Tandem Offloading from an FLNG in Harsh Environments

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Outline

- **Why Tandem Offloading for FLNG systems?**
- **Design Requirements**
- **Development of the Mooring System**
- **Analysis of System**
- **Validation with Model Test Data**
- **Focus on Extreme Design Cases and Operations**
- **Summary**

Offloading from an F(P)SO

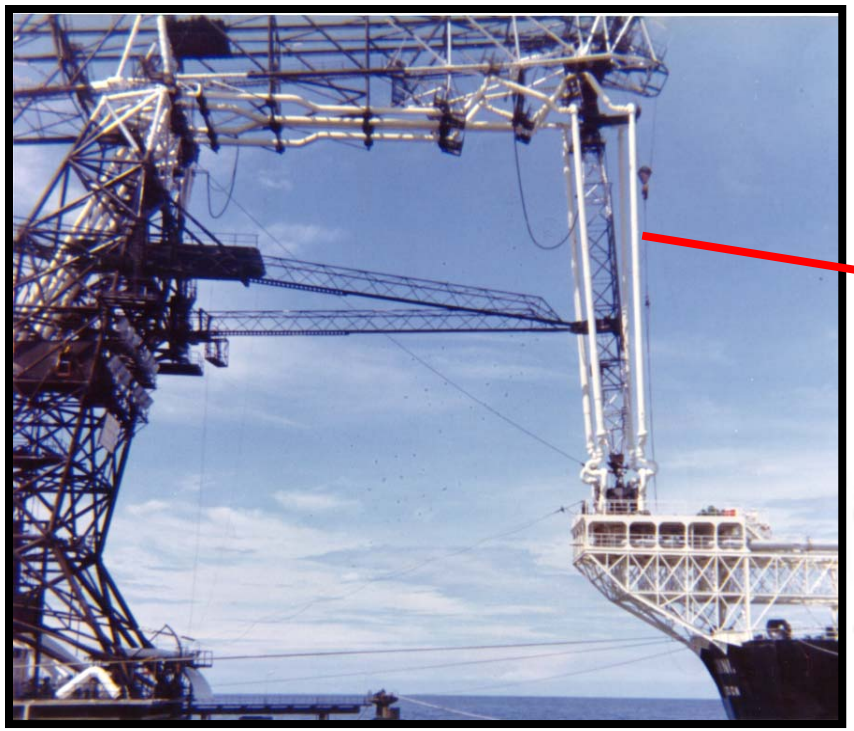
Typical Offload Operation Criteria

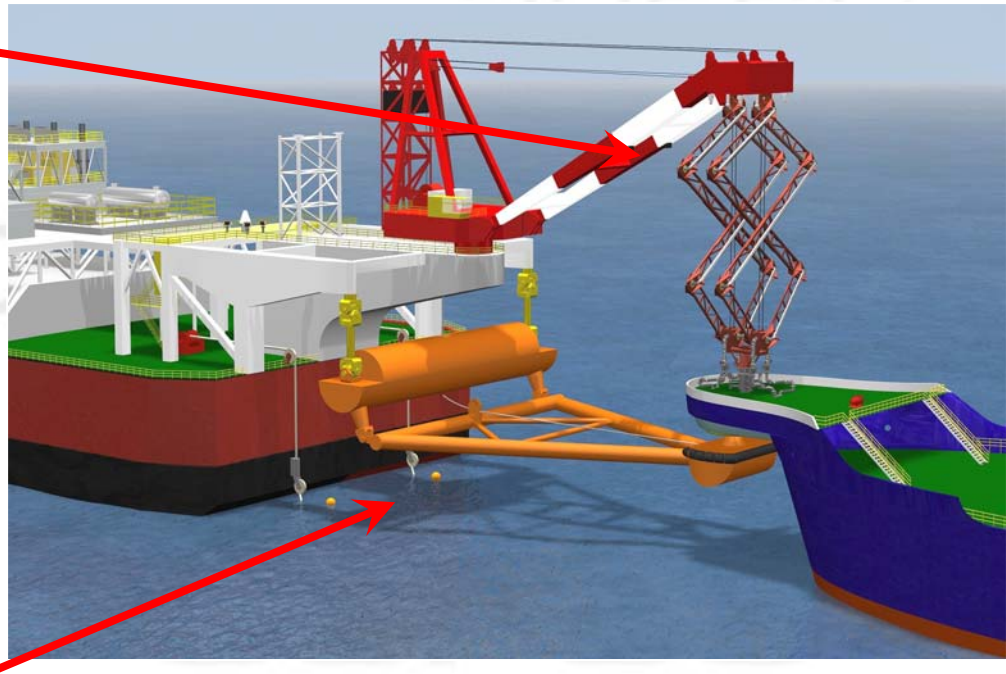
- **Tandem offloading using Nylon Hawser from FPSO to Tanker:**
  - Maximum Connect Hs = 2.5m
  - Maximum Offload Hs = 3.5m
- **Tandem Offloading using DP Shuttle Tankers**
  - Maximum Connect Hs = 4.5m
  - Maximum Offload Hs = 5.5m
- **Side-by-Side Offloading from FPSOs to Oil Tankers:**
  - Maximum Connect Hs ~ 1.5 to 2m
  - Maximum Offload Hs ~ 2.0 to 2.5m

Design Requirements

- **Offloading from Floating LNG Platforms**
- **High Safety and Reliability Requirements**
- **Use Field Proven Technology**
- **Harsh Operational Environmental Conditions:**
  - Offload in Hs = 5.5m seas
  - Connect mooring and LNG transfer system in Hs = 4.5m
  - No additional support vessels
- **Offload Frequency ~ 2 offloads / week**

LNG Tandem Offloading System Developed





Initial Analysis/Validation of System

- **Global System Responses and Loads:**
  - In-house frequency domain tools
  - Ignore wave interaction between two vessels
  - No wind/current shielding between the two vessels
  - Obtain System Load and Response Estimates

- **Model Tests for Validation:**
  - Complete FLNG – Mooring Yoke – LNGC System
  - Yoke Instrumented for Forces and Angular Displacements
  - Relative Motions between the Two Vessels

Tandem Mooring - Model Test Program

- **FLNG System:**
  - LBP ~ 300m
  - Beam ~ 55m
  - LNG Capacity: 240 m^3
- **LNGC System:**
  - LBP ~ 270m
  - Beam ~ 44m
  - LNG Capacity: 140 m^3

Tandem Offloading Design Criteria

Environmental Conditions

	Maximum Offloading Seastates			Berthing	
Cumulative Probability	**99.999%**			**99.40%**	
	Wave Only	Crossed 1	Crossed 2	Crossed	
Water Depth	64	64	64	64	m
Wave					
Wave Spectral Model	P-M	P-M	P-M	P-M	
Significant Wave Height	5.5	5.5	5.5	3.5	m
Peak Period	12	10.5	12	9.5	sec
Direction	180	180	180	180	deg
Wind					
Velocity		42.9	42.9	23.5	knots
Wind Spectral Model		API	API	API	
Direction		225	225	225	deg
Current					
Velocity		1.45	1.45	0.58	knots
Direction		270	270	270	deg

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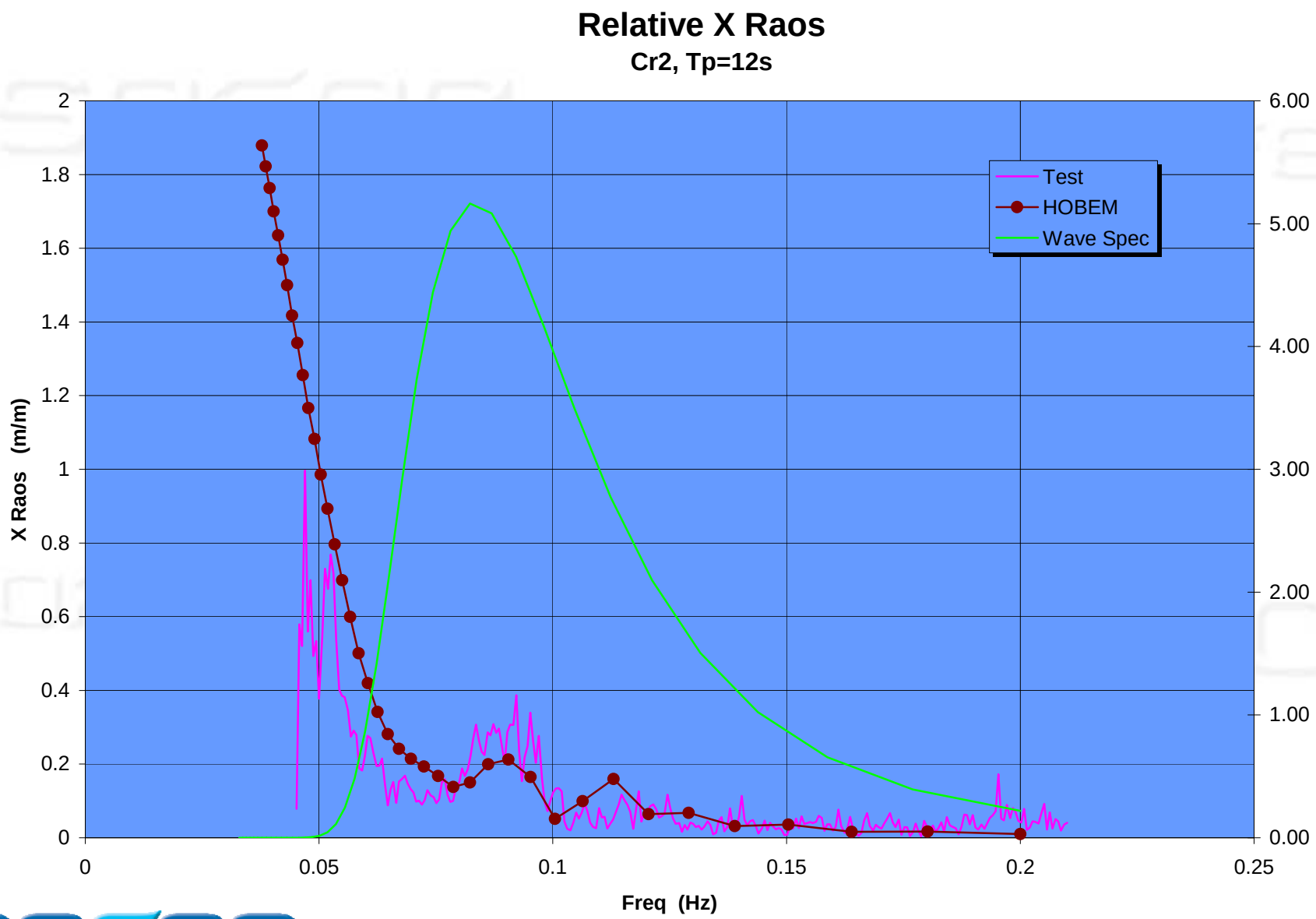
Model Tests: Connected System, Hs = 5.5m

Model Tests: Hook-up, Hs = 3.5m

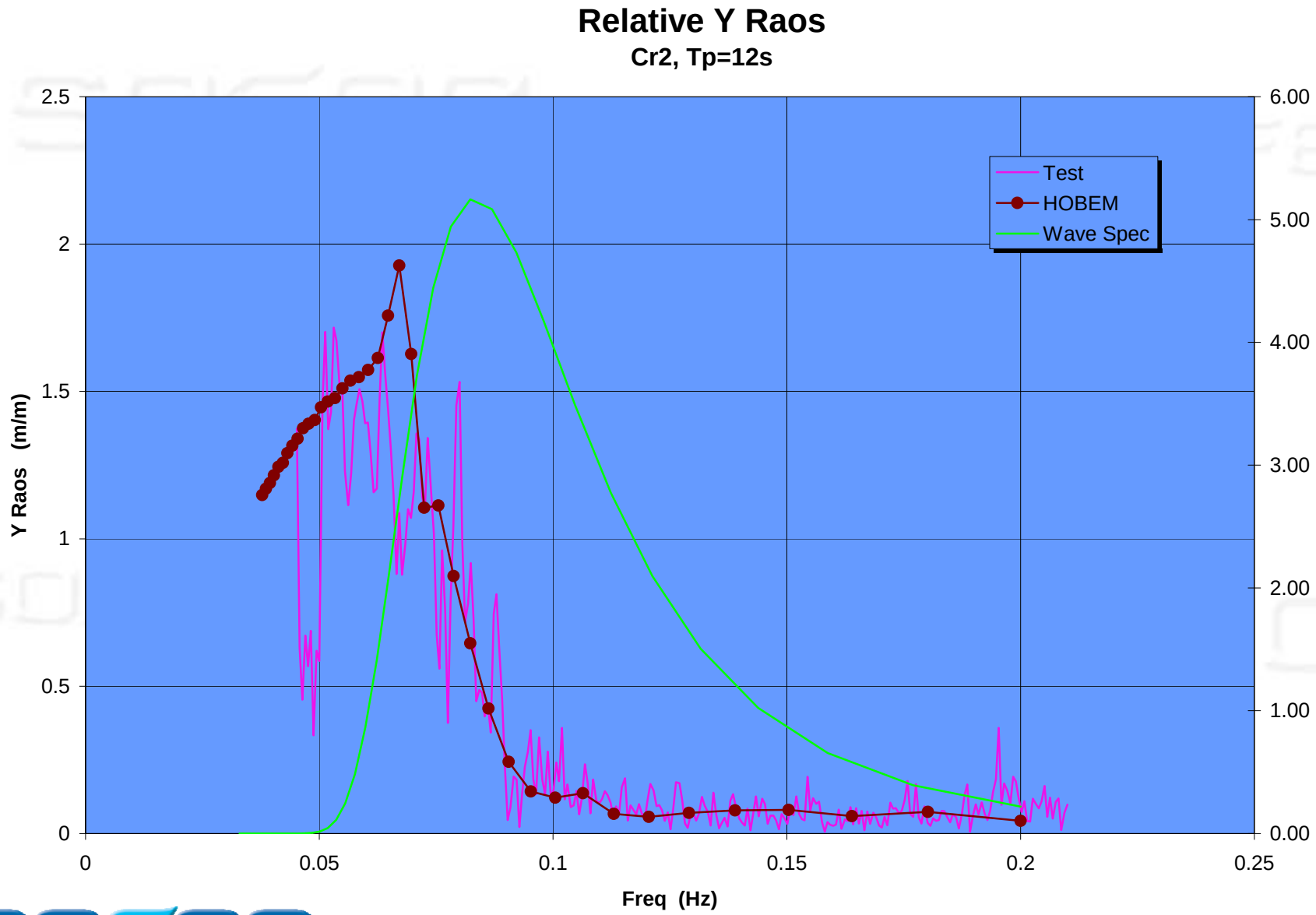
Comparison with Model Test Data

Parameter	Theory	Test	Unit
Relative Vessel Motions			
Surge, Min	-7.10	-8.78	meters
Surge, Max	3.21	2.60	meters
Sway, Min	-9.19	-6.96	meters
Sway, Max	10.53	10.07	meters
Heave, Sig	4.50	4.78	meters
XY, Max	11.27	10.41	meters
XYZ, Max	12.13	11.74	meters
Ball Joint Forces			
Fx- Longitudinal Force	371	467	m. tons
Fy - Transverse Force	-560	-403	m. tons
Fz - Vertical Force	-165	-175	m. tons
Fxy - Resultant Force	591	488	m. tons
Fxyz - Resultant Force	605	516	m. tons
Pendant Tension			
at Upper U-joint	1407	1291	m. ton
Pulling Tension	262.0	265.0	m. ton

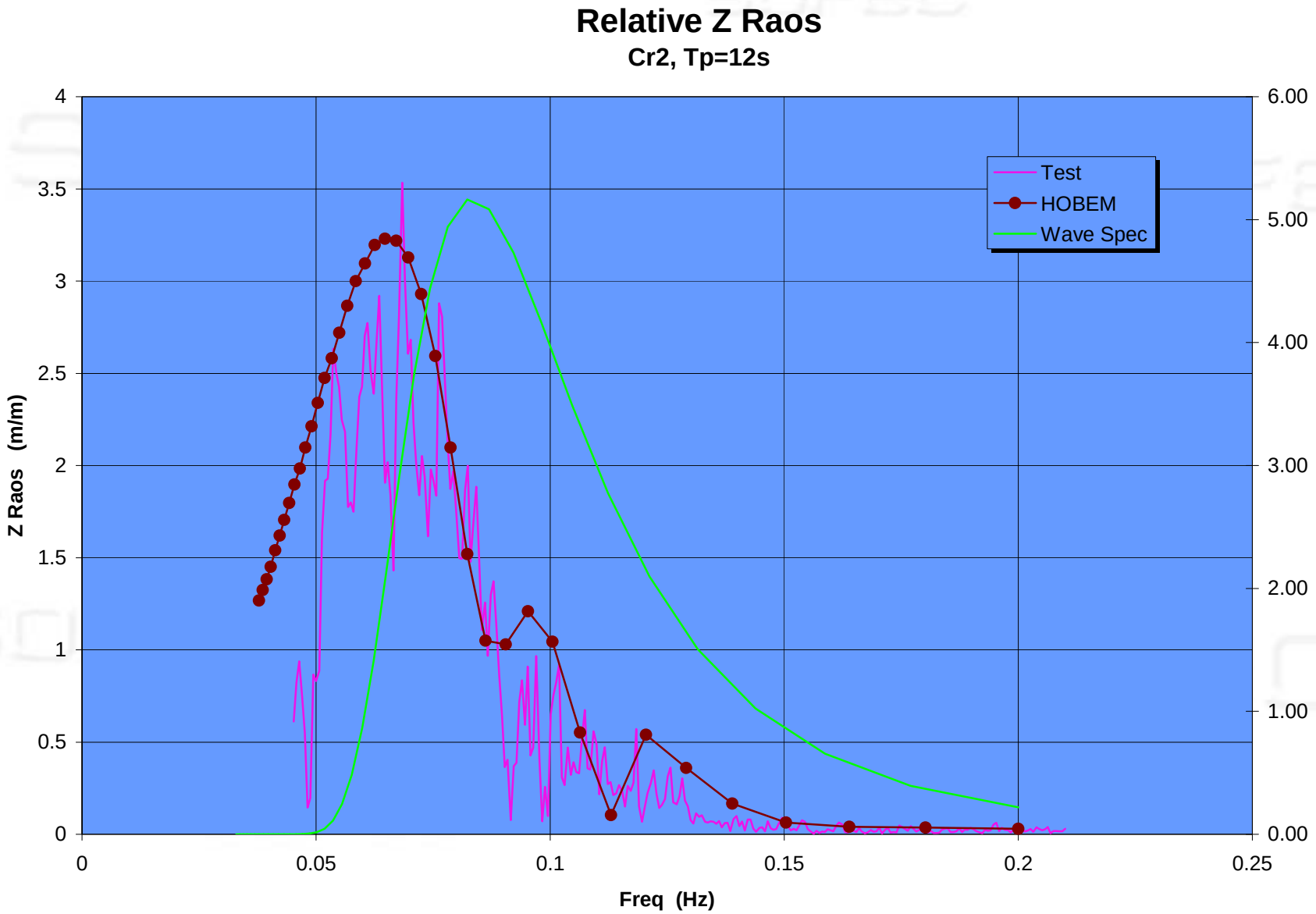
Comparison: Model Test versus Analysis 1



Comparison: Model Test versus Analysis 2



Comparison: Model Test versus Analysis 3

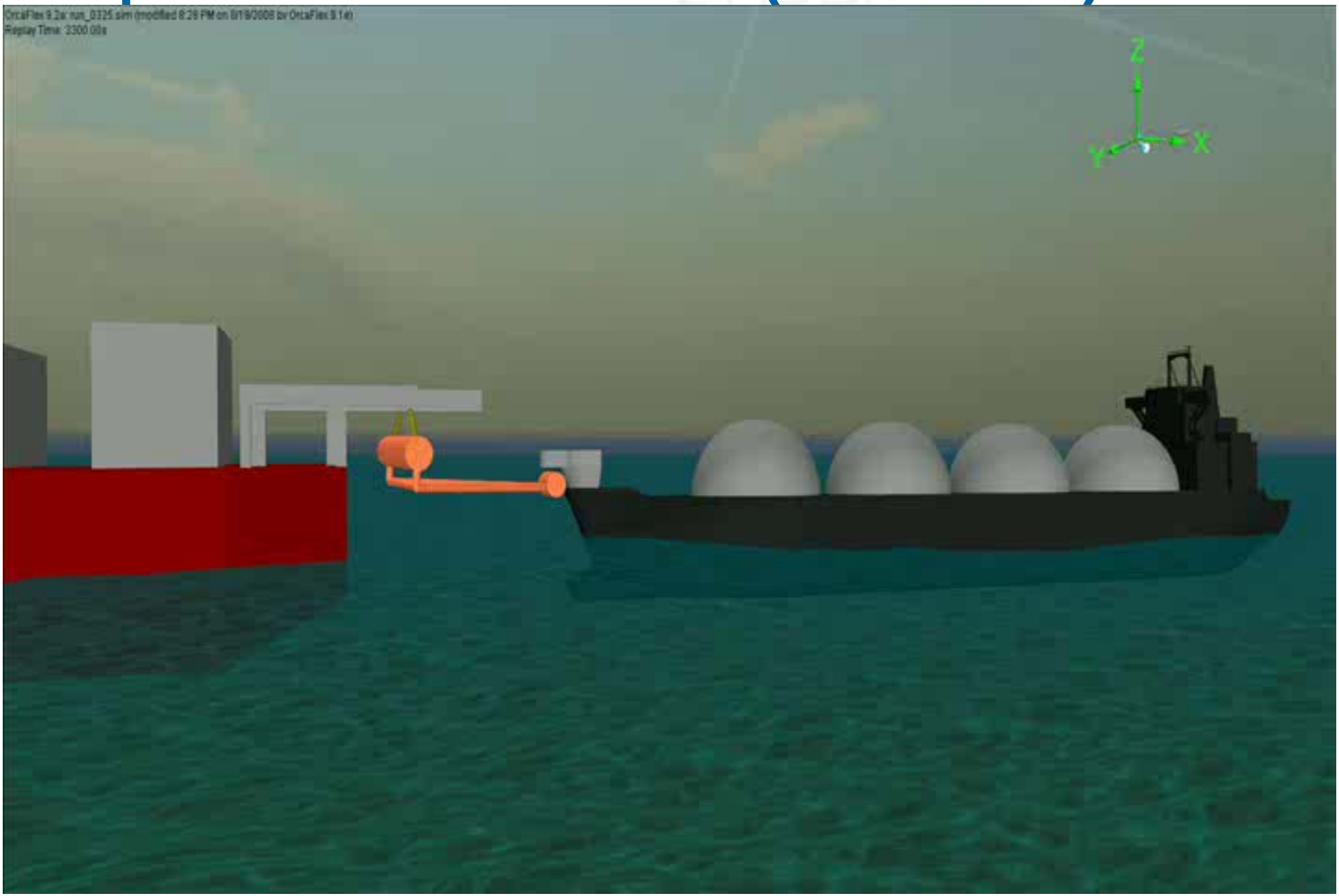


Time Domain Analysis

Analysis of the LNGC hook-up to the FLNG

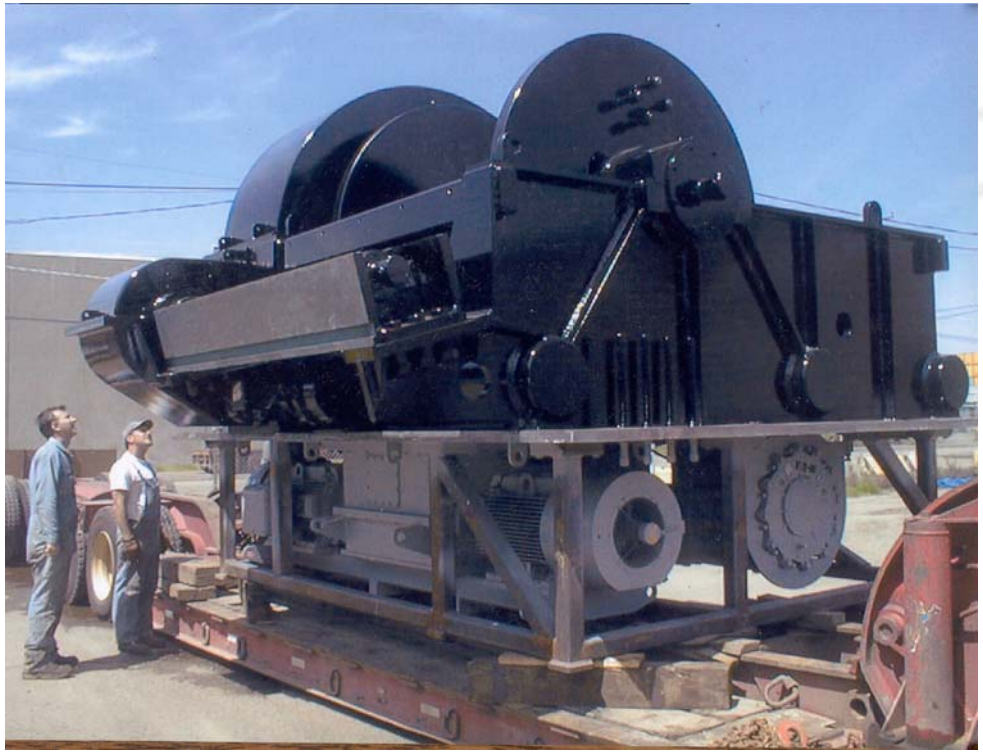
- Time domain analysis using OrcaFlex
- LF motions calculated from wind, wave and current
- WF motions calculated from RAOs
- LF motions fully coupled through yoke and pull-in line
- Duplex yoke modeled in full detail with u-joint friction
- Pull-in winch in constant speed mode (3m/min) with slip clutch at 275 MT
- Stern thrust of 80 MT on LNGC

Response in Hs 5.5m seas (Connected)



Hawser Winch– Similar to 250HP Markey Softline Escort Tugboat Used for LNG Carrier Service

- Scalable to 1000 – 1200 HP, 300 ton
- Existing & Proven control technology
- High thermal energy dissipation for shock load and rendering operation



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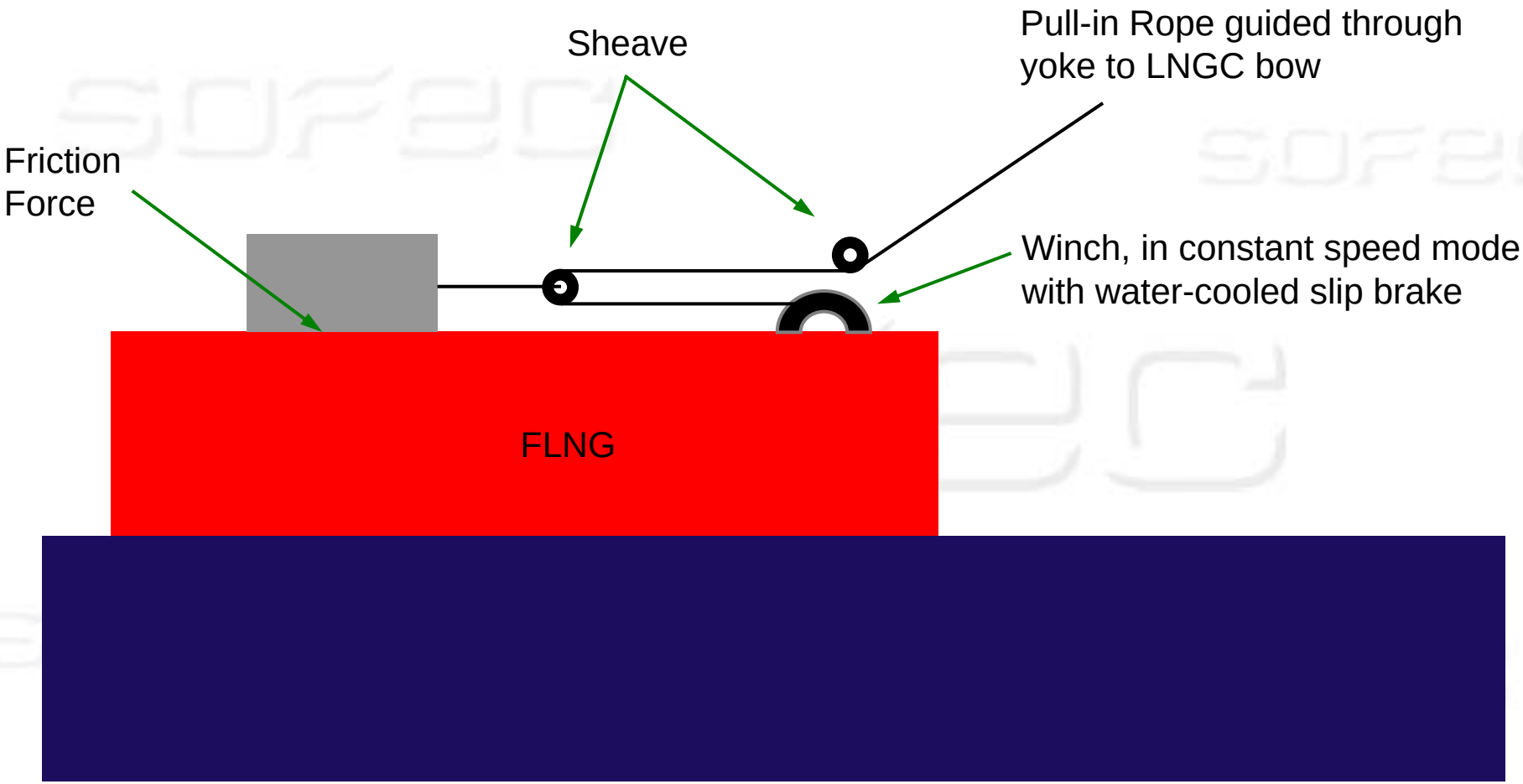
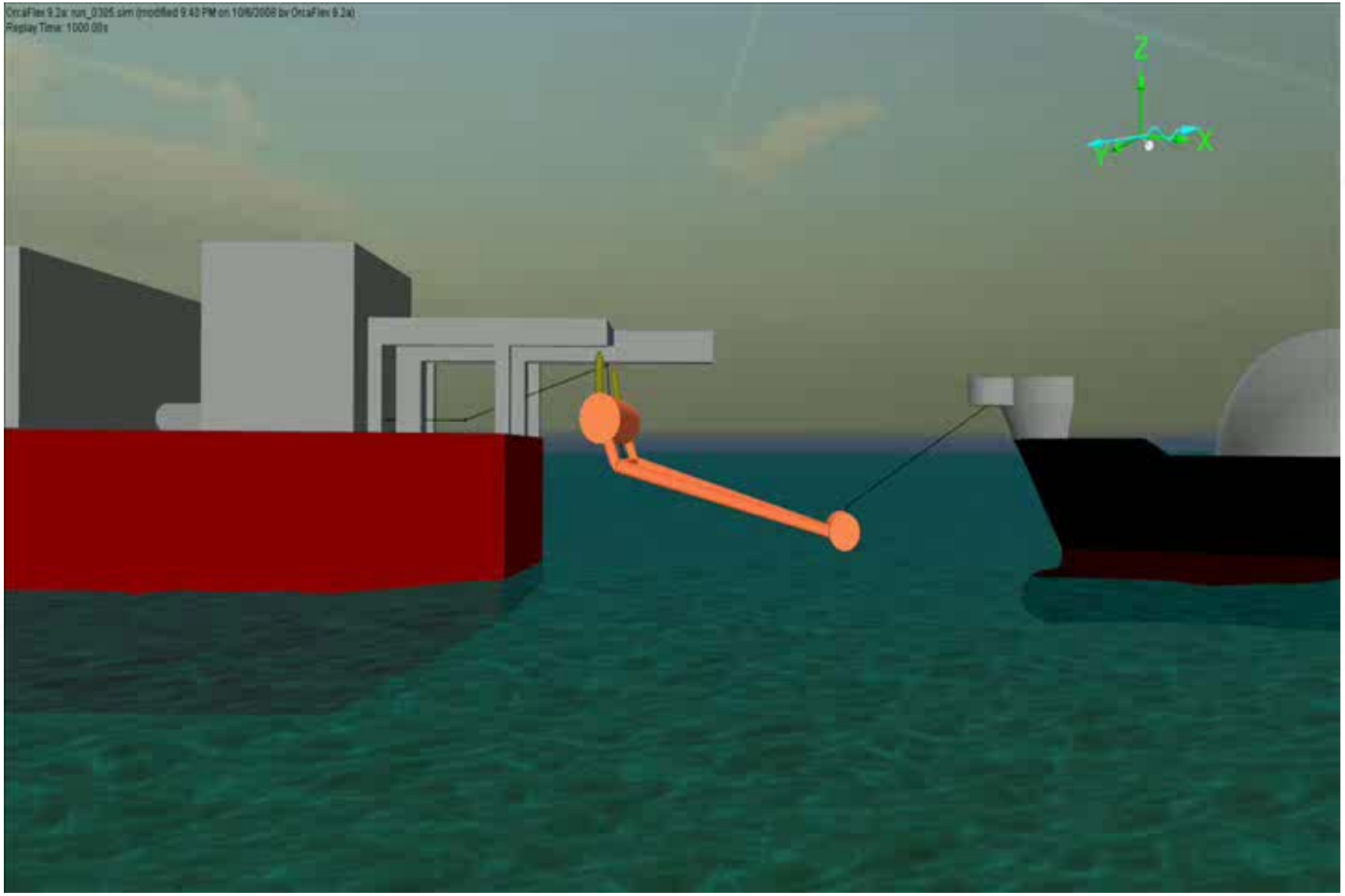
Winch Modeling in OrcaFlex

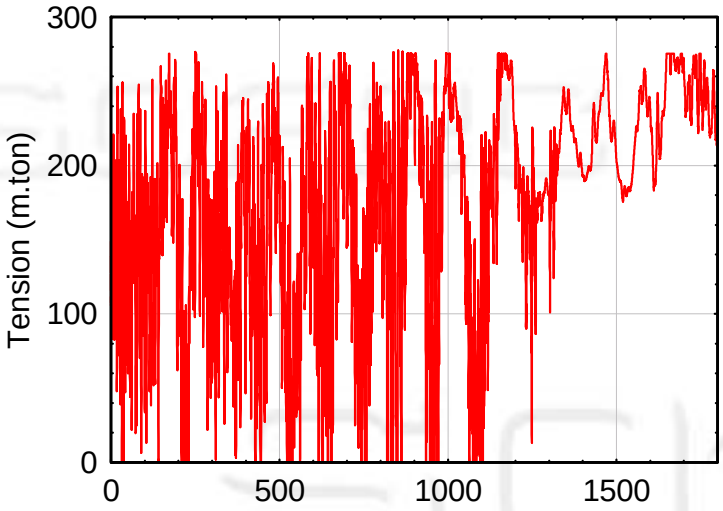


Connection Analysis

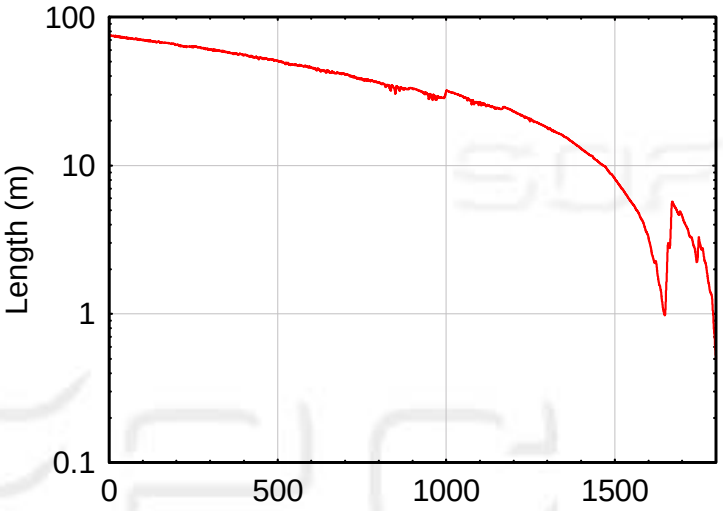


Analysis Results

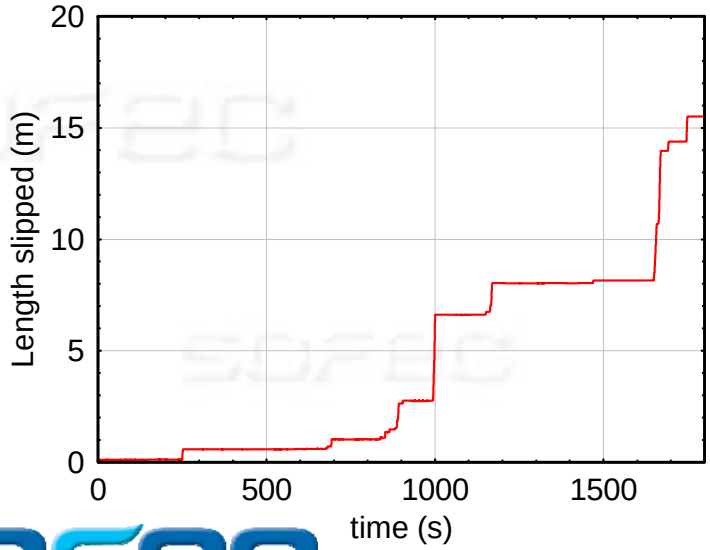
Pull-in Line Tension



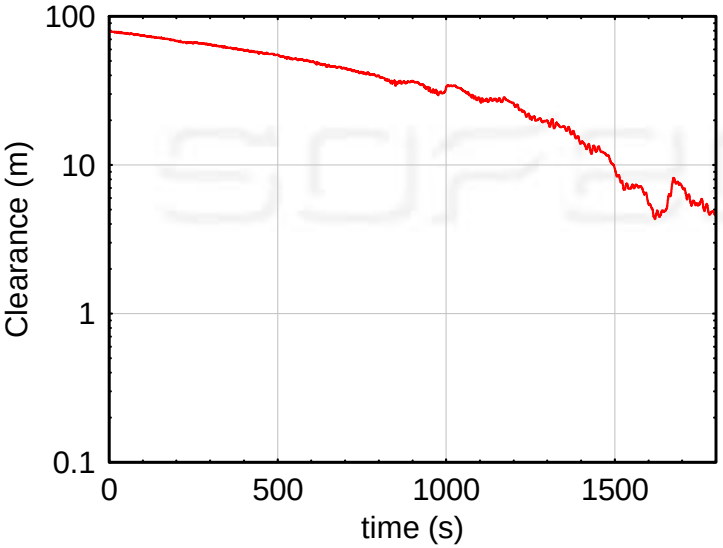
Pull-in Line Length between Yoke Tip and Connector



Slippage of winch line through clutch



Clearance between Buoyancy Tank and LNGC Bow



Summary & Conclusions

- **Robust Tandem Mooring System Developed for FLNG Offloading in Harsh Environments**
- **Can be used with existing LNG Transfer Systems**
- **Also suitable for use with Cryogenic Hoses (under qualification / not yet field proven)**
- **Global Responses Predicted Well by Frequency Domain Analysis**
- **Time Domain Model Used to Model Reconnection of System – also useful for developing site specific operational criteria.**