Roll Motions of FPSOs

SNAME Texas Section

December 14, 2010

'We thought we were gone' says cruise passenger

Importance of Roll Motions

- Hard to predict accurately.
- Roll motions have an effect on:
  - Top sides foundations
  - Risers or their end fittings
  - Turret bearing loads
  - Efficiency of process equipment
  - Crew comfort/wellness
  - Helicopter operations
  - Loading/unloading of supply vessels
  - Shloshing loads in FLNG membrane tanks

Basics of Roll Motion

- Resonant motion amplitude dominated by amount of damping at the natural frequency.
- Roll natural period of typical FPSO between 10-15s -> right in the range where wave spectrum has significant energy.

- Excitation Factors:
  - Relative Wave Angle
  - Separation Tn & Tp
  - Wave Spreading
  - Spectral Peakedness
  - Water Depth
  - Other

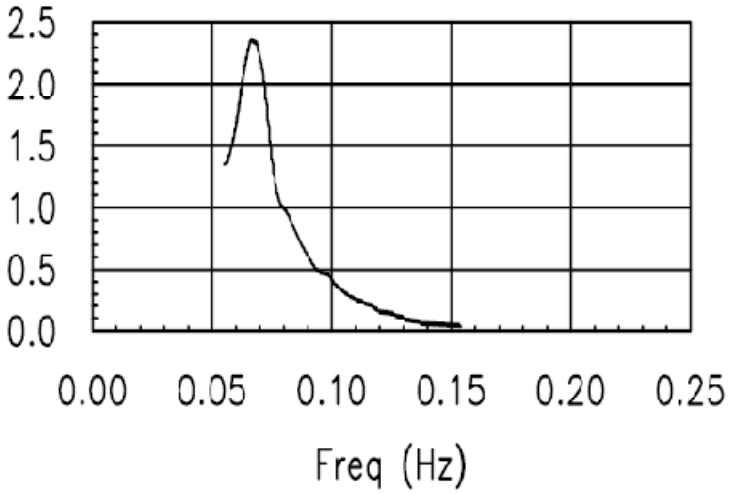
- Damping Sources:
  - Skin friction
  - Wave making
  - Eddy generation
  - Moorings & Risers
  - Internal waves in tanks
  - Other

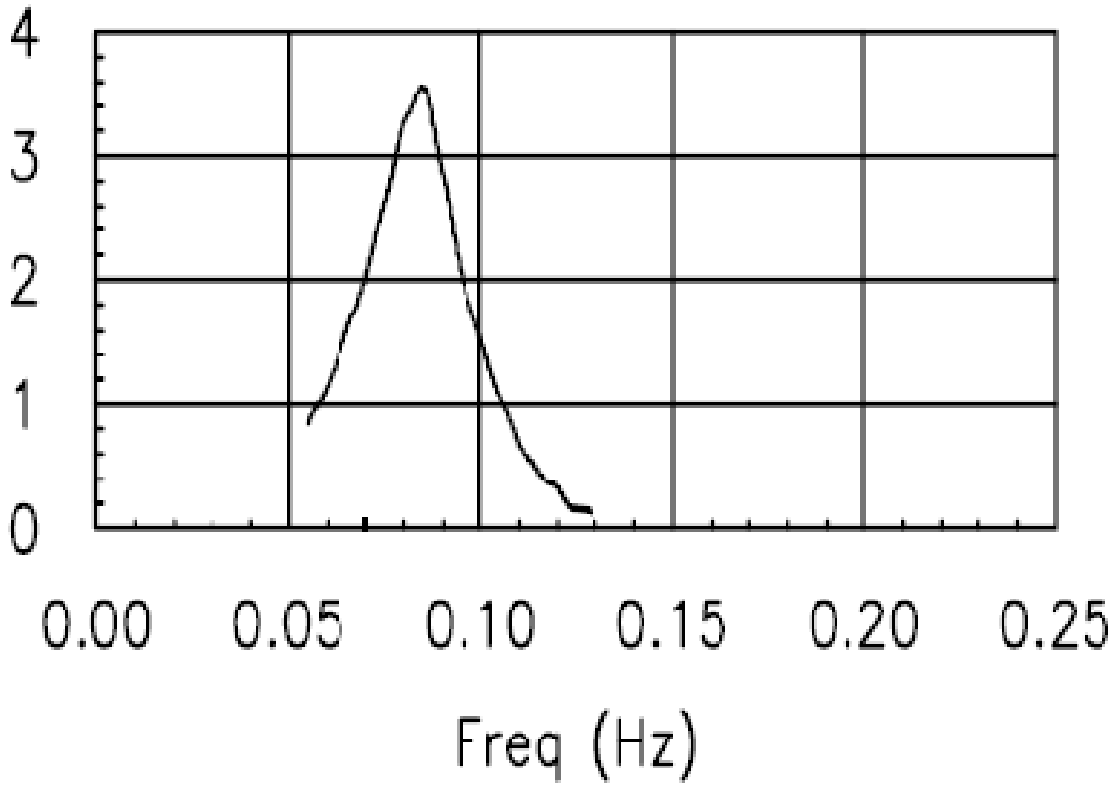
Effect of loading condition

- Wave Condition:
  - Hs = 6.7m
  - Tp = 11.4s
  - Direction = 270deg
- Loading Condition:
  - Ballast, Tn = 11.7s
  - Full, Tn= 14.1s

Effect of Loading Condition - cont'd

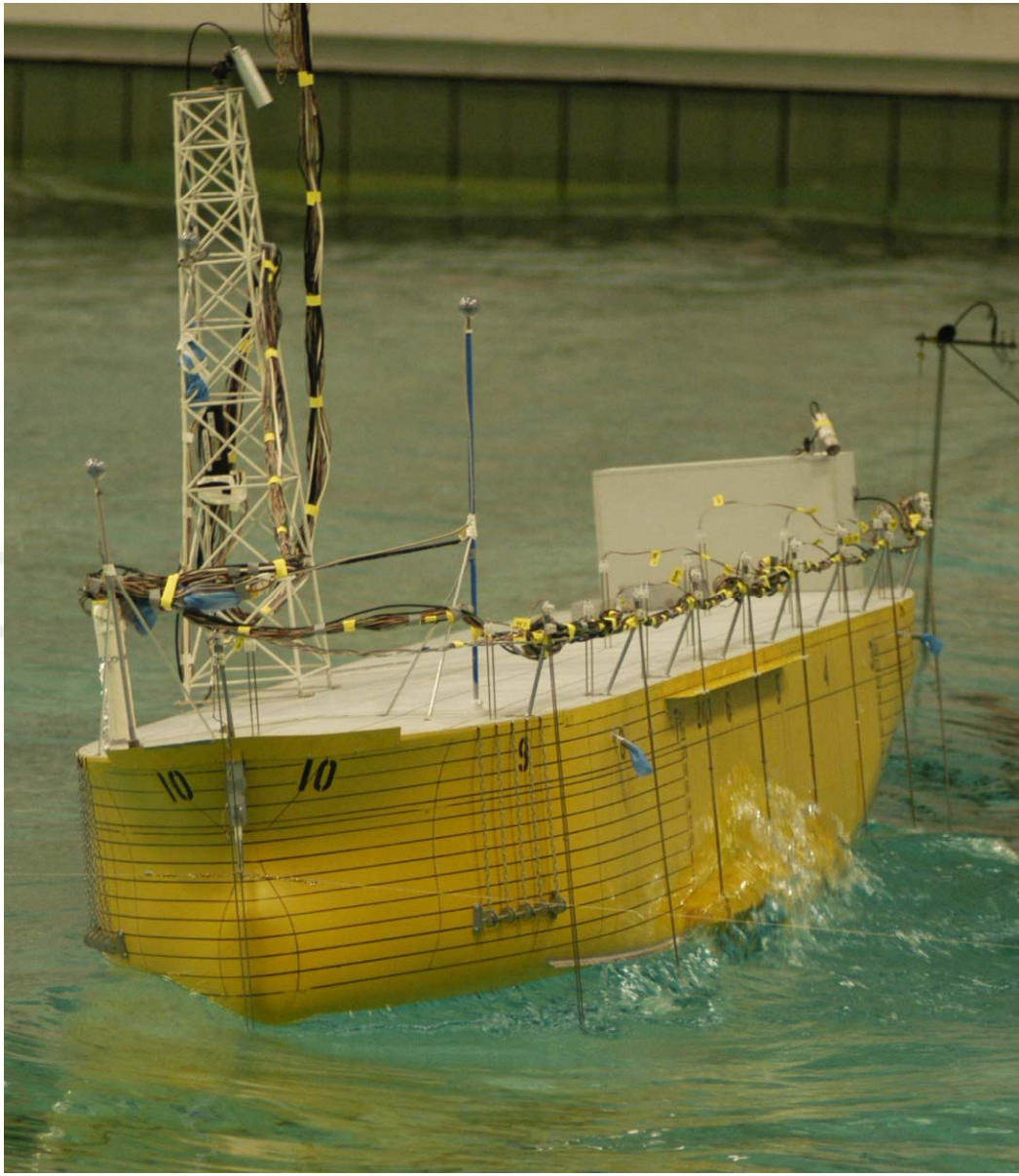
- Test Results:
  - Full, stdev = 1.5deg; mpm = 6.6deg
  - Ballast, stdev = 3.9deg; mpm = 13.3deg





Effect of Bilge Keel Width

- Wave Condition:
  - Hs = 6.7m
  - Tp = 11.4s
  - Direction = 270deg
- Loading Condition:
  - Ballast, Roll natural period = 11.7s
- Caveats:
  - Very shallow draft condition
  - Damping from lower riser balcony



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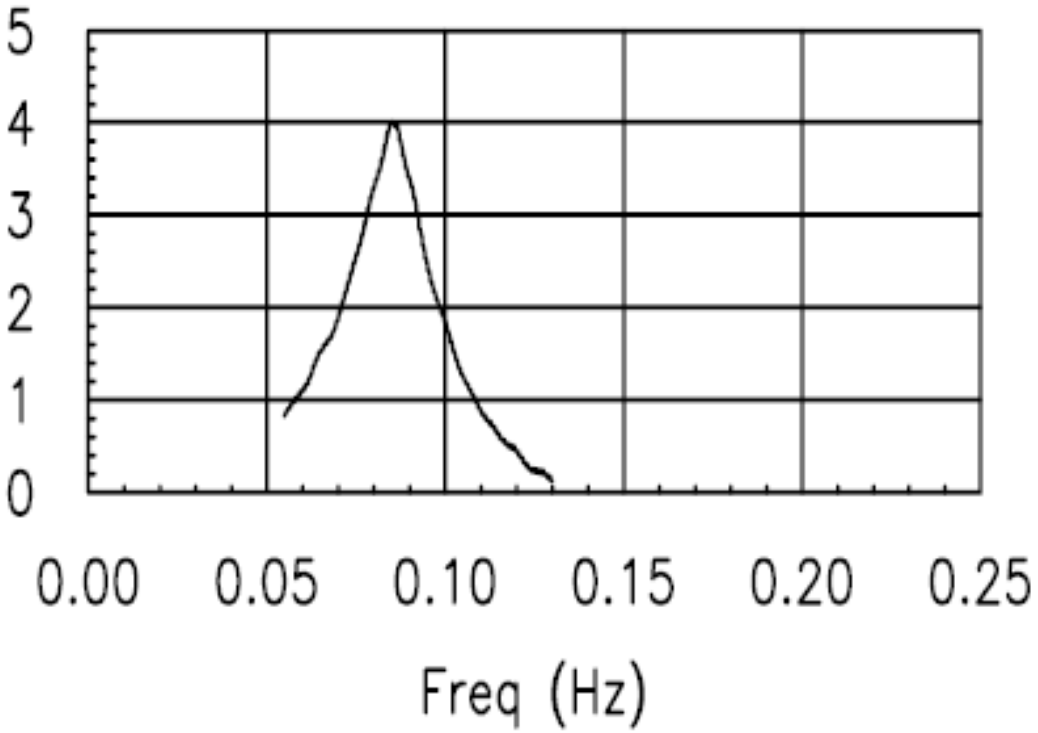
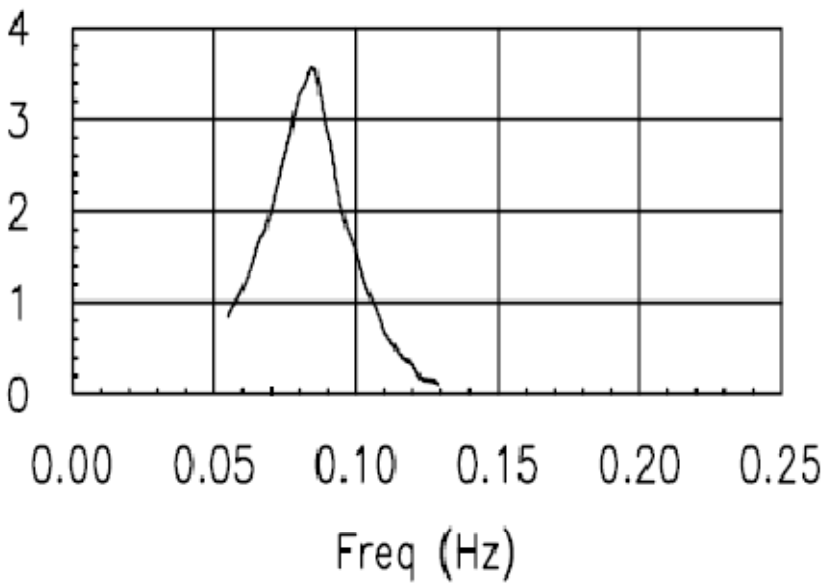
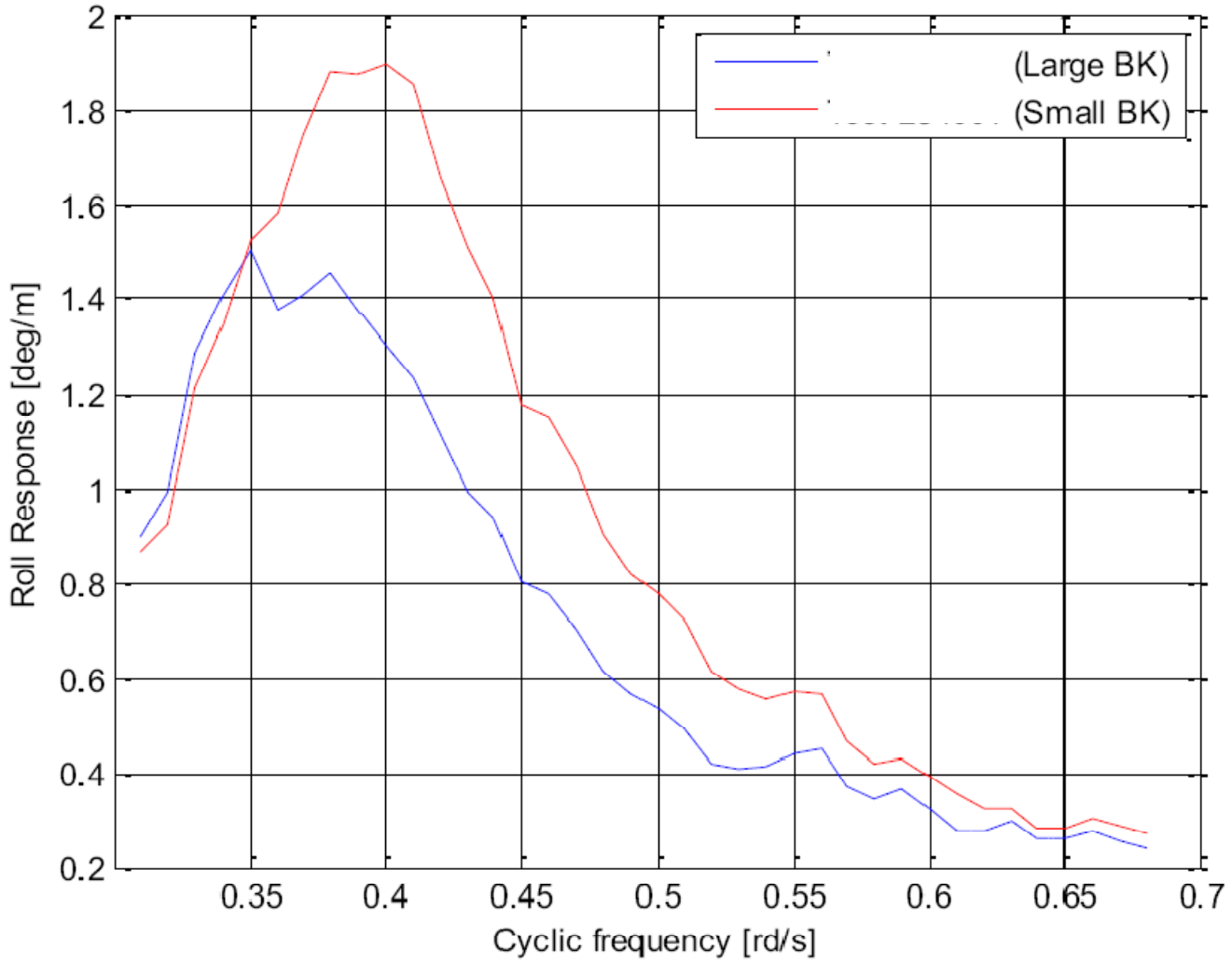
Effect of Bilge Keel Width - cont'd

- Test Results:
  - 1.0m x 185m, stdev = 4.3deg; mpm = 14.5deg
  - 1.5m x 205m, stdev = 3.9deg; mpm = 13.3deg



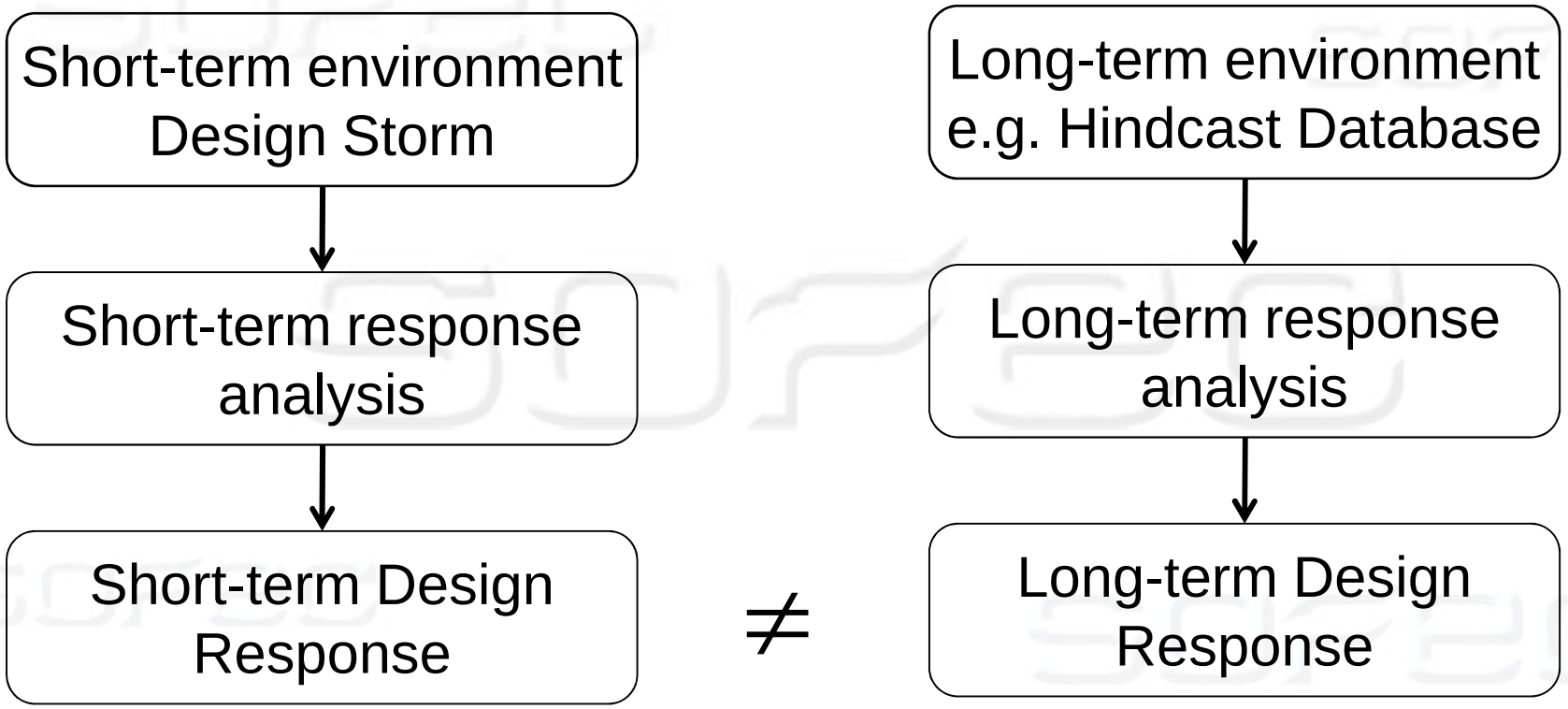


Effect of Bilge Keel Width - cont'd



Long Term Response Analysis

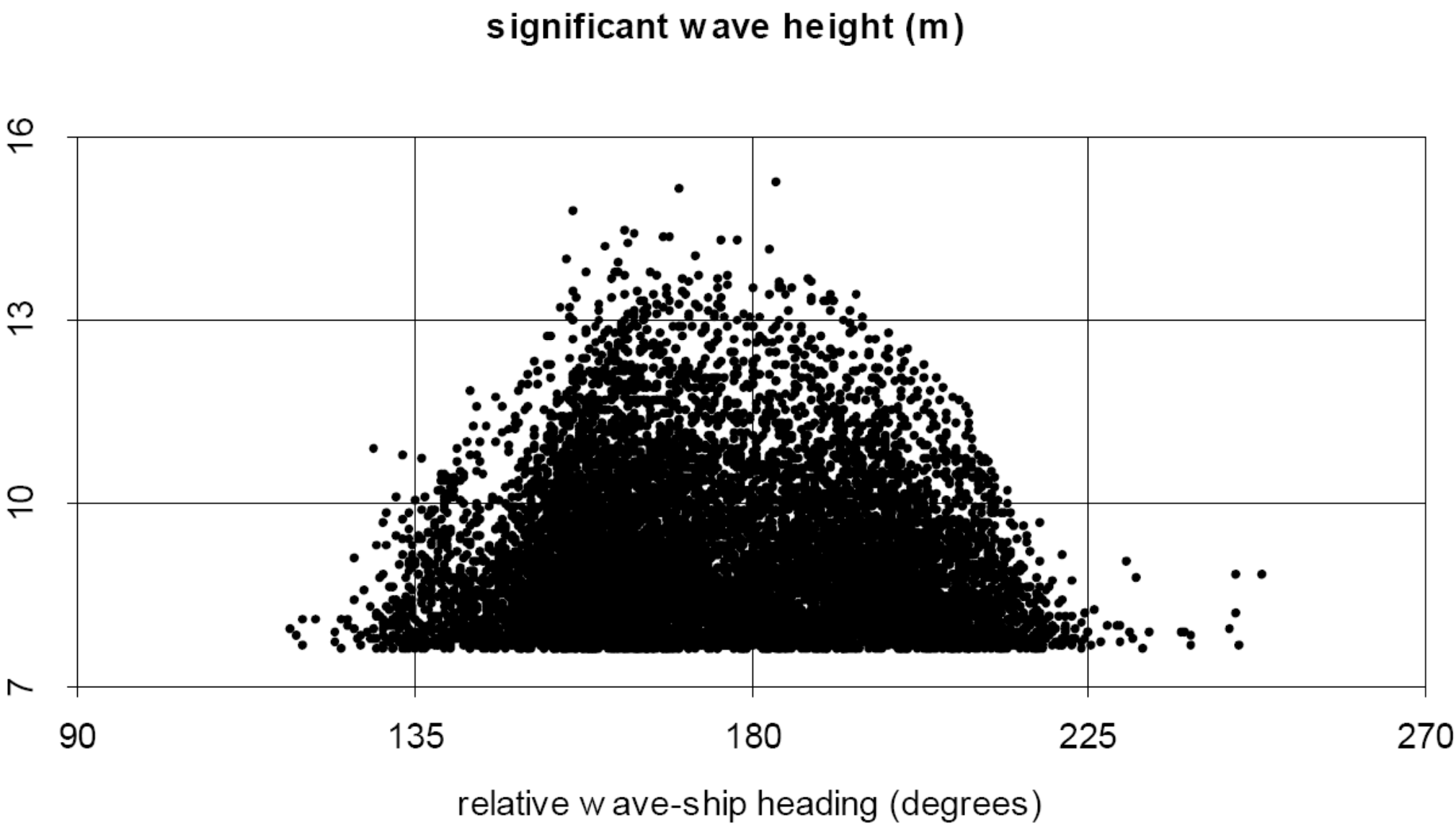
Long Terms vs Short Term Response Analysis



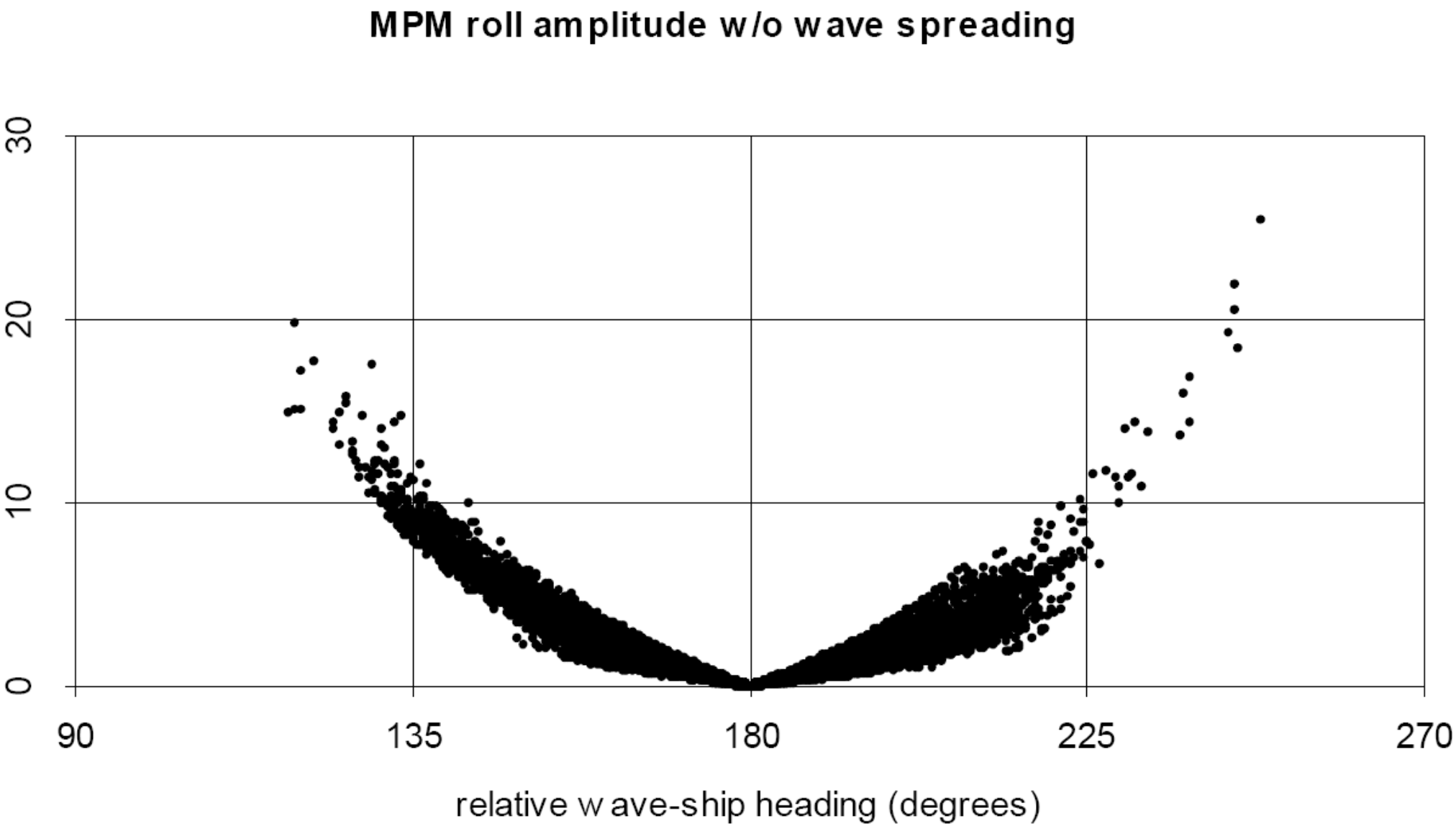
Example Long Term Response Analysis

- Turret moored tanker in GOM
- Hurricane hindcast database
- FD Mooring Analysis using SPMsim
- Resulting 100-year MPM Roll Amplitude
- Response Based Design Criteria

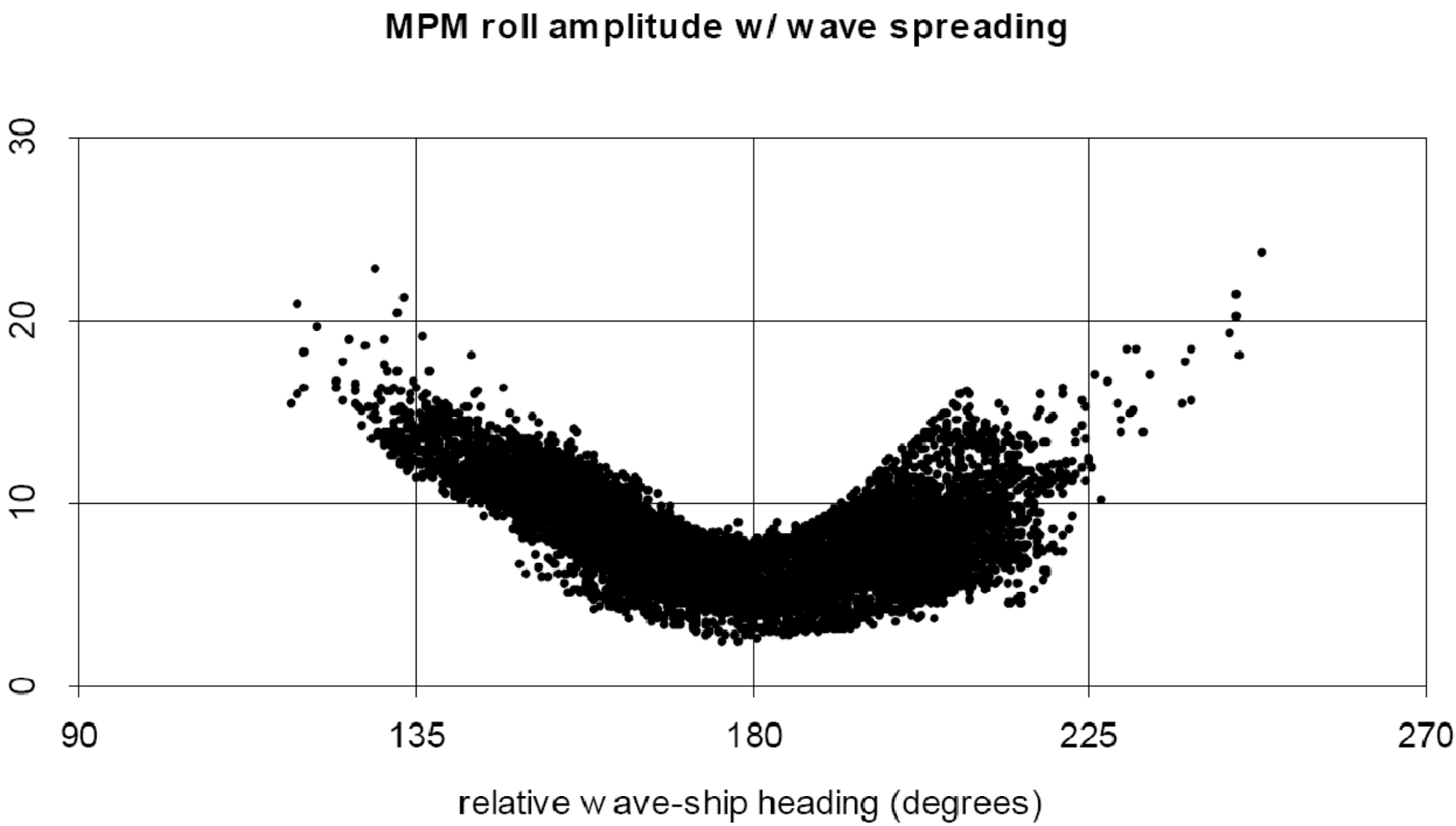
Joint Distribution: Hs – Relative Wave Heading



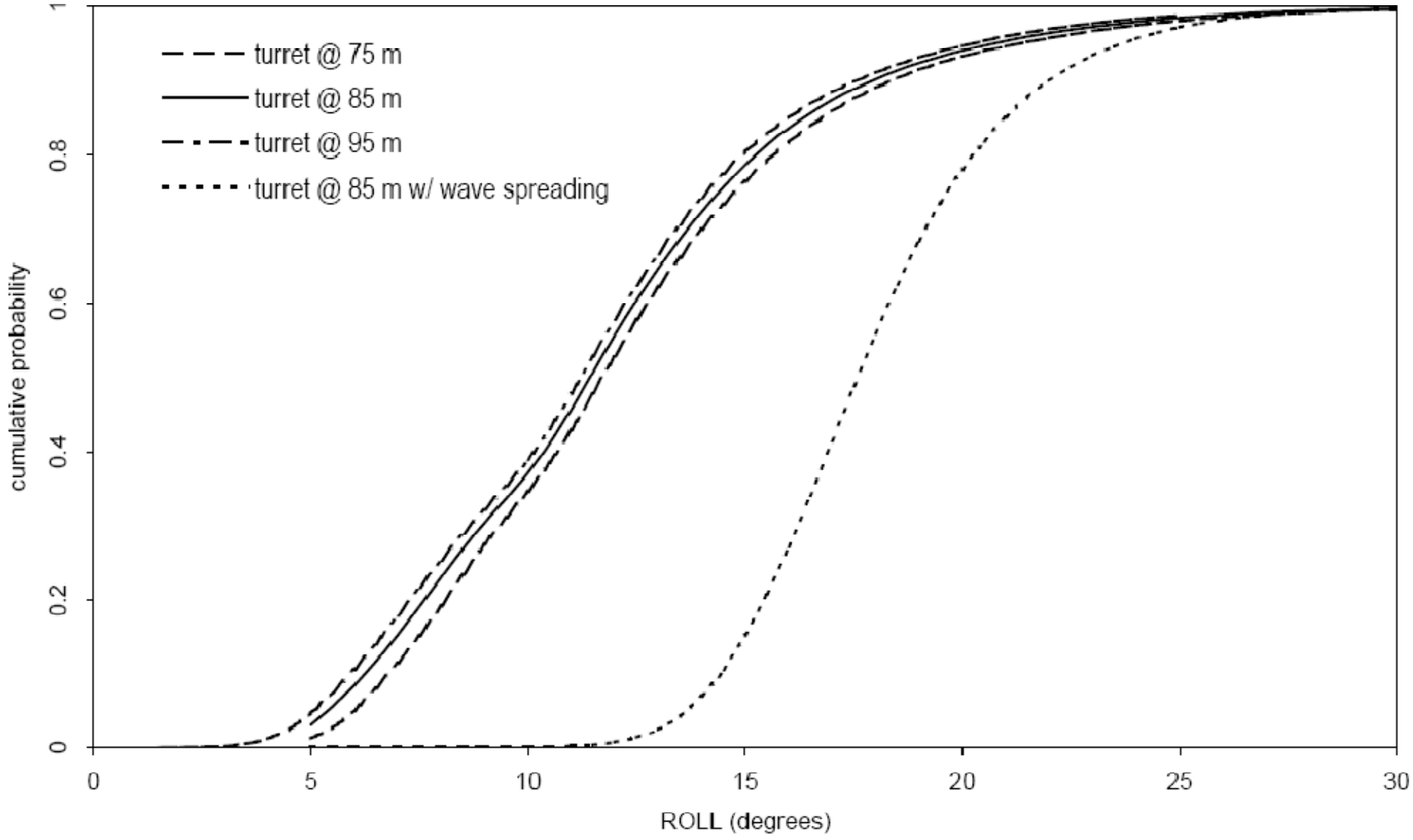
Joint Distribution: Roll – Relative Wave Heading



Joint Distribution: Roll – Relative Wave Heading



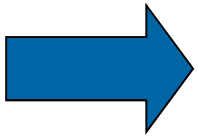
100-yr Cumulative Distribution of Roll



MPM Roll from 100yr Storm vs 100yr Roll MPM

100yr Design Environment

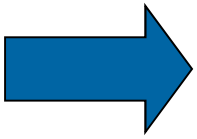
- Hs = 12.2m
- Tp = 14.2s
- Vw = 36.5m/s @ 30deg
- Vc = 1.75m/s @ 45deg



MPM from 100yr storm

= 5.8deg

MPM 100yr Roll = 9.9deg

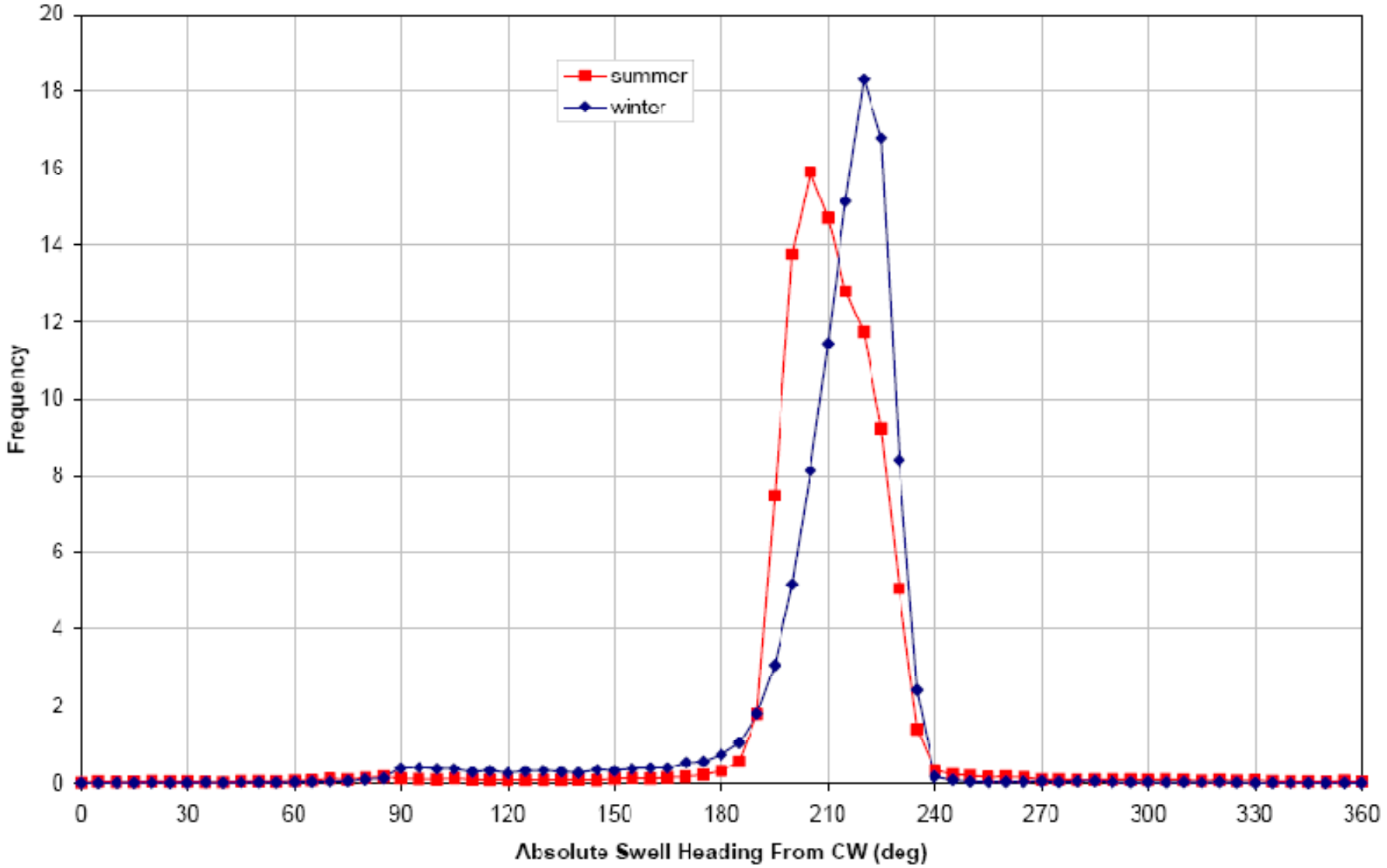


100yr Roll Environment

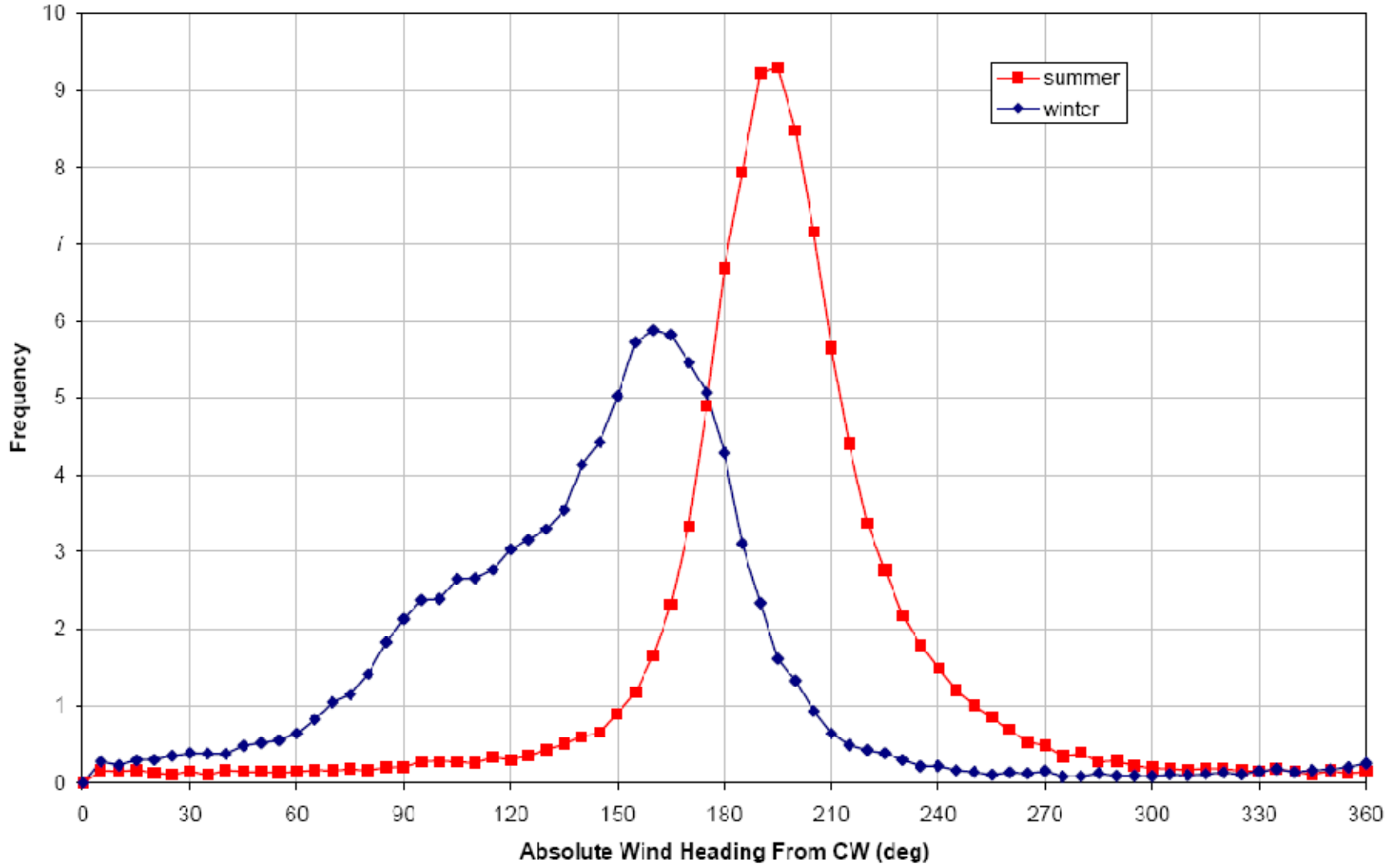
- Hs = 8.9m
- Tp = 14.5s
- Relative Heading = 135deg

Local Conditions that affect Roll Motions

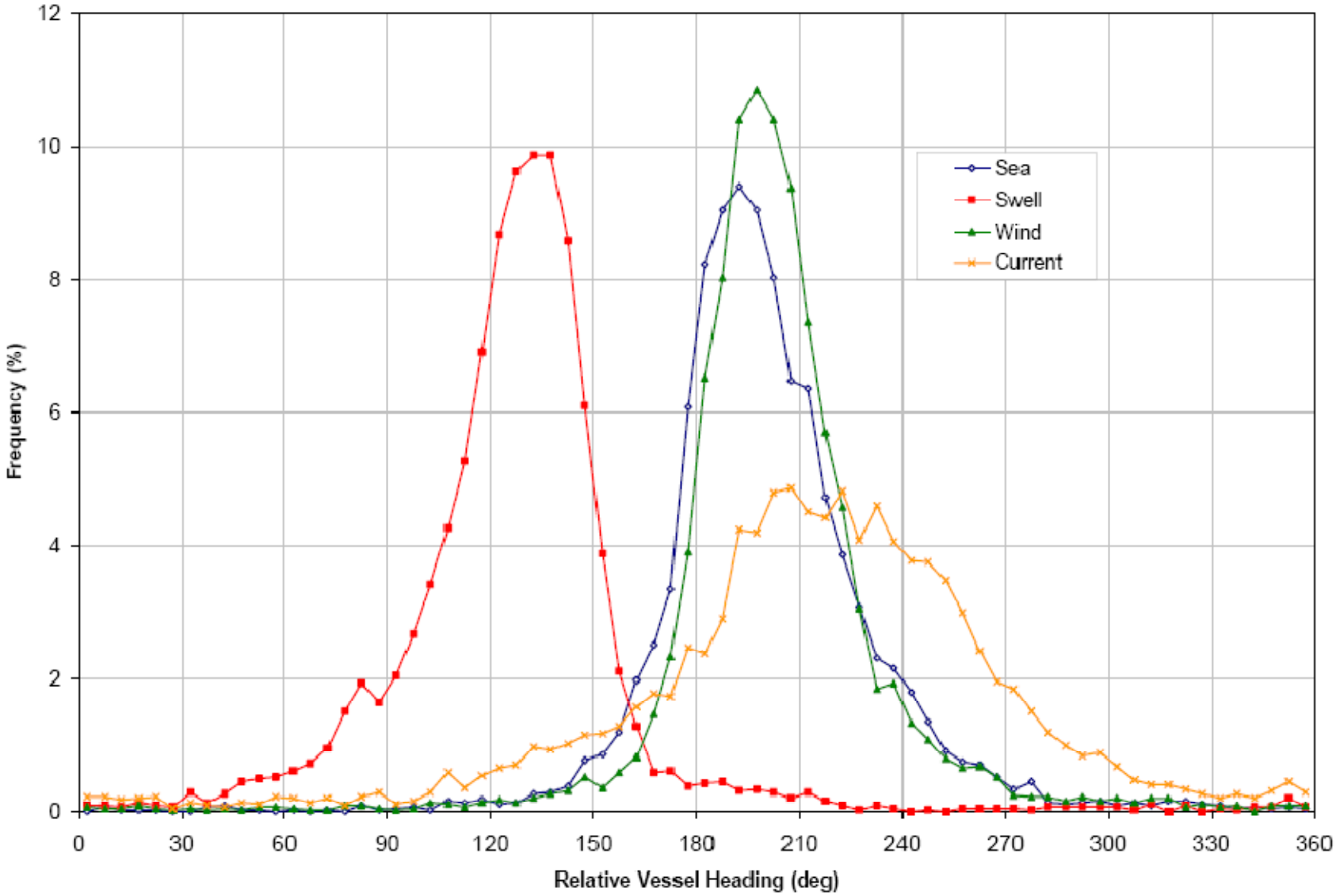
Seasonal swell direction Northwest Shelf, Australia



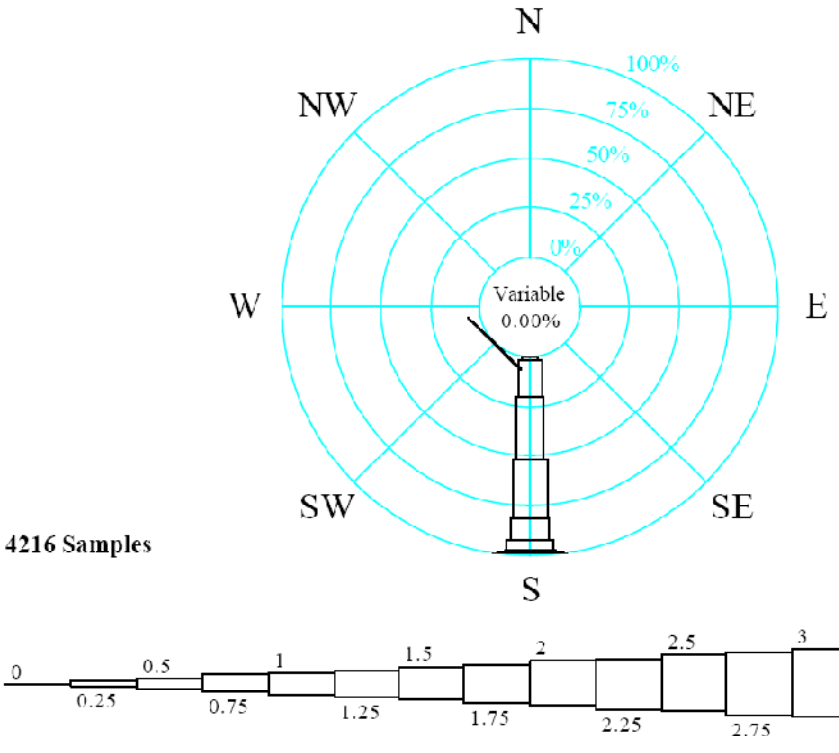
Seasonal wind direction Northwest Shelf, Australia

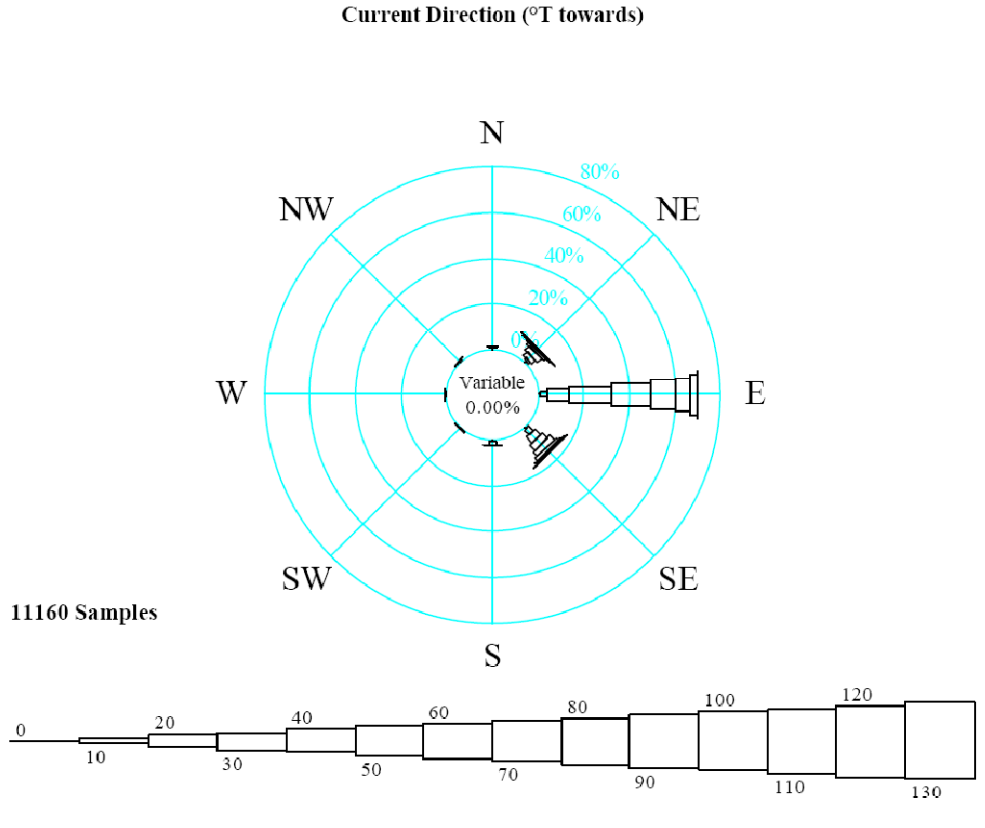


Relative Swell Heading, Northwest Shelf, July

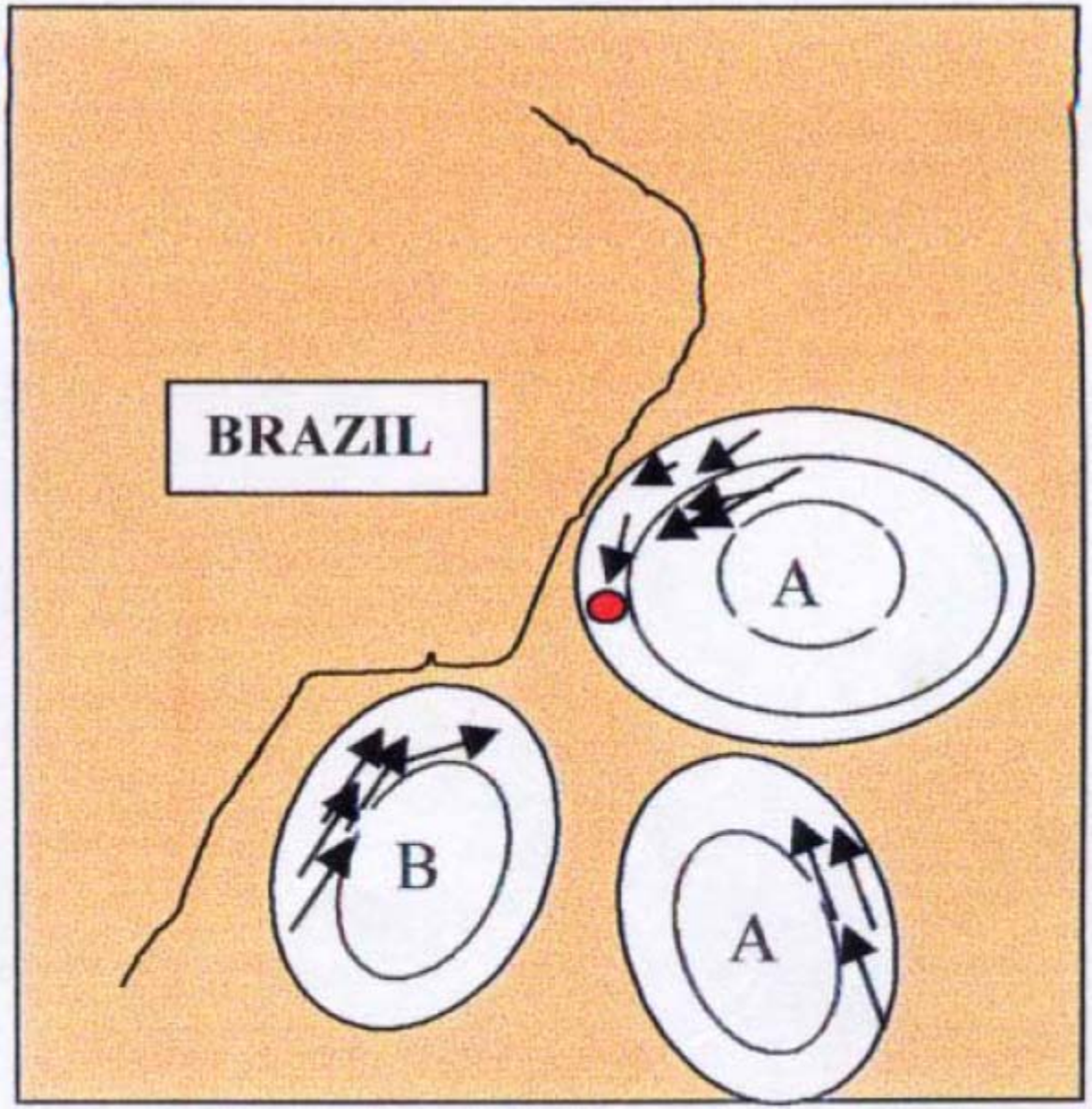


Wave and Current Rose, July, Offshore Ghana





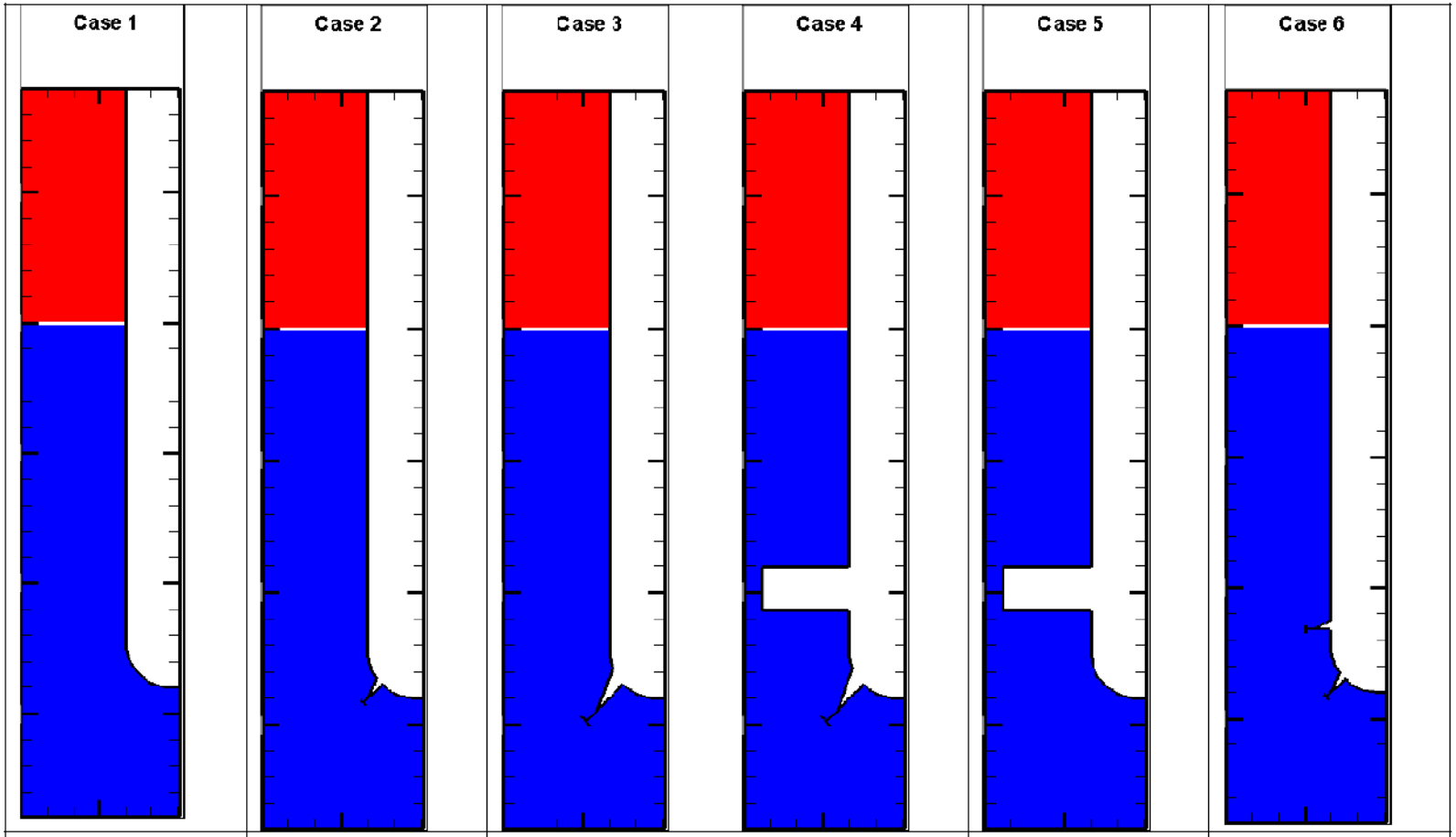
Brazil



Example of CFD for Roll Motions

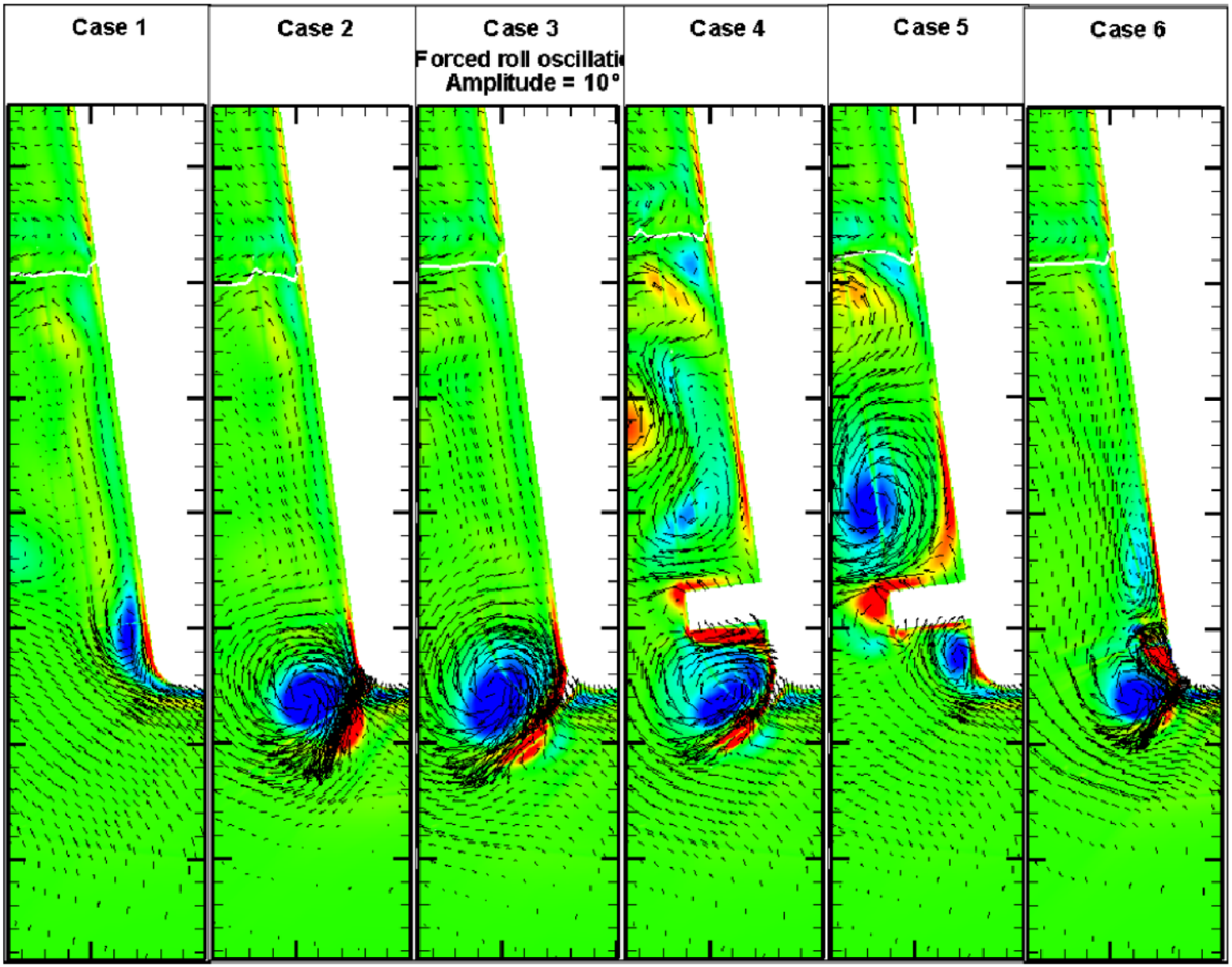
- 2D CFD using EOLE™ by Principia
- Comparison of 6 configurations
- Forced oscillations at Tn = 14s with 5° and 10° amplitudes
- Quadratic damping extracted from moment time series
- Moment around center of roll integrated on 1m wide section: 2D
- Removal of linear damping using 3D diffraction analysis

Configurations Studied

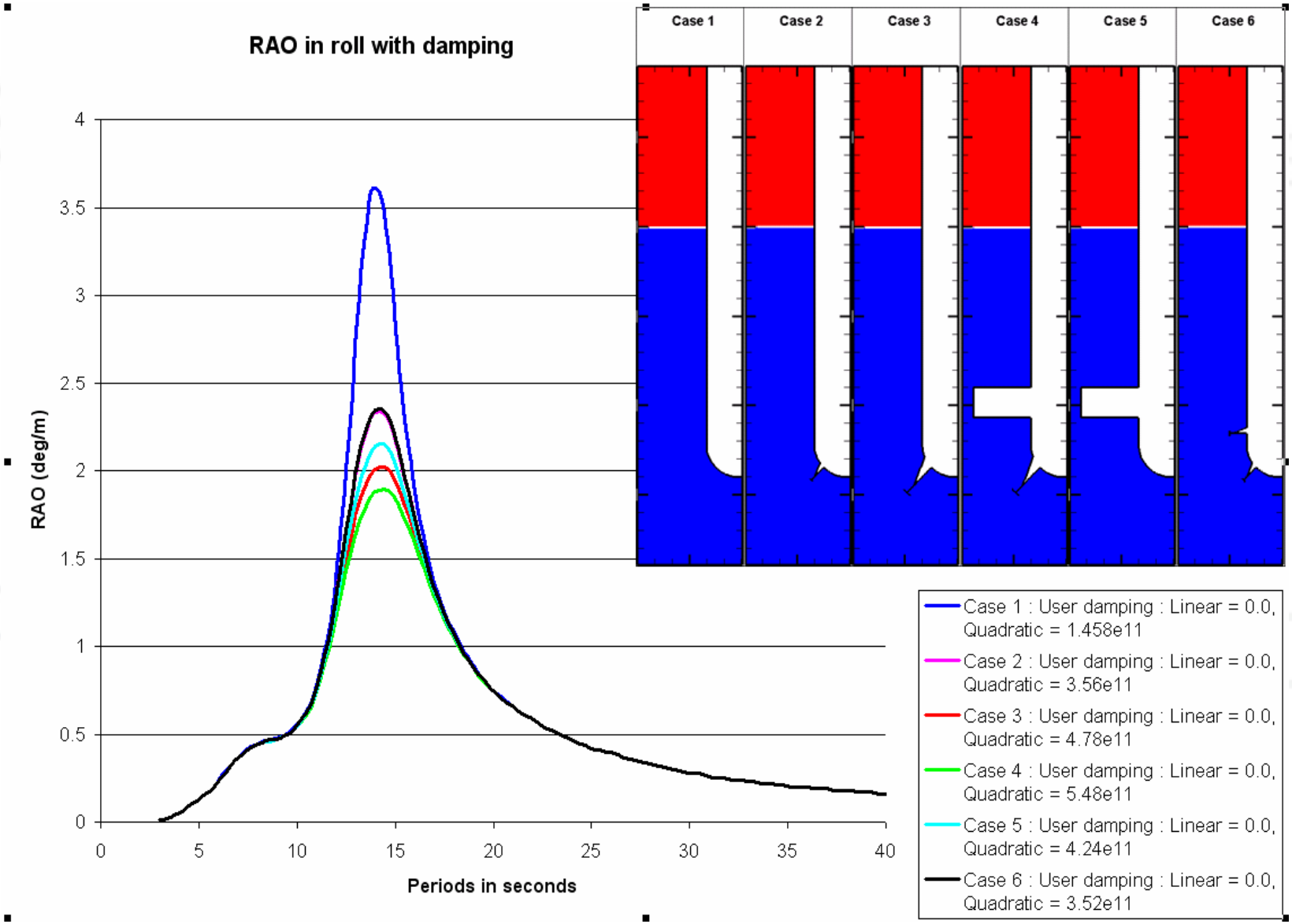


bare hull	hull with one bilge keel of 1 meter length	hull with one bilge keel of 2 meters length	hull with the lower riser support "box" and one bilge keel of 2 meters length	hull with the lower riser support "box" (without bilge keels)	hull with two bilge keels of 1 meter length

Vortex Development induced by Appendages



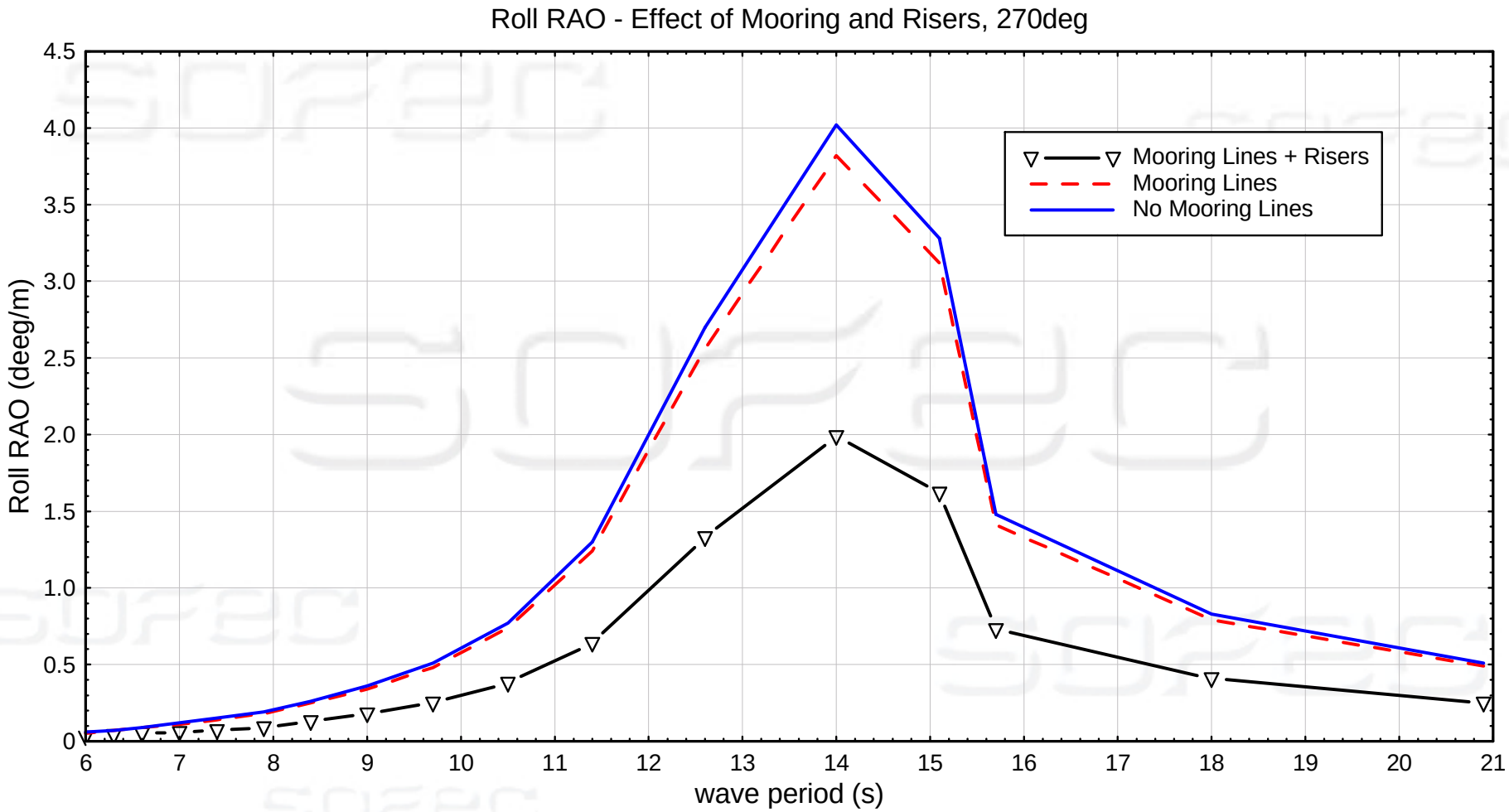
Estimated Roll RAOs for the various cases



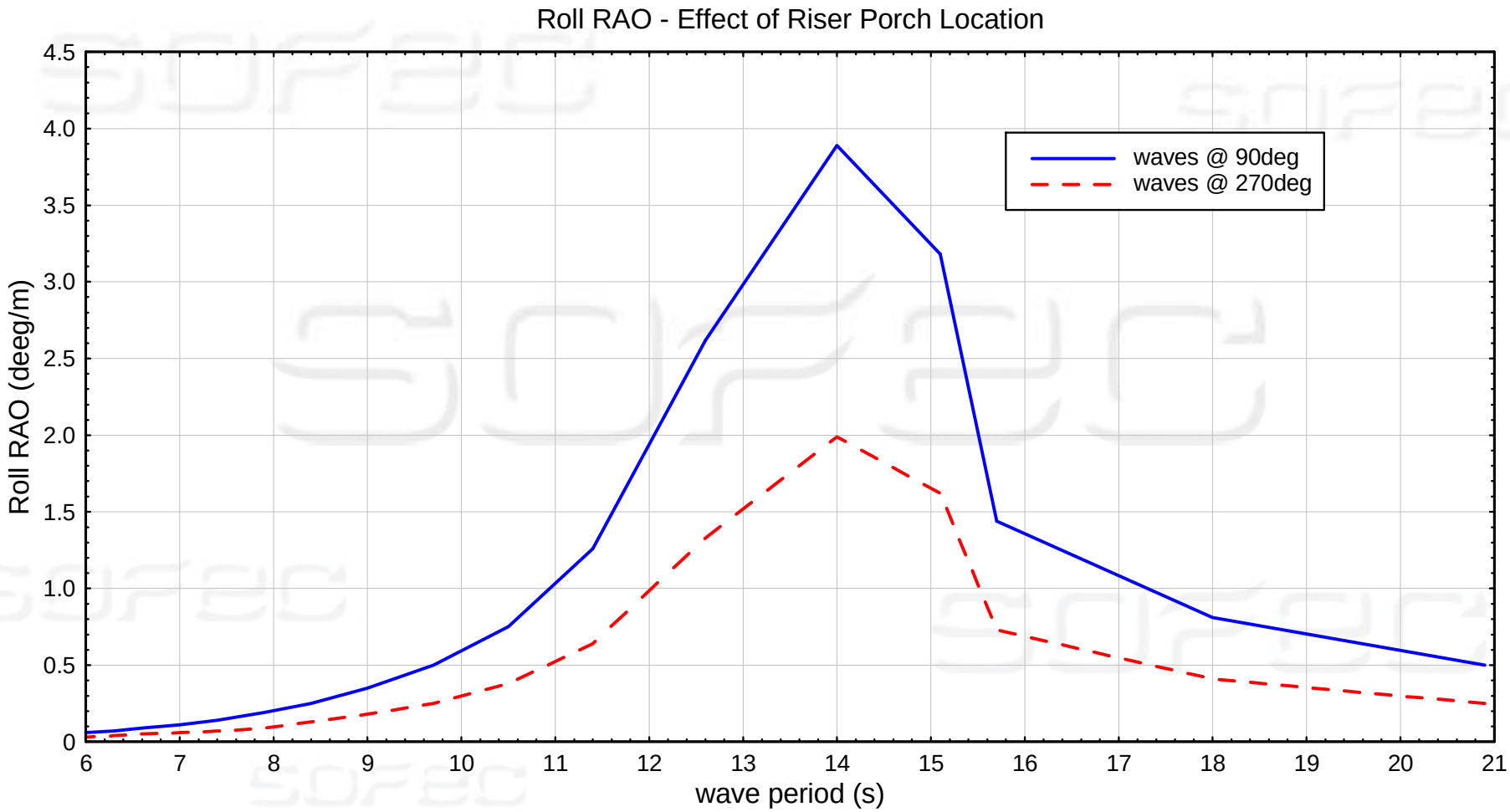
Effect of Mooring and Risers on Roll Motions

- Water Depth: 2140m
- VLCC, Ballast Draft = 8.8m
- Mooring Configuration:
  - Spread mooring, 24 mooring lines
  - Turret mooring, 9 mooring lines
- Riser configuration:
  - 24 catenary risers
  - Total FZ ~ 5500 metric tons
- Beam Sea Condition 1-yr RP:
  - Hs = 4.5m
  - Tp = 9.9s

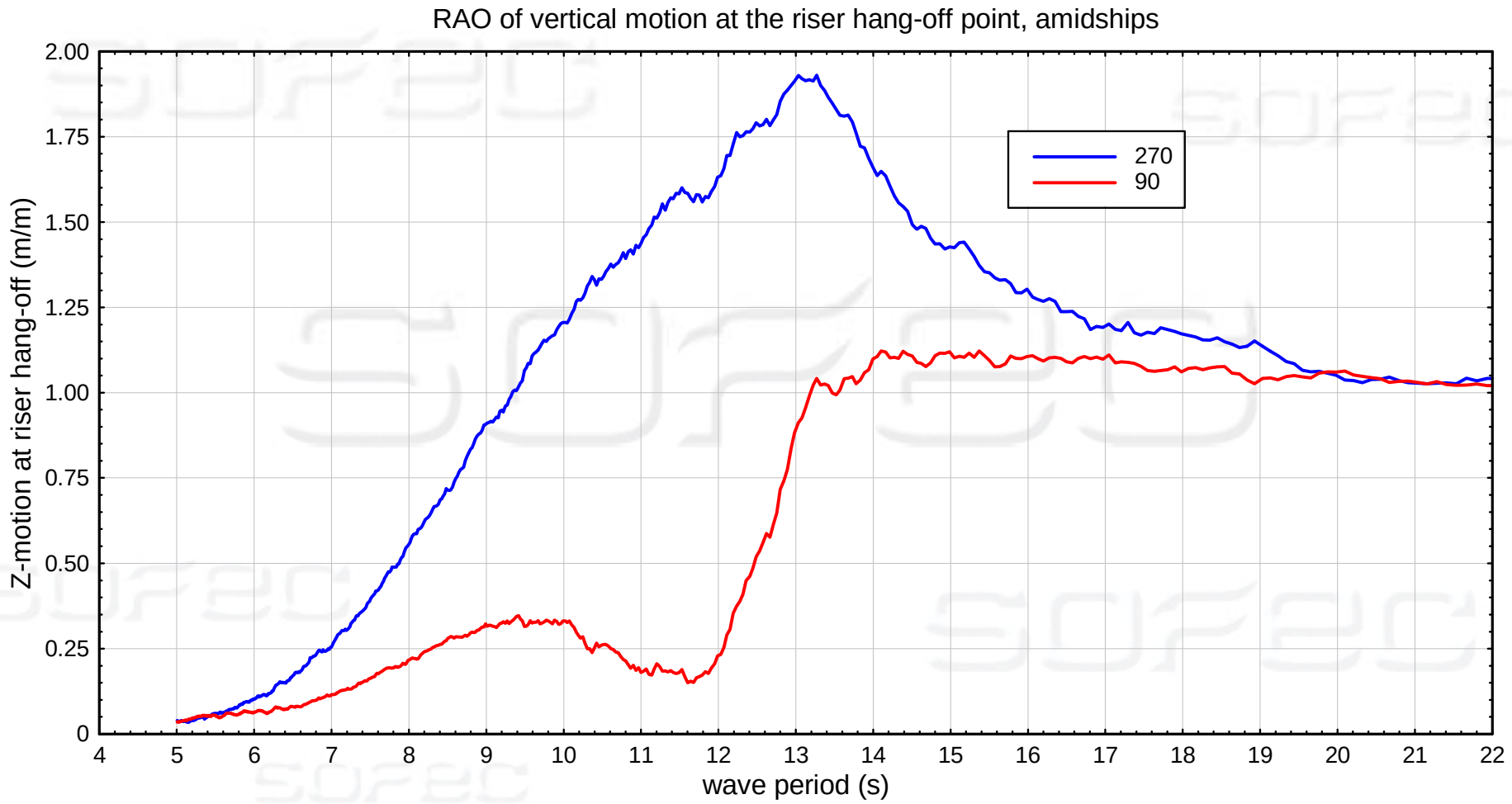
Effect of Risers on Roll RAO



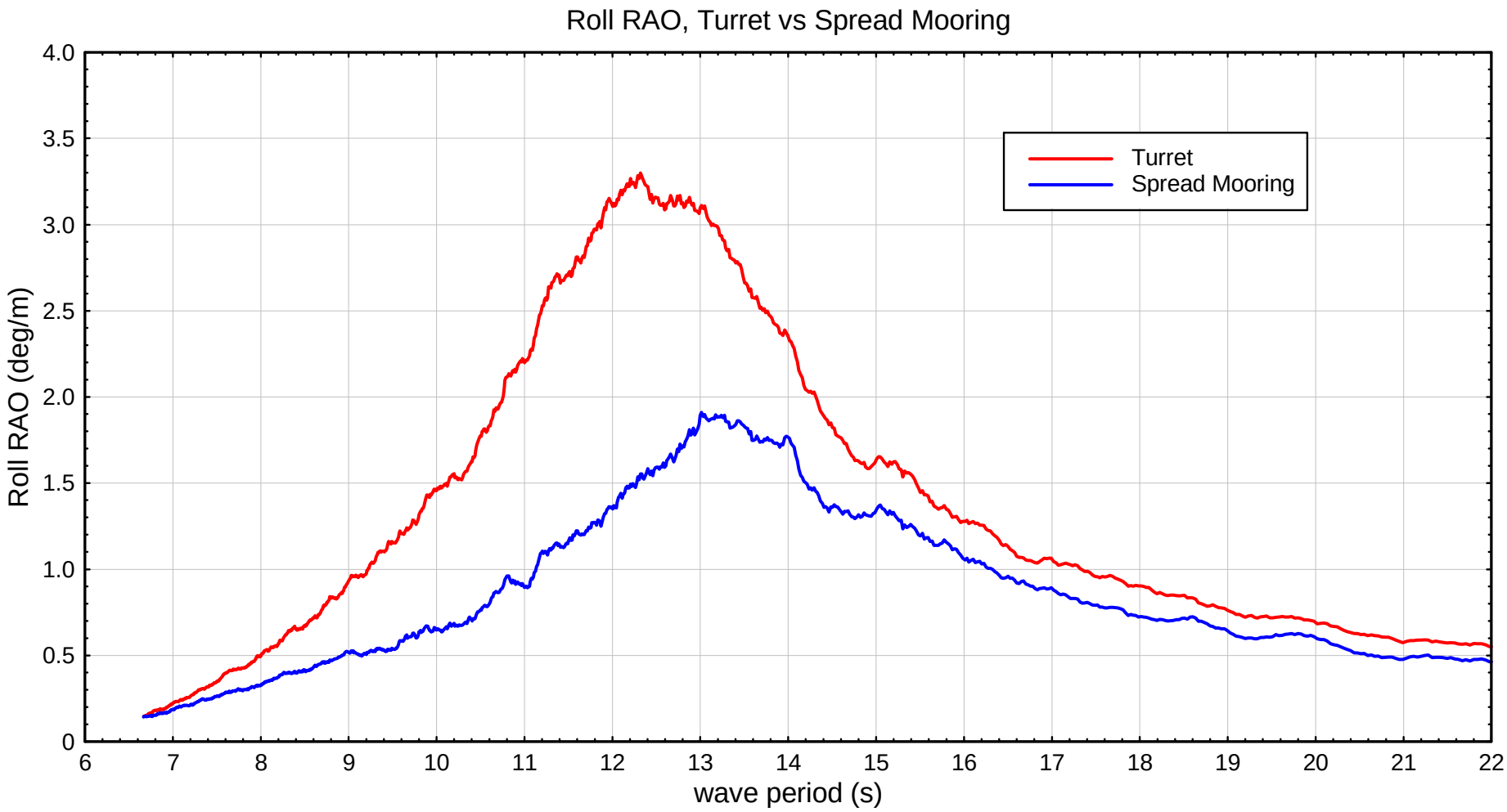
Effect of Riser Balcony Location



Effect of Riser Balcony Location



Effect of Mooring Configuration



Second Order Roll Motions

Motions at Roll Natural Period

driven by

difference frequency moments

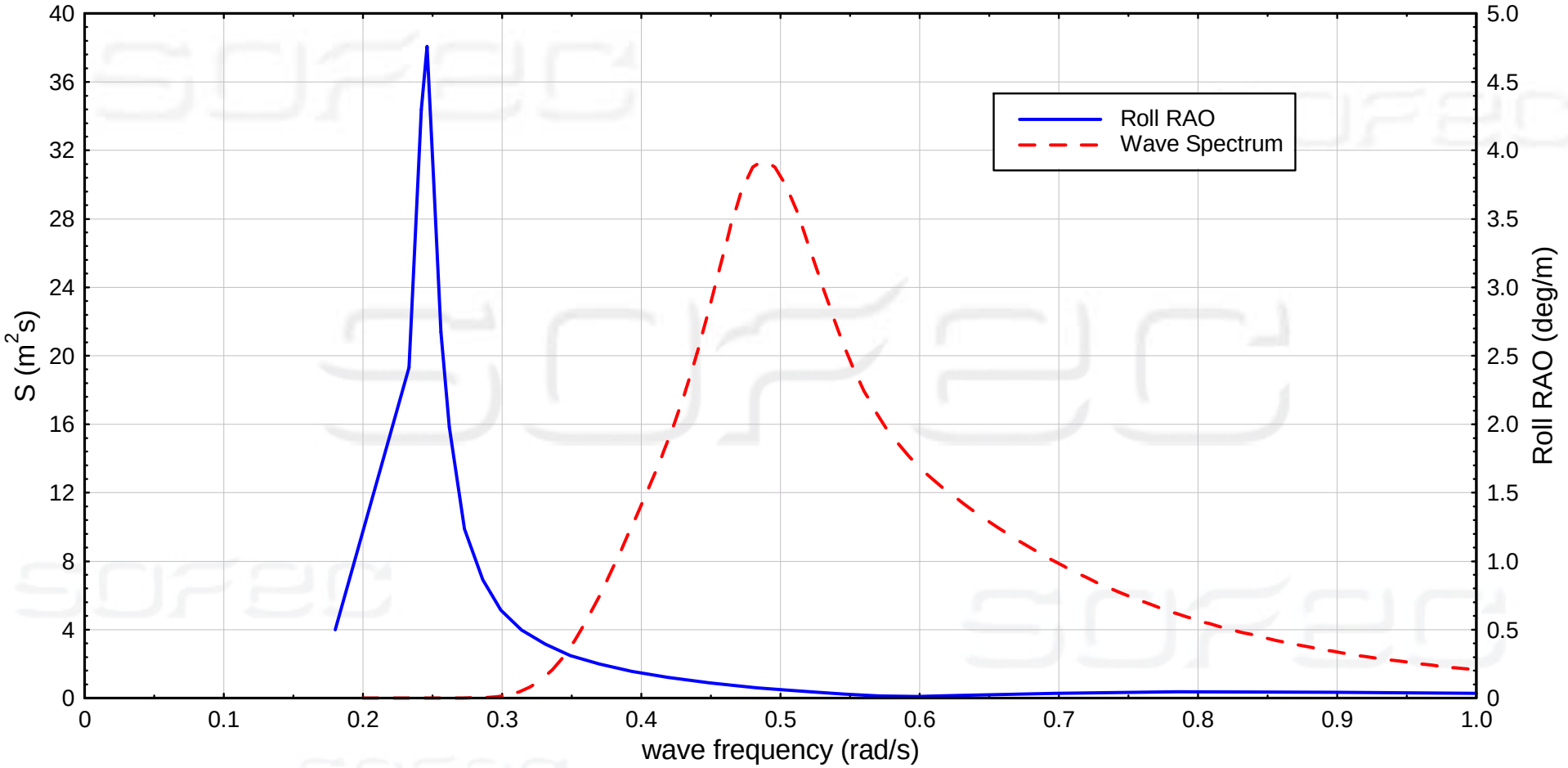
Second Order Roll Motions

- Example
  - 170,000 DWT FPSO – Purpose Built
  - No bilge keels
  - Roll Period: Full = 25.2s; Ballast = 23.7s

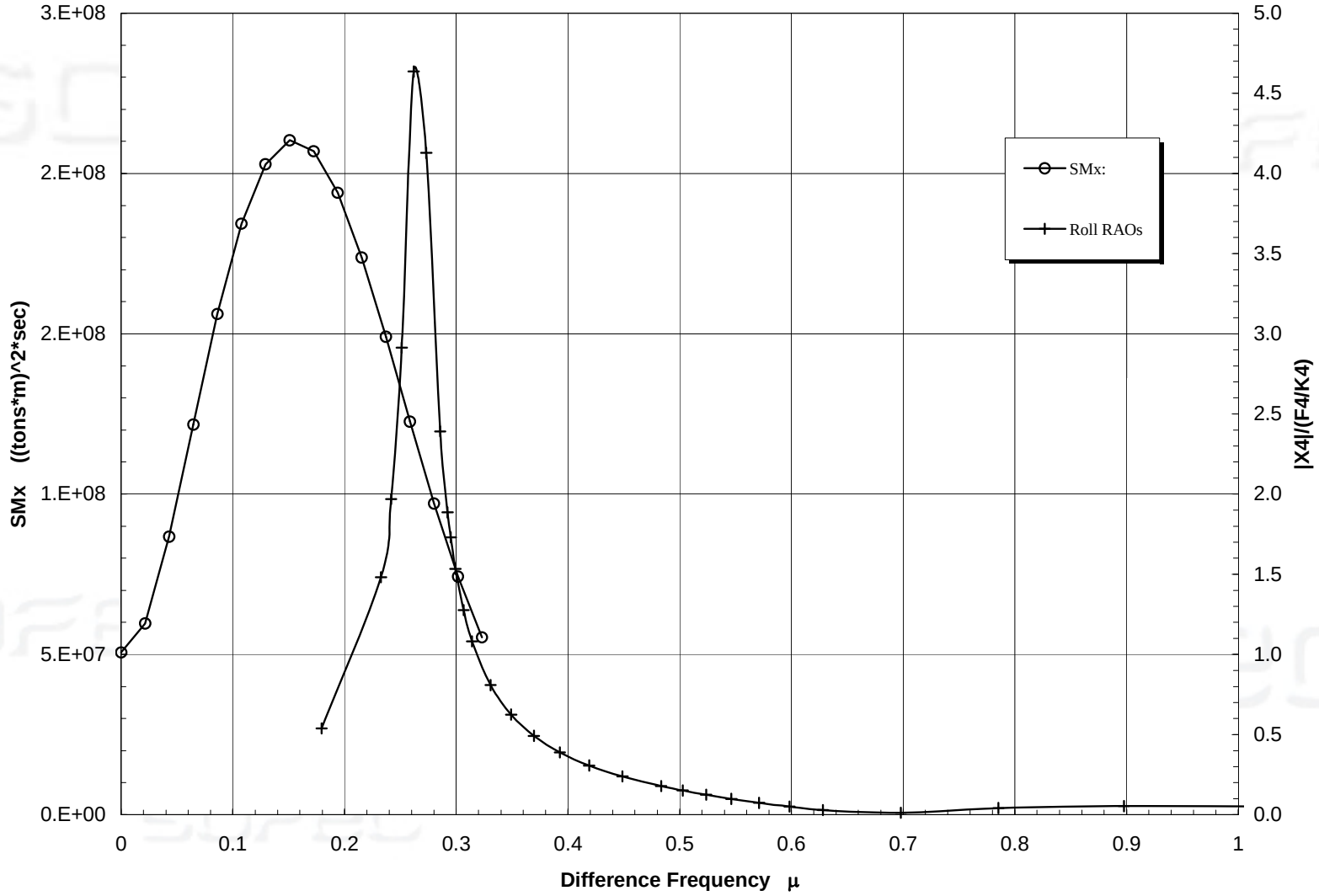
- Test setup:
  - Horizontal mooring
  - Scale 1:60
  - 3-hr duration

- Simulation setup:
  - HOBEM 3D diffraction
  - Second order roll moment spectrum

Separation between Roll period and wave period



Second order Roll Moment Spectrum



Second Order Roll Motions – Simulation vs Test

Full Draft Roll Motions (deg)					
		Mean	Max	Min	Stdev
Simulation	WF	0.0	1.4	-1.4	0.4
	DF	-0.7	10.2	-12.2	3.2
	Total	-0.7	11.6	-13.6	3.2
Test	Total	0.4	9.8	-11.4	2.4

Ballast Draft Roll Motions (deg)					
		Mean	Max	Min	Stdev
Simulation	WF	0.0	2.1	-2.1	0.6
	DF	-0.5	10.3	-11.2	3.1
	Total	-0.5	12.4	-13.3	3.1
Test	Total	-0.3	11.0	-11.9	2.5

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Concluding Remarks

- Accurate Roll predictions still difficult
- Bilge keels are very effective in reducing roll
- For SPMs LTRA is necessary to find extreme roll
- Determine critical sea state and bilge keel before model test
- Bilge/ bilge keel configurations can be compared using CFD
- If roll period is long don’t forget about second order roll

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Thank you.

References

- FPSO roll damping prediction from CFD and 2D and 3D model tests investigations, ISOPE 2004 Toulon.
- On Second Order Roll Motions of Ships, OMAE2003-37022
- Extreme Responses of Turret Moored Tankers, OTC 12147
- FPSO Roll JIP, MARIN