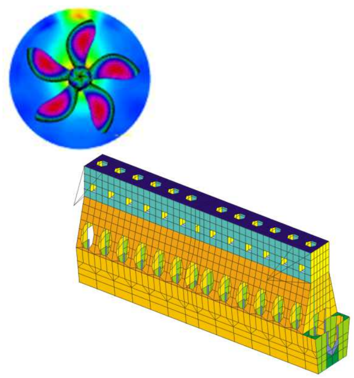
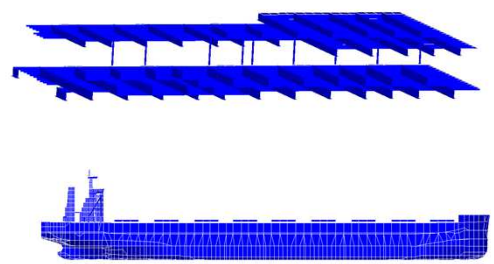
DNV GL Noise and Vibration Control Programme

How to meet the specified criteria?

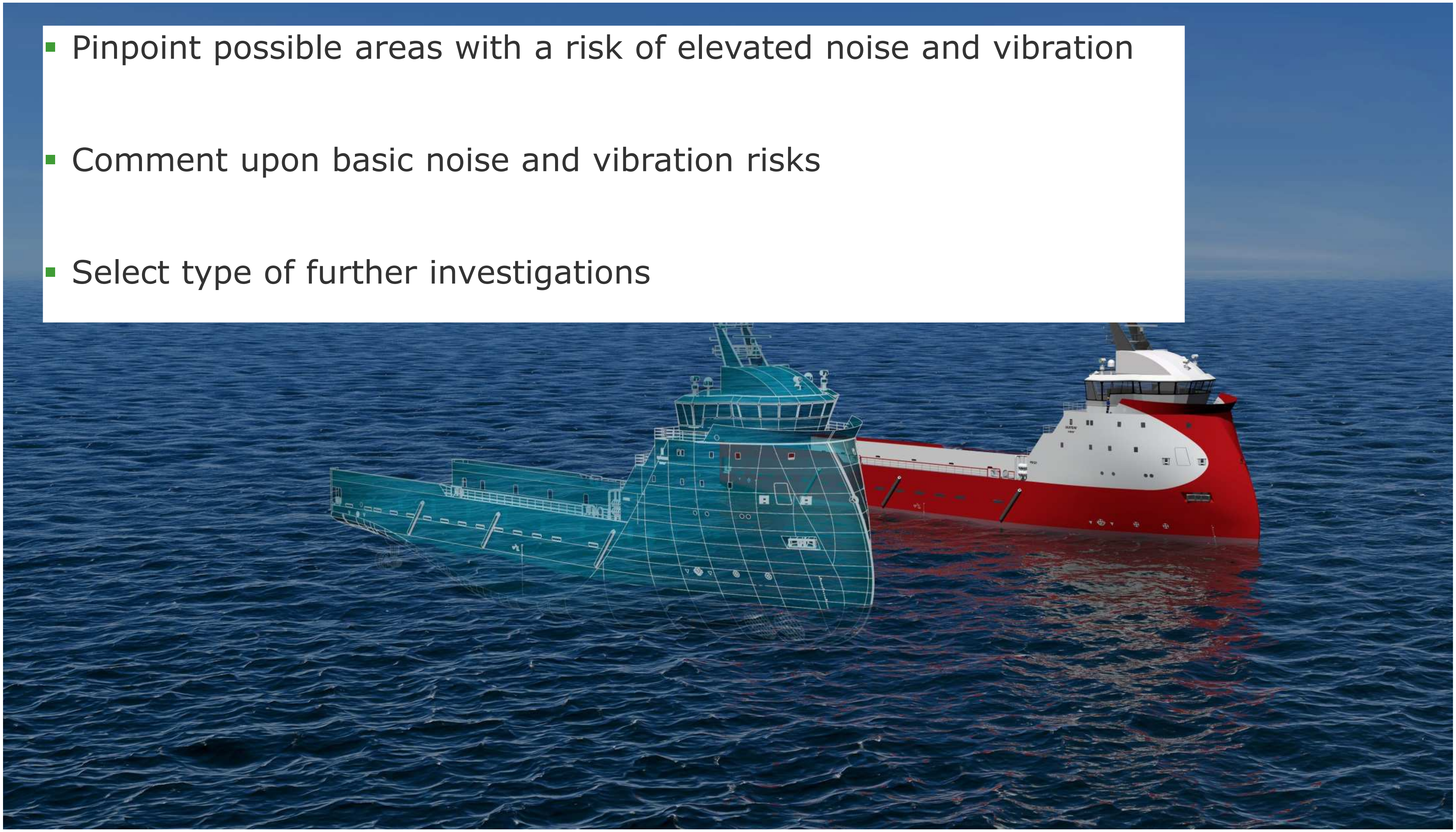
DNV GL – Noise and Vibration control programme

Stage 1: Early design review	Stage 2: Evaluation of excitation sources	Stage 3: Noise and Vibration analyses	Stage 4: Noise and Vibration measurements
			
▪ Pinpoint possible basic problems early in design phase.	▪ Propeller analysis ▪ Engine excitation analysis	▪ Local vibration analysis ▪ Global vibration analysis ▪ Noise prediction	▪ Verification measurements ▪ Troubleshooting measurements – Noise – Vibration – Pressure impulses – Underwater noise

Stage 1 – Early design review

Early design review

- Pinpoint possible areas with a risk of elevated noise and vibration
- Comment upon basic noise and vibration risks
- Select type of further investigations

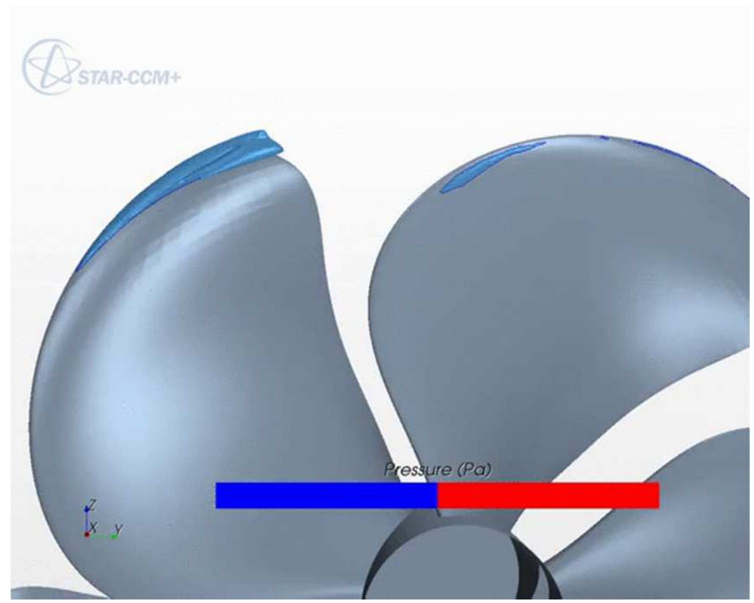


Stage 2 – Evaluation of excitation sources

Analysis of Excitation Sources - Propeller

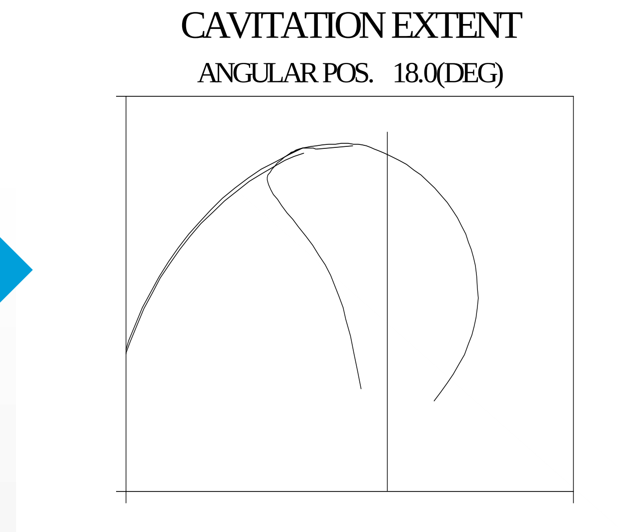
- **Propeller excitation analysis**
  - Semi-empirical **T**ip **V**ortex **I**ndex Method
  - In-house Lifting Surface Method
  - **C**omputational **F**luid **D**ynamics

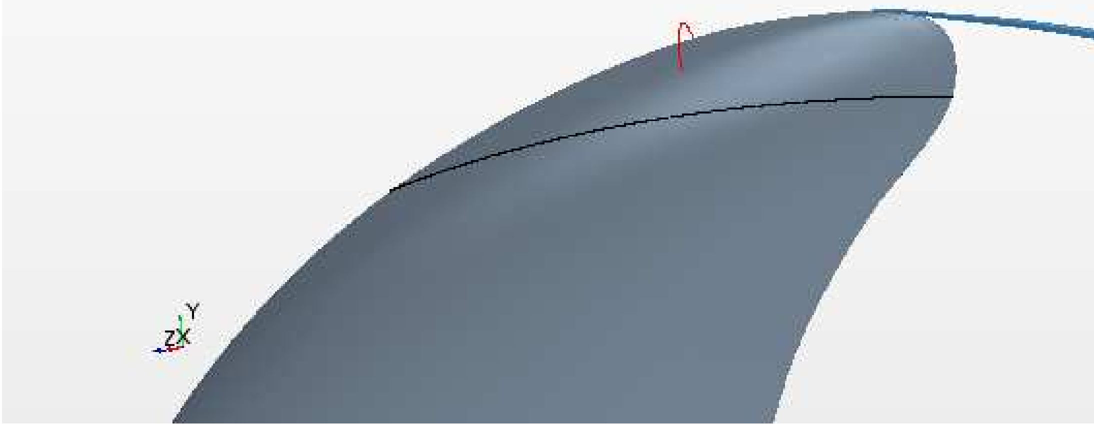
- **Provide input to noise and vibration analysis**

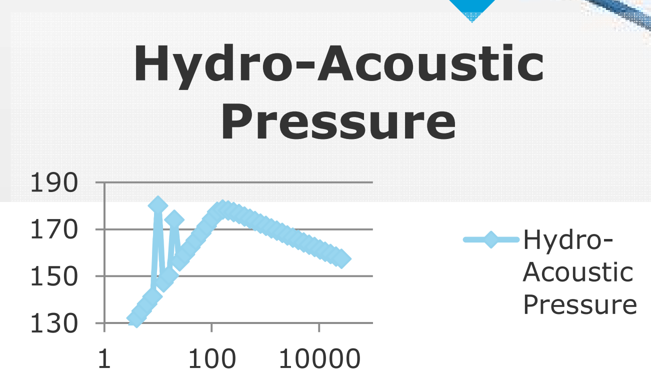


Semi-empirical TVI Method

- A tip vortex diameter is determined from the load distribution of the blade at each circumferential station and the local hydrostatic pressure.
- Semi-empirical model computes the resulting reference pressure, and the inboard noise in a reference location in the aft ship by a transfer function







Analysis of Excitation Sources - Propeller

- Correlation study between analysis and measurements – TVI method

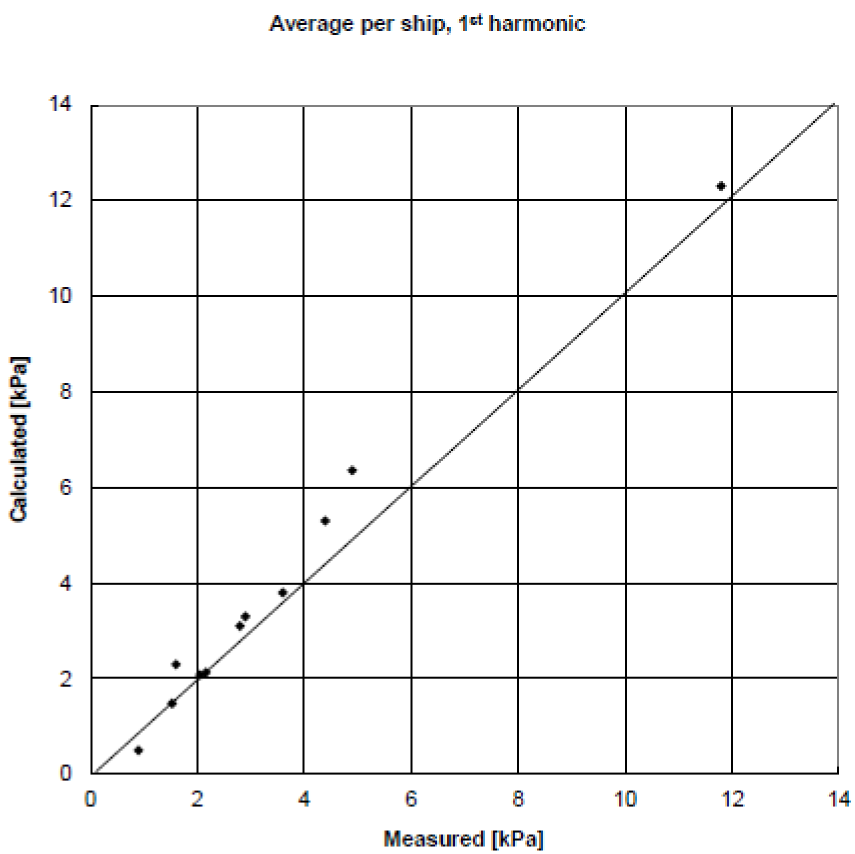


Figure A3: Average 1st harmonic pressure for each ship/condition

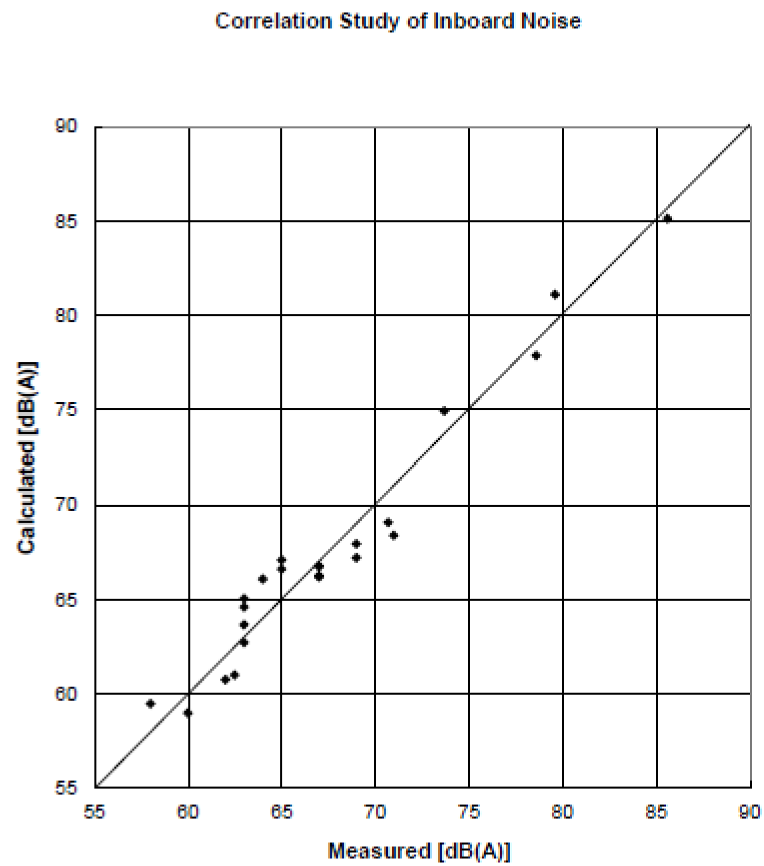
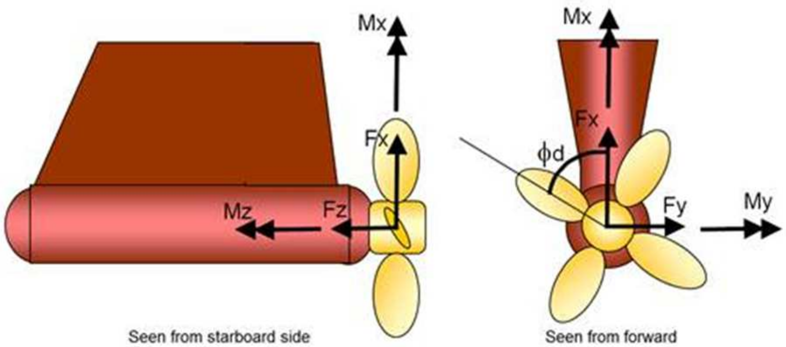
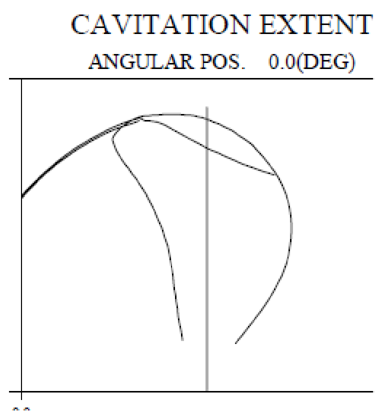
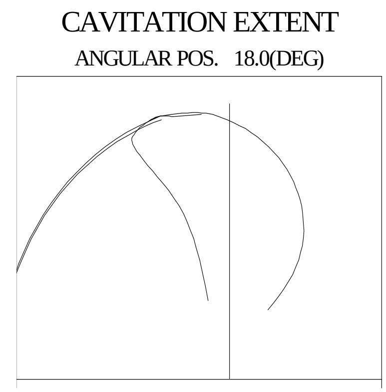


Figure A4: Noise data for 11 ships at different conditions

Lifting Surface Method, Sheet Cavitation







	Mean	n = 1x Z		n = 2xZ	
		a_n	θ_n (deg)	a_n	θ_n (deg)
Thrust (kN)	1021	4.9	107	0.4	-140
Torque (kNm)	1224	4.2	113	0.4	-131
FX (kN)	101	5.0	60	0.0	-157
FY (kN)	16	5.8	131	0.3	-154
MX (kNm)	319	12.0	27	0.3	-47
MY (kNm)	197	18.7	102	0.7	-157

Output:
- Fluctuating and mean shaft forces and moments
- Pressure pulses in an arbitrary number of points
- Blade loading distribution
- Hull surface forces including phase angles

Condition	FX_{1xZ} (kN)	θ_{1xZ}(deg)	FX_{2xZ} (kN)	θ_{2xZ}(deg)
78 % MCR	1.2	-75	0	-

Table 5. Vertical hull surface forces

Condition	FY_{1xZ} (kN)	θ_{1xZ}(deg)	FY_{2xZ} (kN)	θ_{2xZ}(deg)
78 % MCR	0.2	161	0	-

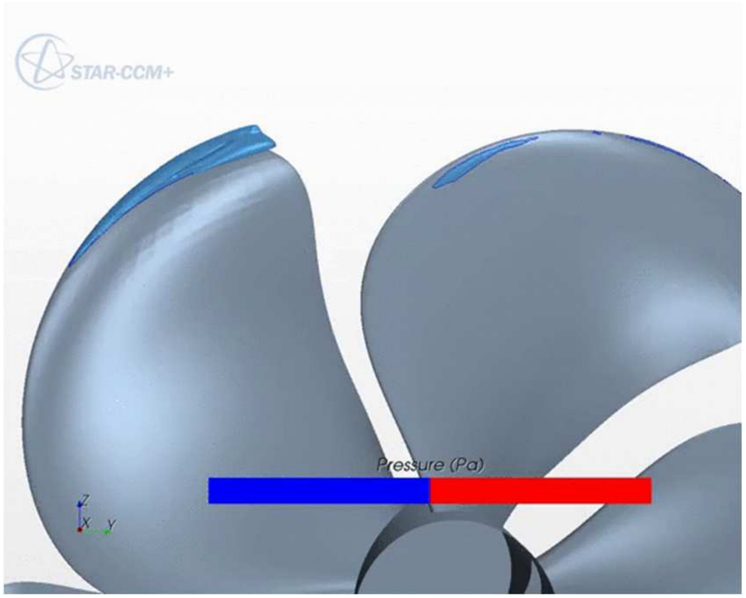
Table 6. Transverse hull surface forces

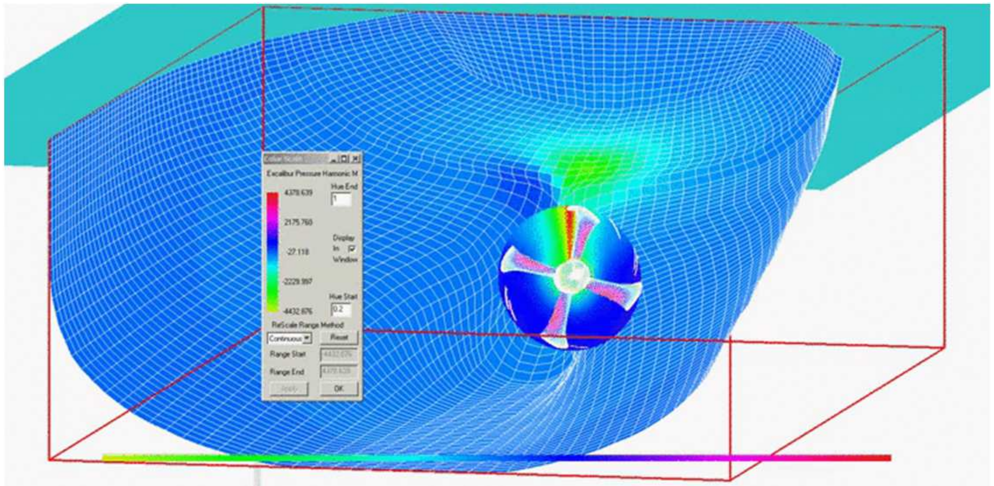
Condition	78 % MCR	100 % MCR
Noise Index dB(A)	57	61

Table 7. Reference noise

Analysis of Excitation Sources - Propeller

- **C**omputational **F**luid **D**ynamics





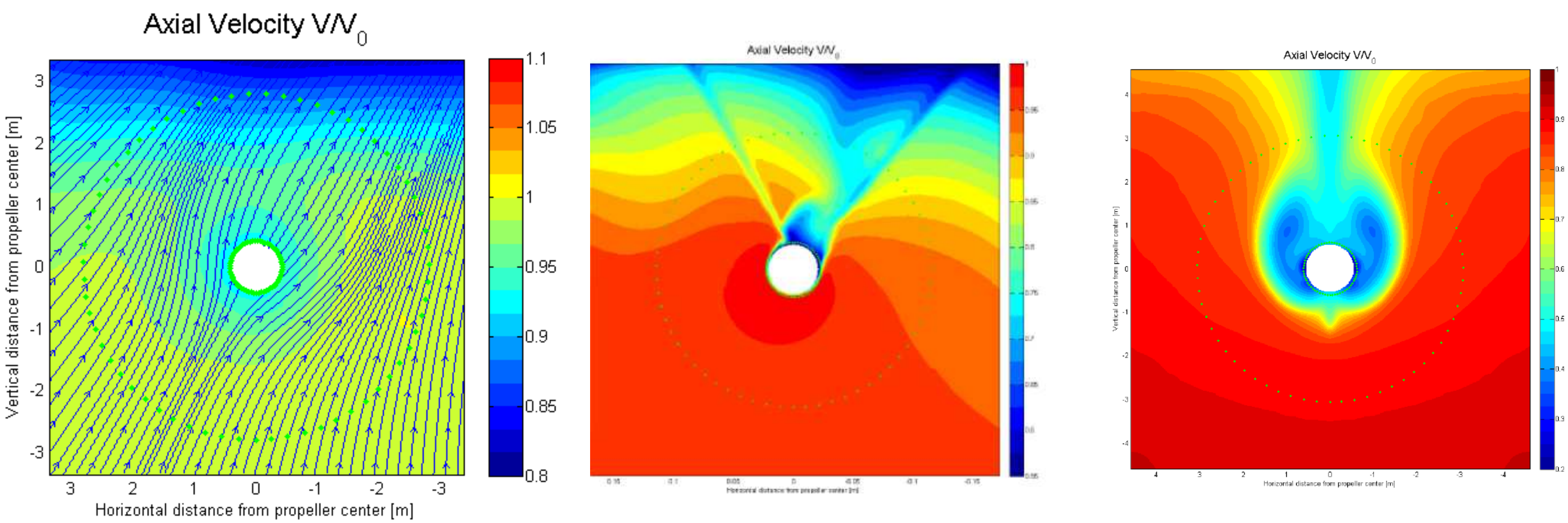
Cavitation pattern on propeller blades

Pressure distribution on hull surface

Analysis of Excitation Sources - Propeller

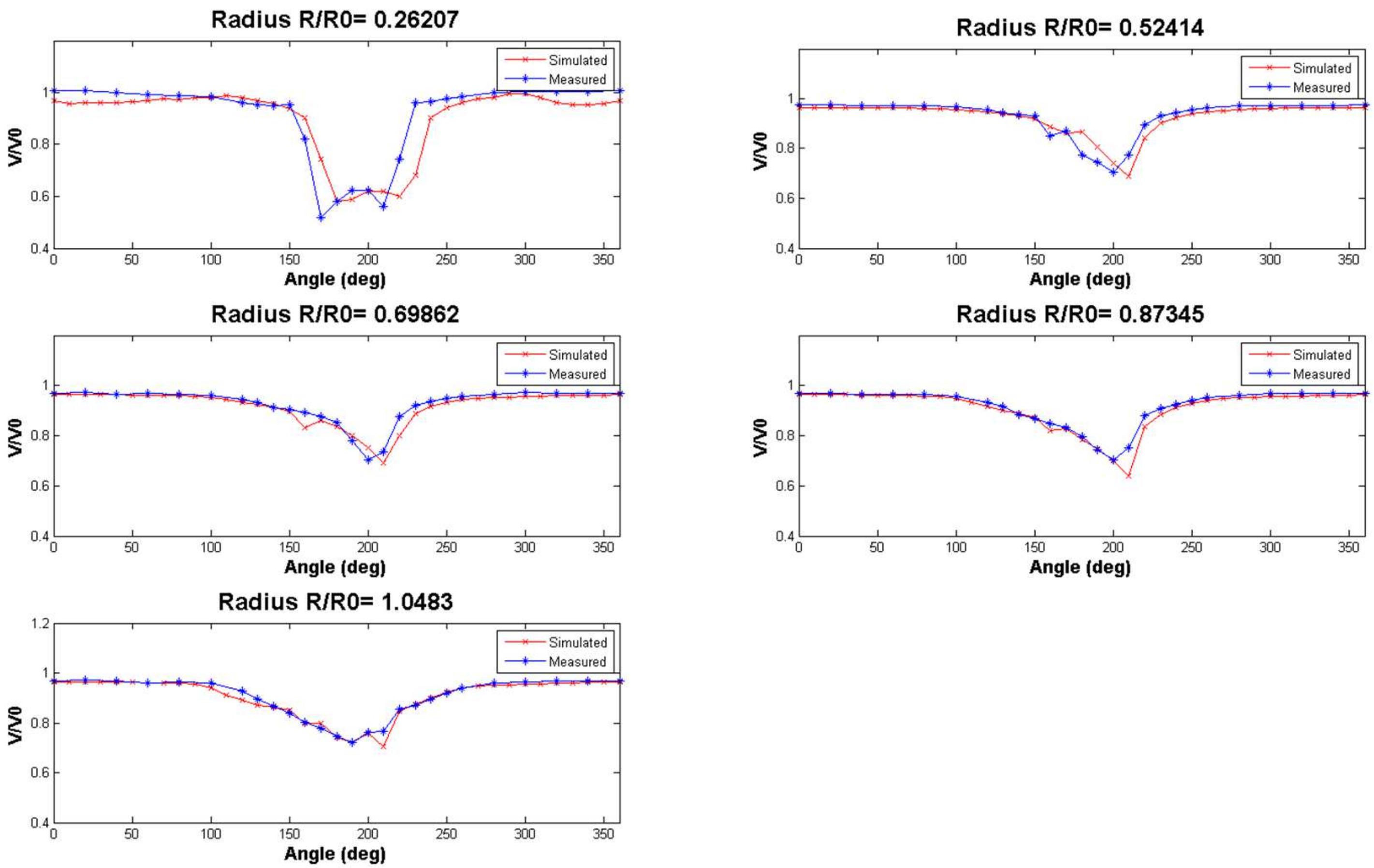
- **C**omputational **F**luid **D**ynamics

Prediction of wakefield



Analysis of Excitation Sources - Propeller

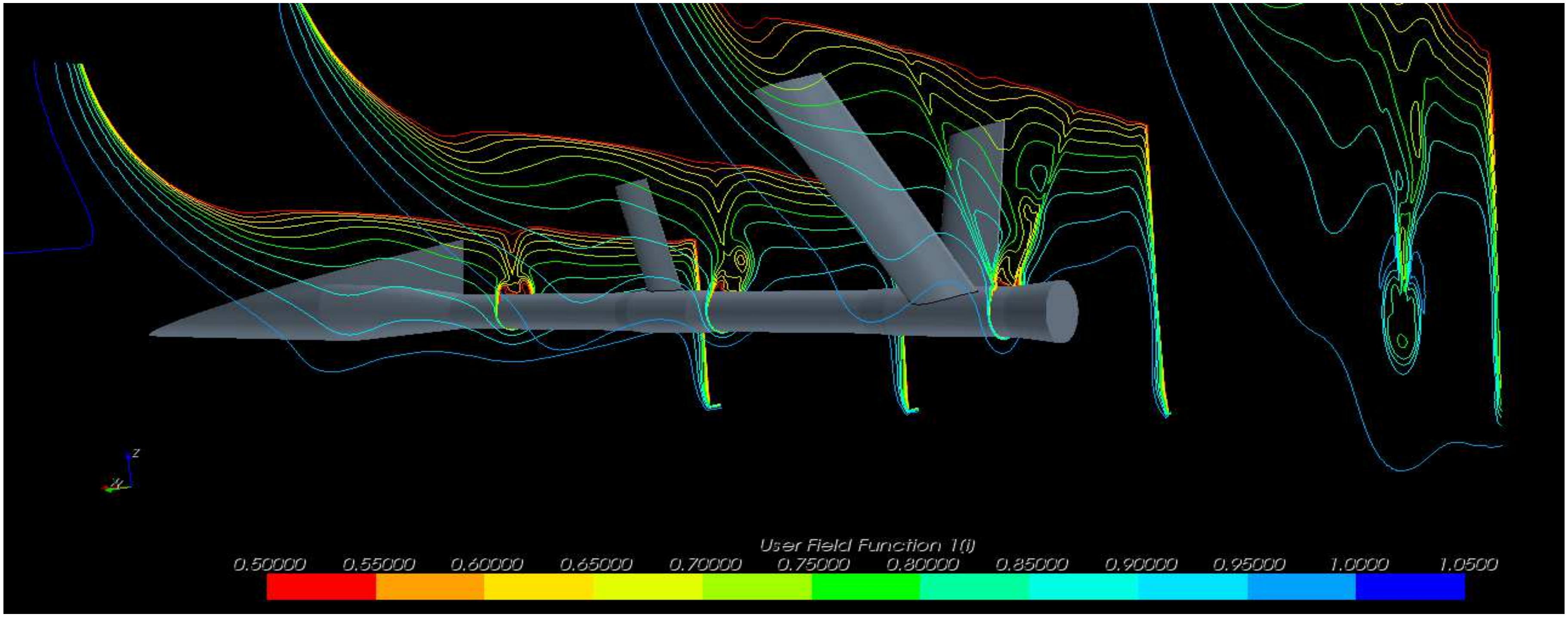
- Twin screw cruise vessel – correlation study with model test result



Analysis of Excitation Sources - Propeller

- Wakefield optimization

Example from a yacht with open propeller shaft and brackets.

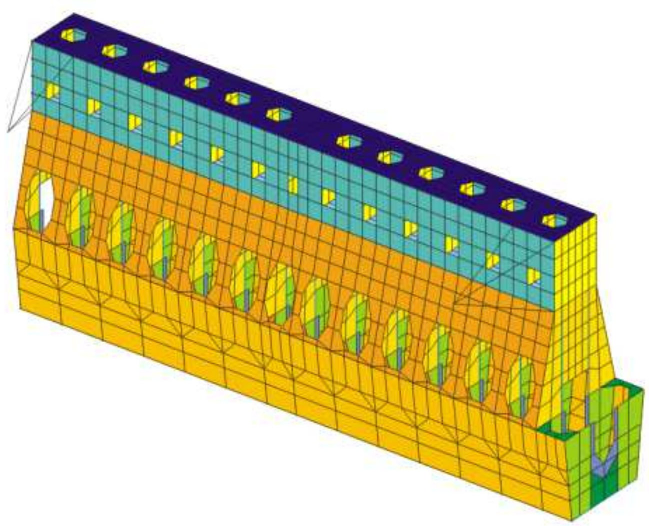


When geometry is defined - easy to see and evaluate possible modifications

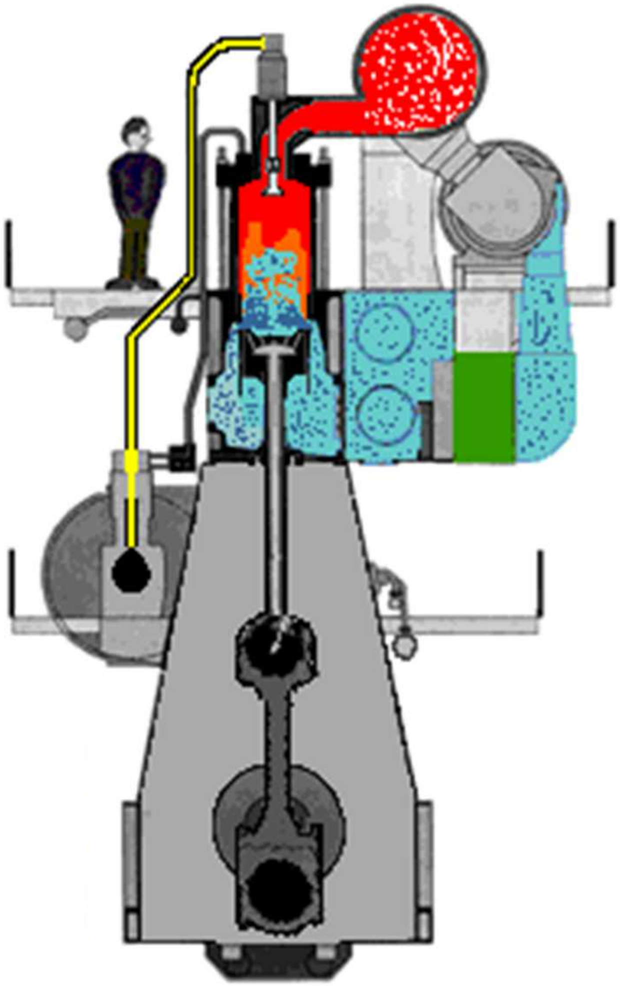
Analysis of Excitation Sources - Engines

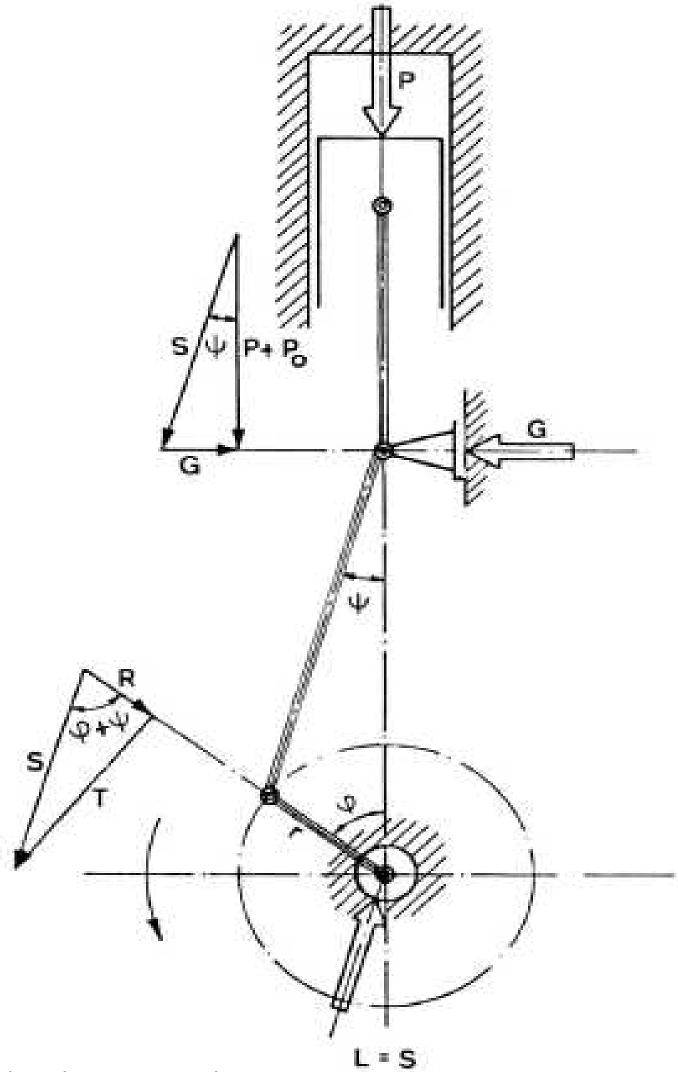
- **Engine excitation analysis**
  - Calculation of internal/external excitation forces
  - Phase information included
  - Properly transmission of forces to ship structure

- Input to noise and vibration analysis



Analysis of Excitation Sources - Engines



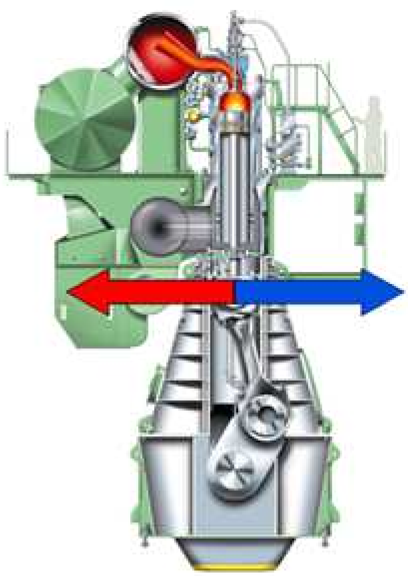


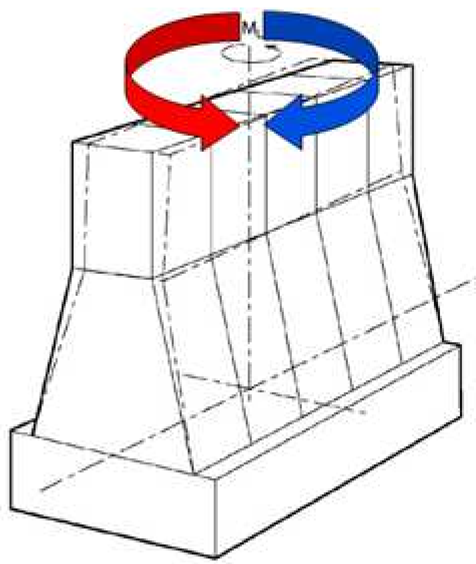
Animation Source:
http://www.dieselduck.info/machine/01%20prime%20movers/diesel_engine/diesel_engine.01.htm

Analysis of Excitation Sources - Engines

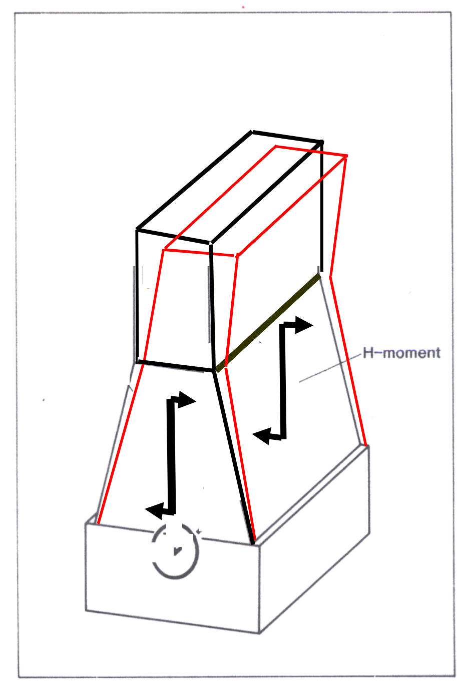
- Guide force moments

The transverse reaction forces that occur when the engine crossheads are acting on the engine upper structure causes guide force moments



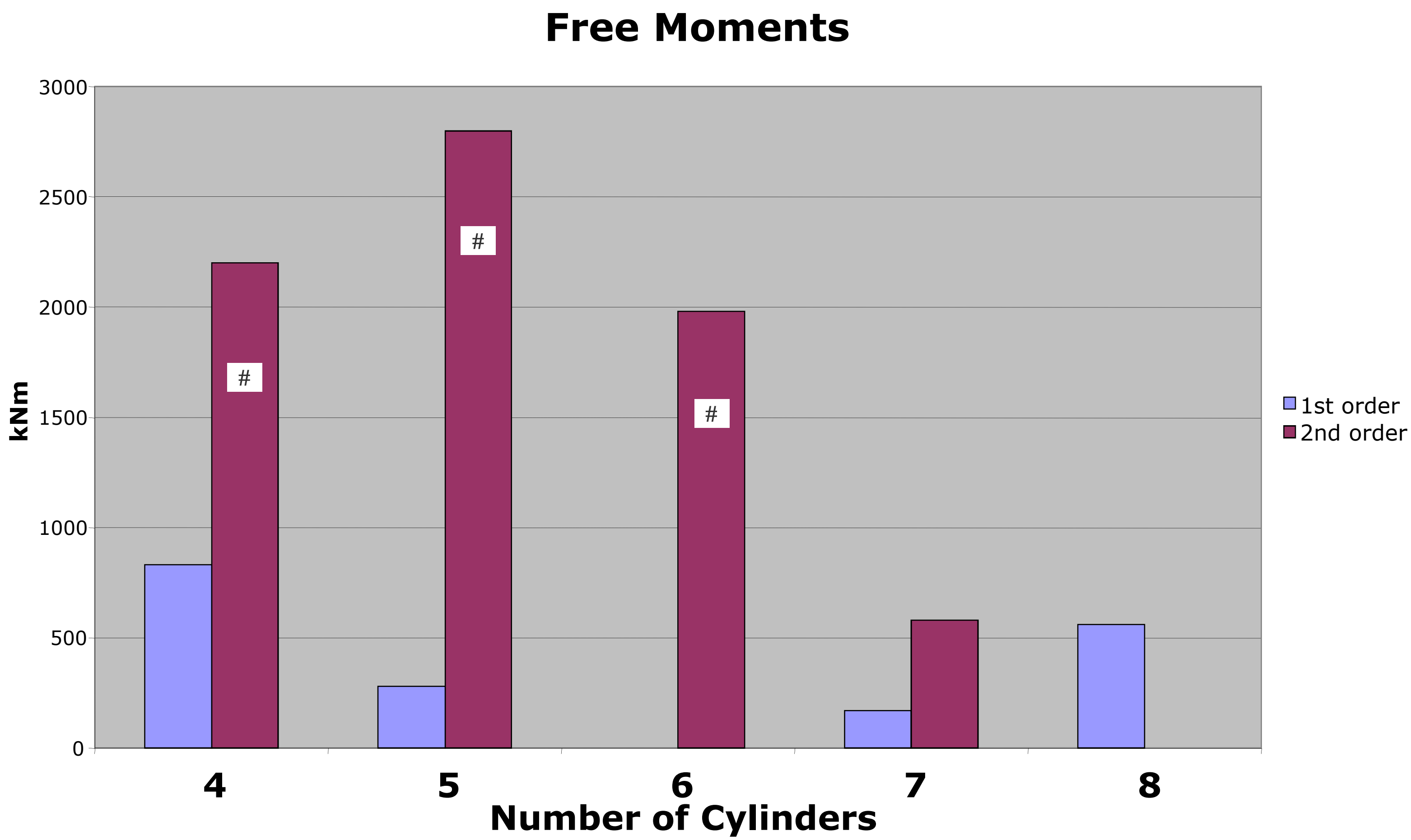


Resulting X-moment



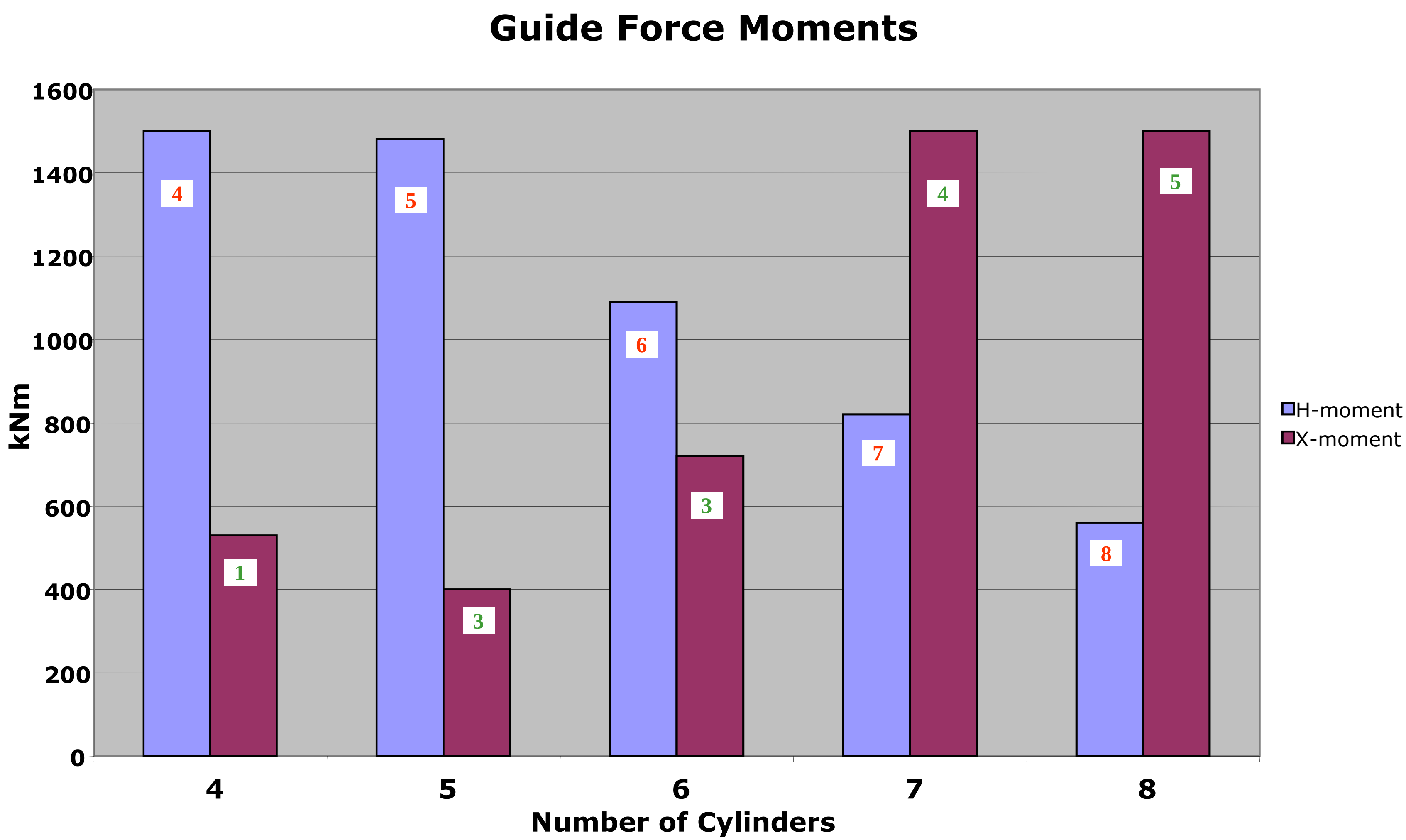
Resulting H-moment

Machinery induced vibration



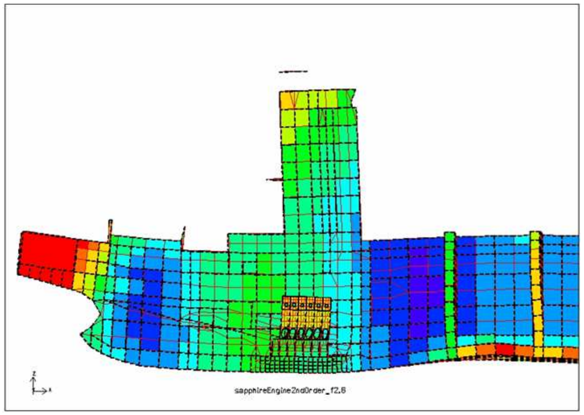
\# May be delivered with mechanical moment compensator

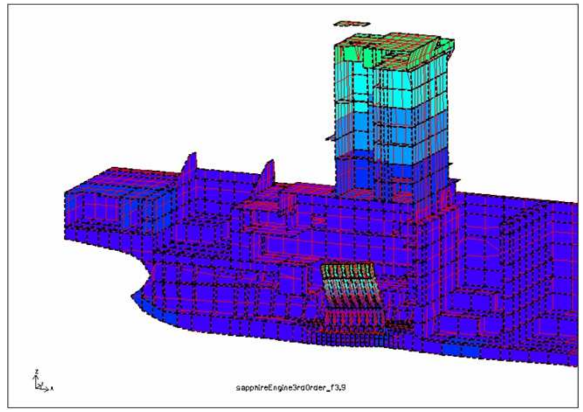
Machinery induced vibration

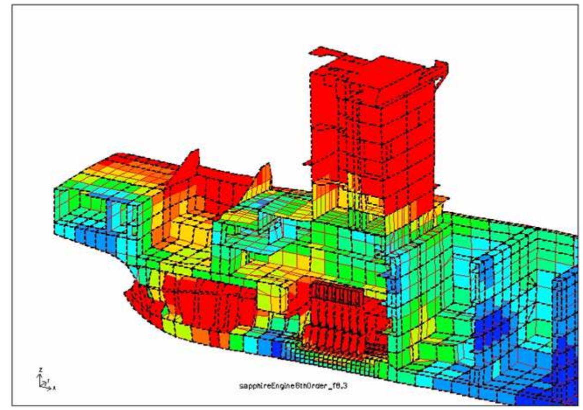


DNV·GL

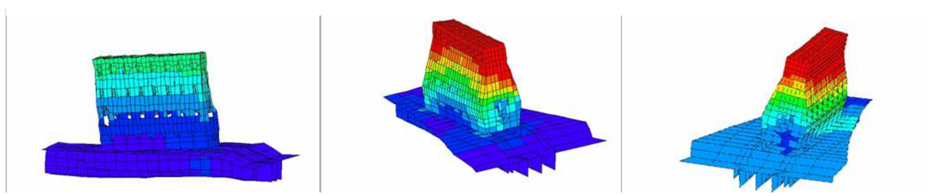
Examples of response







2nd Order, 3.4 Hz | 4th Order 6.8 Hz | 7th Order 11.9 Hz

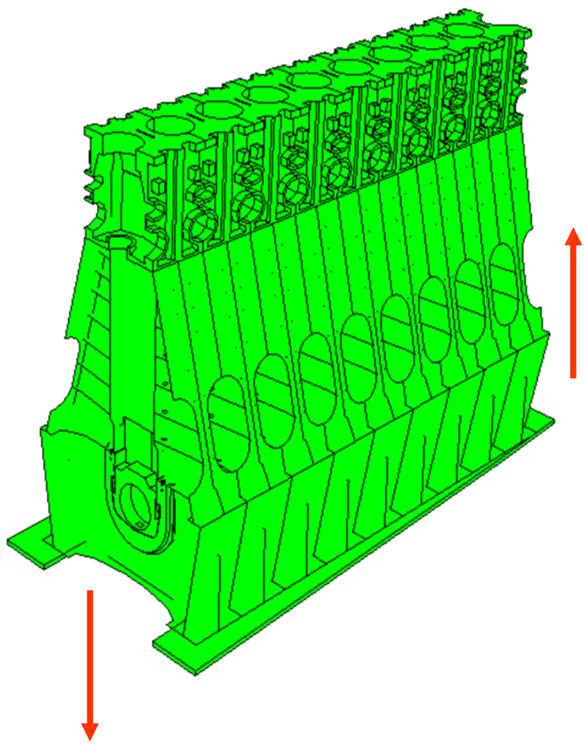


Coupled vibration of slow-speed engine frame and ship's double bottom at different excitation frequencies

How to minimise machinery excitation

Large Bore Main Engines, Free Moments

The moment created by the engine can be counteracted by means of an exciter in each end of the engine. In some cases engines are also provided with an exciter force in only one end of the engine. This exciting device is called moment compensator.



Moment Compensator

Example of moment compensator placed in aft end only

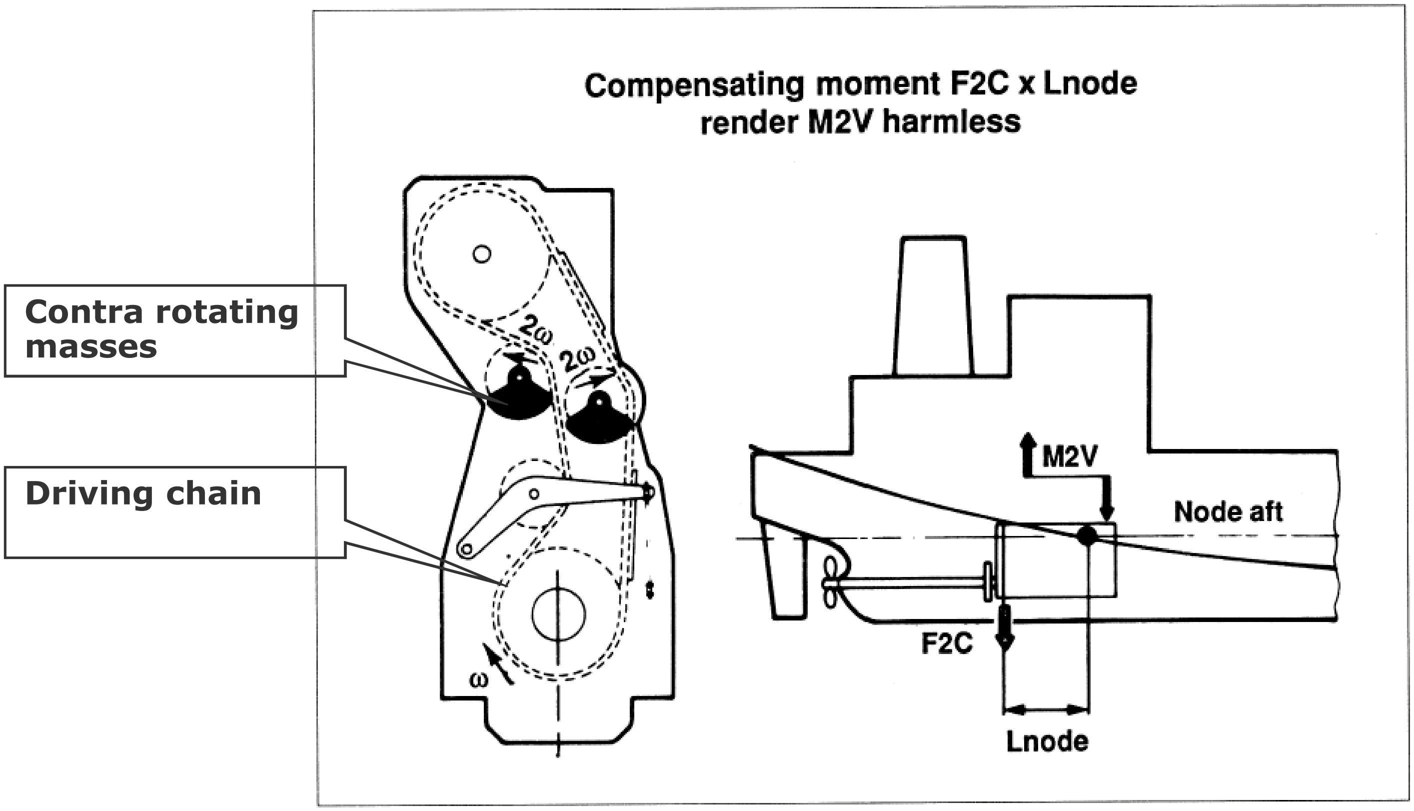
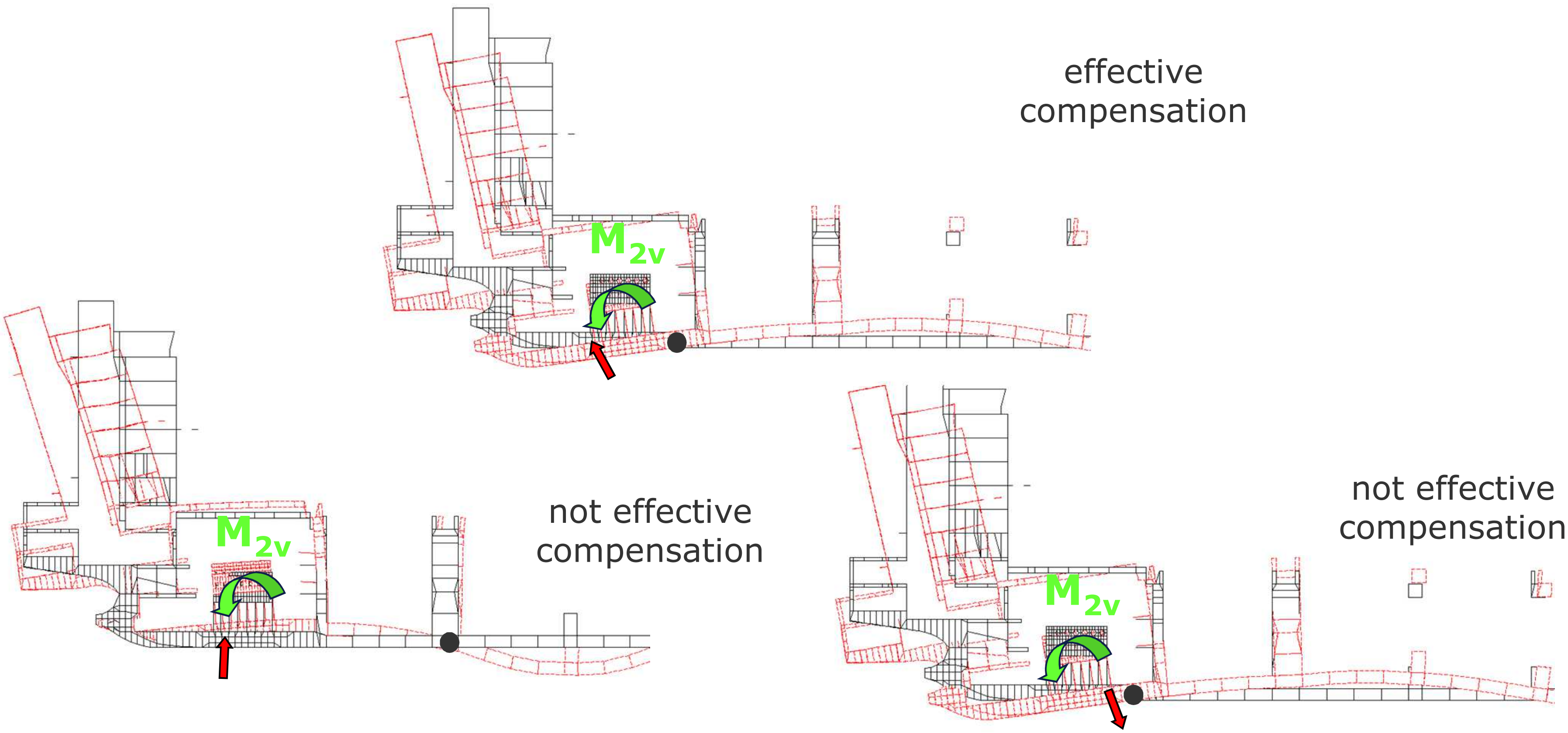


Fig. 8: 2nd order moment compenstor located on aft end

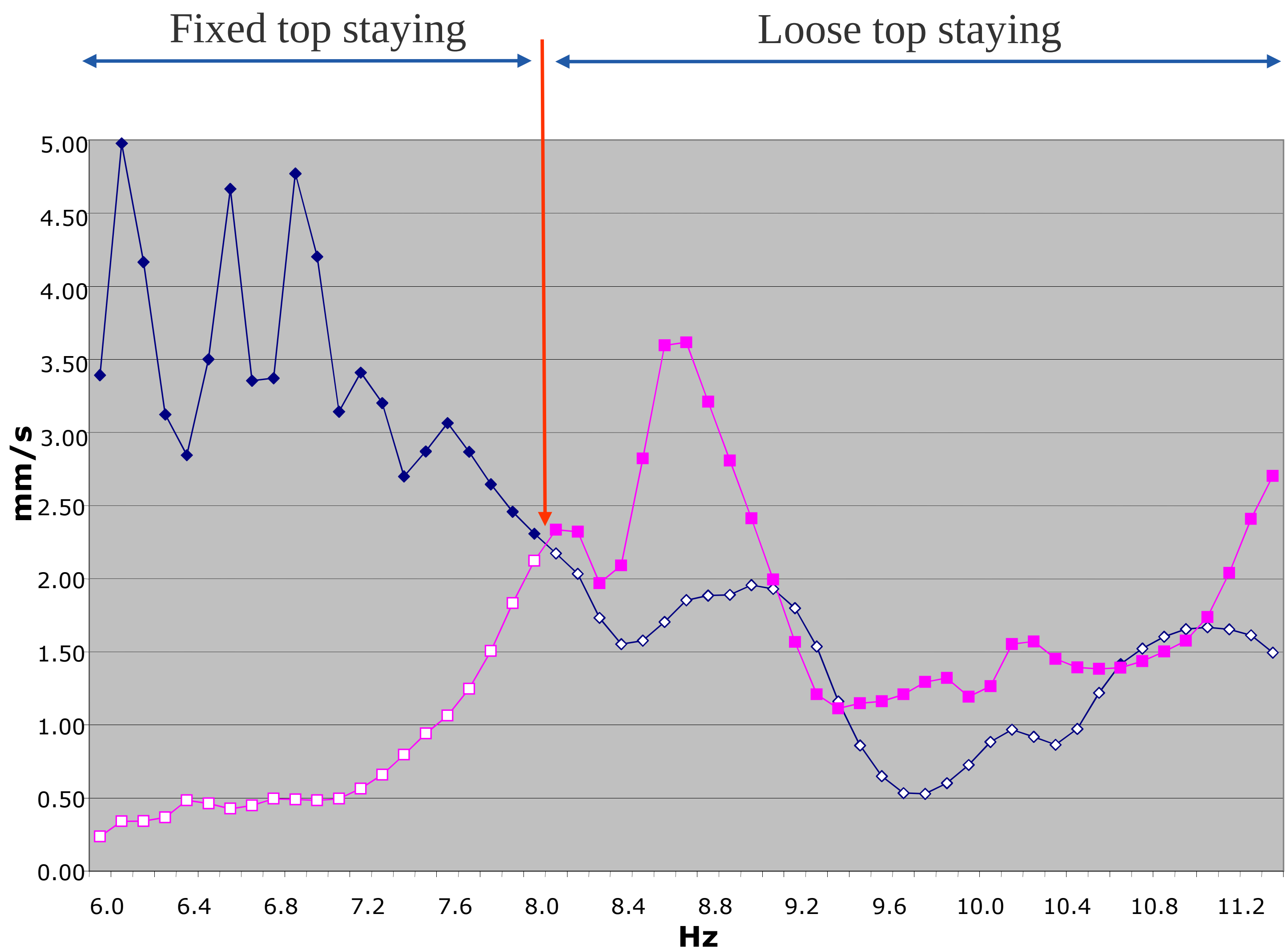
Remedy for excessive excitation force from main engine

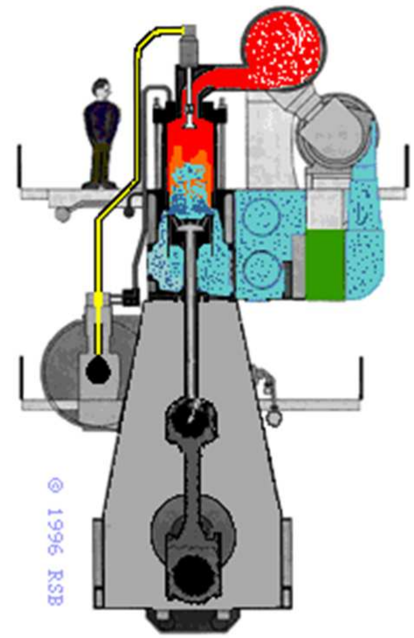
Assessment of effectiveness of 2nd order mass moment compensation

- compensation force may increase vibration levels
- potential money savings by omission of one or both compensators



Active Top Staying of Large Bore Engines

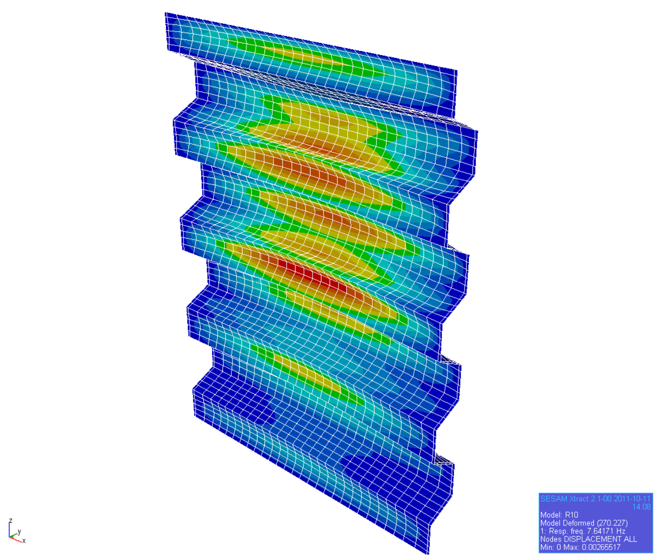


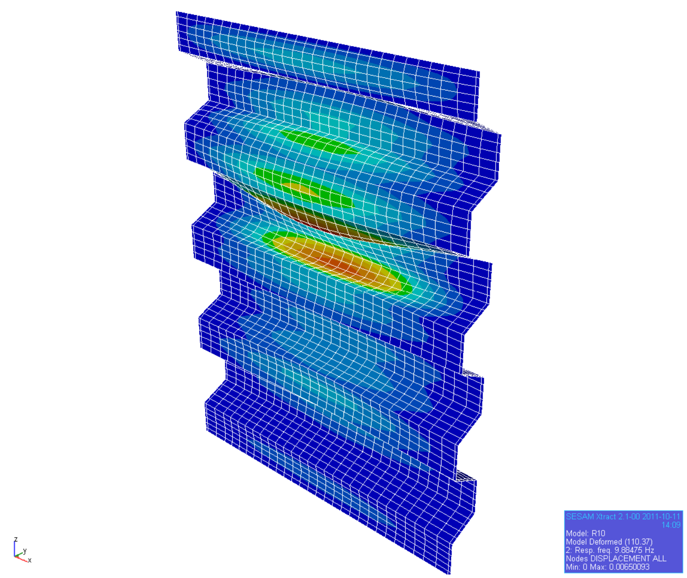


DNV·GL

Case: Chemical tanker – Fatigue in corrugated bulkheads

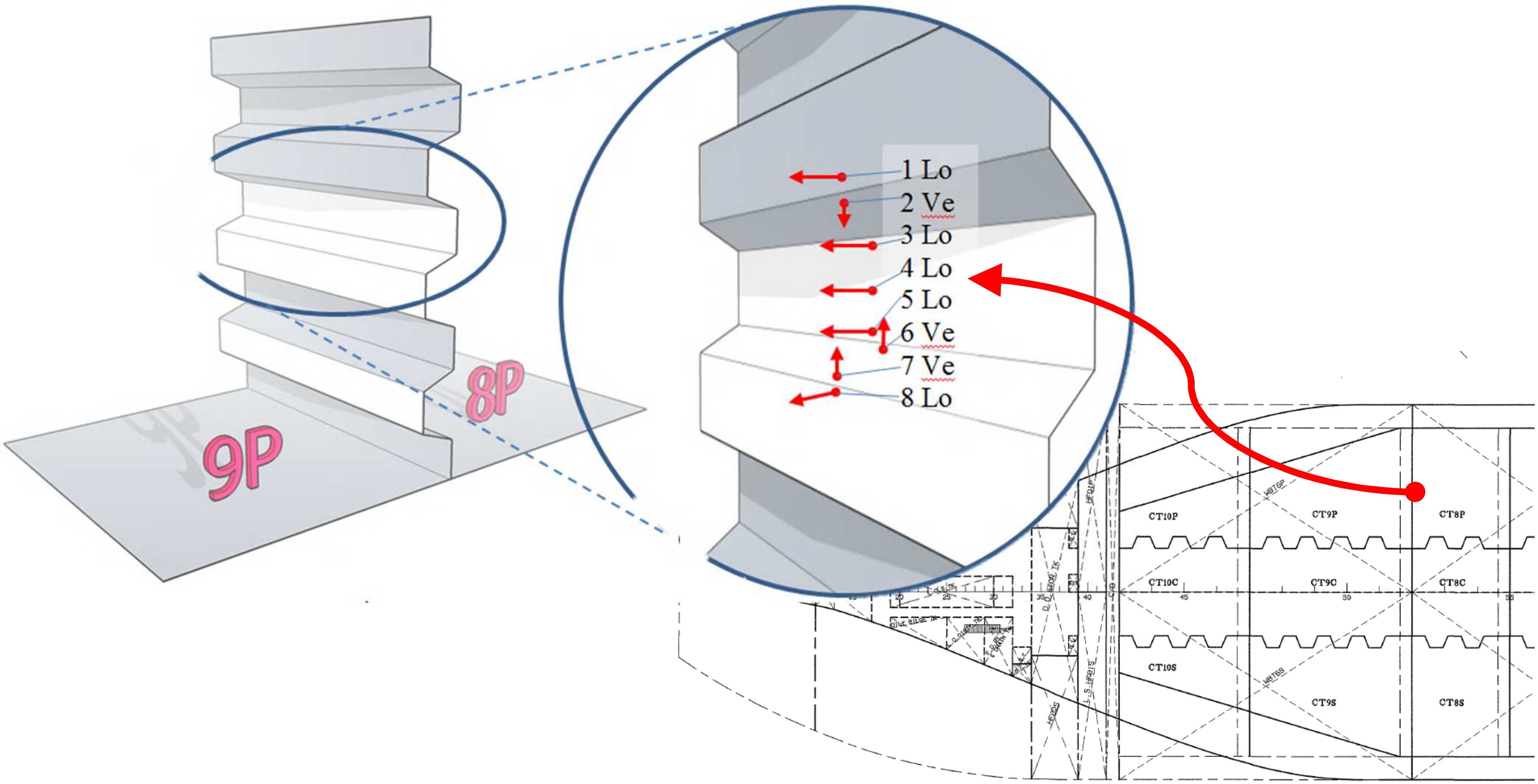
- Cracking found in corrugated bulkheads
- Natural frequency calculation were carried out
- Several natural frequencies found to be in range of H-moment of main engine





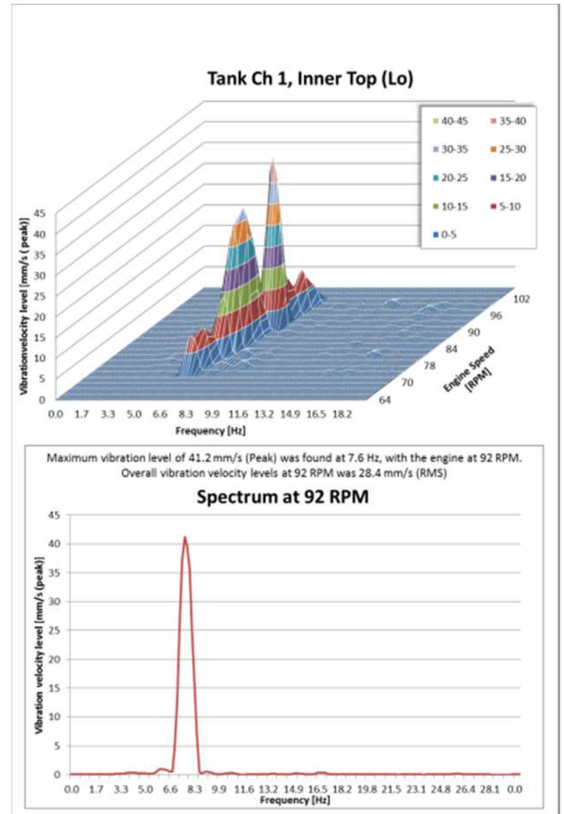
Full scale vibration measurements were carried out on bulkheads

Measurement Locations Tank 9P



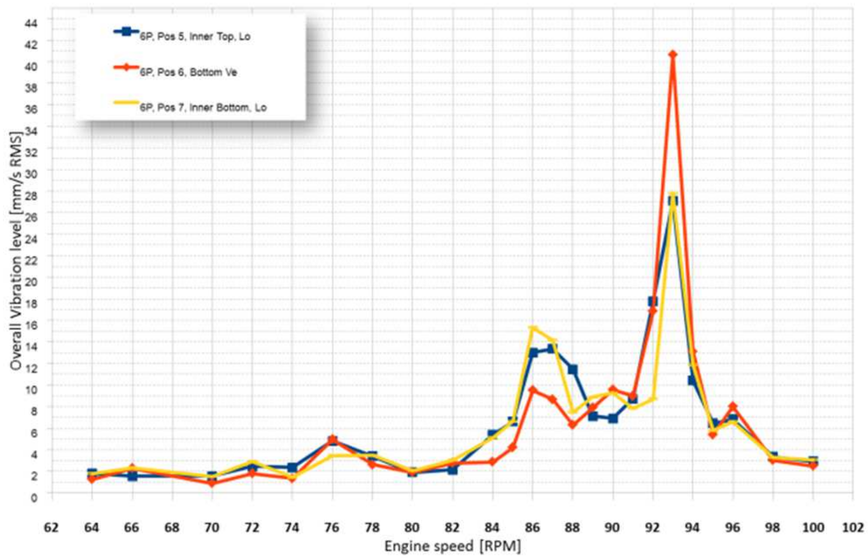
Results from measurements

- Measurements indicated high vibrations – above values termed as critical for fatigue – caused by main engine

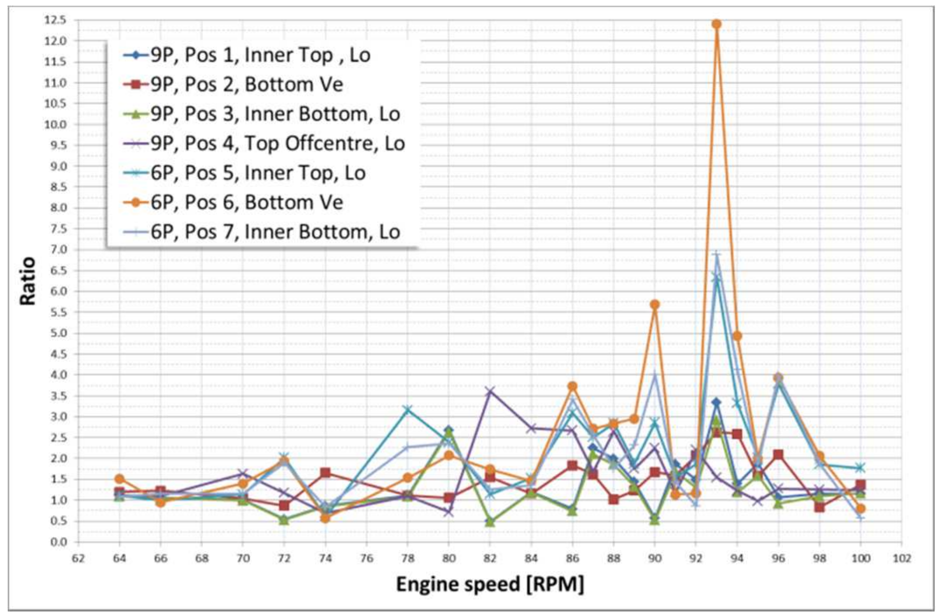


Solution: H-moment compensator on top of main engine

Full scale vibration measurements were carried out on bulkheads



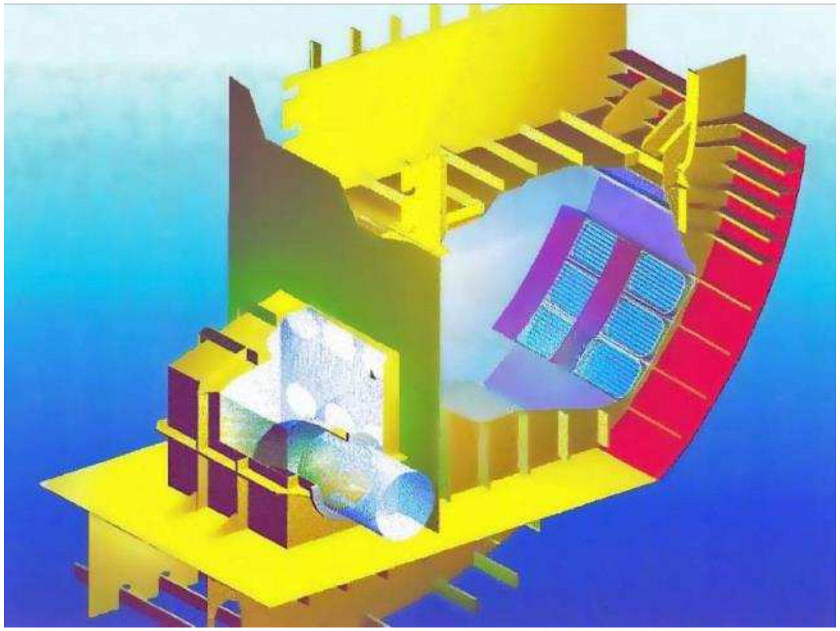
Vibration levels – initial condition

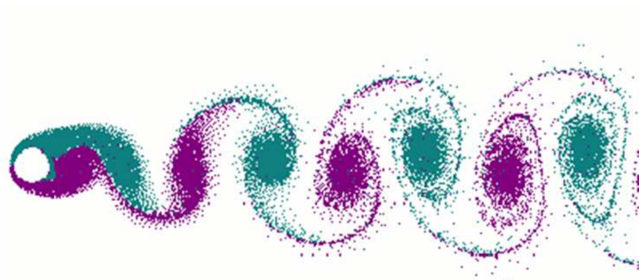


Effect of compensator on main engine – ratio before/after

Analysis of Excitation Sources – Vortex Shedding

- Vortex shedding around openings in hull (sea chest, moonpool, etc.)



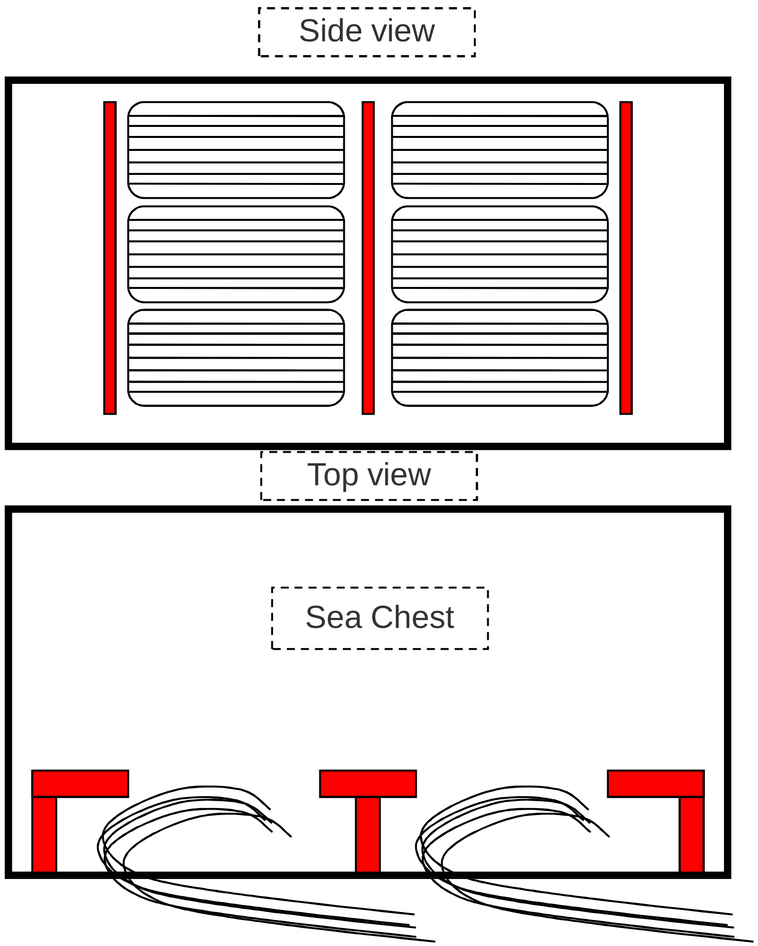


Animation Source:
https://en.wikipedia.org/wiki/Vortex_shedding

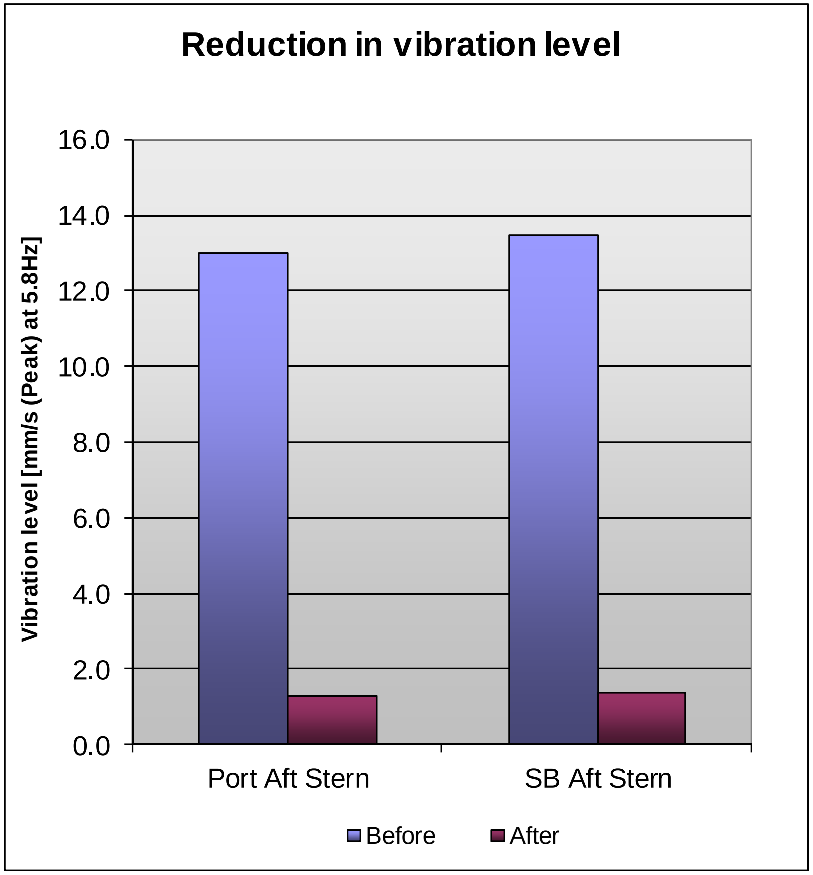
Case - Vortex generated vibrations

- Above 25 knots – high vibrations
- Full scale measurements:
  – Torsional hull girder mode: ~6 Hz
  – No "typical" continuous excitation source
  – High vibrations adjacent to sea chest
- Solution:
  – Geometry of sea chest opening altered

Sea chest – alteration of excitation frequency

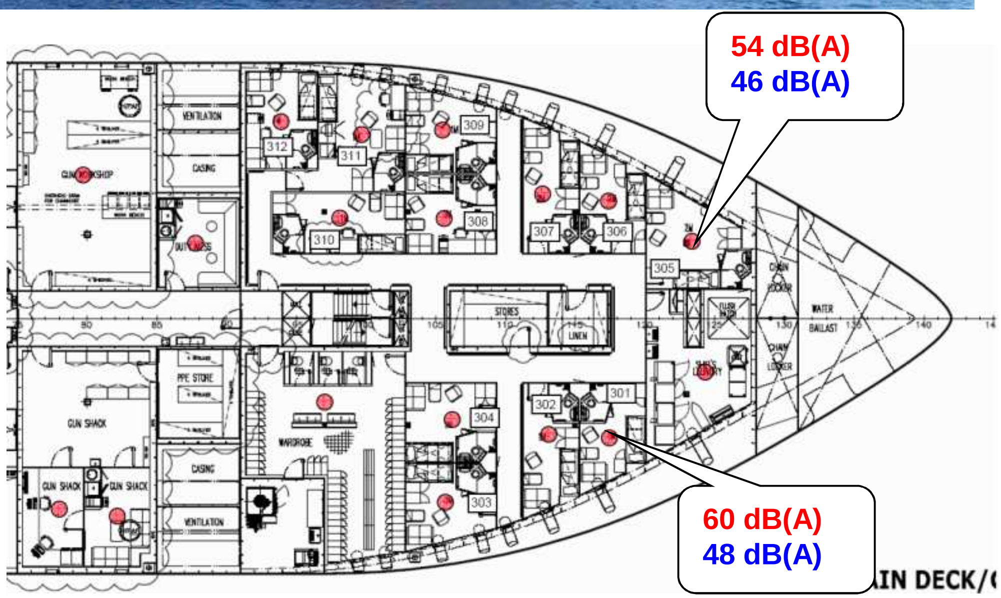


Changes shown in red. Drawing not to scale



Luxury Yacht/ Vortex -shedding

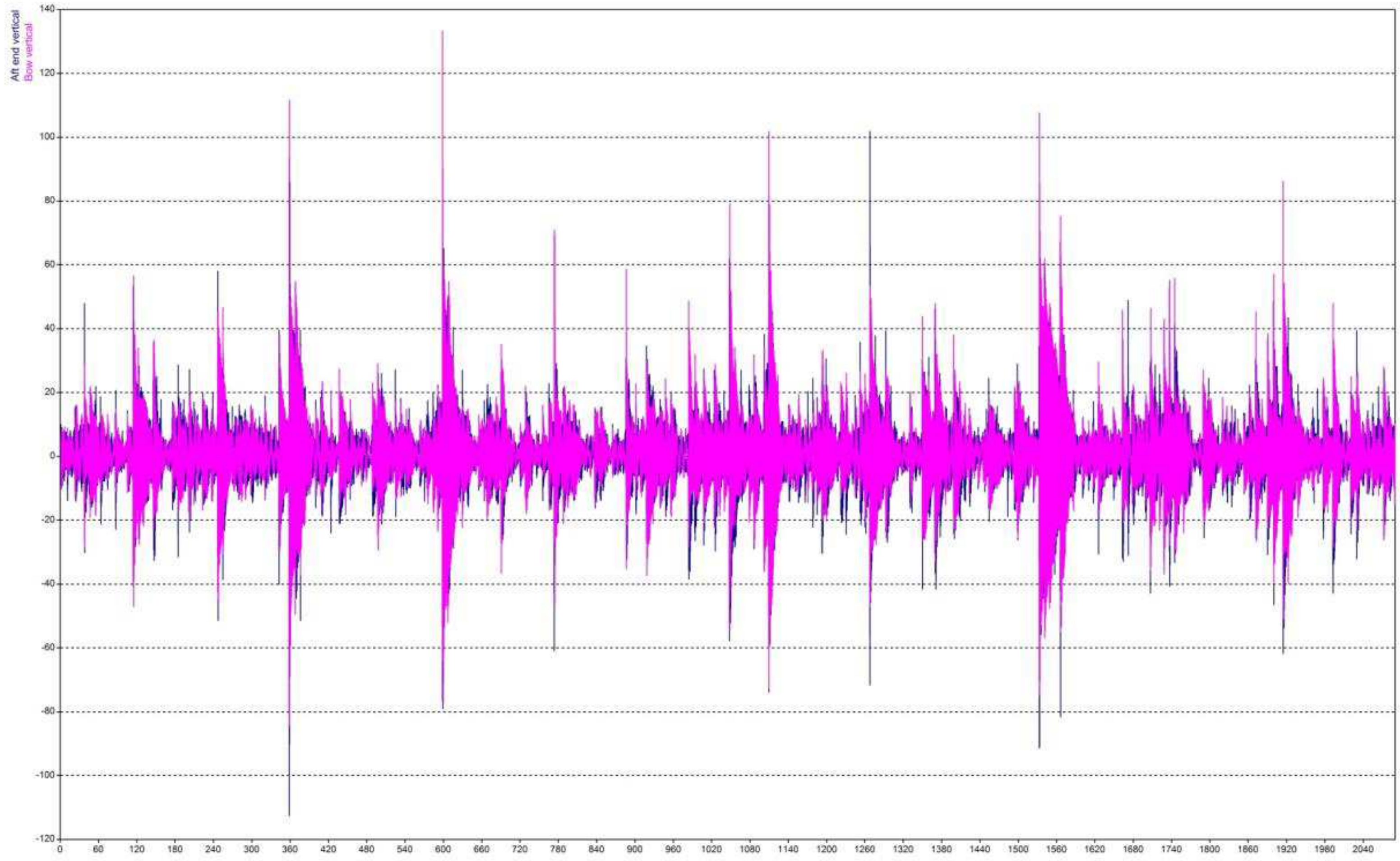
Seismic vessel – vortex shedding in azimuth trunk



Evaluation of excitation sources - Slamming

- Slamming forces may cause significant vibrations in hull girder

Response slamming – supply ship

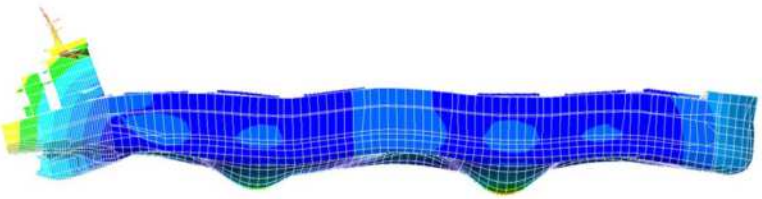


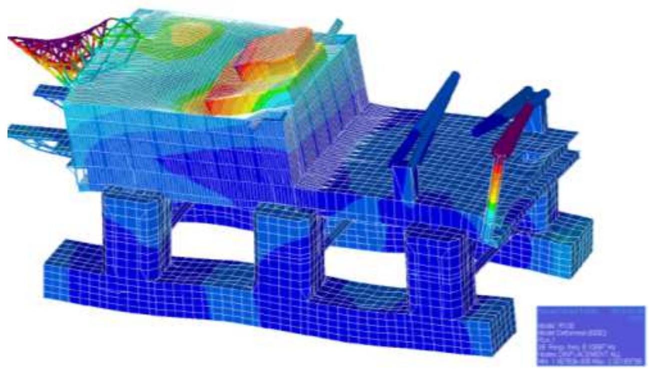
Stage 3 – Noise and vibration analysis

VIBRATION

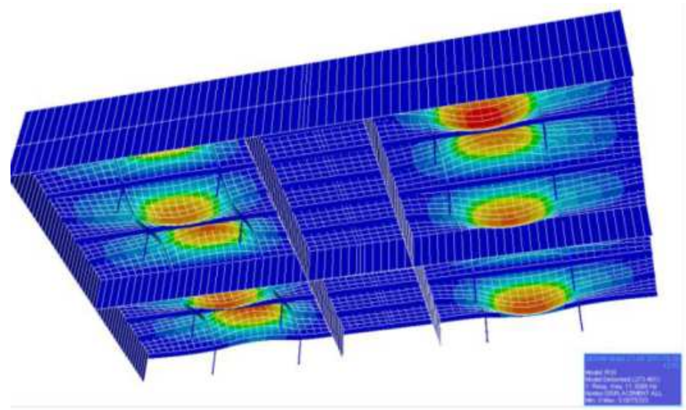
Global and Local Vibration Analysis

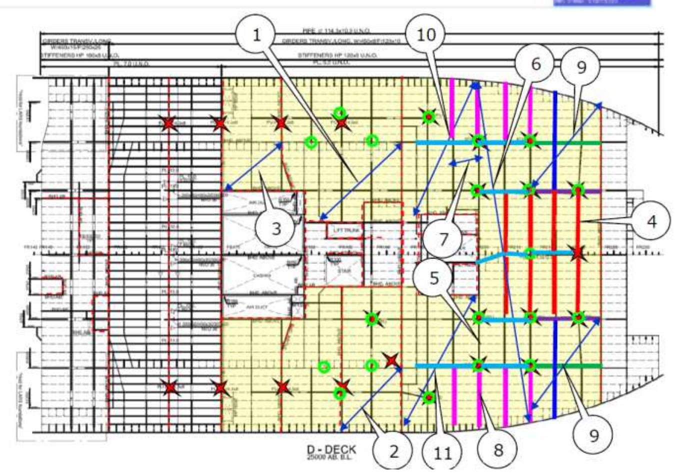
- Global response





- Local response





Approaches for Vibration Analyses

- Cruise / Passenger vessels:
  - Forced vibration analysis hull and deck girders
  - Natural frequency of stiffeners/plates
- Merchant vessels:
  - Forced vibration analysis hull, deck house and girders (decided case by case)
  - Natural frequency of stiffeners and plates
- Offshore service vessels
  - Natural frequency of girders, stiffeners and plates

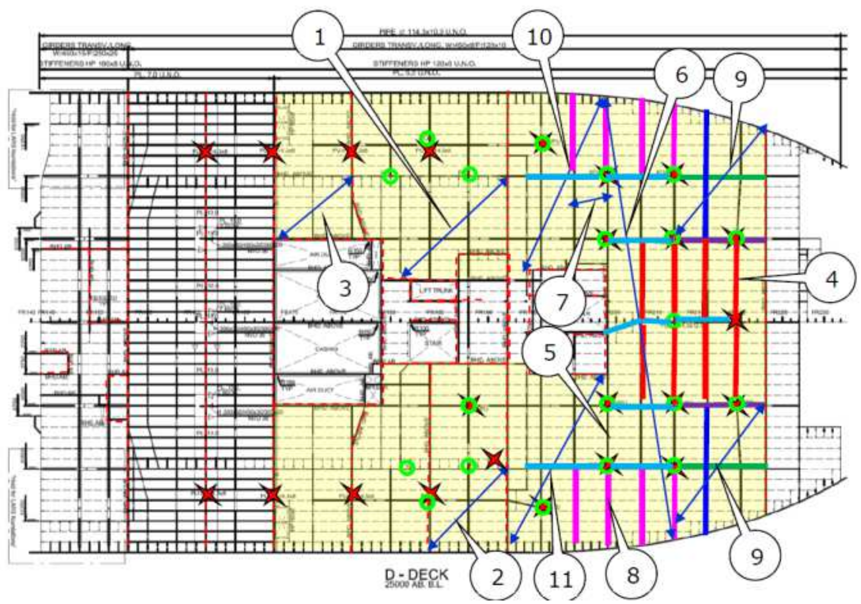
Approaches for Vibration Analyses

- Mobile Offshore Units:
  - Forced vibration analysis hull, deck house and girders (decided case by case)
  - Natural frequency of stiffeners and plates
  - Finite Element study of thruster and engine foundations (decided case by case)

Local Vibration Analysis

- Compare excitation frequencies and natural frequencies
- Avoid resonance with relevant excitation sources
- Propose and verify structural modifications

A time and cost effective evaluation



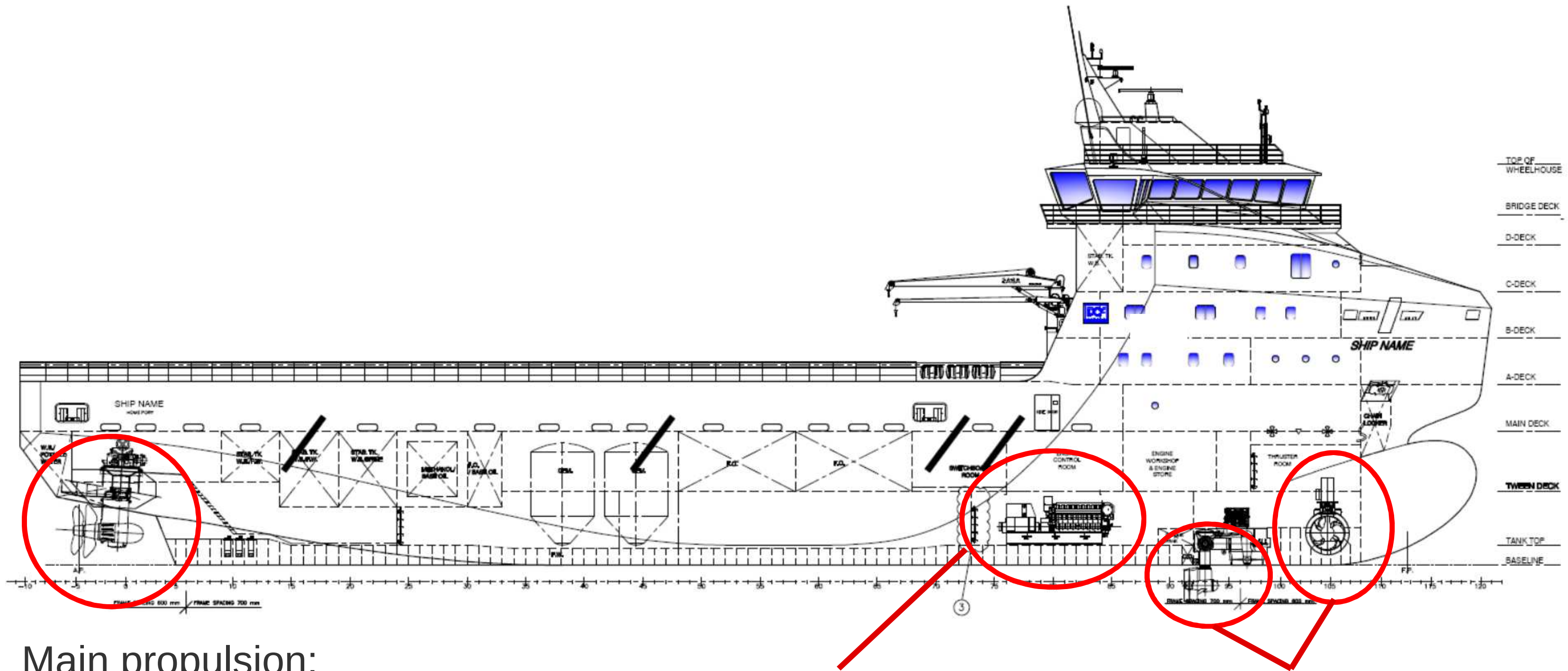
Local Vibration Analysis

- **Analytical approach by Rayleigh-Ritz method**
  - In-house program ”Platefreq”
  - All beams considered as simply supported
  - All boundaries described by rectangular areas
  - Only fundamental vibration modes
  - Accuracy range: +15% / -30%

- **Finite Element Method**
  - DNV GL program ”SESAM”
  - Clamping due to adjacent girder/pillar systems can be considered
  - More complex areas
  - Higher order vibration modes
  - Accuracy range: ±10%

Local Vibration Analysis

Define Excitation sources



<u>Main propulsion:</u>

- RPM
- Number of blades
- Power
- Type

<u>Main engines:</u>

- RPM
- Number cylinders
- Mounting

<u>Side thrusters:</u>

- Type
- RPM
- Number of blades
- Mounting

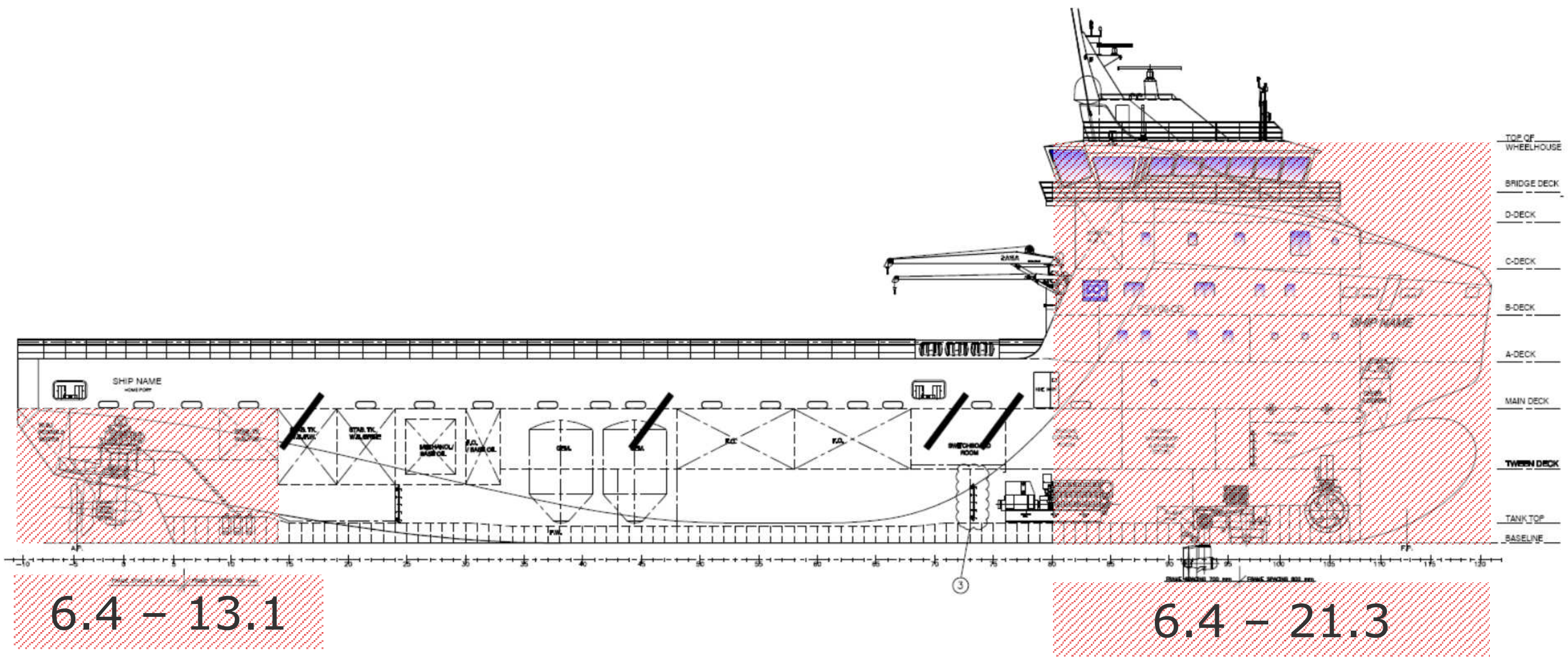
Local Vibration Analysis

Define excitation frequency ranges

Excitation source	Excitation frequency [Hz]	Lower limit [Hz]	Upper limit [Hz]
Main propulsion: Propeller speed: 171 RPM - Blade passing frequency (4 blades)	11.4	6.4	13.1
Main engines: Speed: 720 RPM - 1st order	12.0	8.4	13.8
Bow tunnel thrusters: Propeller speed: 0 – 278 RPM - Blade passing frequency (4 blades)	18.5	13.0	21.3

Local Vibration Analysis

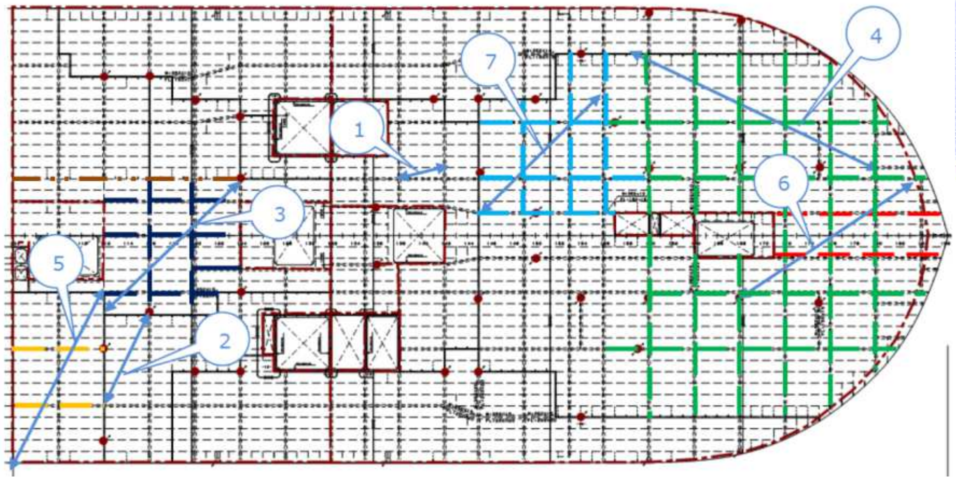
Define Critical areas

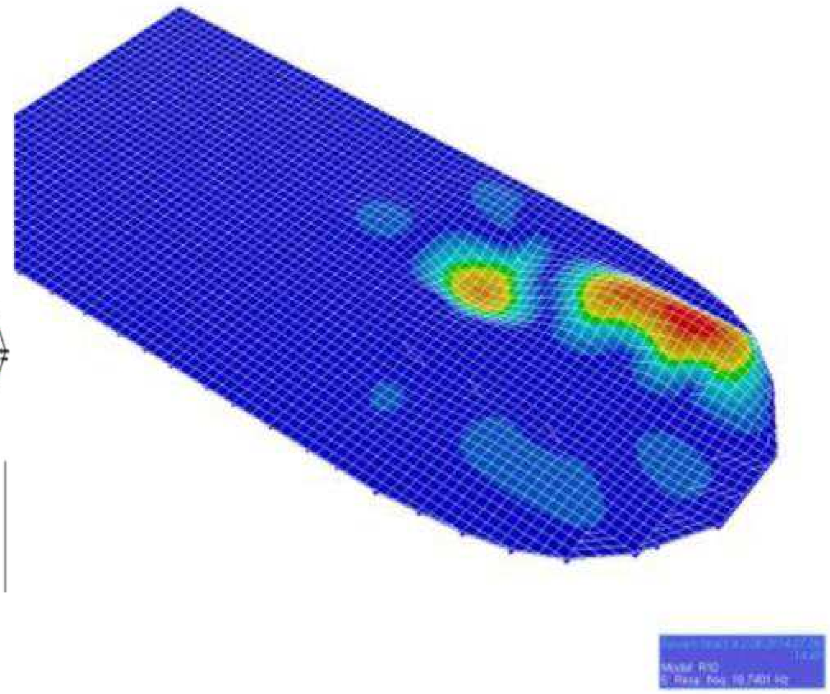


Local Vibration Analysis

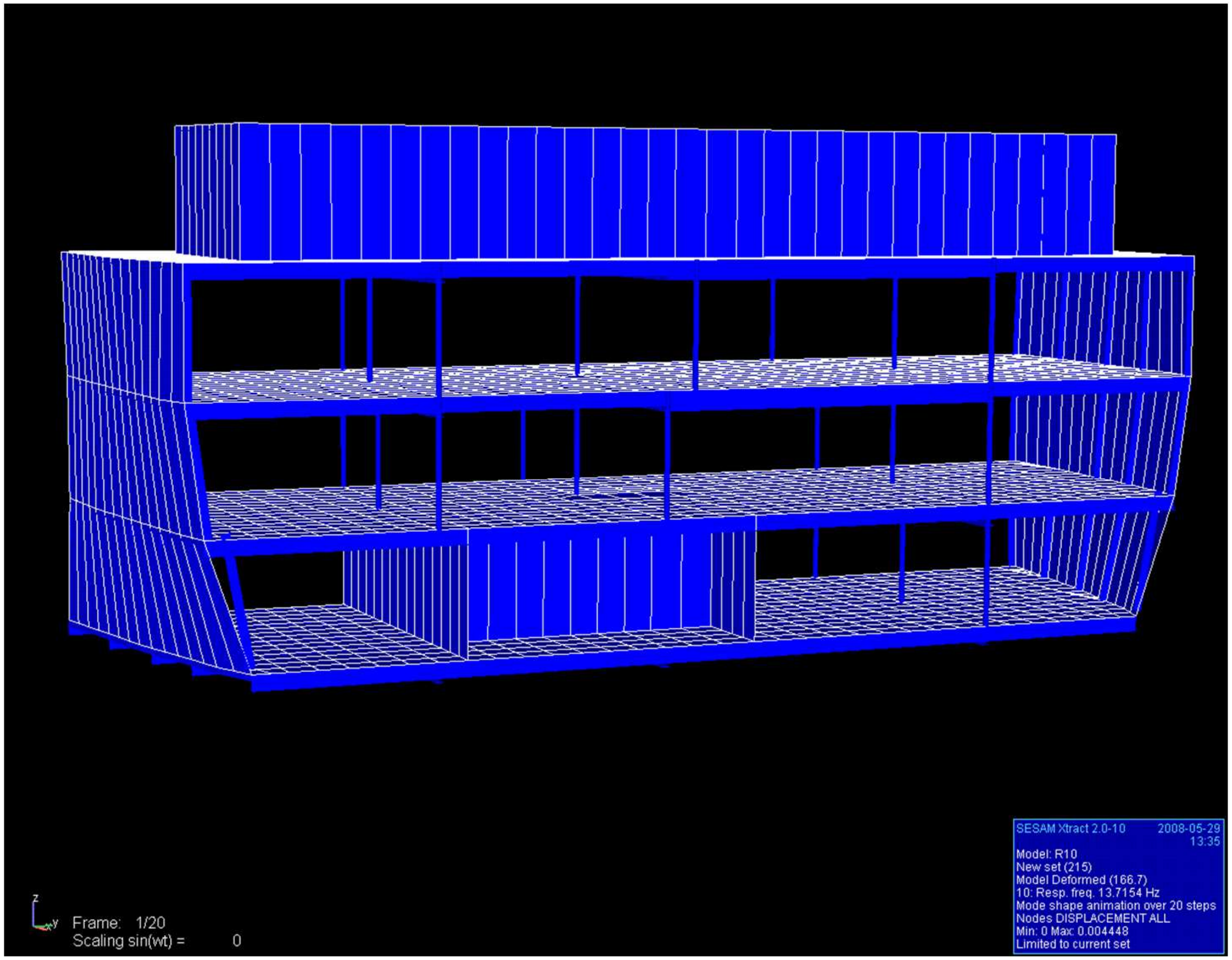
Girder systems with complicated boundaries

Finite Element Method may be needed to give relevant results

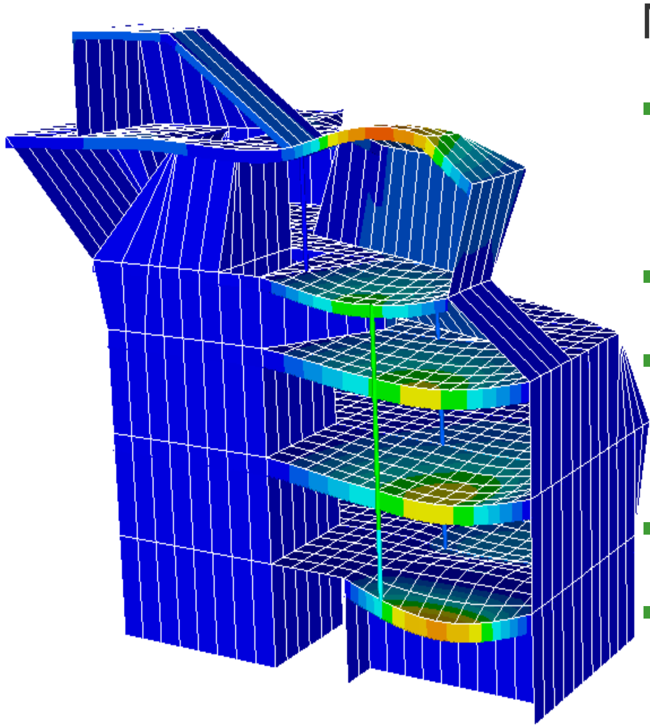




Semi-local FE model



Local Vibration Analysis



Measures to adjust local vibrations:

- Increase plate thickness
- Increase stiffener dimensions
- Reduce stiffener length(by introducing additional girder)
- Increase girder dimensions
- Introduction and/or changing positions of pillars

> Increased stiffness gives higher natural frequency
>
> Increased mass gives lower natural frequency

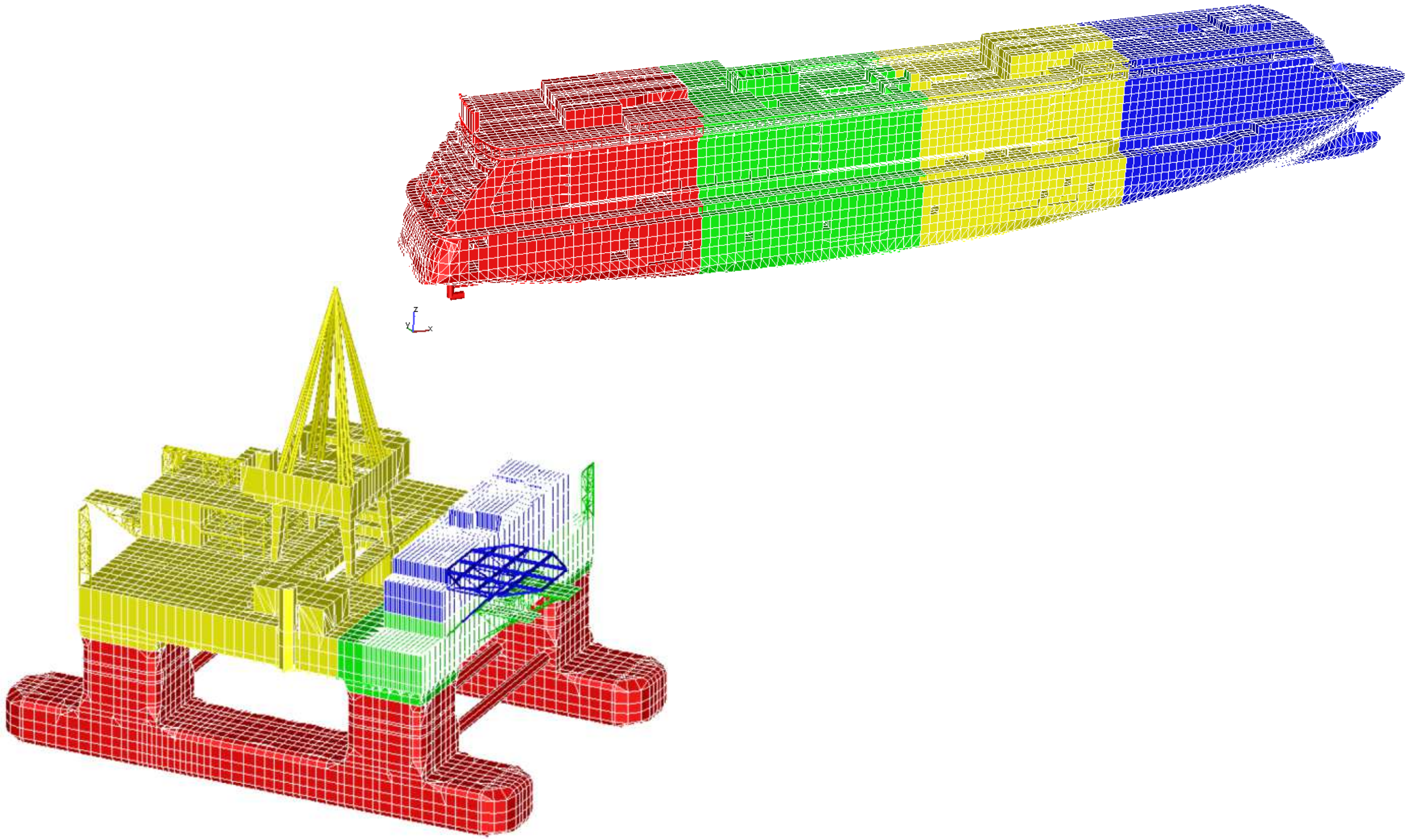
Natural Frequency

$$F = C \cdot \sqrt{\frac{E \cdot I}{m \cdot l^4}}$$

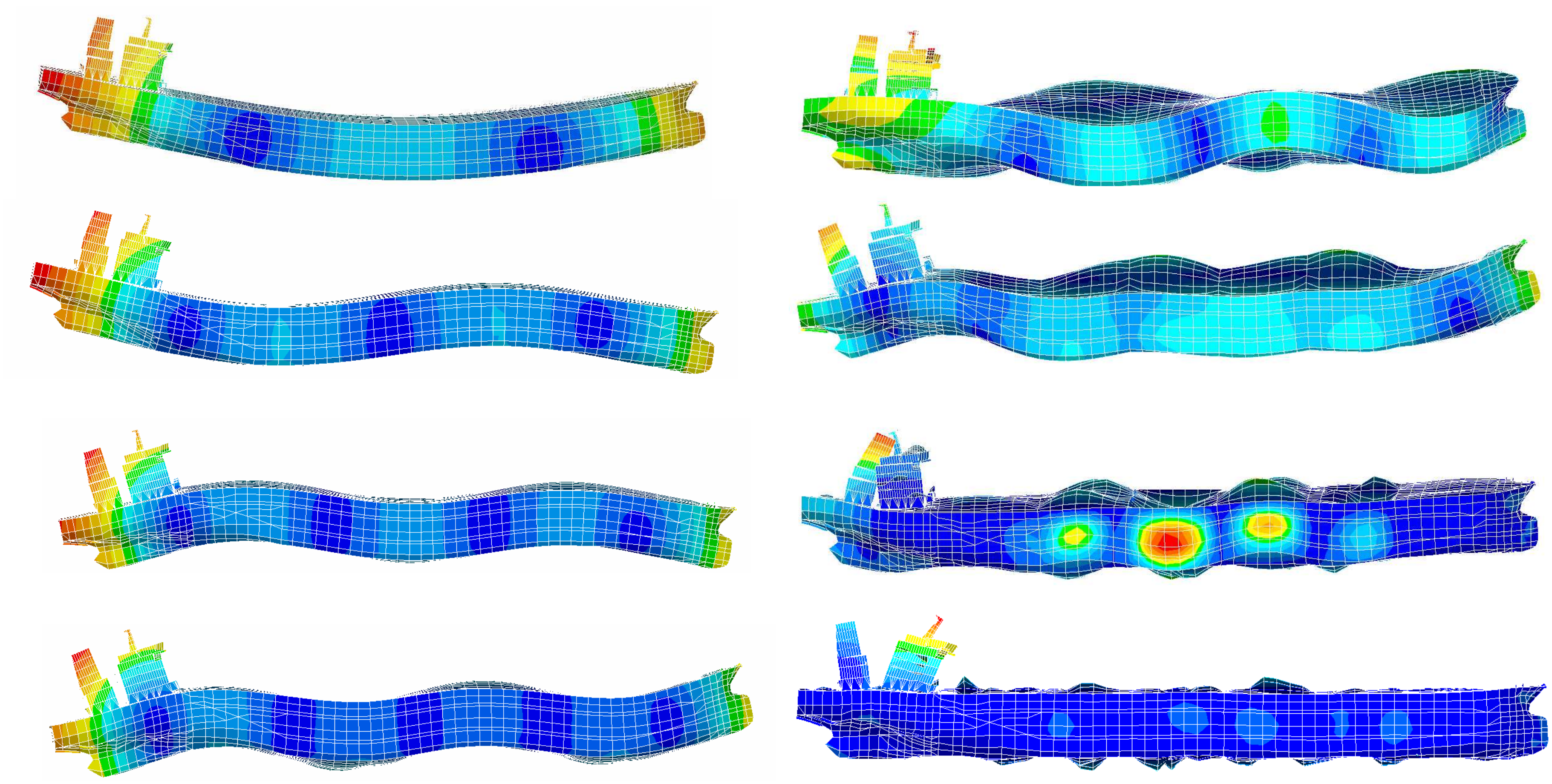
Natural frequency to increase 10%

- Moment of inertia to increase ~ 20%
- Reduce length by ~ 5%

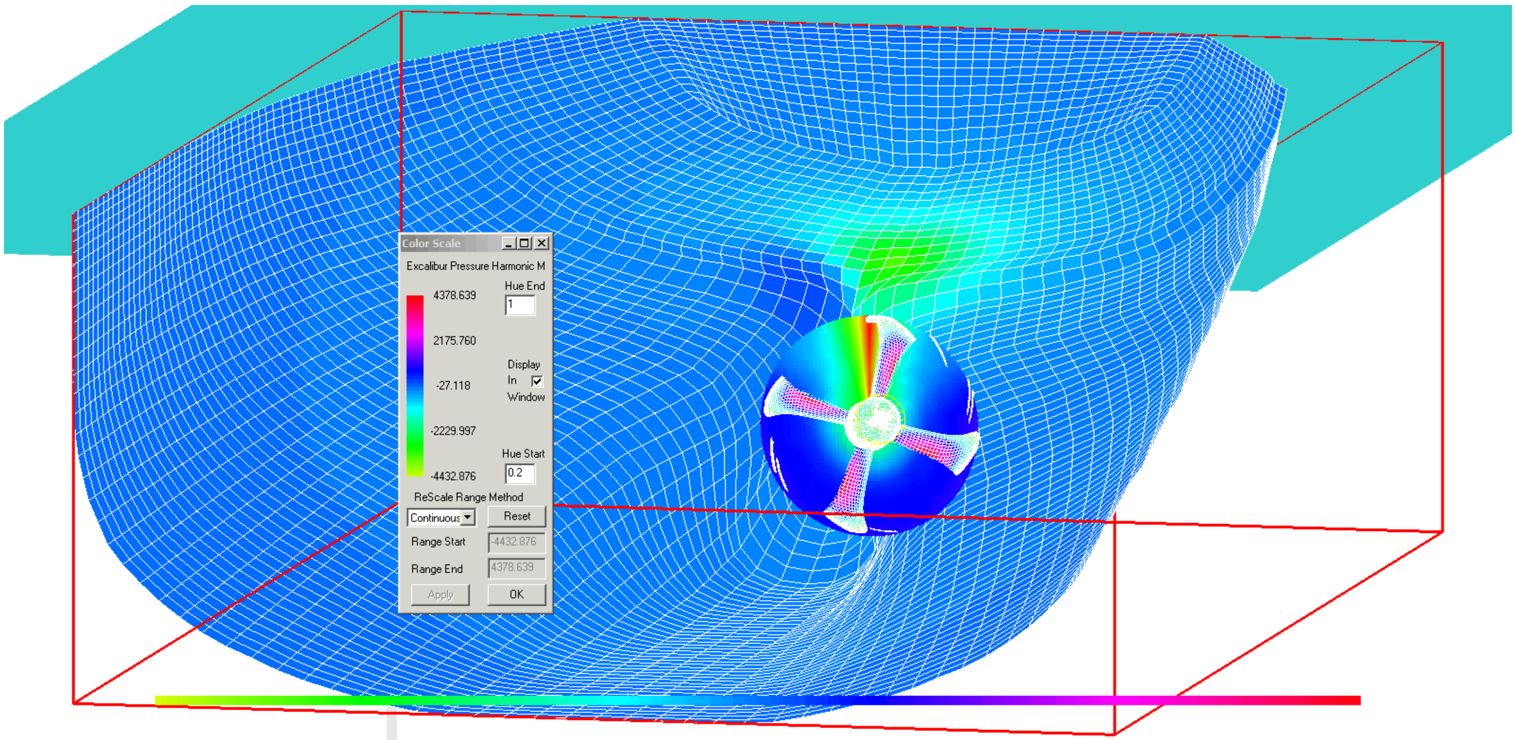
Global Vibration Analysis



Selected vibration modes between 0.4 – 7.9 Hz

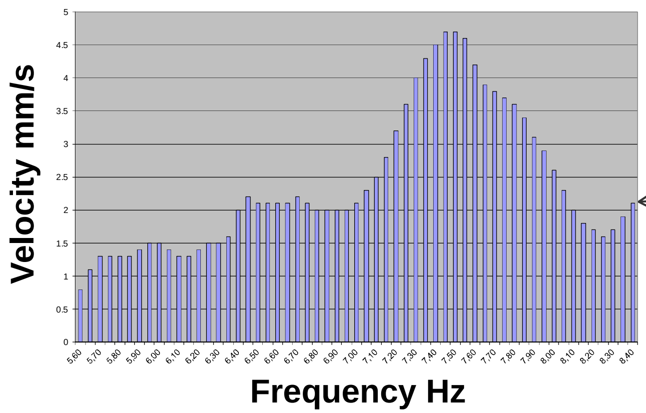


Propeller Excitation

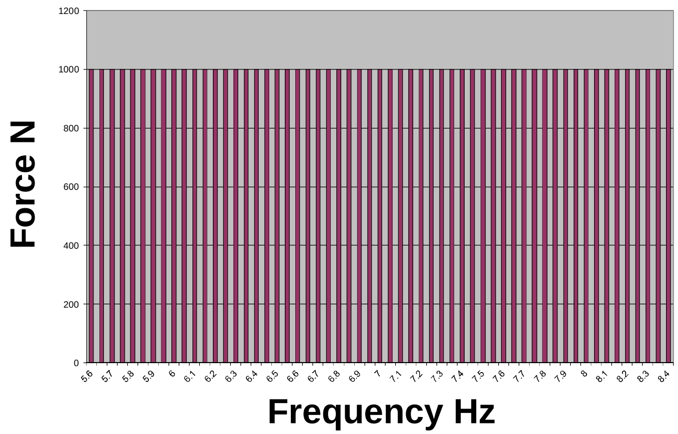


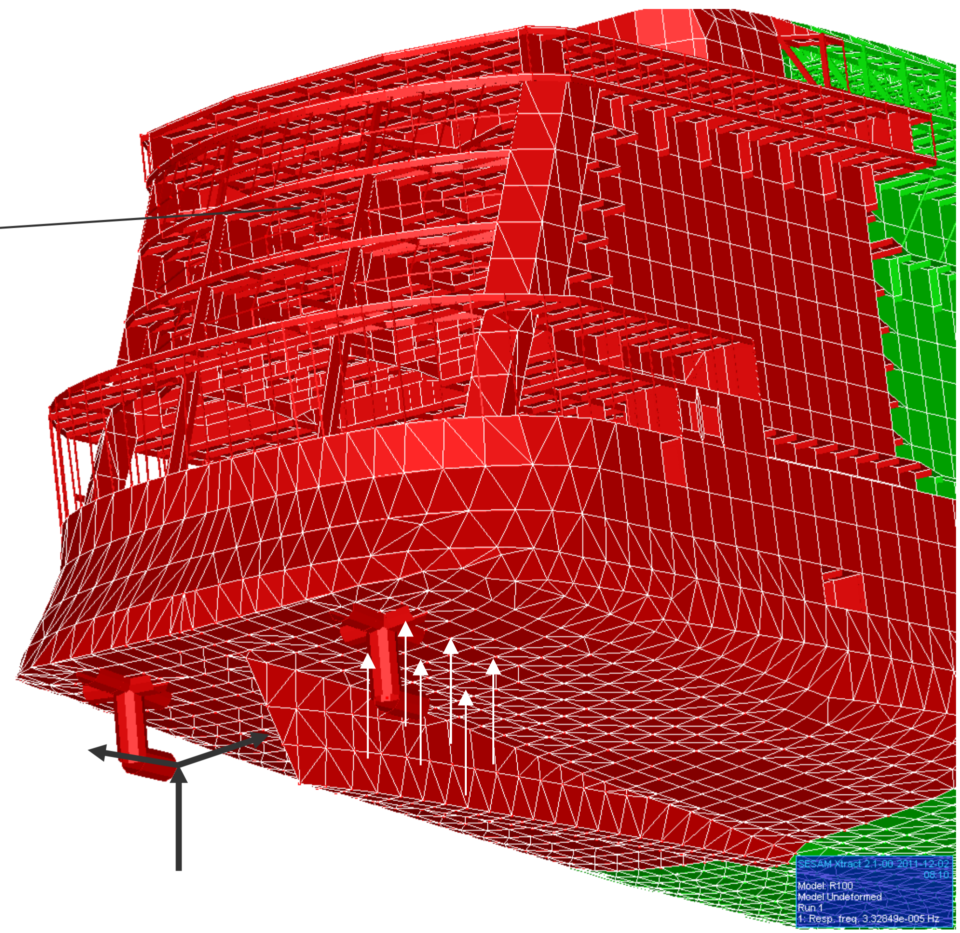
Propeller Excitation

Local vertical

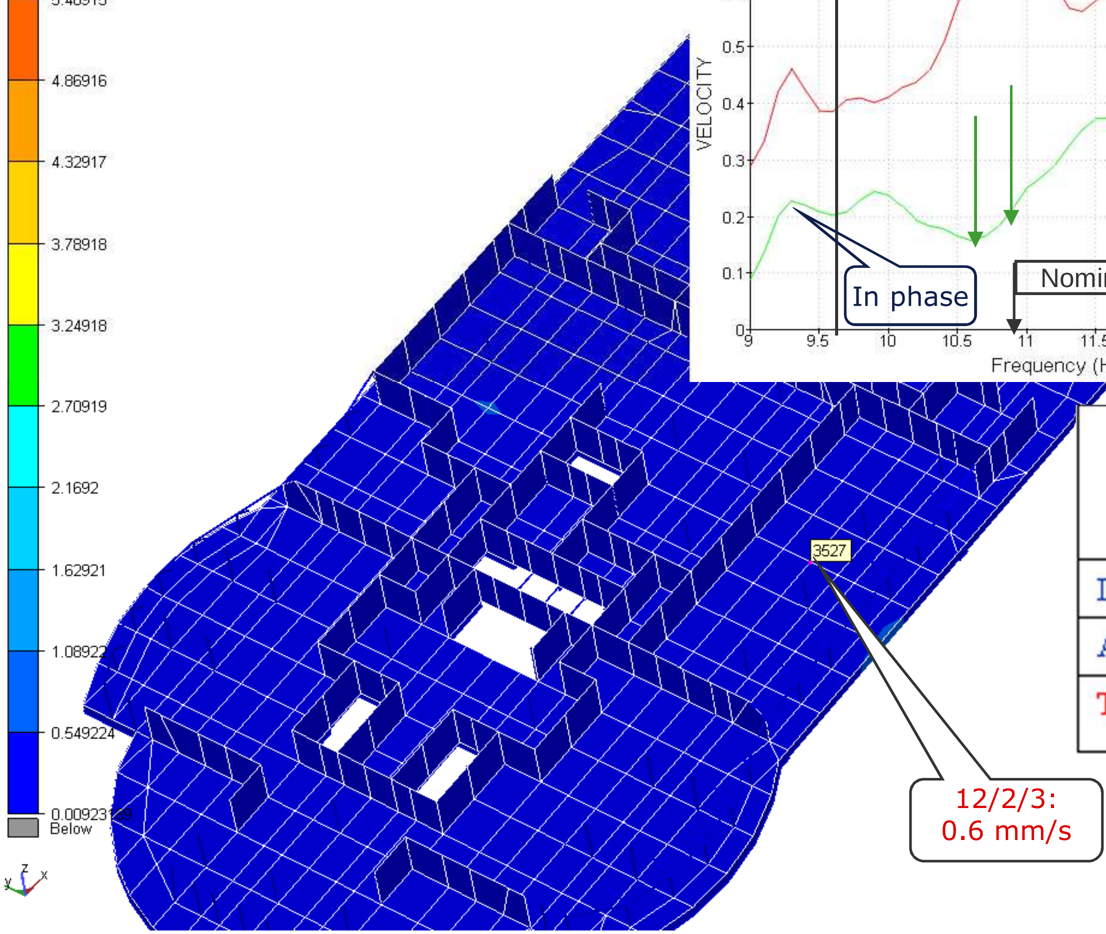


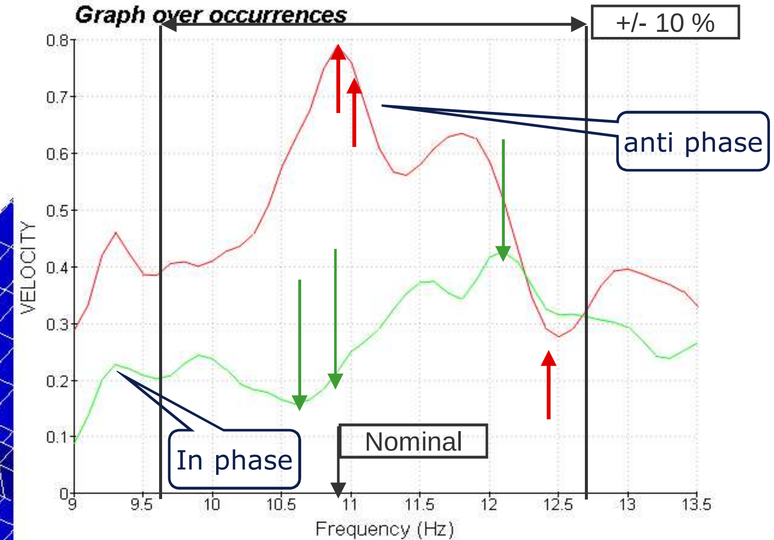
Propeller Forces





Selection of vibration response





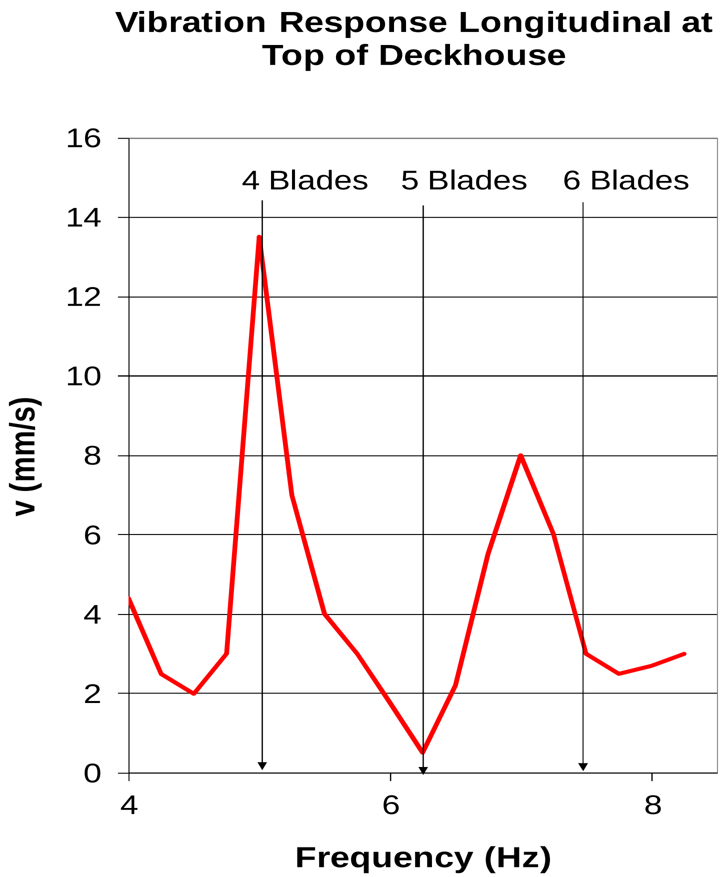
Excitation mode	Velocity mm/s		
	Min.	Nom.	Max.
In phase	0.15	0.20	0.40
Anti phase	0.30	0.70	0.80
Total range	0.15		0.80

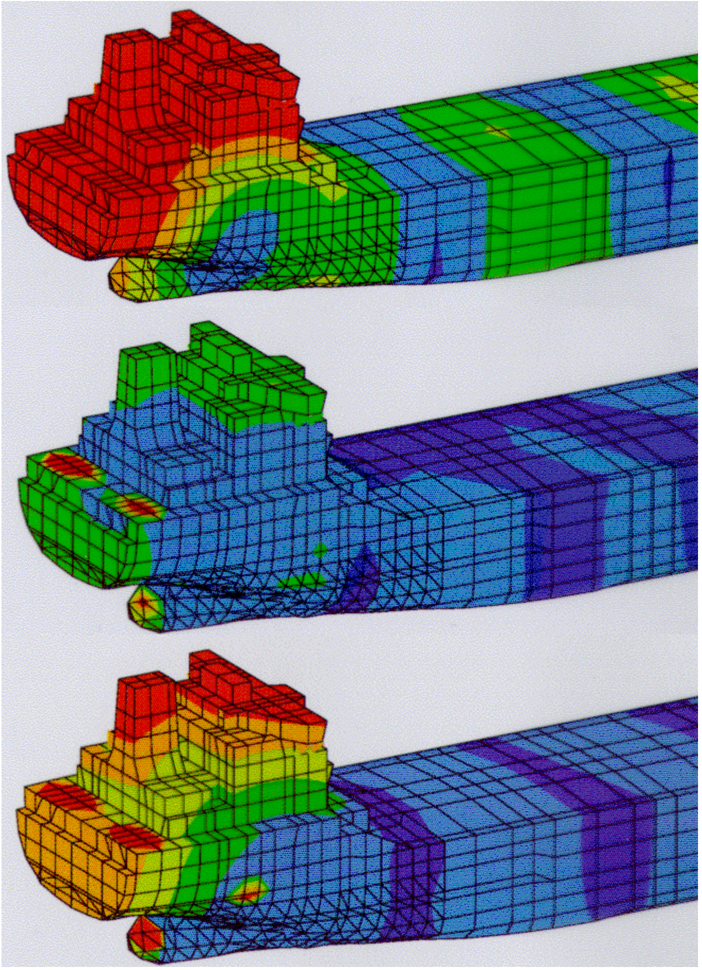
SESAM Xtract 2.0-10 2011-02-24 10:26
Model: R100
Deck 12
Model Undeformed
Run 2, Result case 2
1: Excit. freq. 9 Hz
Nodes VELOCITY ALL
Min: 0.00923189 Max: 5.94914
Complex magnitude

Case: Vibration Analysis of Chemical Tanker

- Chemical tanker designed with 4 bladed propeller
- Global vibration analysis revealed high vibrations with 4 bladed propeller
- 5 and 6bladed propellers were investigated

Case: Vibration Analysis of Chemical Tanker



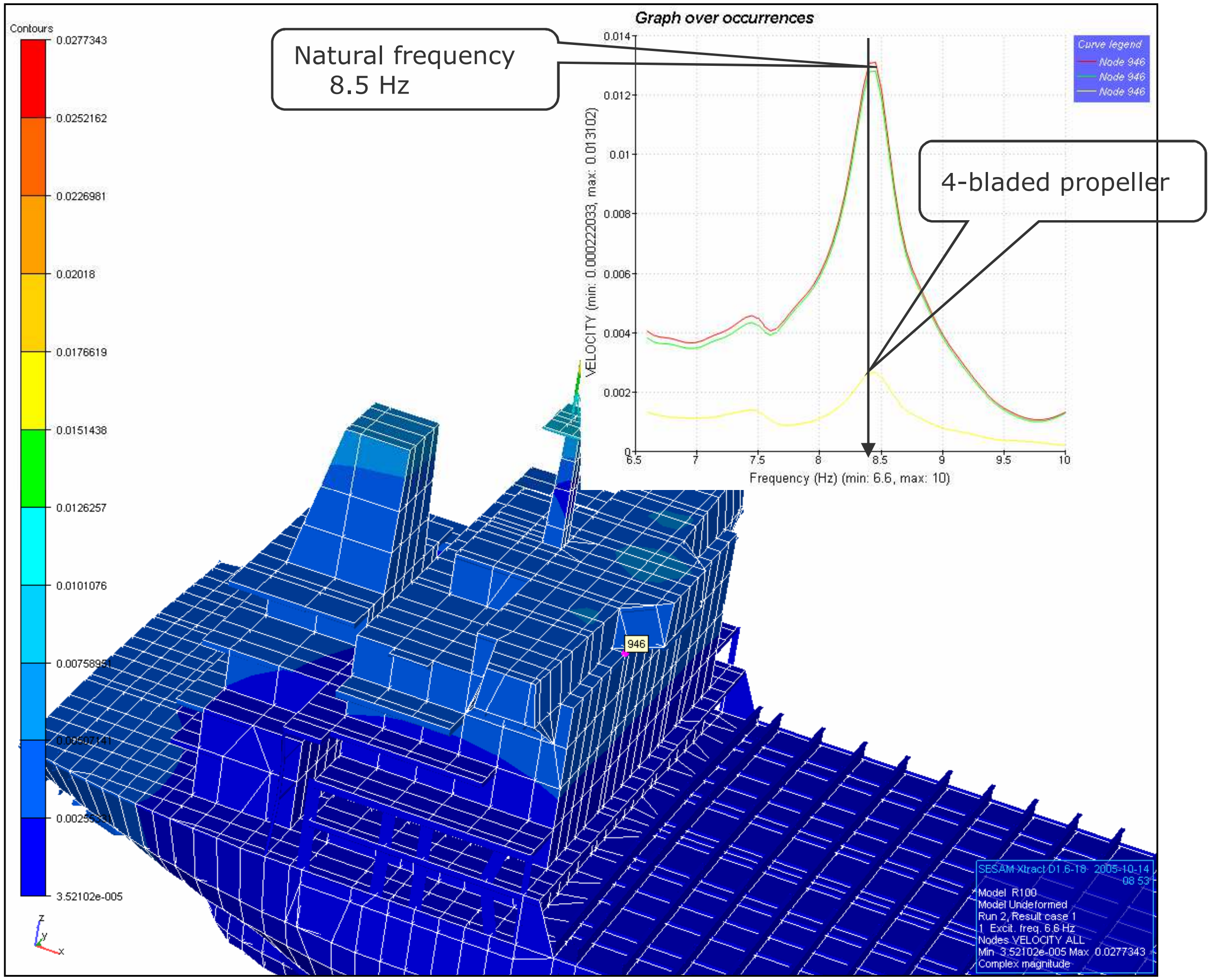


Case: Vibration Analysis of Chemical Tanker

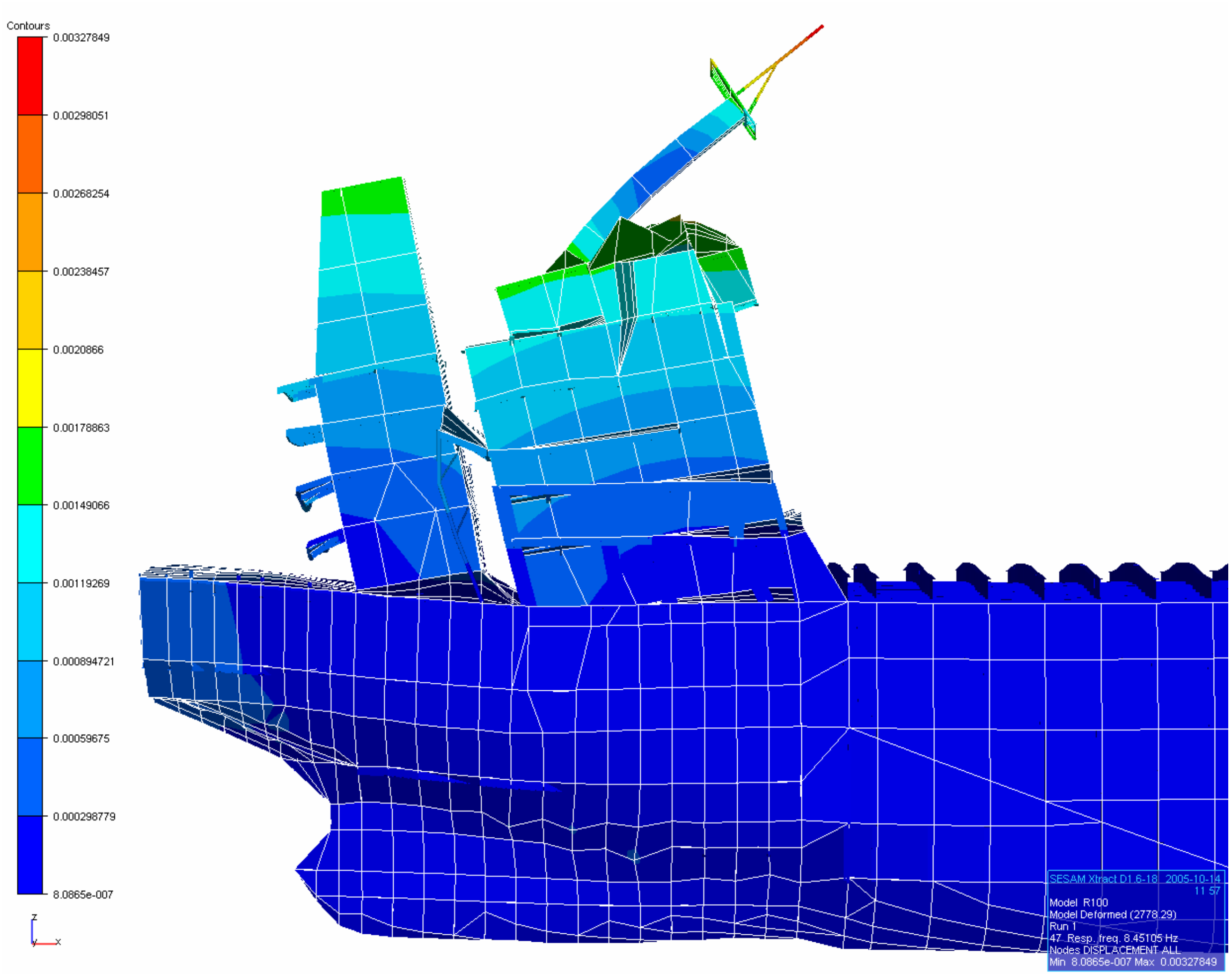
- The main findings of the analyses were:
- The 4-bladed propeller excites a hull girder resonance in the full speed range
- The 5-bladed propeller is favourable.

No. of blades	Predicted vibr. Level	Measured vibr. Level
4	13 mm/s	
5	1 mm/s	1.7 mm/s
6	3 mm/s	

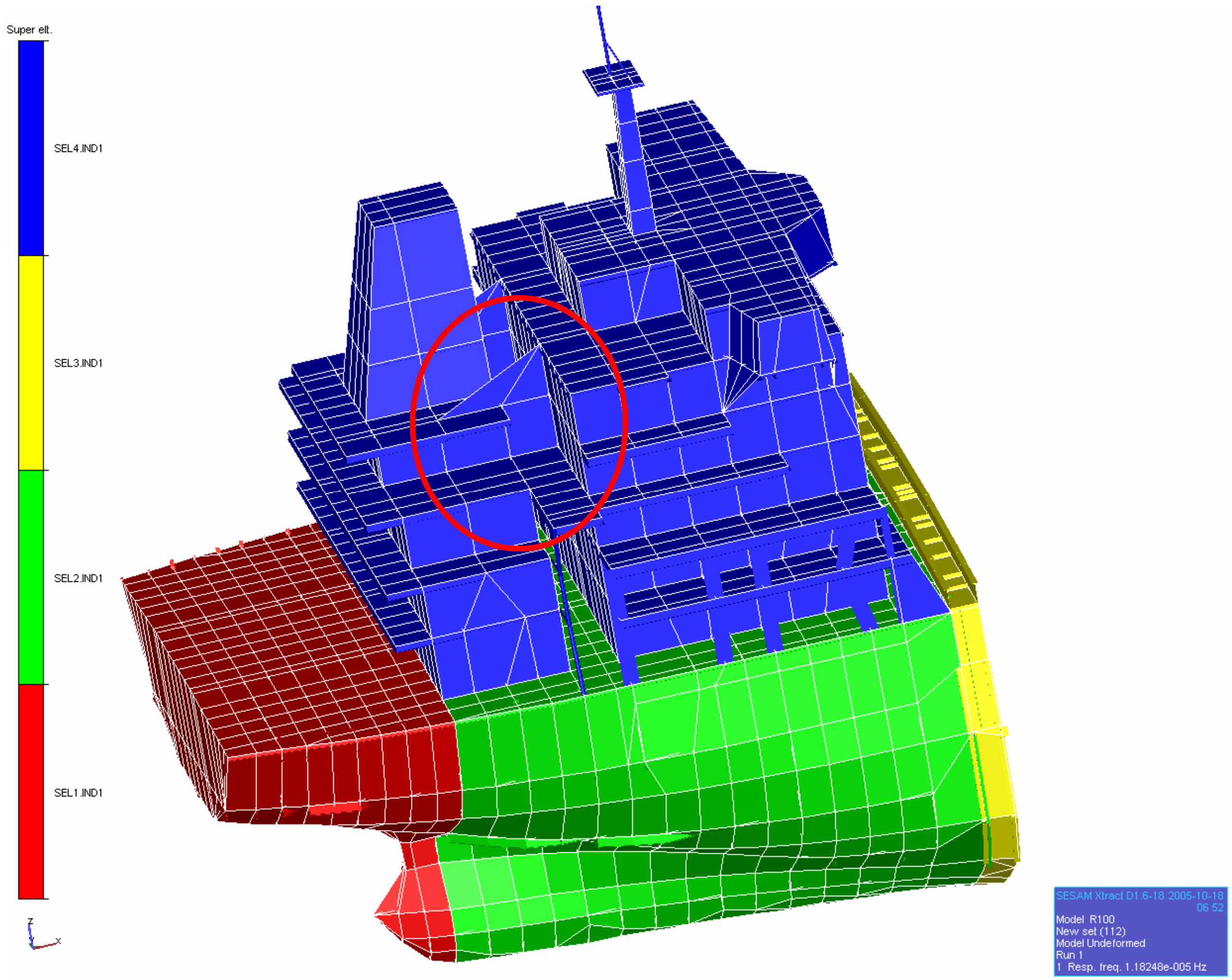
Study of deck house - Tanker



Study of deck house - Tanker

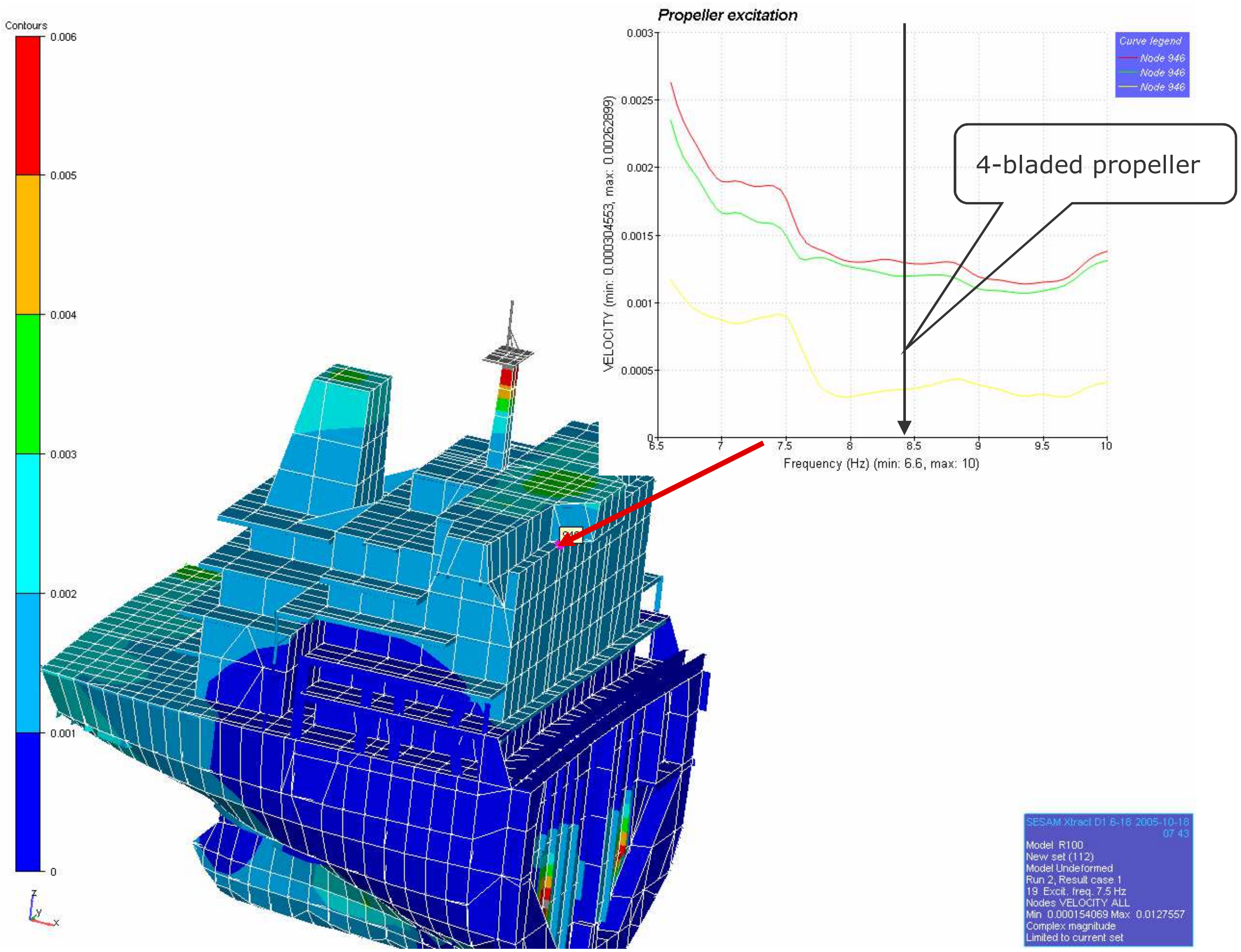


Study of deck house - Tanker



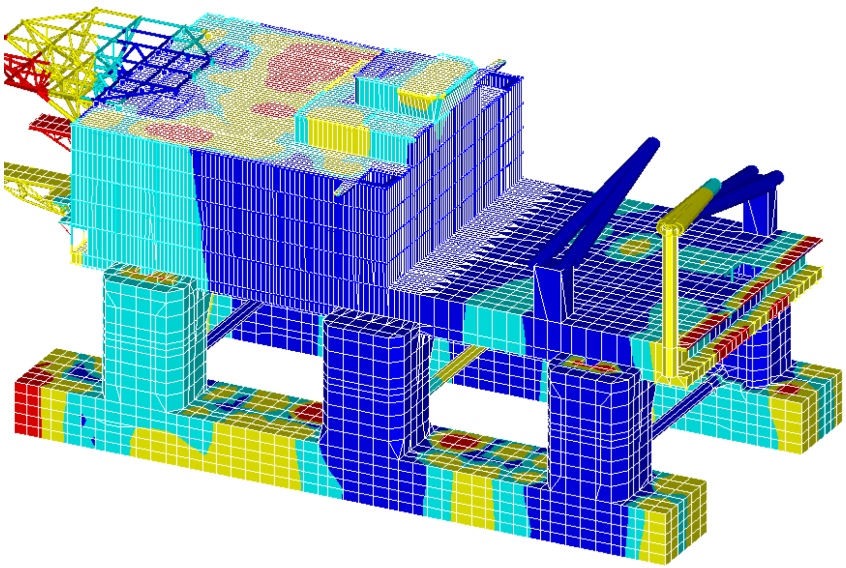
DNV·GL

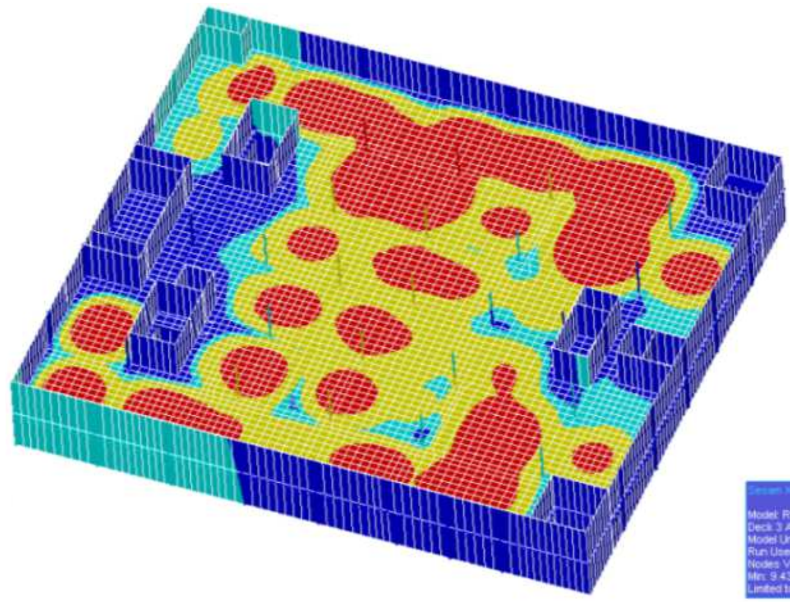
Study of deck house - Tanker



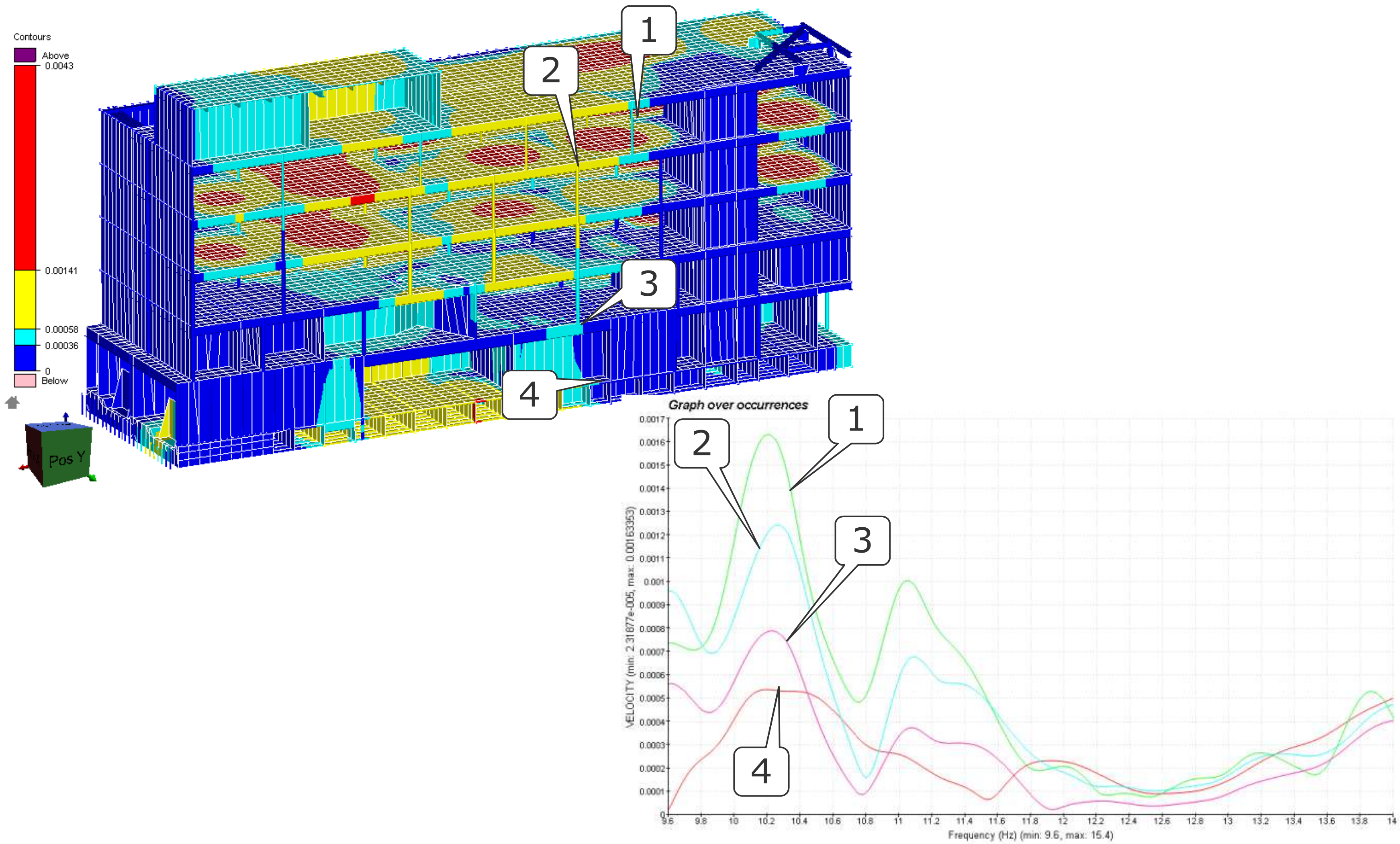
Semi submersible – Global vibration analysis

Scanned maximum vibration level between 9.6 – 13.9 Hz

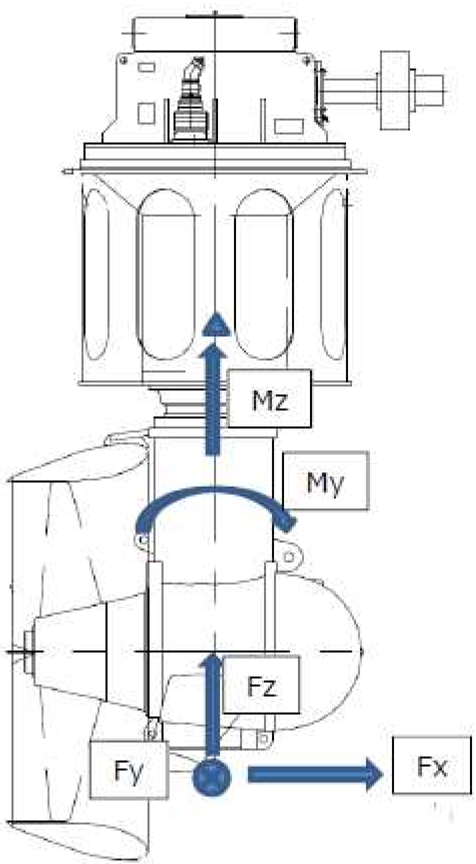


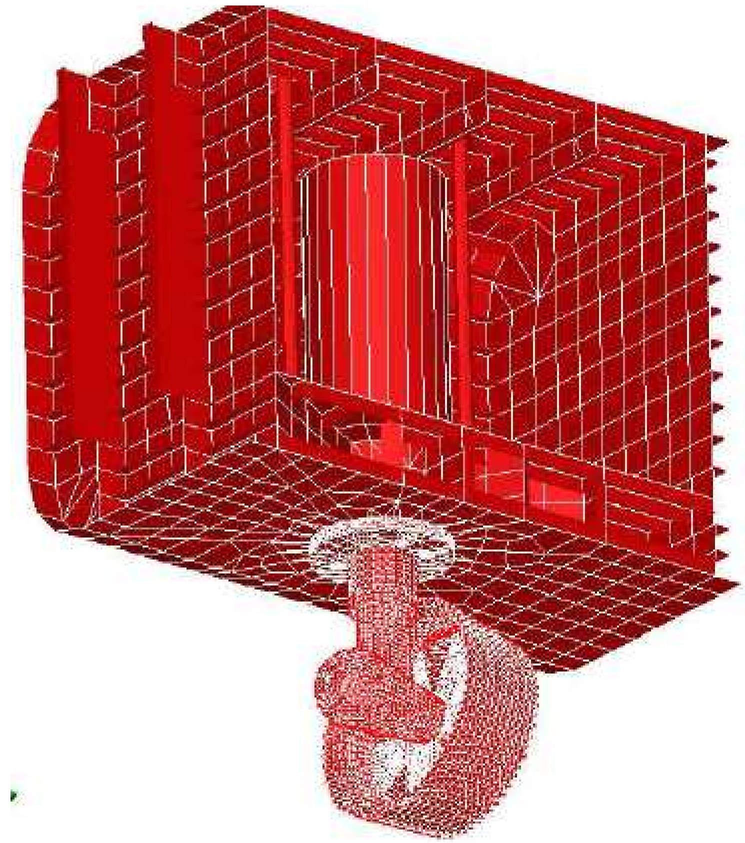


Semi submersible - Study of pillar system

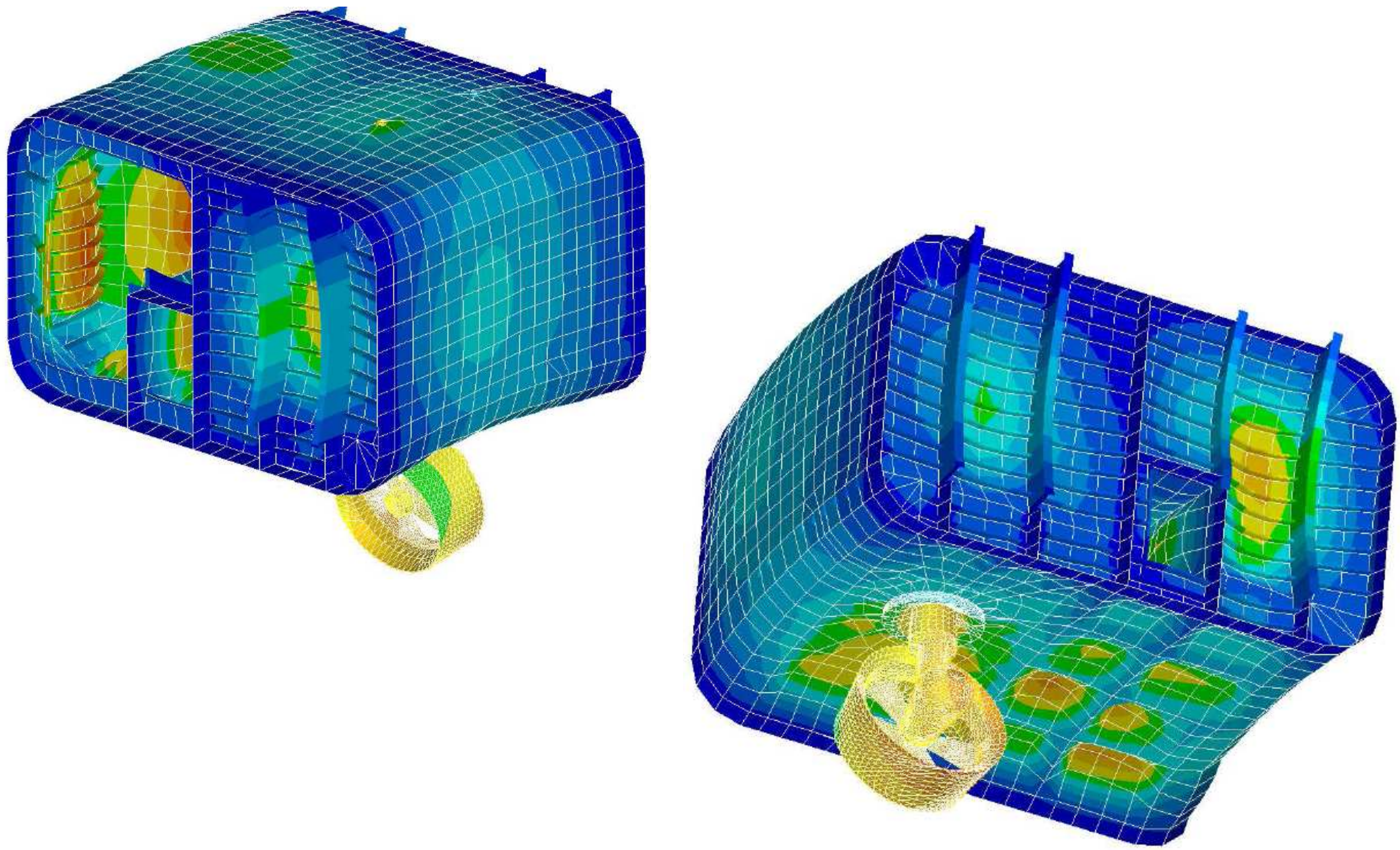


Propeller excitation



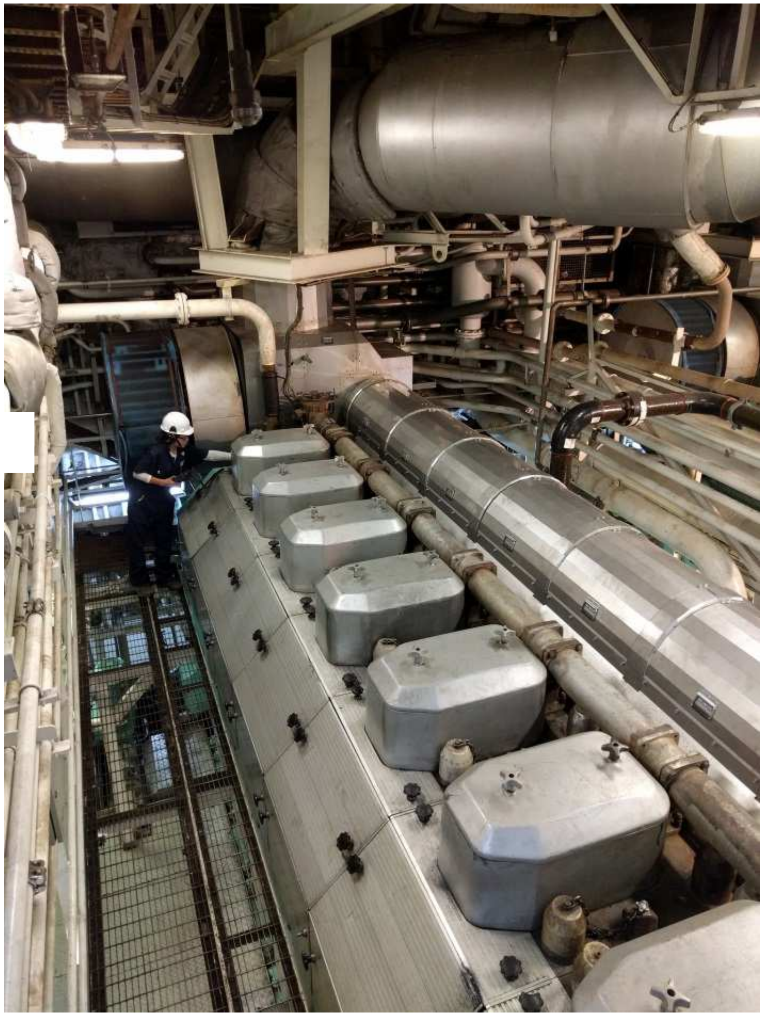


Thruster Foundations - FEA



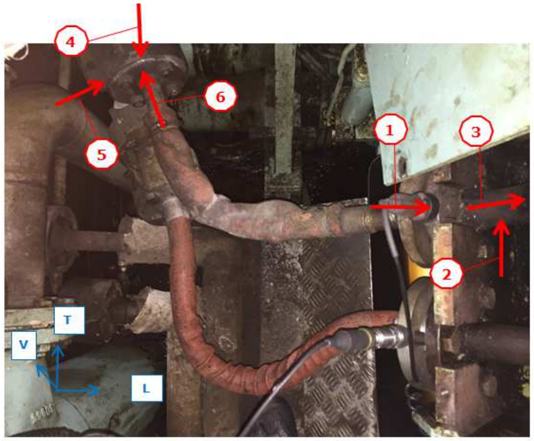
Stage 4 – Noise and vibration measurement VIBRATION

Measurement on Main Generators and Flexible Hoses

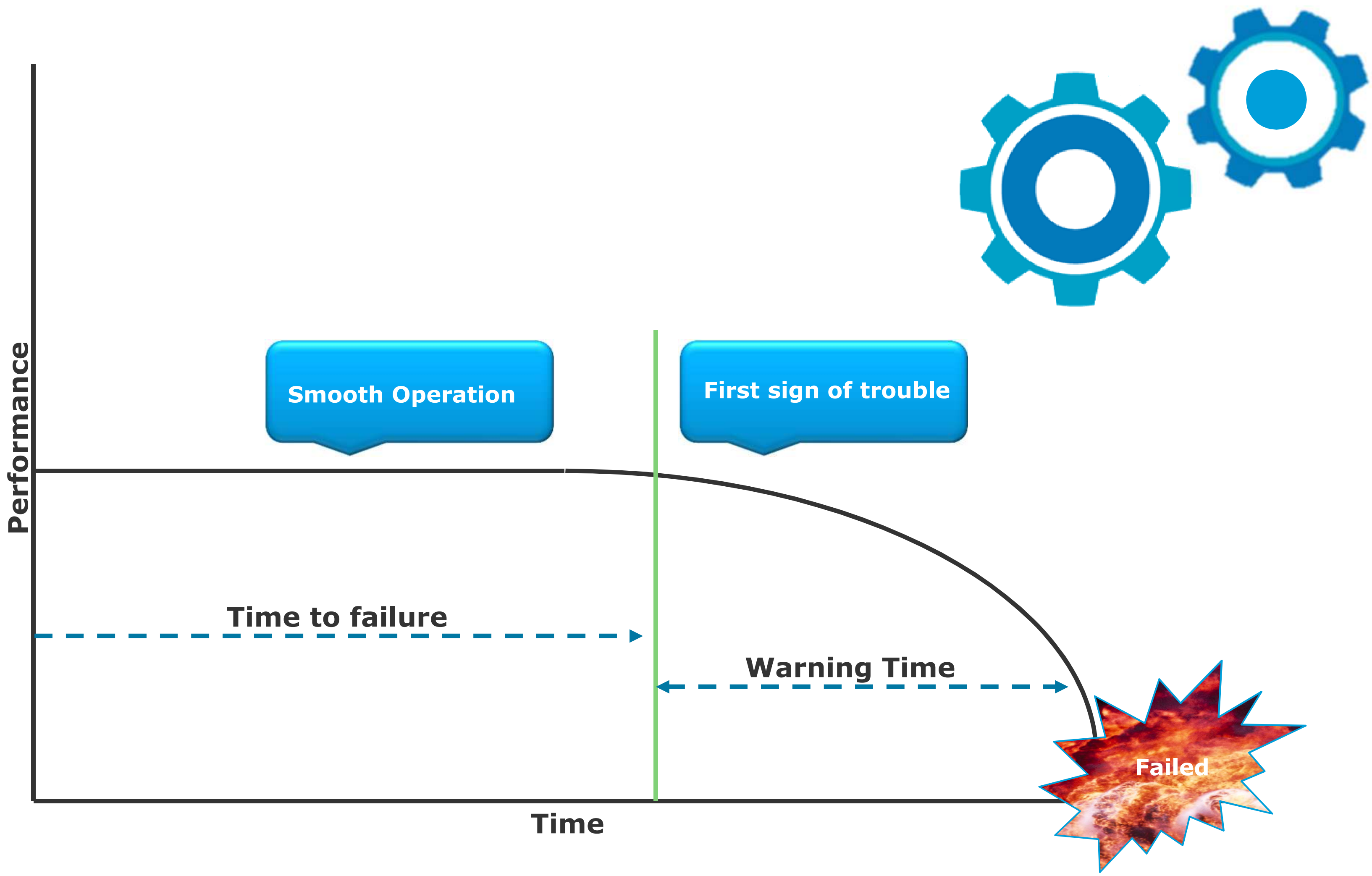


- Consider aligning the flexible hoses, adjusting the length and curvature radius of the hoses

- Consider performing pressure pulsation measurement



Condition Based Monitoring



Reference: Knusten K.E., Manno G., Vartdal B.J.,: 2014: Beyond Condition Monitoring in the Maritime Industry

Purpose of Work

- Reduce unplanned machinery downtime
- Avoid costs associated with sudden failure
- Improve machinery reliability
- Avoid unnecessary intrusive maintenance and use data to make better decisions
- Increase overall efficiency by better channelling time and effort

Vibration Survey and Condition Monitoring for Thrusters

- Vibration measurements are performed quarterly by handheld equipment's
- On thrusters, compressors, main engines/generators, scrubbers and other piping and equipment
- All results are compared to relevant DNV GL criteria
- If excessive vibrations are found, modification proposals will be provided and discussed with crew.

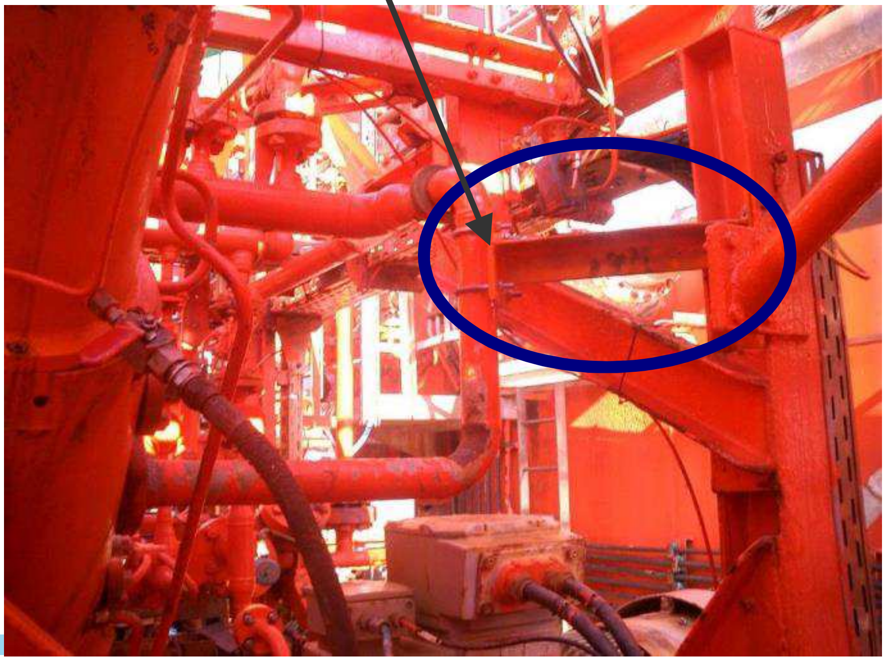
Vibration survey onboard FPSO

After: ~ 30 mm/s

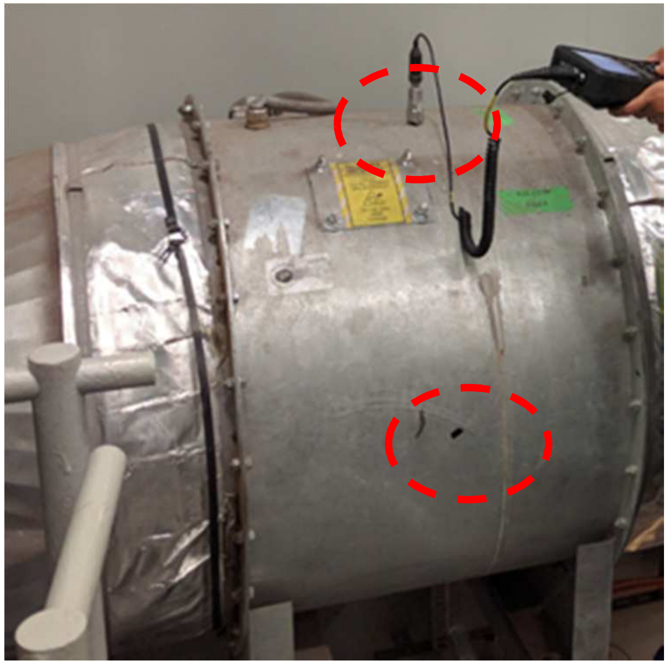
Transverse vibration

Before: ~ 60 mm/s

Modified Pipe Support



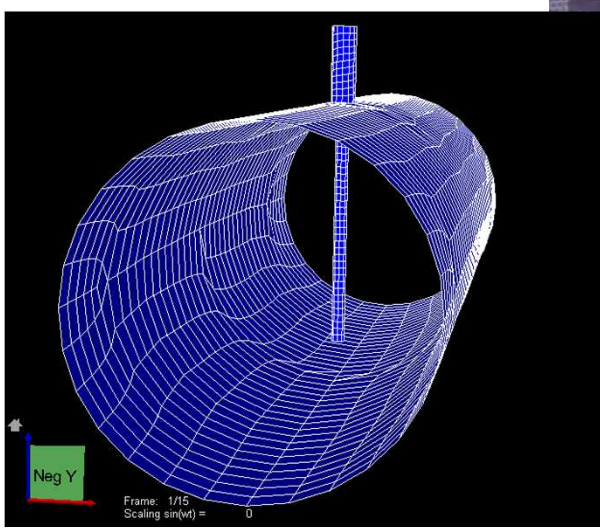
Vibration survey



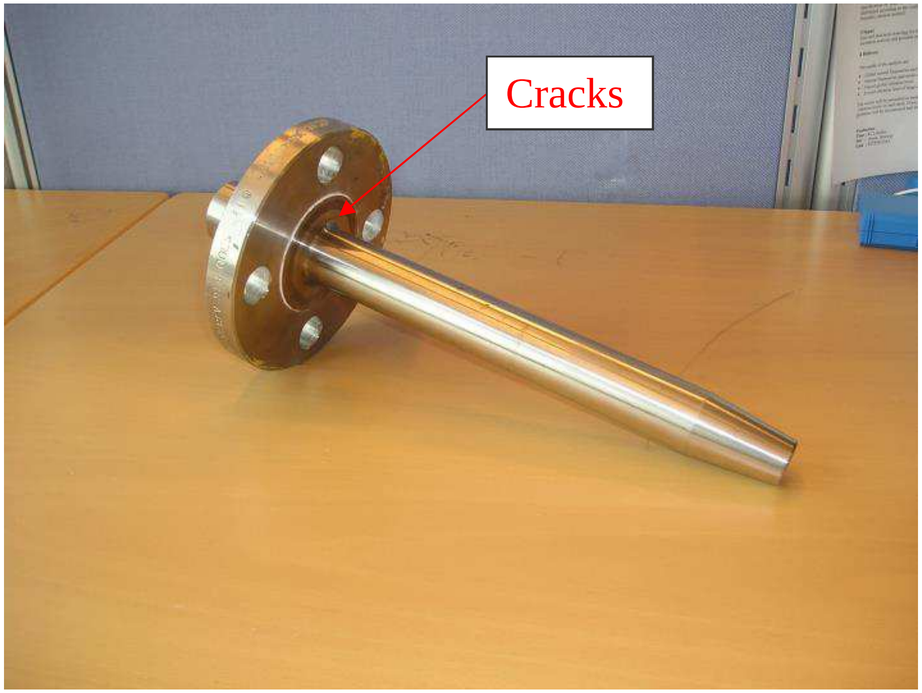
- Measured operating condition
- Measured locations
- Criteria/Alarm set-up
- Result analysis

Thermo-pockets, Vortex Shedding

Vibration level of 22 mm/s, 195 Hz at flange



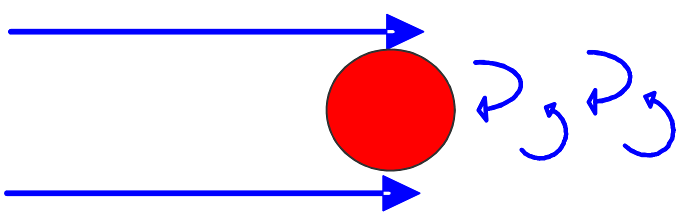
Thermo-pockets, Vortex Shedding



- Vibration level of shaft probably higher than 22 mm/s

- Estimated natural frequency of shaft

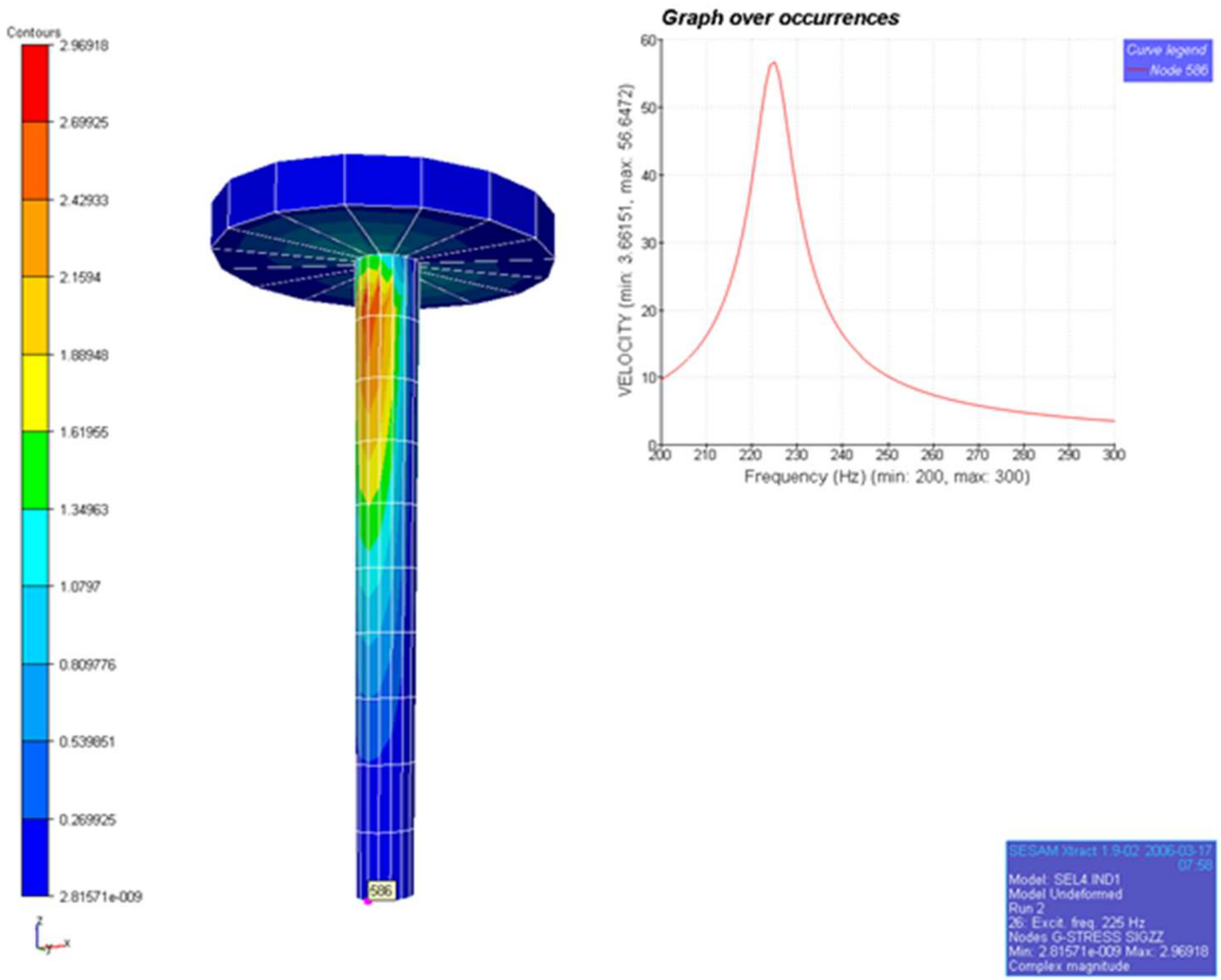
  188 Hz



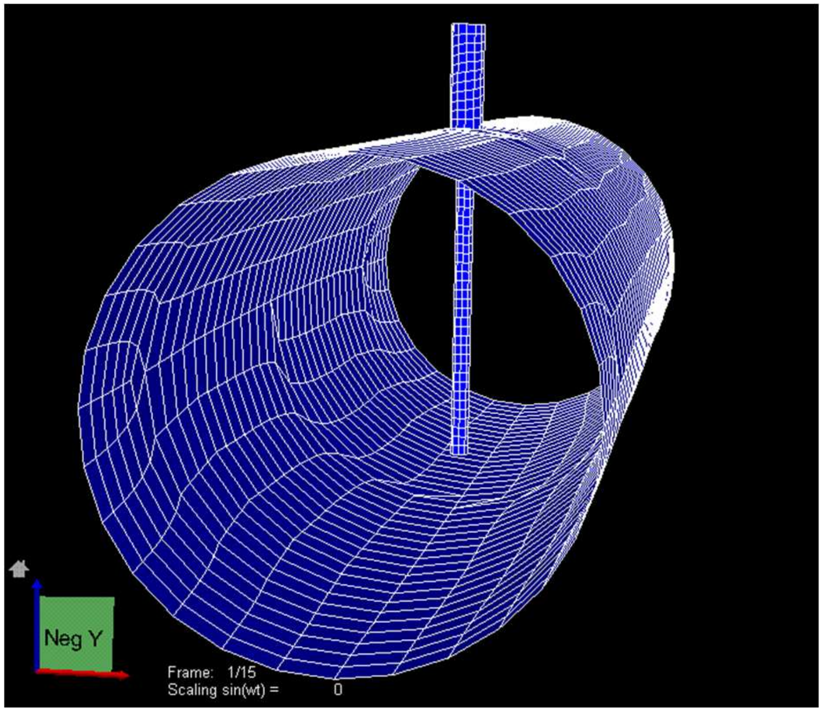
- Estimated vortex shedding frequency

  150 -200 Hz

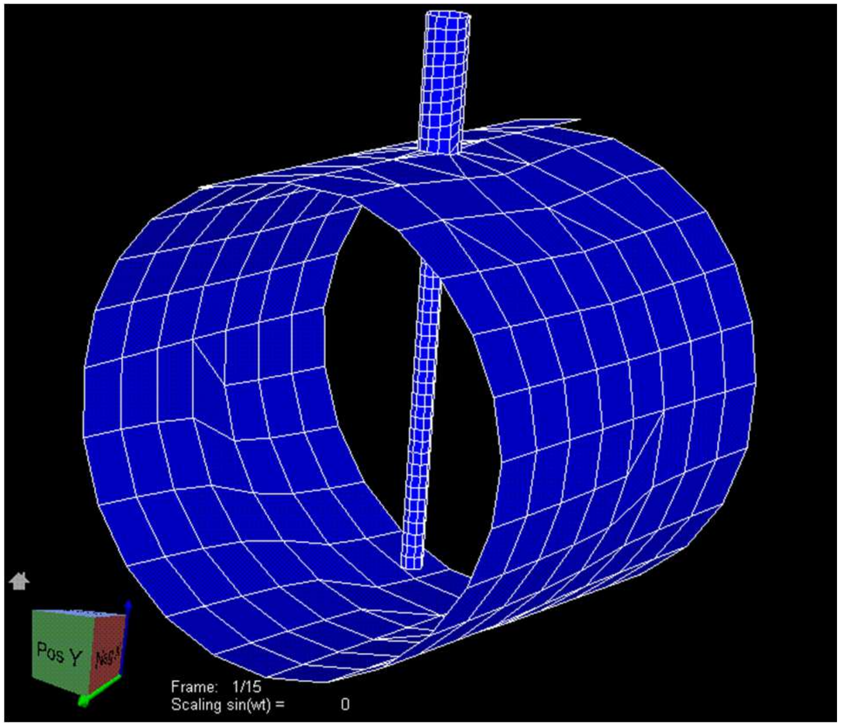
Thermo-pockets



Practical example 1 – Finite element analysis results

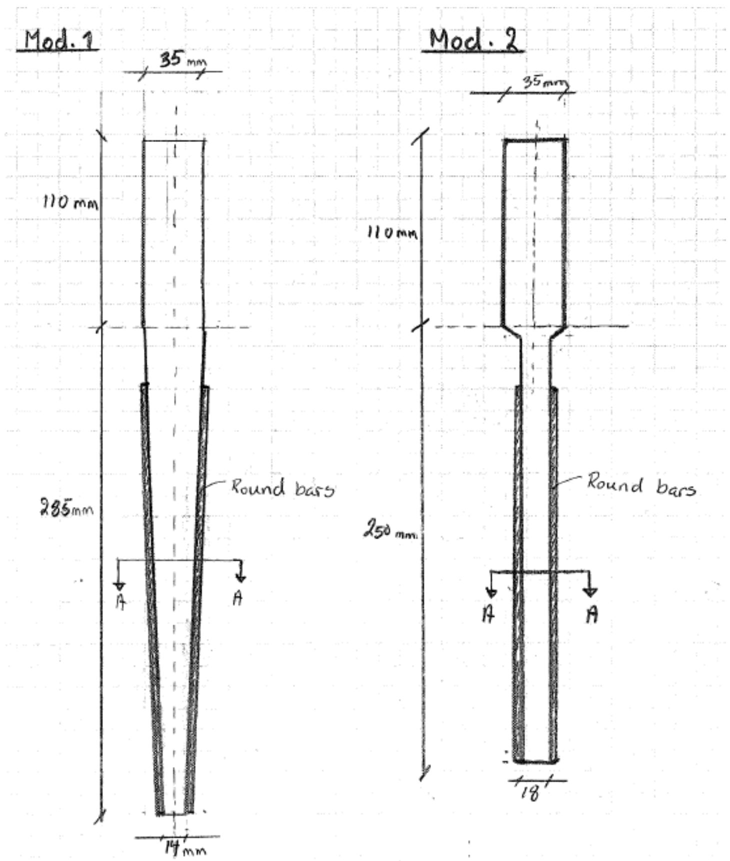


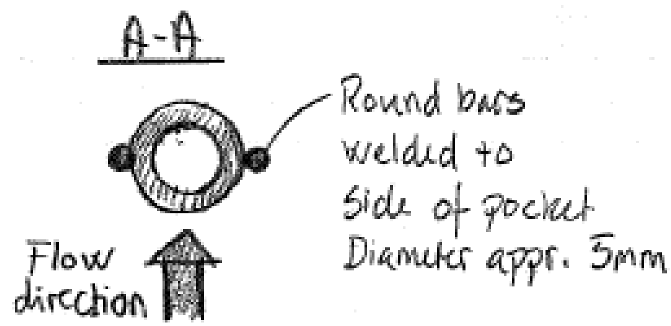
Transverse vibration mode animation, 1st order



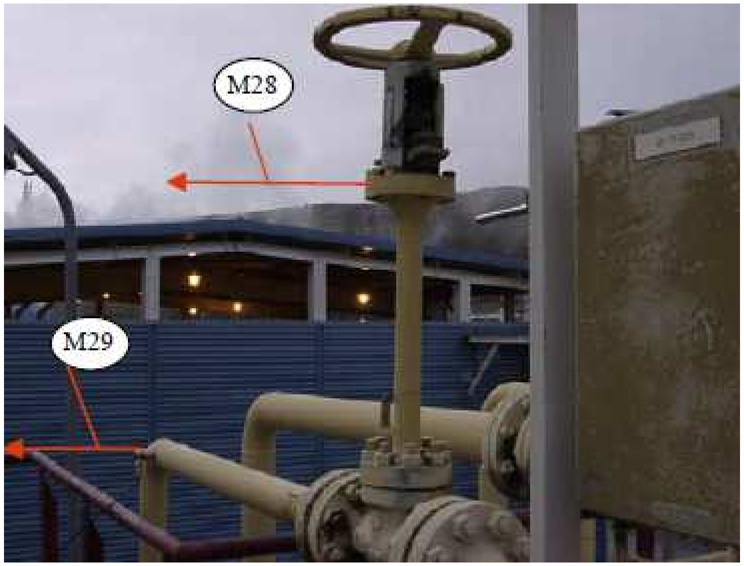
Longitudinal vibration mode animation, 1st order

Practical example 1 – Proposed modifications





Examples of bad small bore connections and supports



The aim of the noise and vibration control efforts

Stage 3 – Noise and vibration analysis

NOISE