The Exact Solutions of Tower-Yoke Mooring Systems

ISOPE 2007

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Introduction

- Extreme Shallow Water
- Catenary Mooring Systems Neither Feasible Nor Effective
- Solution: Tower Yoke Mooring System
- Easy and cost-effective Riser Systems
- Exact Solutions of Tower Yoke Mooring System
- Verified and Validated with Model Test Results

Tower Yoke Mooring System

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Tower Yoke Mooring System

- a tower fixed at the seabed
- a mooring yoke assembly
- a heavy weight
- a turntable on the tower
- a two-axis joint on yoke
- two pendant linkages
- one double-axis joint on upper end (upper U-joint)
- one triple-axis joint on lower end (lower U-Joint)

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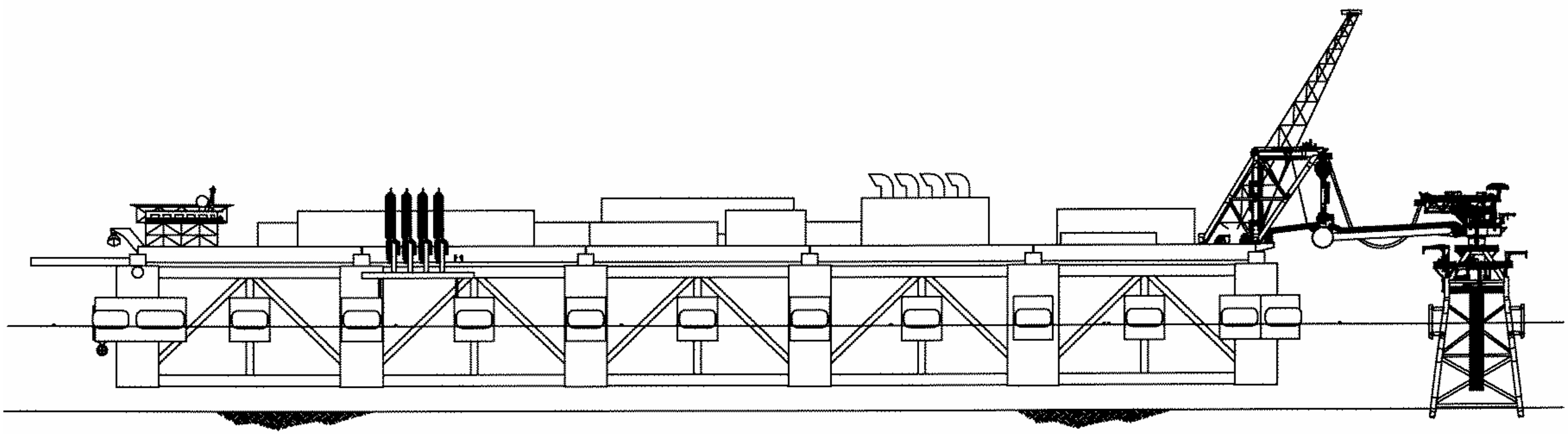
Tower Yoke Mooring System

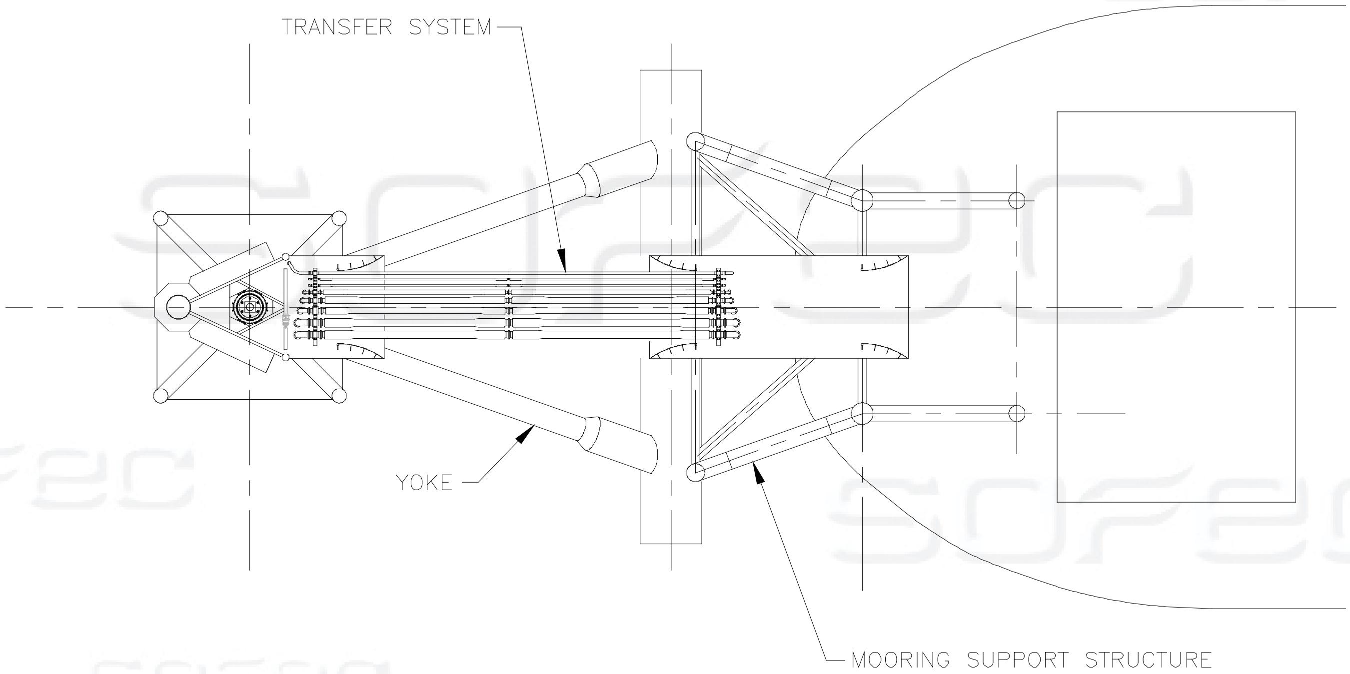
Tower Yoke Mooring System

LNG receiving platform in shallow water



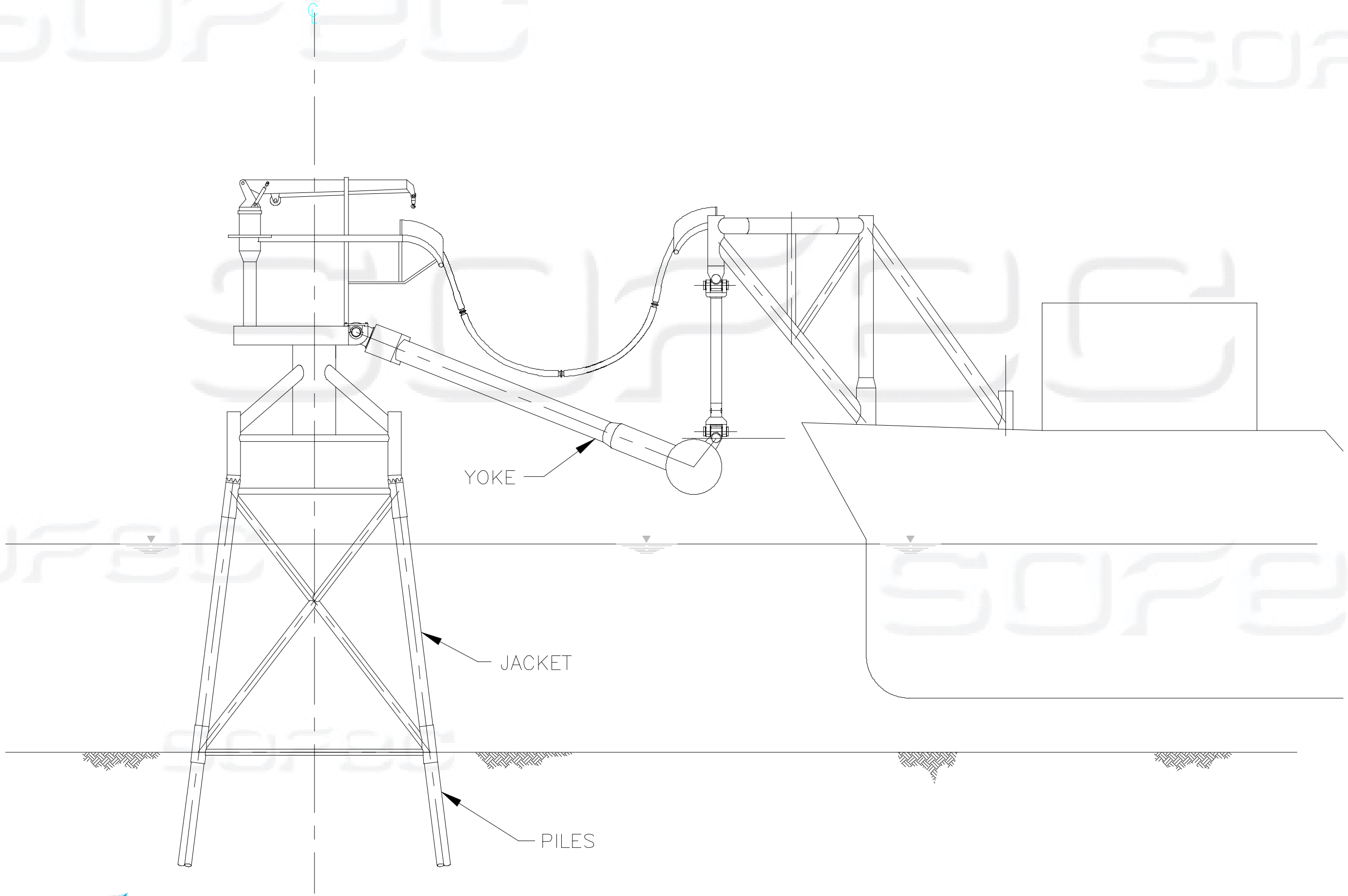
Tower Yoke Mooring System

General arrangement



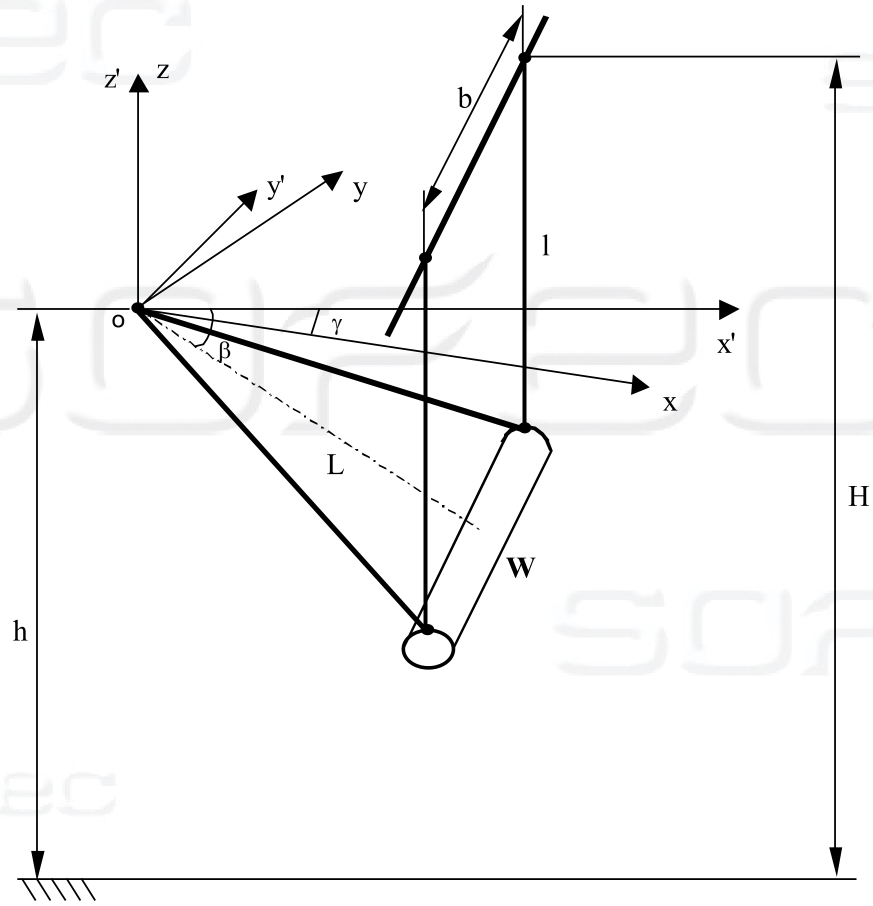
Tower Yoke Mooring System

General arrangement



Tower Yoke Mooring System

Analysis Coordinates



Tower Yoke Mooring System

Assumptions

- Yoke and linkages un-stretchable rigid bodies
- Small distance between yoke weathervaning axis, i.e. yow axis, and pitch/roll axis ignored
- Weights of pendant linkages negligible
- Rotation sequence: z-axis, γ , y-axis, β , and x-axis, α

Tower Yoke Mooring System

Positions of lower U-Joints in oxyz coordinate

$$\begin{cases} x^{s,p} = L\cos\beta\cos\gamma \mp \dfrac{b}{2}\cos\alpha\sin\gamma \\ y^{s,p} = L\cos\beta\sin\gamma \pm \dfrac{b}{2}\cos\alpha\cos\gamma \\ z^{s,p} = -L\cos\beta \pm \dfrac{b}{2}\sin\alpha \end{cases} \qquad (1)$$

Tower Yoke Mooring System

Pendant angles by vessel motions at upper U-Joint, (x_v, y_v, z_v)

$$\begin{cases} \cos\gamma_x = (x_v - x)/l \\ \cos\gamma_y = (y_v - y)/l \\ \cos\gamma_z = (z_v - z)/l \end{cases}$$

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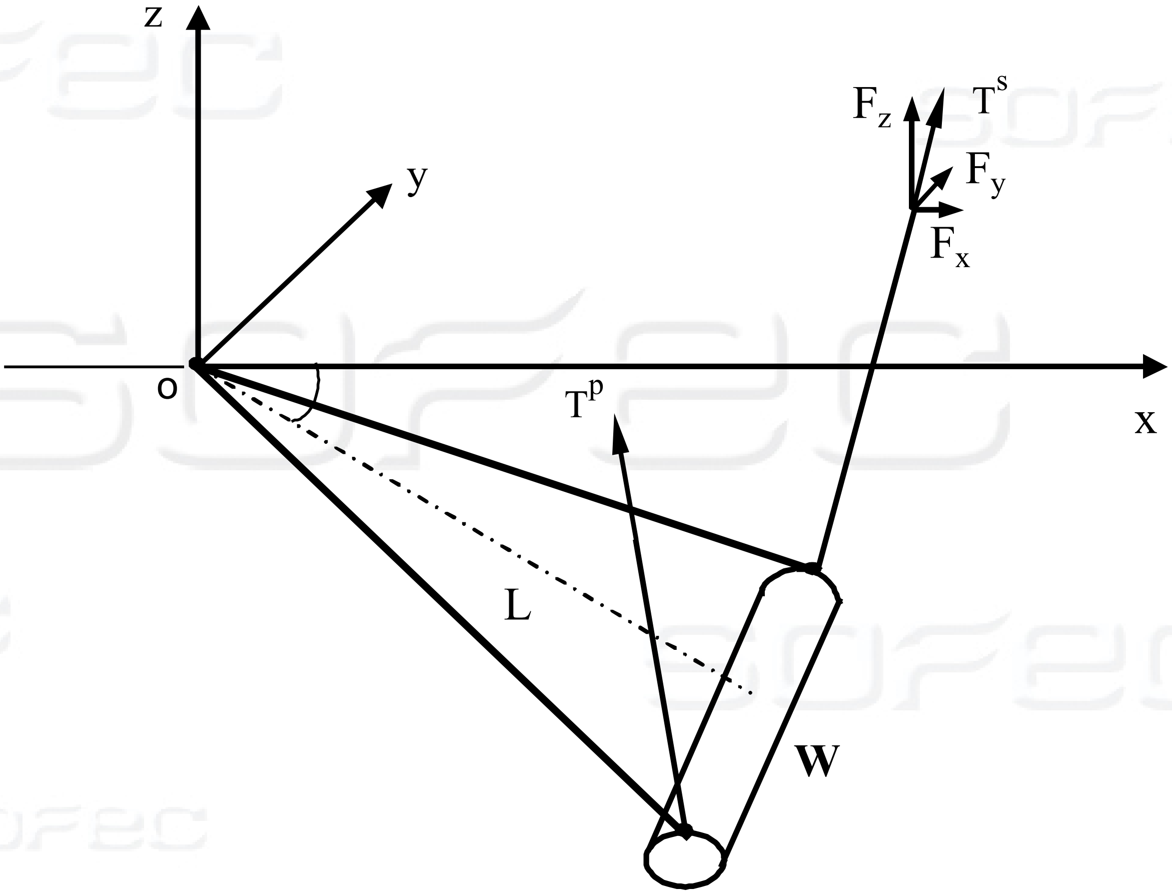
Tower Yoke Mooring System

Forces on yoke:



Tower Yoke Mooring System

Moments at the yoke pivot point:

$$T^{p}(y^{p}\cos\gamma_{z}^{p} - z^{p}\cos\gamma_{y}^{p}) + T^{s}(y^{s}\cos\gamma_{z}^{s} - z^{s}\cos\gamma_{y}^{s}) - W\frac{(y^{p}+y^{s})}{2} = 0$$

$$T^{p}(z^{p}\cos\gamma_{x}^{p} - x^{p}\cos\gamma_{z}^{p}) + T^{s}(z^{s}\cos\gamma_{x}^{s} - x^{s}\cos\gamma_{z}^{s}) + W\frac{(x^{p}+x^{s})}{2} = 0$$

$$T^{p}(x^{p}\cos\gamma_{y}^{p} - y^{p}\cos\gamma_{x}^{p}) + T^{s}(x^{s}\cos\gamma_{y}^{s} - y^{s}\cos\gamma_{x}^{s}) = 0$$

Tower Yoke Mooring System

Pendant linkages un-stretchable rigid bodies:

$$(x_v^p - x^p)^2 + (y_v^p - y^p)^2 + (z_v^p - z^p)^2 = l^2$$

$$(x_v^s - x^s)^2 + (y_v^s - y^s)^2 + (z_v^s - z^s)^2 = l^2$$

α, β, γ

Tower Yoke Mooring System

The five unknowns:
Yoke rotation angles: α, β, γ
Pendant tensions T^p and T^s

can be solved exactly from the five equations above

Tower Yoke Mooring System

Restoring forces and yaw moments on vessel:

$$
\begin{cases}
F_x^v = -T^p \cos\gamma_x^p - T^s \cos\gamma_x^s \\
F_y^v = -T^p \cos\gamma_y^p - T^s \cos\gamma_y^s \\
F_z^v = -T^p \cos\gamma_z^p - T^s \cos\gamma_z^s \\
M_z^v = \dfrac{b}{2}(-T^p \cos\gamma_x^p + T^s \cos\gamma_x^s)
\end{cases}
$$

Tower Yoke Mooring System Model Tests

Principle particulars of tower yoke mooring systems

Tower Yoke Mooring		1	2	
Water Depth		20	33	(m)
Yoke Length	L	35	40	(m)
Yoke Height	h	40	60.3	(m)
Yoke Breadth	b	28	28	(m)
Ballast Weight	W	1172	1460	(MT)
Pendant Length	l	15	18	(m)
Pendat Height	H	45	65.7	(m)

Tower Yoke Mooring System Model Tests

(at Shanghai Jiao Tong University Ocean Engineering Lab.)

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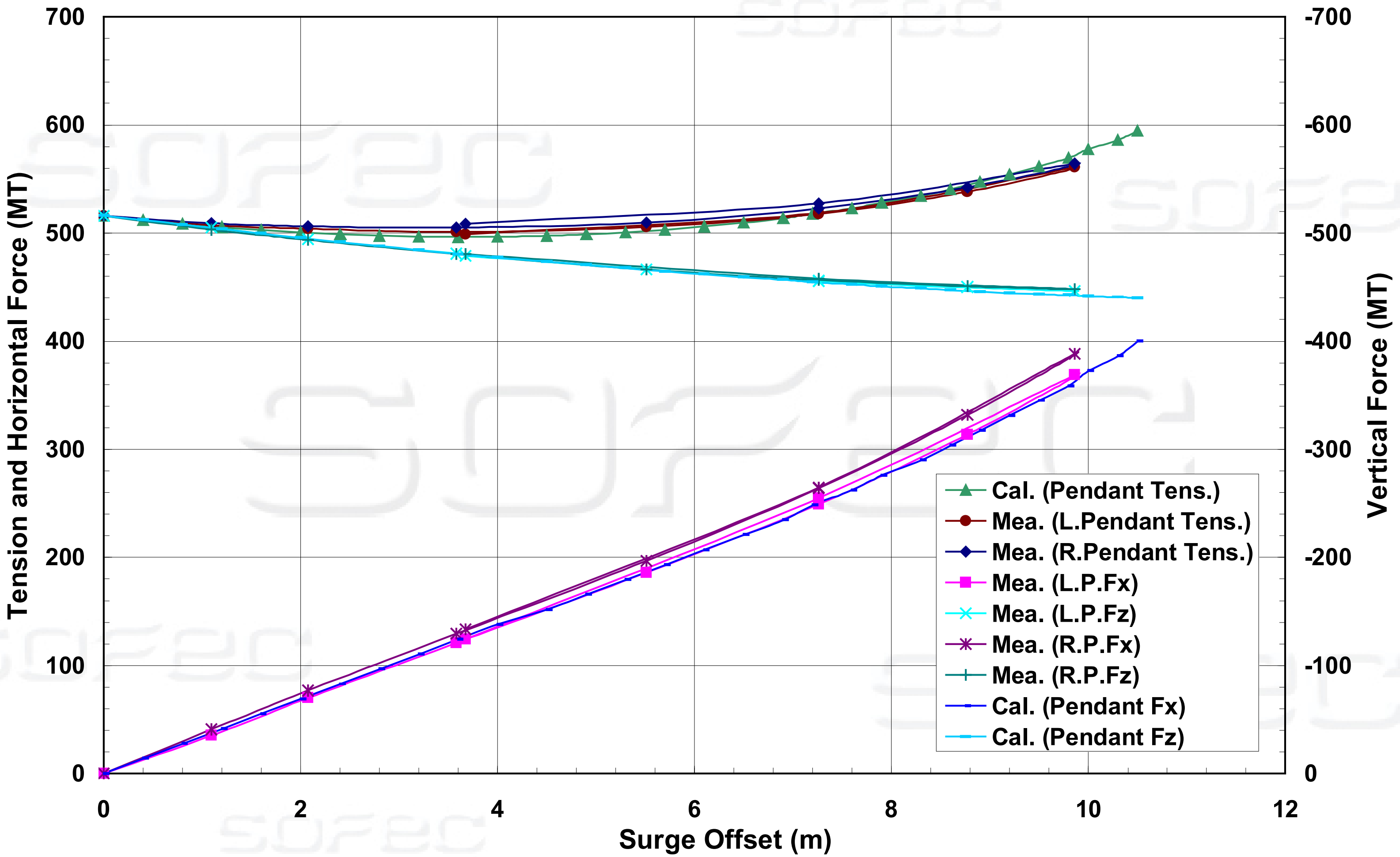
Tower Yoke Mooring System Model Tests



System surge force-deflection characteristics

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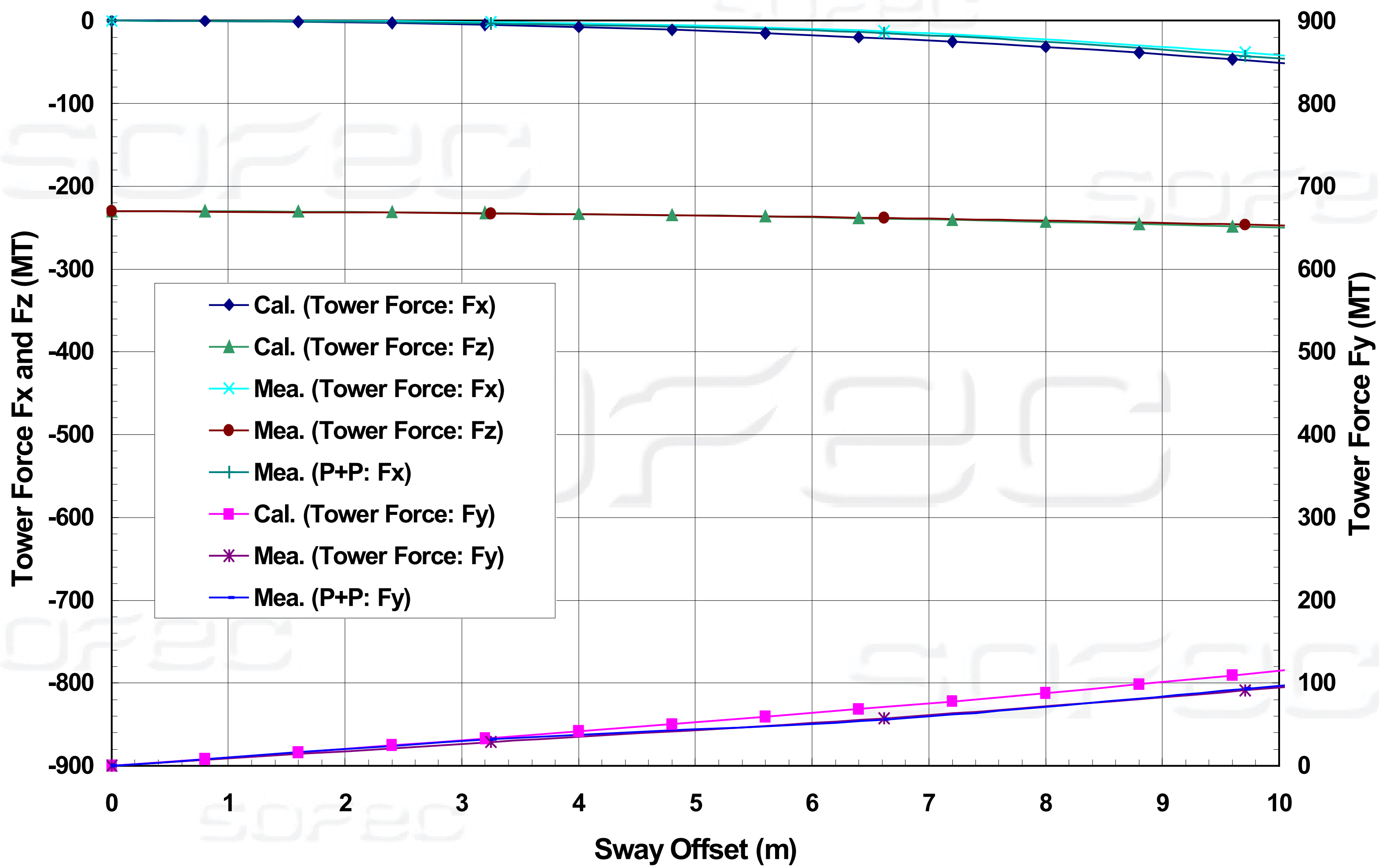
Tower Yoke Mooring System Model Tests



System sway force-deflection characteristics

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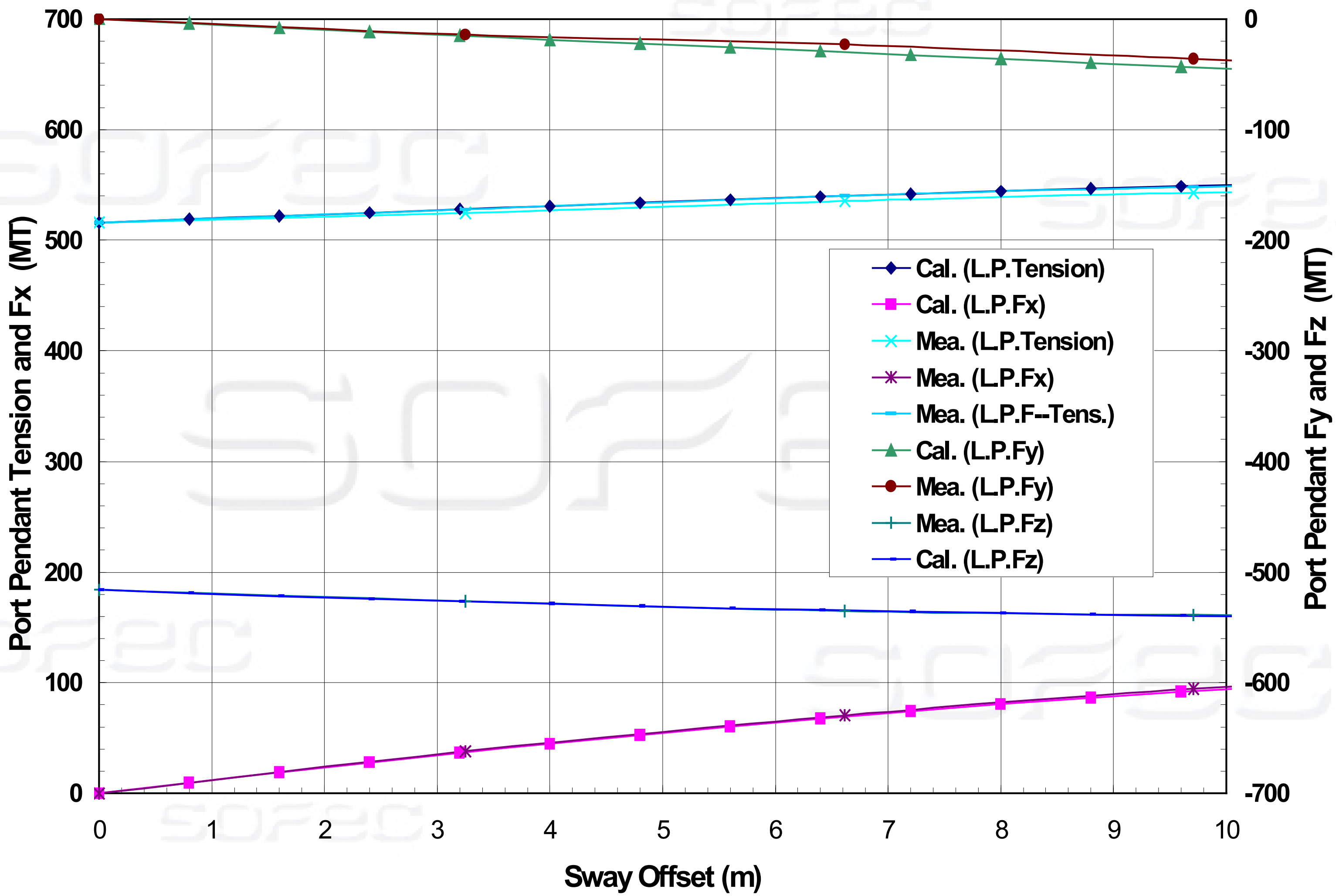
Tower Yoke Mooring System Model Tests



Sway and port pendent tension characteristics

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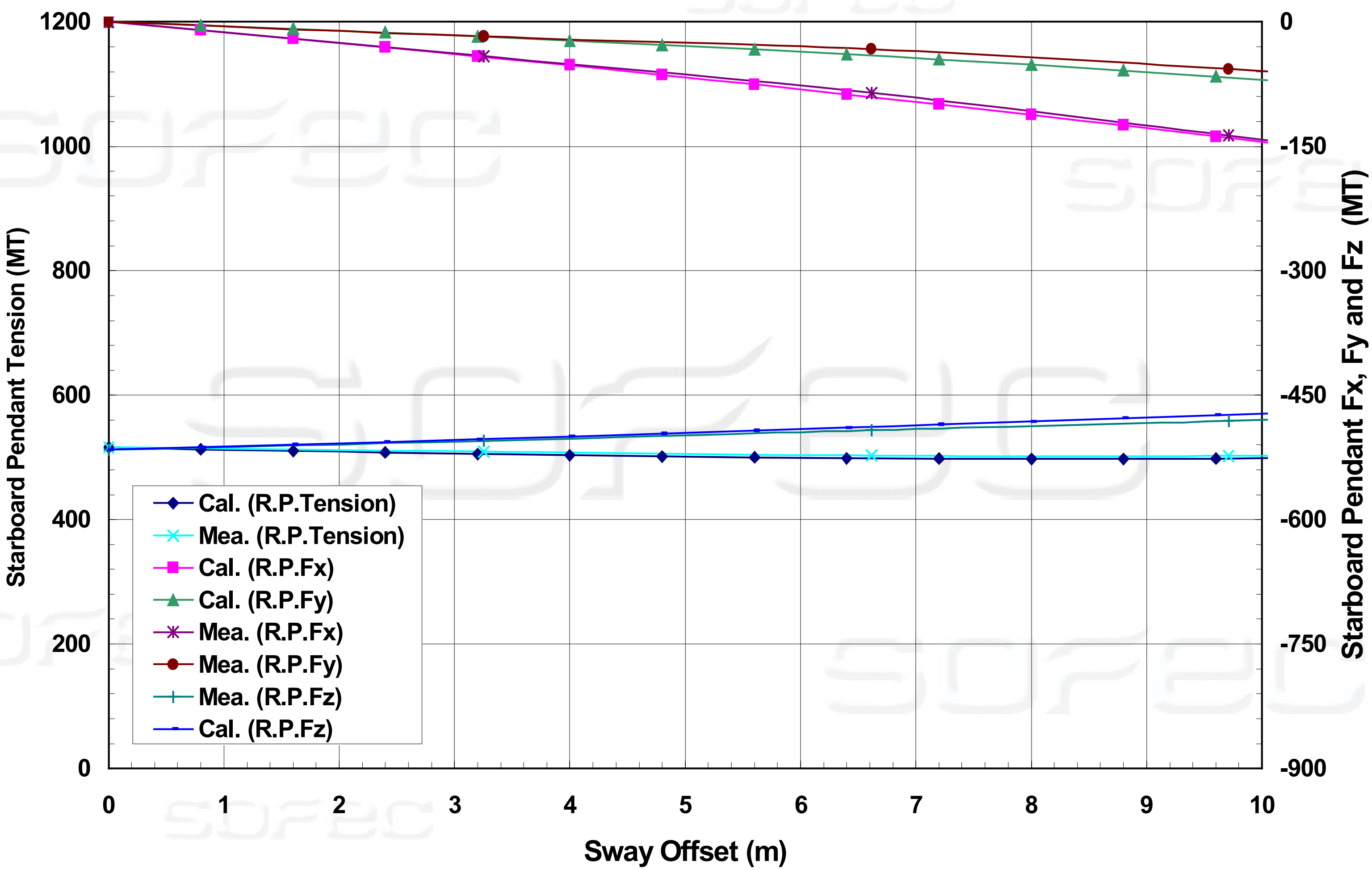

Sway and starboard pendent tension characteristics

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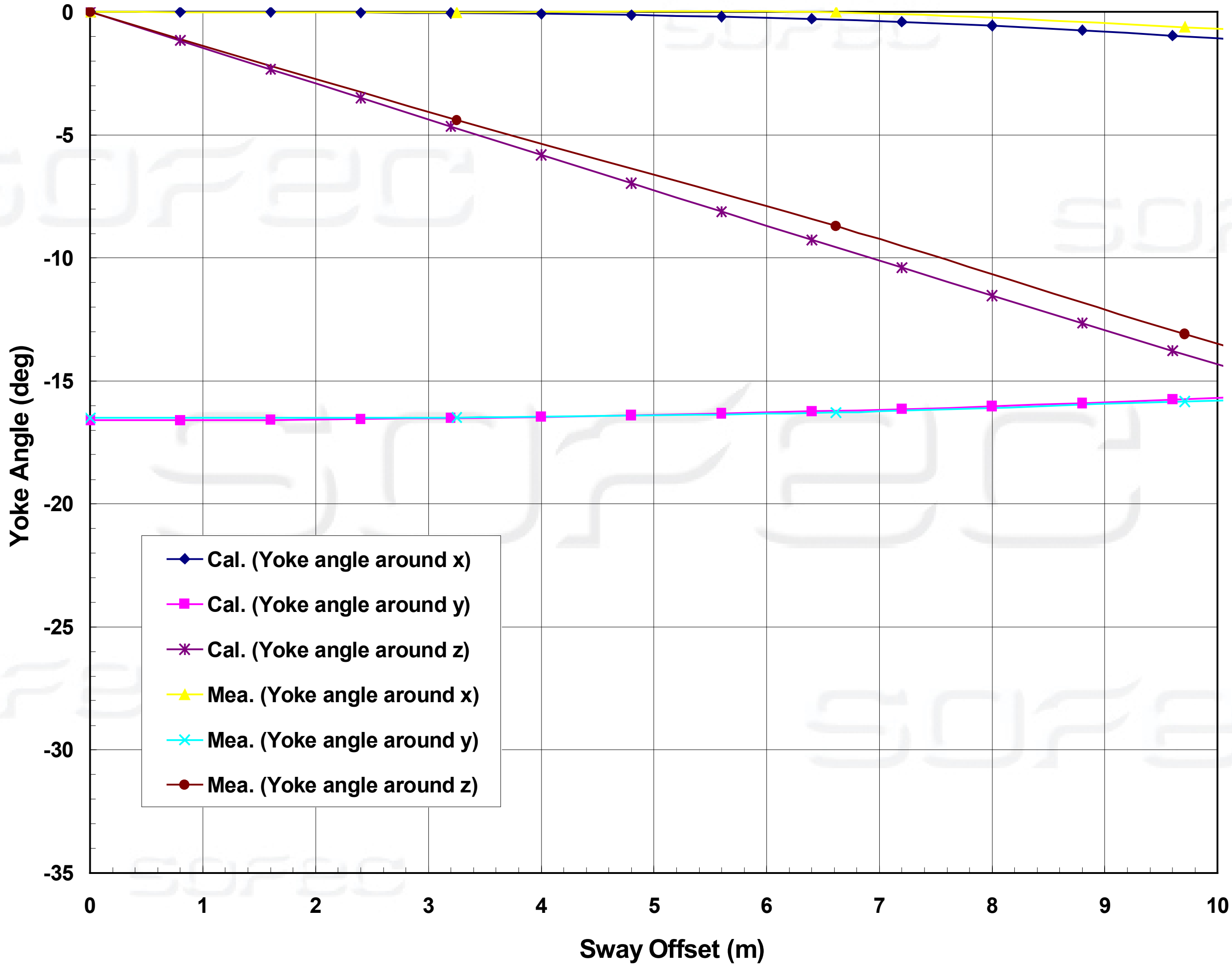
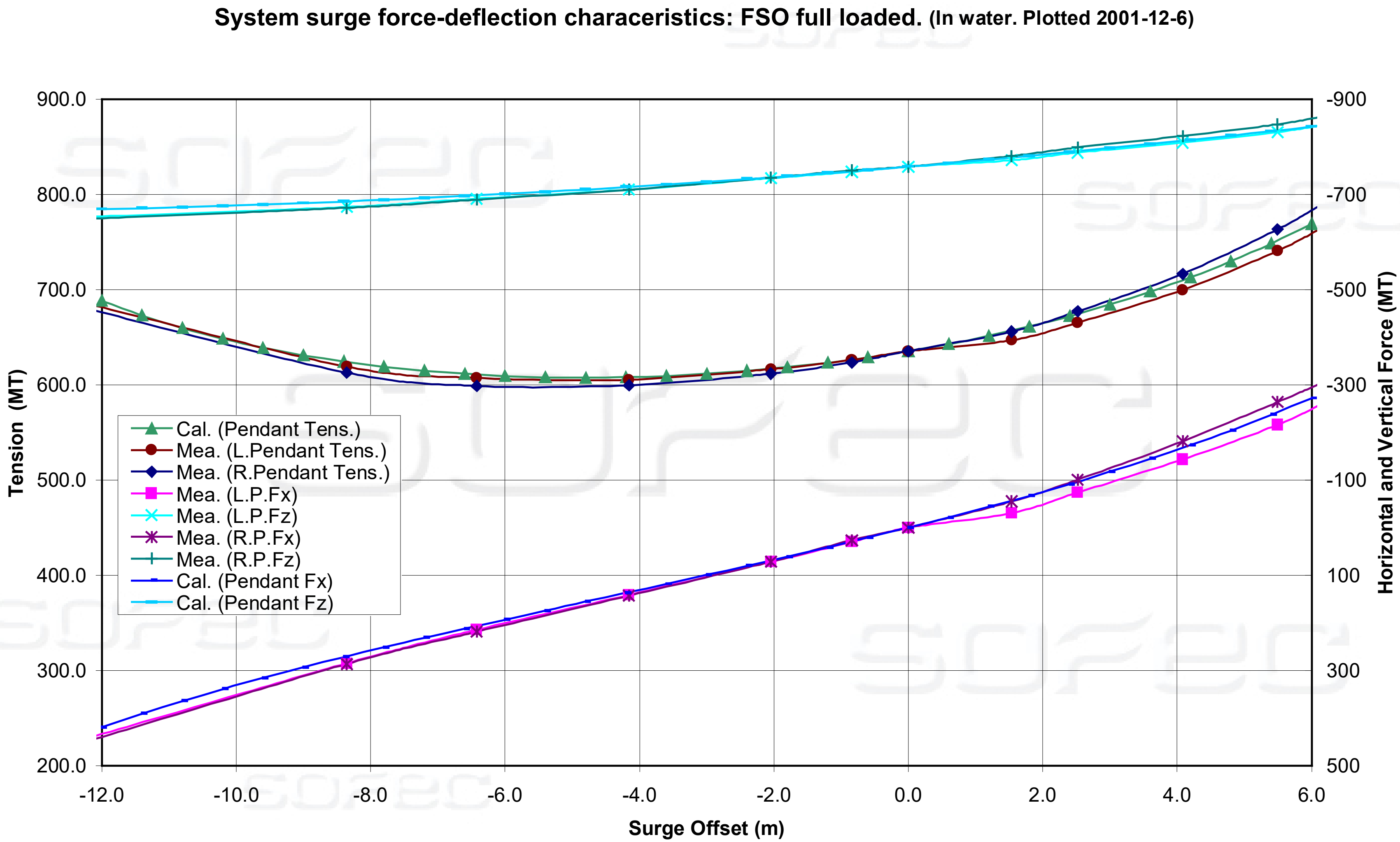
Tower Yoke Mooring System Model Tests



Sway and yoke rotations characteristics

Tower Yoke Mooring System Model Tests



System surge force-deflection characteristics

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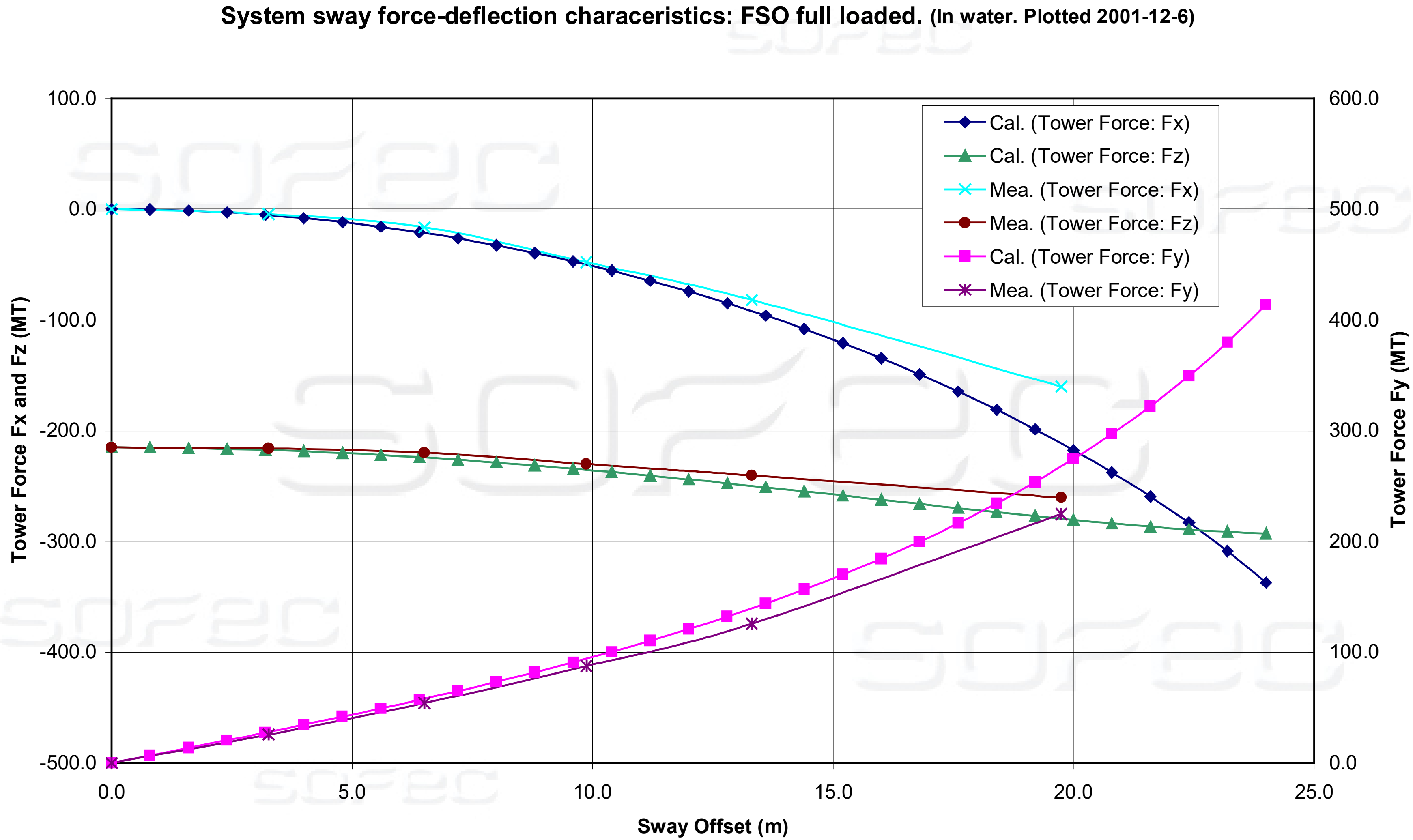
Tower Yoke Mooring System Model Tests



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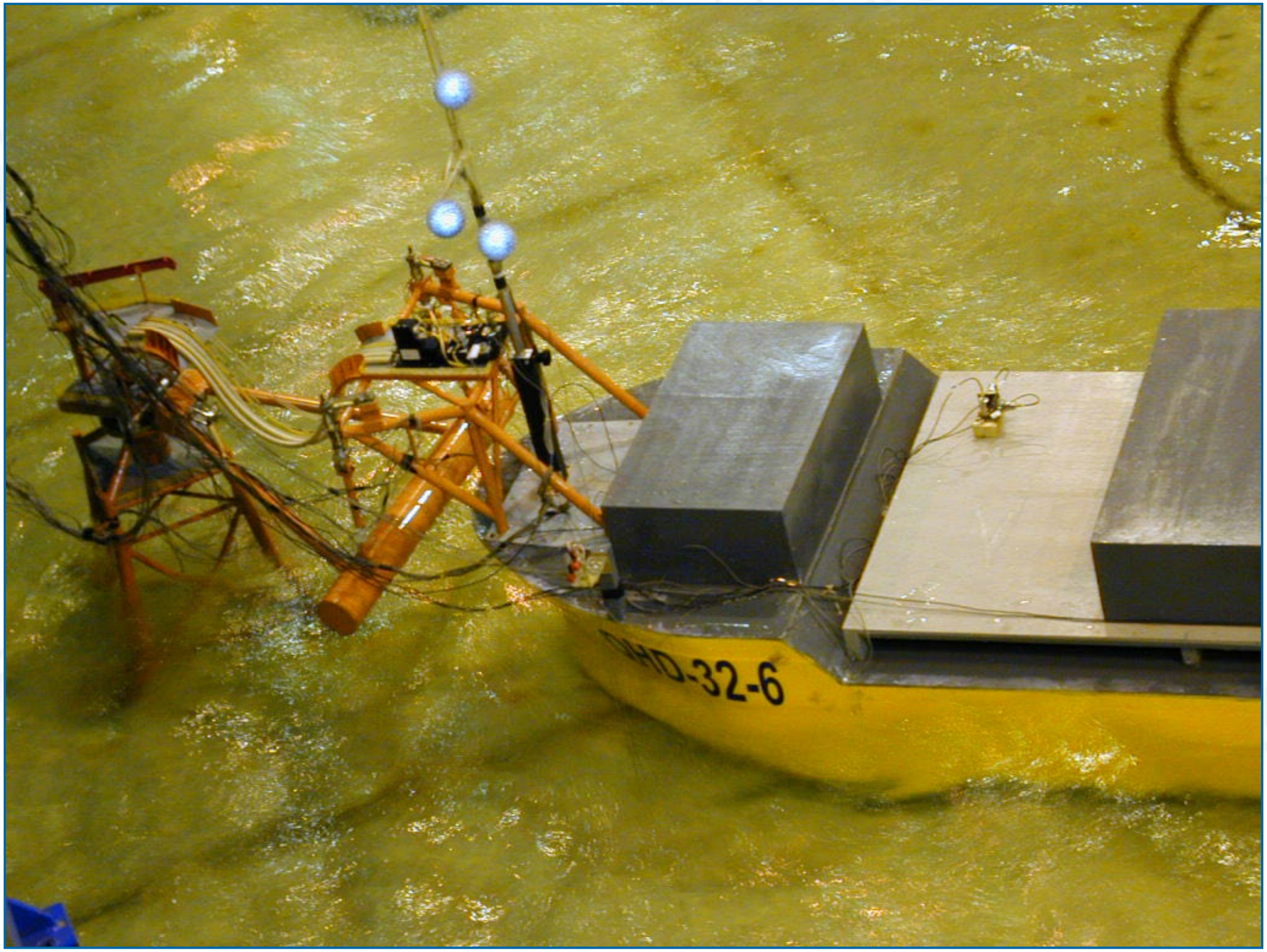

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Tower Yoke Mooring System

Conclusions

- Exact solutions has been derived for tower yoke mooring systems
- Theoretical solutions verified and validated through comparisons with model tests
- Excellent agreement has verified the theoretical methodologies presented
- Mathematical model successfully implemented in the design and analysis of tower yoke mooring systems
- Easily incorporated with time-domain and frequency-domain methods