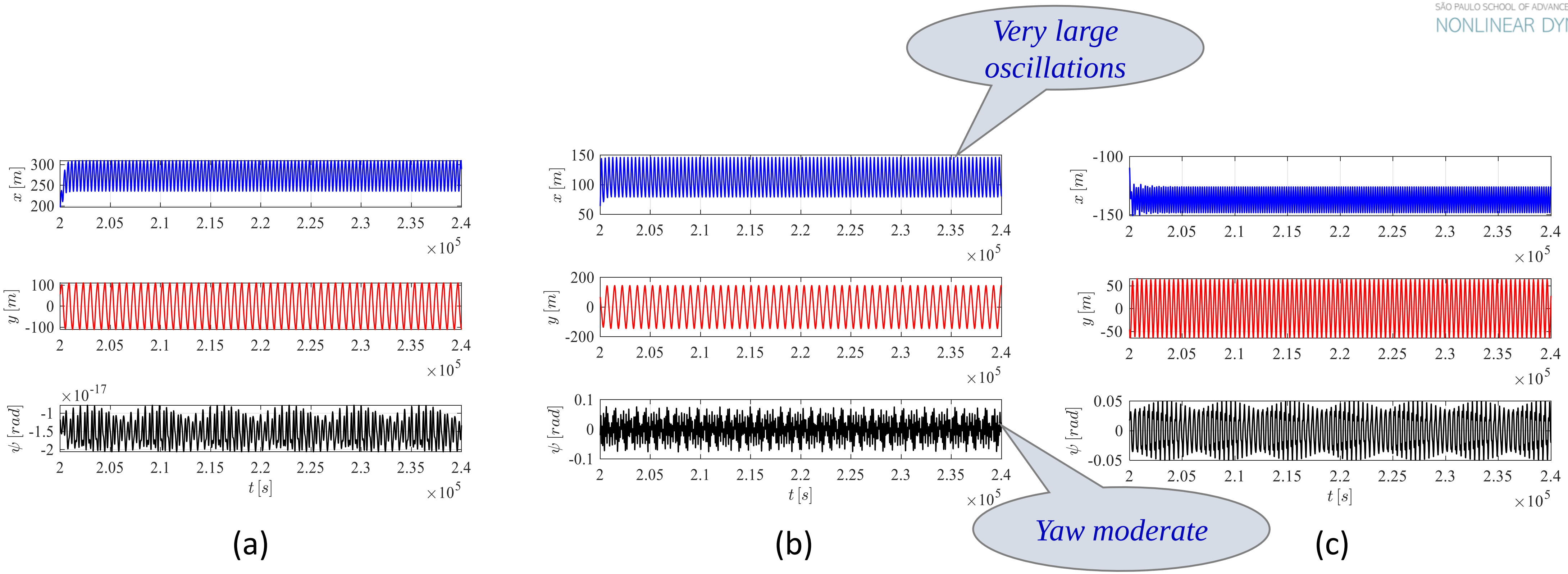
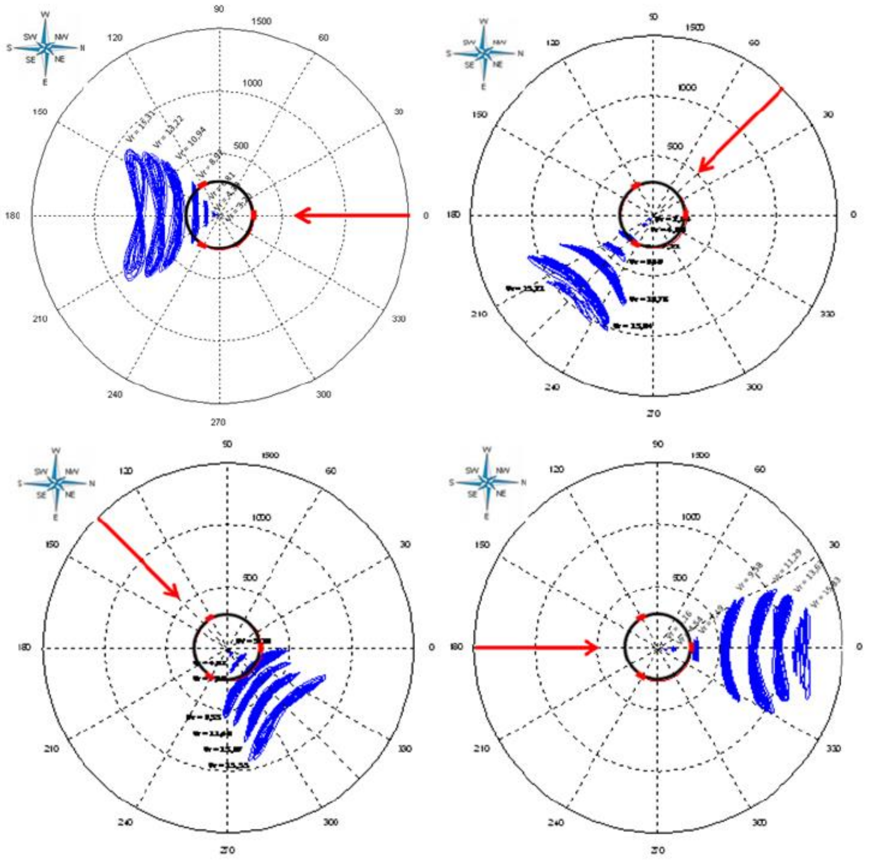
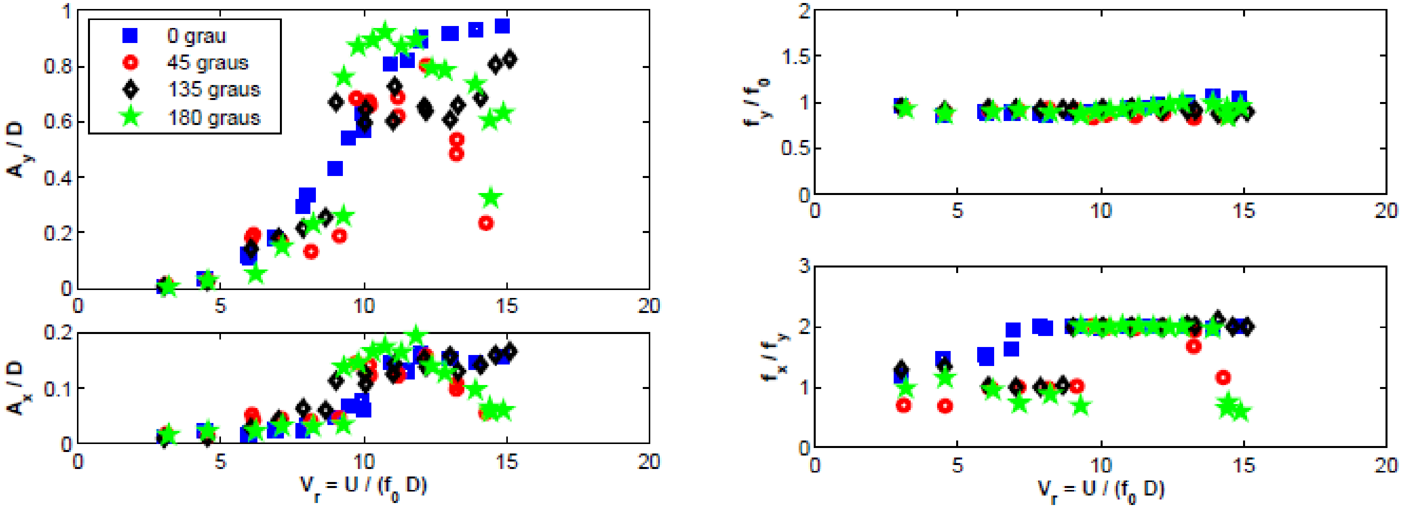


Figure 8. Surge, sway and yaw motions. V=2.0m/s; V_r=15.7.
(a): linear mooring model, α = 0, π; (b): nonlinear mooring model, α = 0; (c): nonlinear mooring model, α = π.

MONOBR – TRAJECTORIES AND DYNAMIC RESPONSE





MonoBR, Experimental data, *linear mooring lines*
Gonçalves, R.T., PhD Thesis, 2013
Gonçalves et al 2010, J Offshore Mech and Arctic Engineering

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