Hull Stress Monitoring System (HSMS) / Advisory Monitoring Systems (AMS)

Dr. G. Sagvolden (Light Structures) & Dr. A.E. Jensen (FiReCo)

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Outline

- The Companies Light Structures and FiReCo
- Introduction to Hull Stress Monitoring Systems (Sagvolden)
  - Principles and Enabling technology
  - Application Examples from commercial shipping
- FiReCo Application Examples of the Light Structures Toolbox (Jensen)
  - Fatigue stress recorder
  - Design verification of a 60kn GRP military vessel
  - Operator guidance. Early warning systems
  - Scaled model tests in a towing tank (Marintek)
  - Advisory Monitoring Systems
- Conclusions

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Light Structures AS

Evolved from Norwegian Military project in 2001

Mechanical production in Norway and Korea.

World's leading supplier of fiber optic Hull Stress Monitoring Systems (HSMS)

Approx. 100 solutions implemented on LNGCs, VLCCs, FPSOs, shuttle tankers, container, high-speed and naval vsls

Scientific approach and adaption to individual client needs

Market and application areas

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Light Structures' products are generic and may be applied to monitoring of a wide range of structures

- Ships
- Wind power turbines
- Oil & Gas Offshore
- Infrastructure
- Earthquake integrity
- Aerospace

Customers

DNV MANAGING RISK

HYUNDAI HEAVY INDUSTRIES CO.,LTD.

umoe

OSG Overseas Shipholding Group, Inc.

DSME

Statoil

SAMSUNG

HÖEGH LNG

قطـرللغـاز
QATARGAS

TOTAL

MITSUBISHI HEAVY INDUSTRIES, LTD.

"K" LINE LNG SHIPPING (UK) LTD.

RasGas

TK TEEKAY CORPORATION

FiReCo AS

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8 Employees (2 Ph.D, 5 M.Sc. and 1 personal assistant).

- Marine Engineering and Naval Architects, Mechanical Engineering, and Civil Engineering.

20 years of experience in:

- FEM analyses of large load carrying structures made of FRP composite materials and/or metals.

  (E.g. Marine vessels, Offshore and seismology structures, Wave- and wind power installations, Bridges, and Vehicles)
- Material testing, characterisation, and qualification
- Evaluation and determination of design parameters for structural design
- Third-party verifications
- Fire protection and fire resistant of composite and metal structures
- International R&D programs like: Euclid, Thales, Agard, Bondship,....
- Class rules development (in cooperation with DNV)

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FiReCo AS - Typical projects

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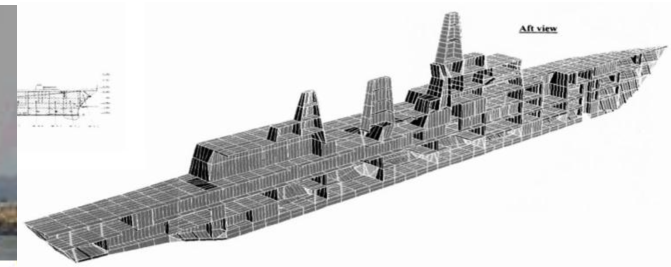
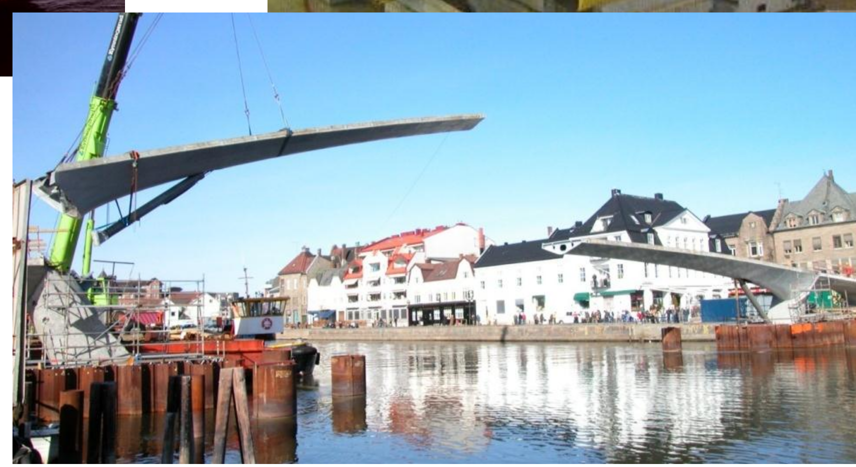
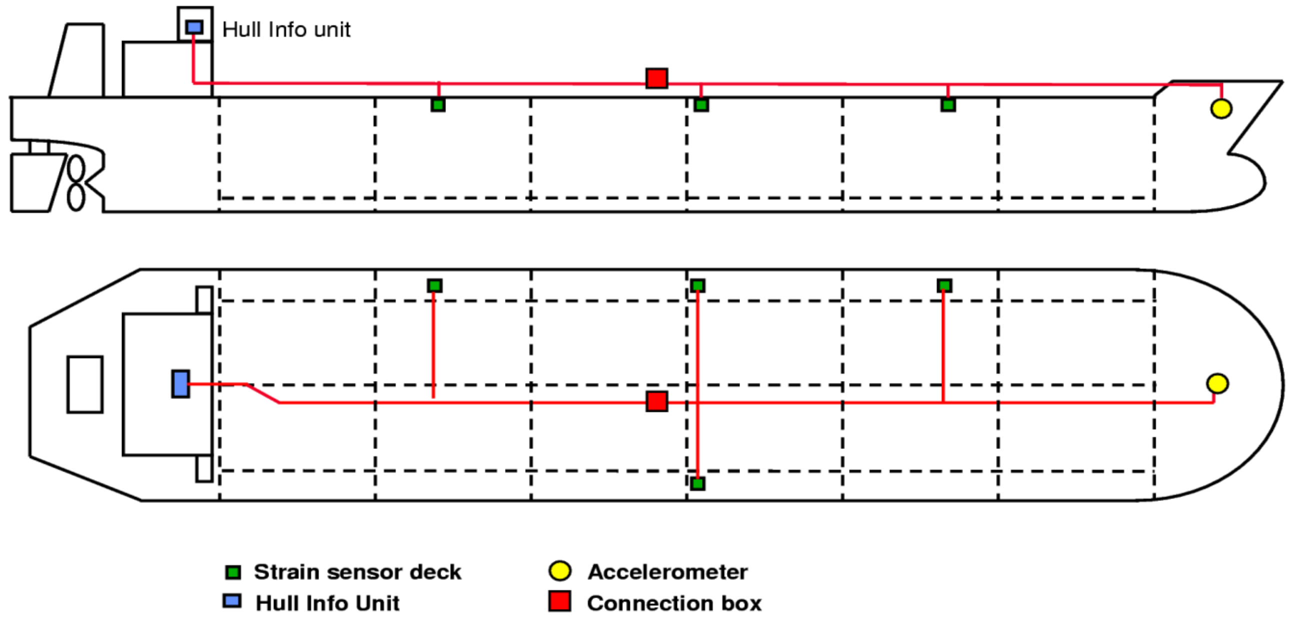


Standard minimum arrangement



HMON ShipRight SEA HM MON-HULL

Overload warning

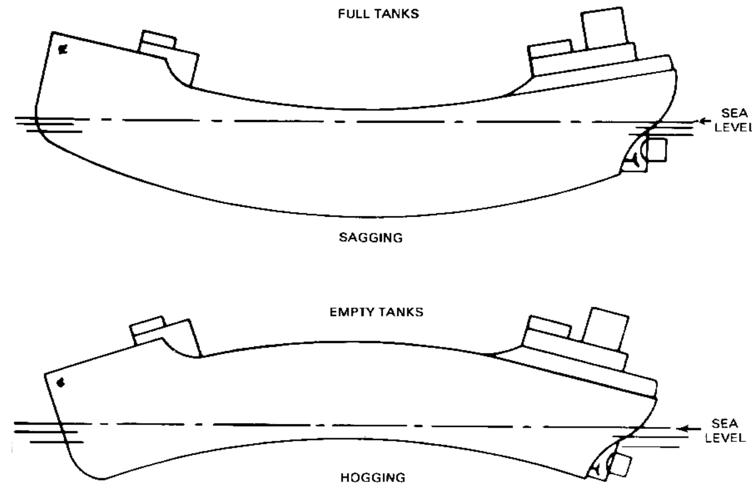
Std arrangement: hull vertical bending moment (VBM)

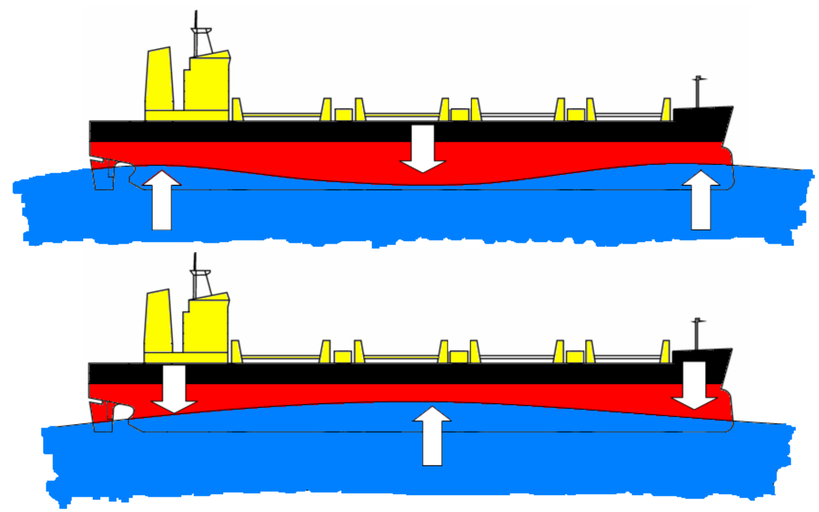
Overload from Cargo and Ballast operations

Wave-induced overload

Unexpected loads from major damage/water ingress

... Quite rare events





Fatigue management

HSMS follows every hull load cycle

Processed to calculate:

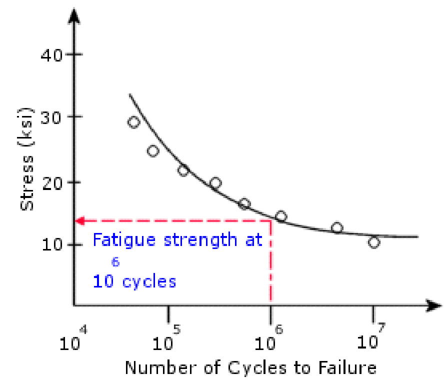
- fatigue accumulation rate

- total accumulation so far

Pinpoint causes

Promote operational awareness

Minor adjustment – major gain



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Fiber Optic Sensor Systems

Direct strain measurement

Low noise: No EMI/EMC

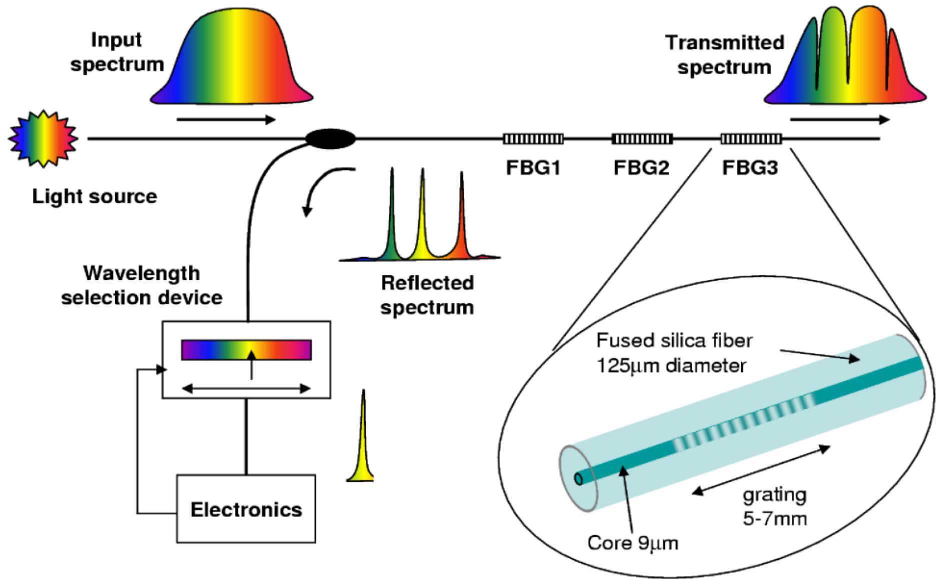
Intrinsically EX safe

Multiplex

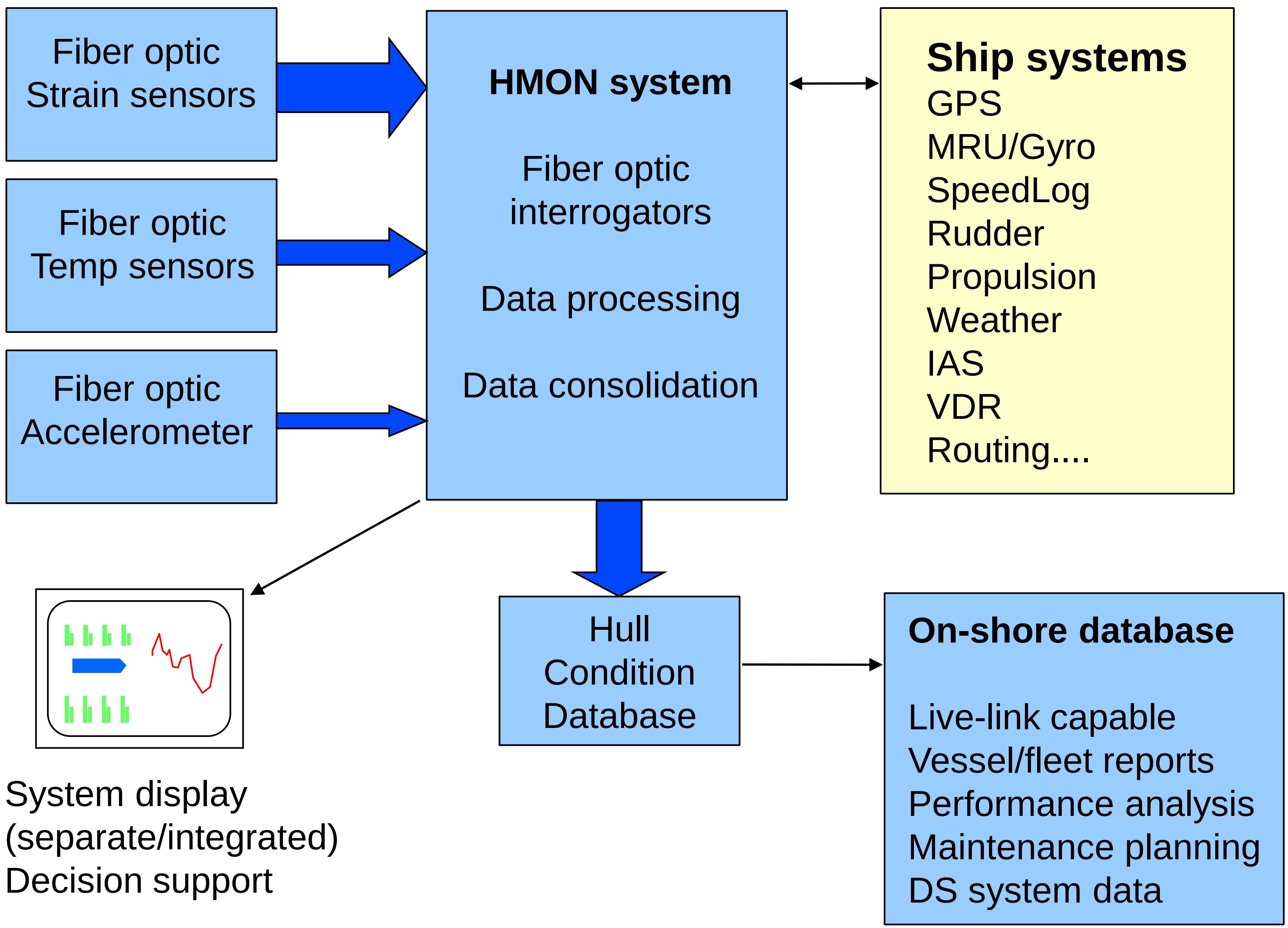
Long life

Cold environments

Flexible placement (WBTs / Containment systems etc)



System data flow



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Onshore reports – Voyage reports

Document hull condition in fleet

Identify cost in terms of hull lifetime for any voyage/trade/vessel

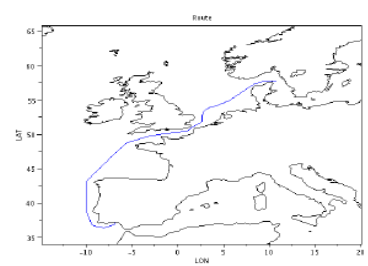
Identify overloading events

Identify vibration-driven fatigue

Keep track of vessel corrective actions to adverse weather

EXAMPLE -- SENSFIB VISTA VOYAGE REPORT

Vessel	M/V Testcase		
Voyage ID	27		
Start Date	2009/12/05 19:30		
Start Position	<Voyage start pos>		
End Date	2009/12/20 09:00		
End Position	<Voyage end pos>		
Duration	14.5 days		
Loading condition	BALLASTED		
Draft	N/A		
GM	N/A		
Shear Forces	N/A		
Bending Moment (1/4L, 1/2L, 3/4L)	236109.3	336415.3	138763.7
Mean Speed Over Ground (kn)	13.4		
Mean Significant Waveheight	3.8		
Fatigue accumulation rates	Total	Wave	Vibration %
GS 1 (Deck 1/4L Port)	0.006	0.002	64.7 pct
GS2 (Deck 1/2L Port)	0.778	0.481	38.2 pct
GS3 (Deck 3/4L Port)	0.109	0.063	42.5 pct
GS4 (Deck 1/2L Stbd)	0.880	0.565	35.8 pct
LS5	0.101	0.074	26.0 pct
LS6	0.058	0.036	38.3 pct
LS7	0.103	0.078	24.1 pct
LS8	0.060	0.038	36.1 pct
Midships fatigue life cost (days)	12.01		
Vibration fatigue life cost (days)	4.43		



EXAMPLE - Note that report format will be tailored according to information available on vessel

LIGHT STRUCTURES

Document no:

Project:

Author:

Approved:

Date:

INTERNAL/CONF

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Hasleveien 38, entr. 6
NO-0571 OSLO, Norway
Tel: (+47) 23 89 71 33
Fax: (+47) 22 37 13 28
www.lightstructures.biz

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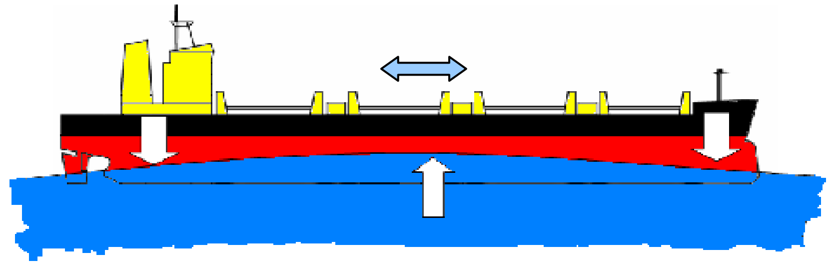
Linear Structural Response Models

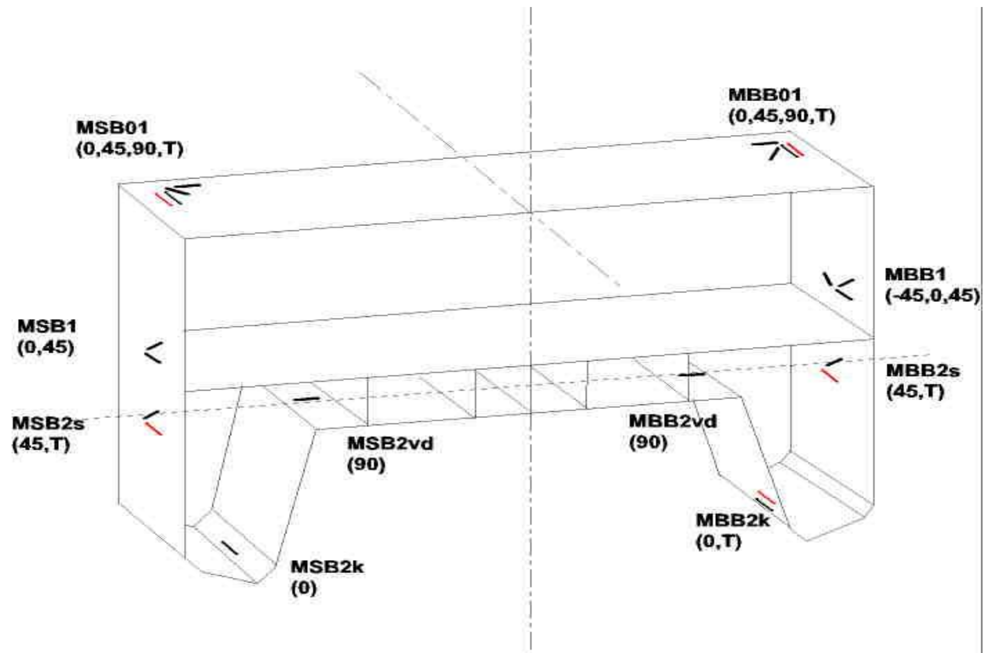
Calc. Loads

Meas. Strains

$$\vec{F} = K^{-1}\vec{E}$$

Response factors from FE models or Calibration





Installation on Bulk Carriers

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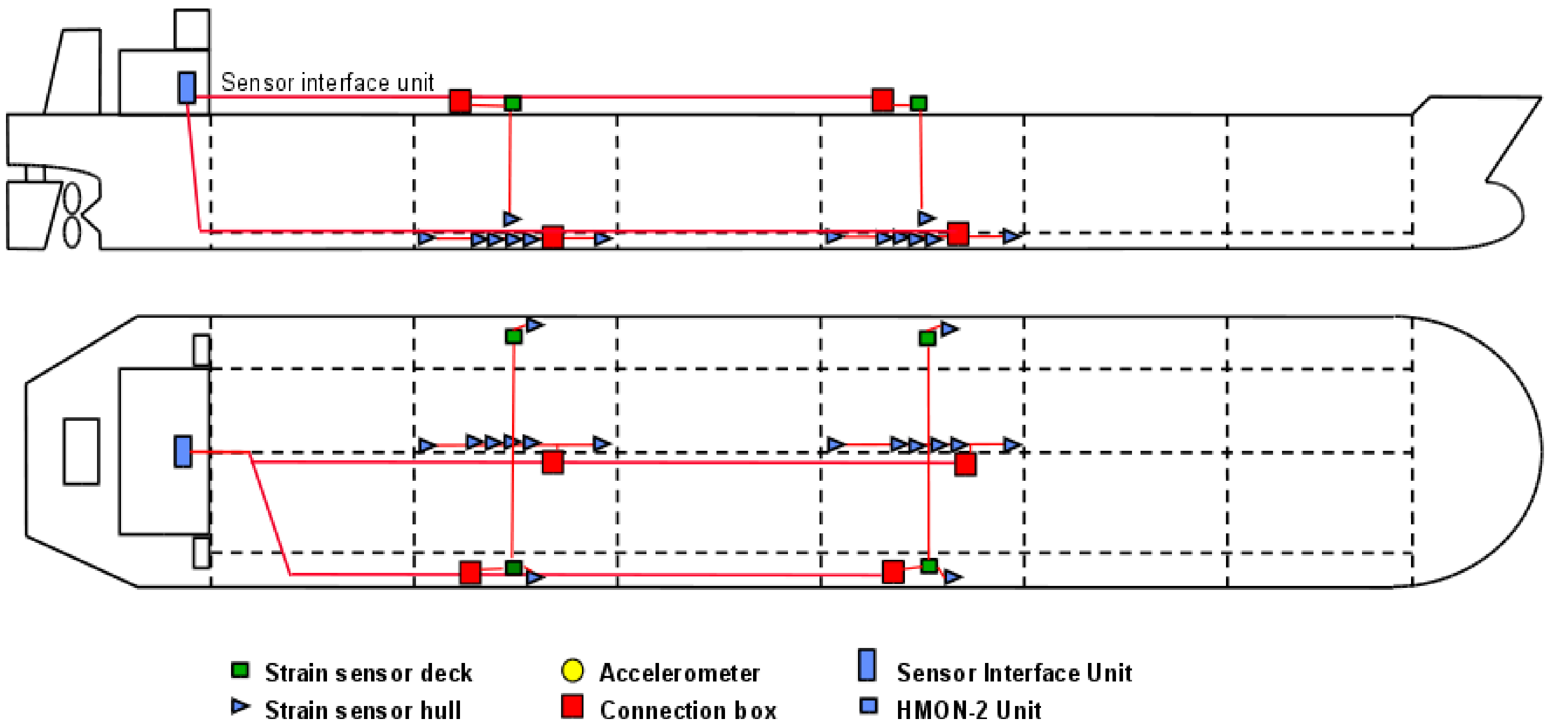
Hold Monitoring: Impact of ore loading rate

Standard HMON measurements

Project with DNV and large ore carrier owner



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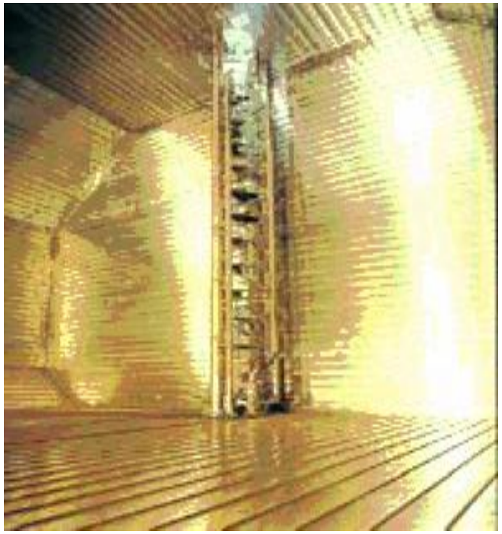
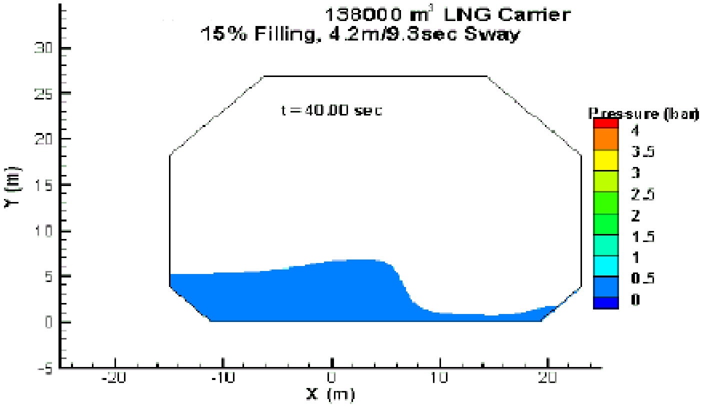
LNG tank sloshing monitoring

Monitors the pressure and force exerted by liquid cargo sloshing inside cargo tank

Qualified for very low temperatures

Provides information about condition of hard-to-inspect parts of the containment system





Ice load monitoring

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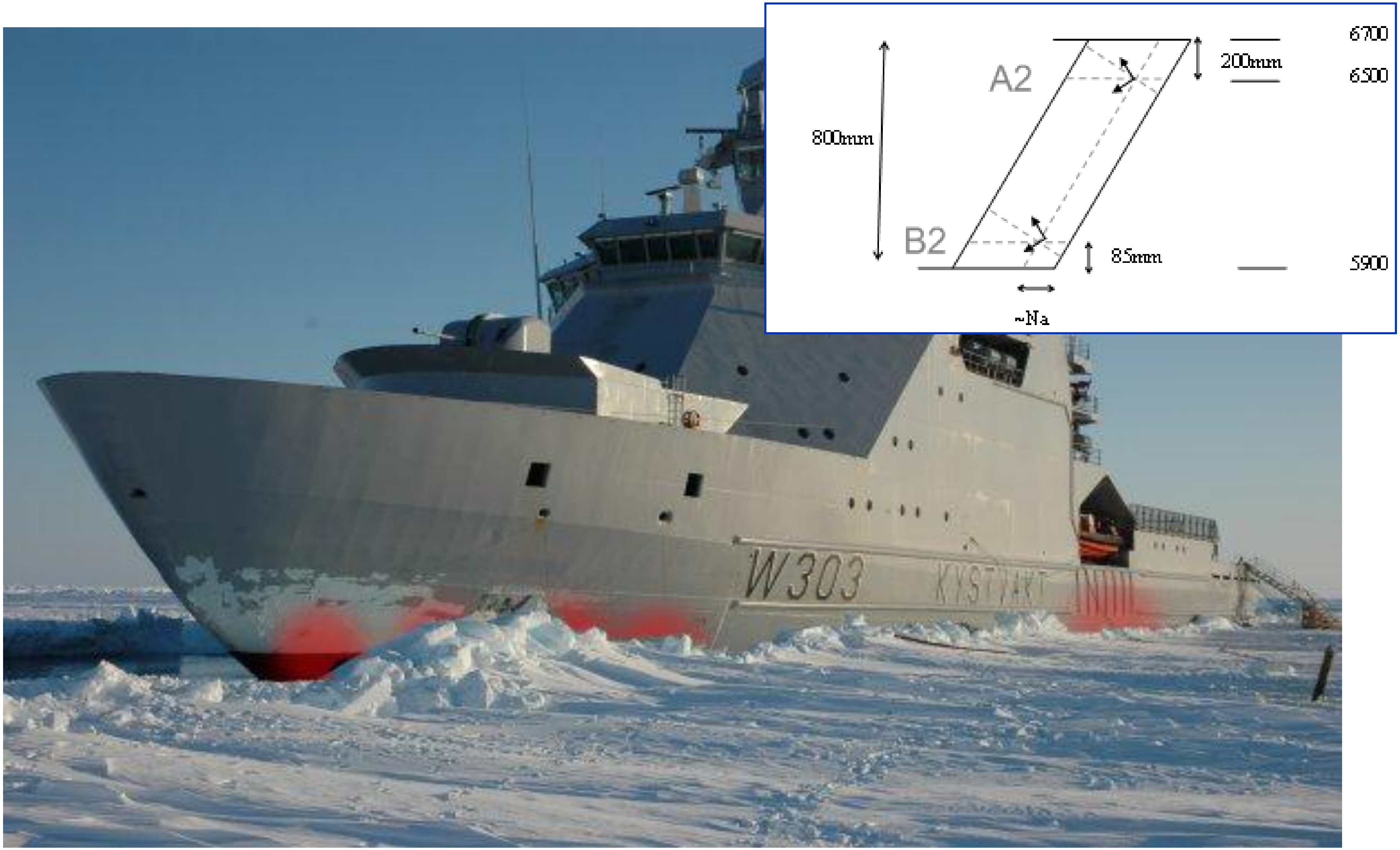


Whipping/Springing and Extreme Loading on Container Vessels

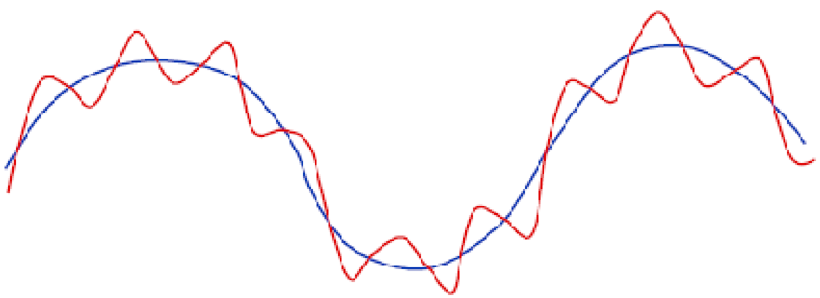
Most results from LS installations for DNV R&D projects

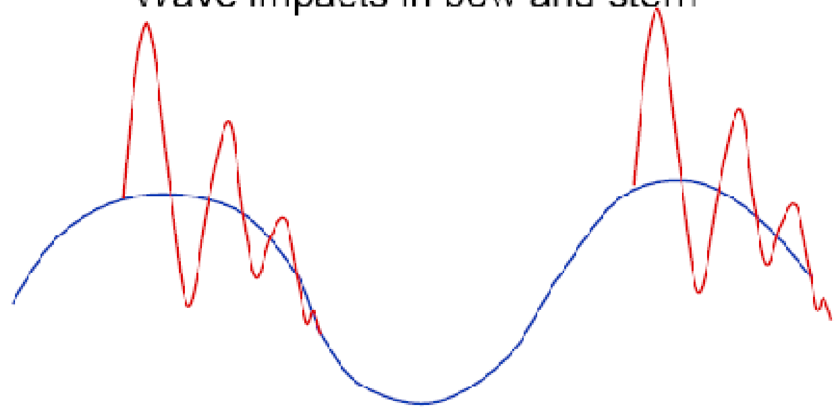
Slides by kind permission from Dr G. Storhaug, DNV

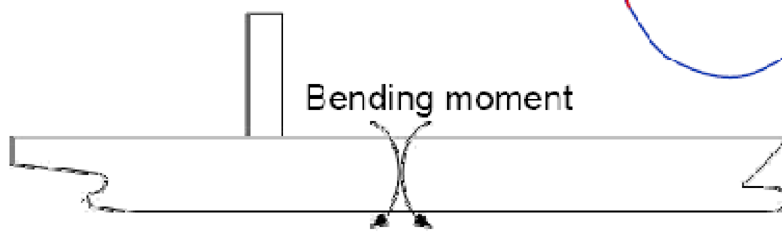
Vibration phenomena

- Springing
  - Resonance
  - Oscillating loads along the hull
- Whipping
  - Transient response
  - Wave impacts in bow and stern

Moment that tries to break vessel in two







Vibration shape

2 seconds period

Springing and whipping increases fatigue and extreme loading

Springing and whipping is not accounted for in design of ships!

HMON, Extreme Loading, Vibration and Fatigue (DNV)

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Recent incidents illustrating why!

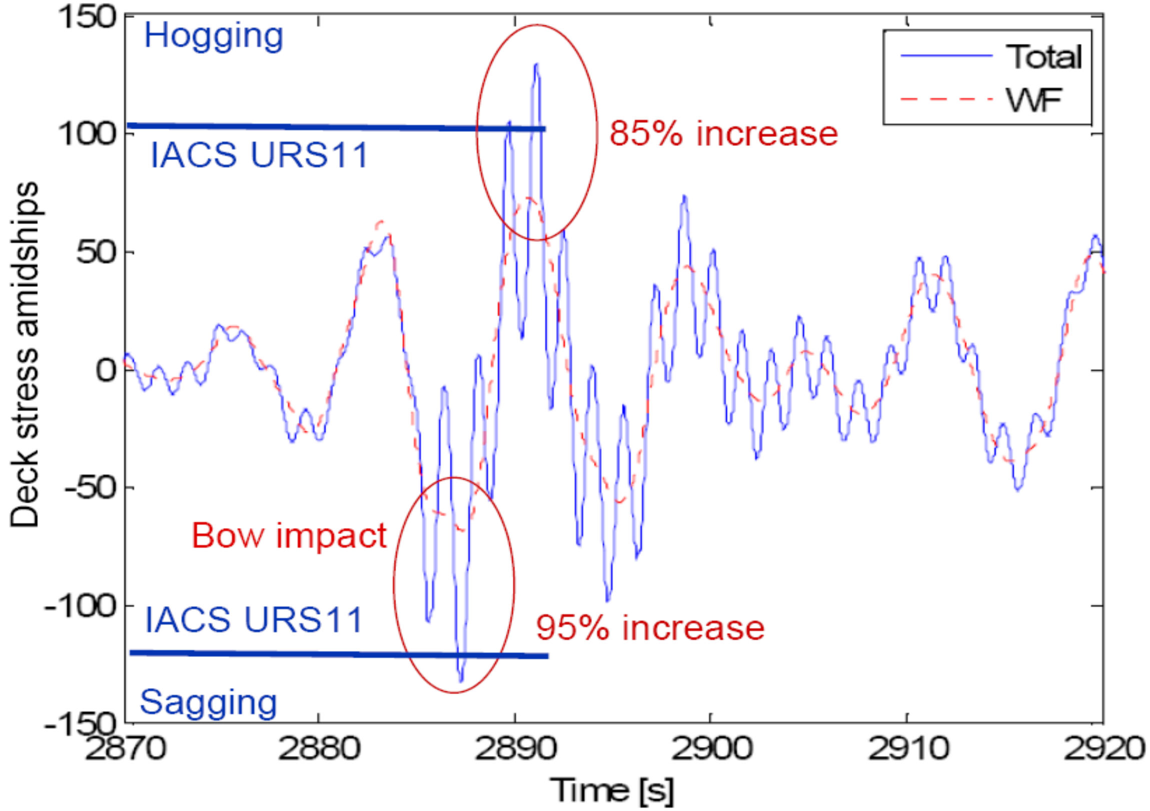
MANAGING RISK DNV

- Full scale measurements of another 4400TEU vessel

Only!

6m significant

wave height



Trends – larger vessels

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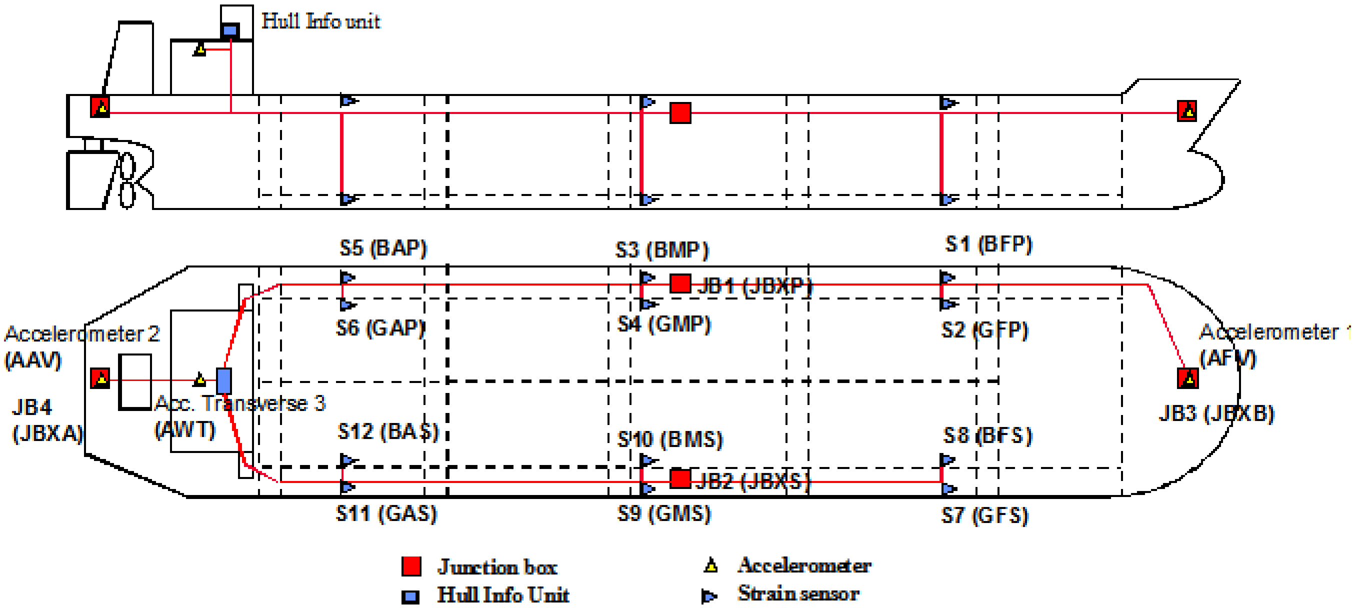
Wide. Large bow flare + high speed leads to whipping vulnerability

Hull flexibility and material choice

Local accelerations from slamming (1g+)

Climate changes



Fatigue stress recorder

Objective: Reduced the load uncertainties and increase the accuracy in the calculations of fatigue lifetime consumption.

Measure strain at “cold spots” in stead of “hot spots” for load and stress determination.

- Cold spot: (Kaminski, 2007, Jensen et.al. 2000)
  - dominated by the nominal stress (minor stress gradients)
  - free of stress concentration factors (SCF=1)
  - one dominant loading mechanism
  - far from areas prone to damage
  - preferable in voids free from direct weather and ballast/cargo loads
  - representative for the whole structure, or parts of interest
  - locations included in the contractual documentations

Fatigue stress recorder

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Step 1 - Section models (FEM) to calculate the following relations:

- local cold spot strain/stress field due to local loading and global loading

Step 2 - Local fine mesh FE models to calculate the following relations:

- local stresses at hot spots versus cold spot stresses due to local and global loading

⇒ Separate the hot spot stresses in components due to local and global loading

$$\sigma_{Fatigue} = \sigma_{Global} + \sigma_{Local\ loading}$$

⇒ Accurate “measurement” of the experienced hot spot stress and the ***actual*** fatigue lifetime consumption at e.g. weld toe.

Fatigue stress recorder

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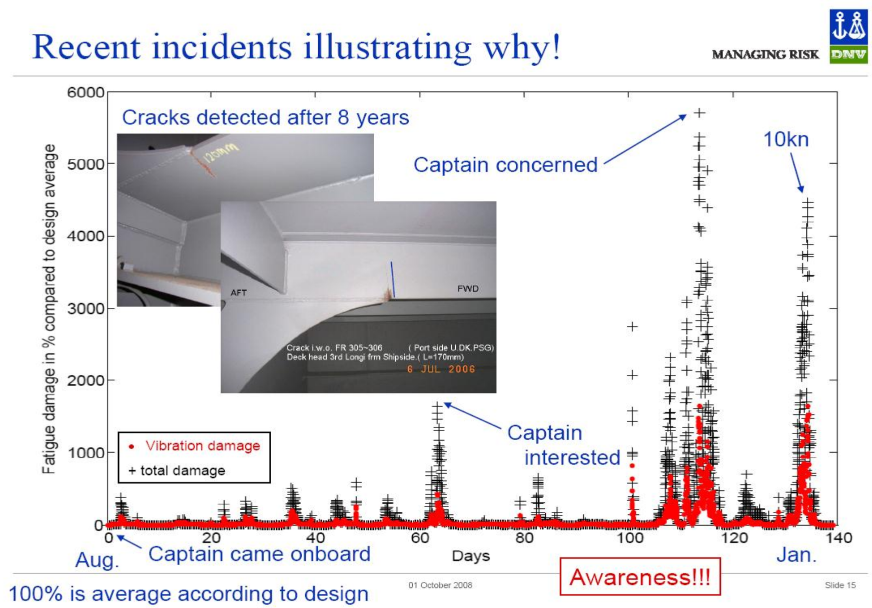
- Rain-flow analysis to determine the stress ranges and mean values
- Standard fatigue analyses to calculate the actual fatigue lifetime consumption
  - lifetime consumption from local and global loading can be separated
  - mean value and/or stress range effects can be included



Local hot spot analyses - Maintenance purposes

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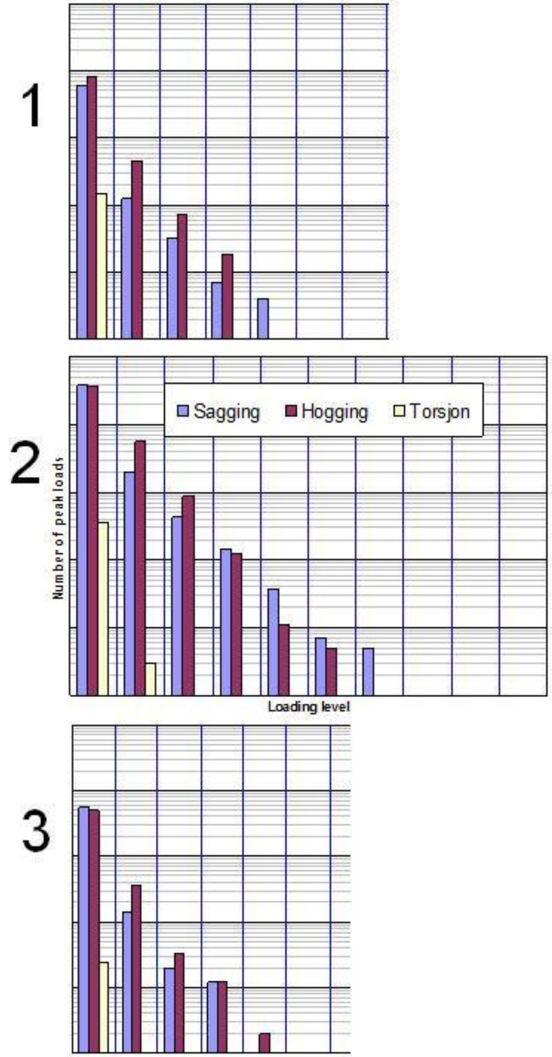
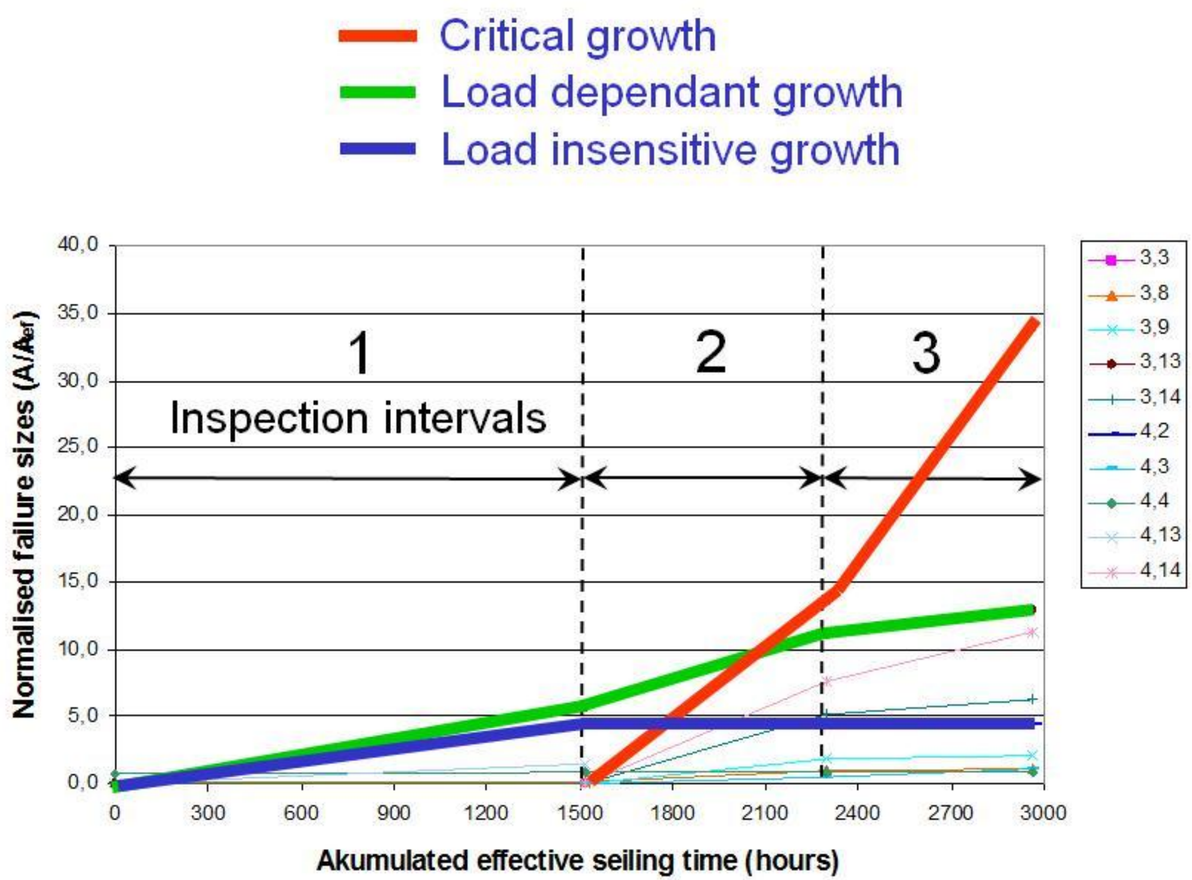
Accumulated Peak loads in between inspections



Example - growth of debonding in FRP sandwich structures



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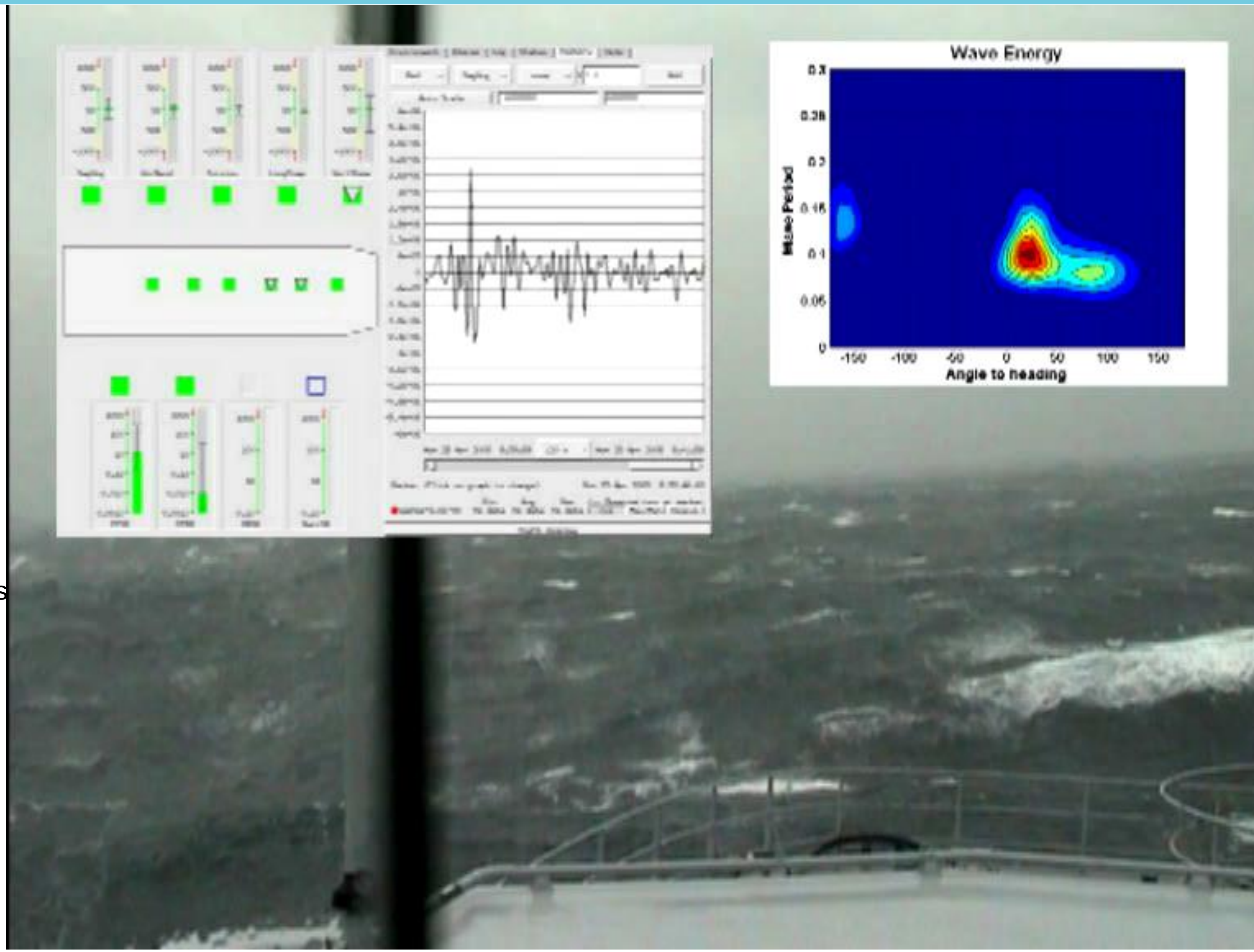
Design verification - Extreme loading

Sea trails with the MCMV vessel, KNM OTRA, 2005 (Movie)

Sea state 6.
Wind speed up to 63knots



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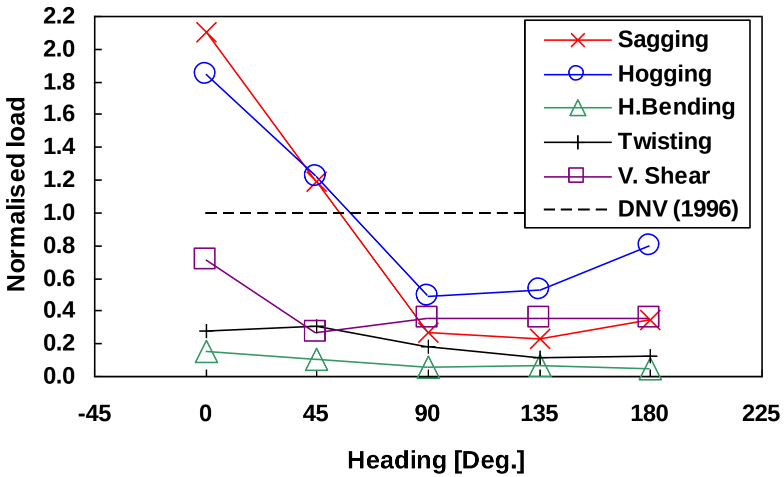
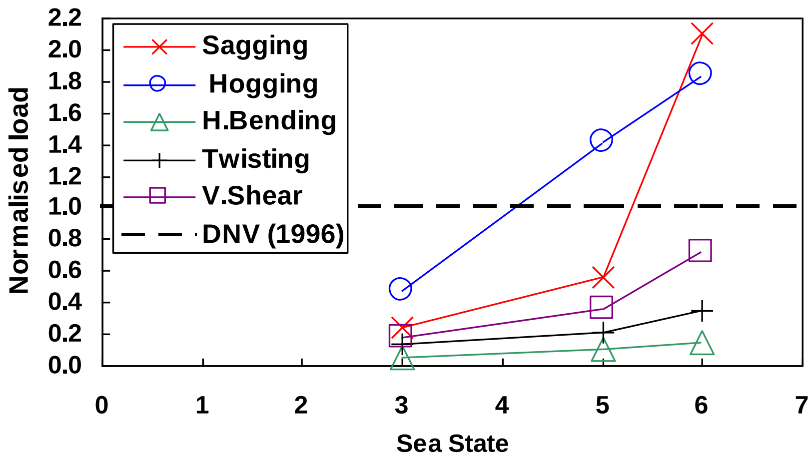
Design verification – Extreme loading

Sea state 6





Sea trials with the pre-series fast patrol vessel, KNM Skjold, in1999.

1 - Early warning of “near-future” extreme loading

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Objective: To avoid severe loading (E.g. wet deck slamming and bow flare slamming)

Method: Extreme value statistics applied to resent experienced load peaks

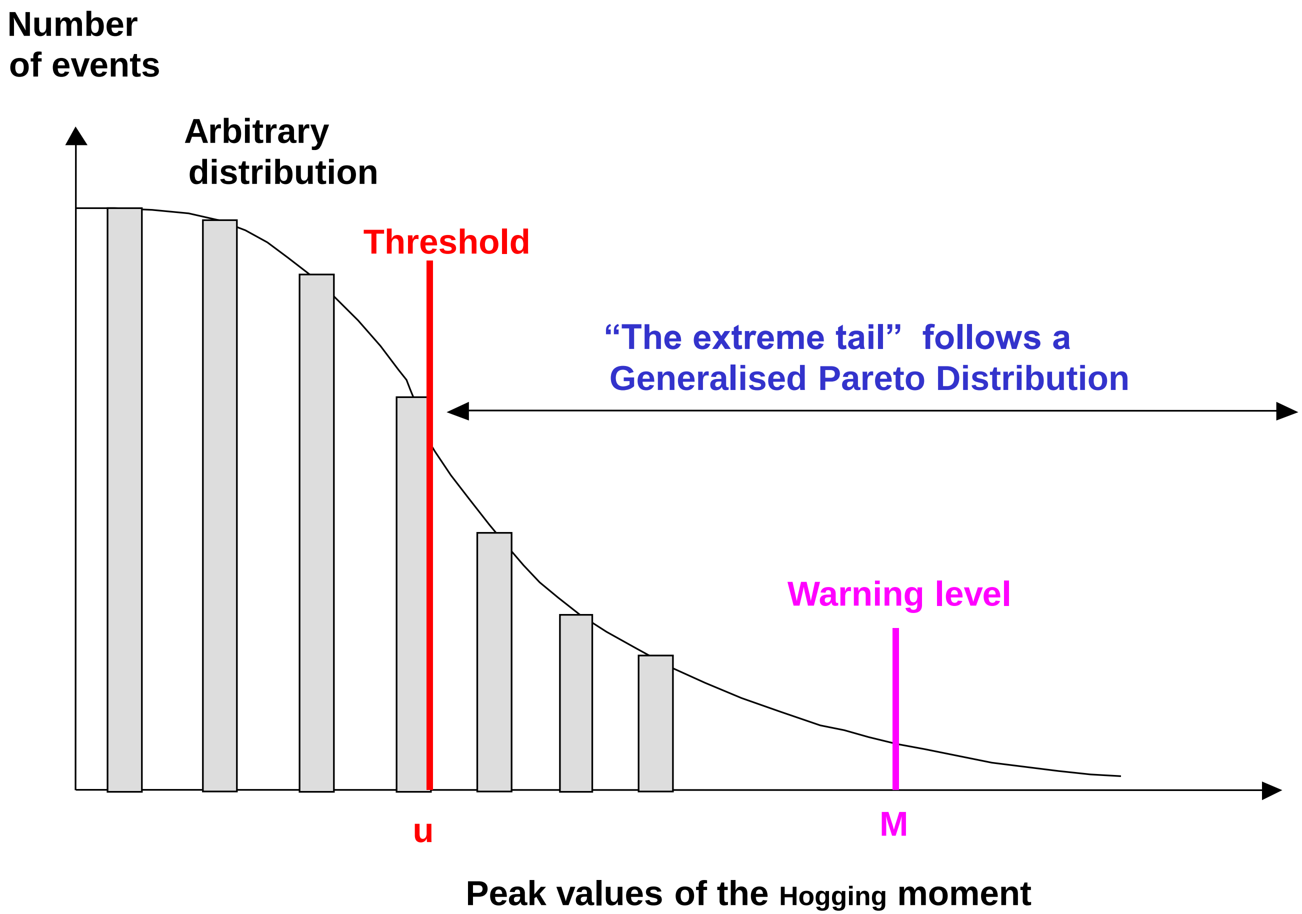
- Requires minimum 10minutes of global load measurements
- Approx. 2 hour return level for max. predicted extreme value

  (The value which on average is experienced one time within the next two hours)

+60knots

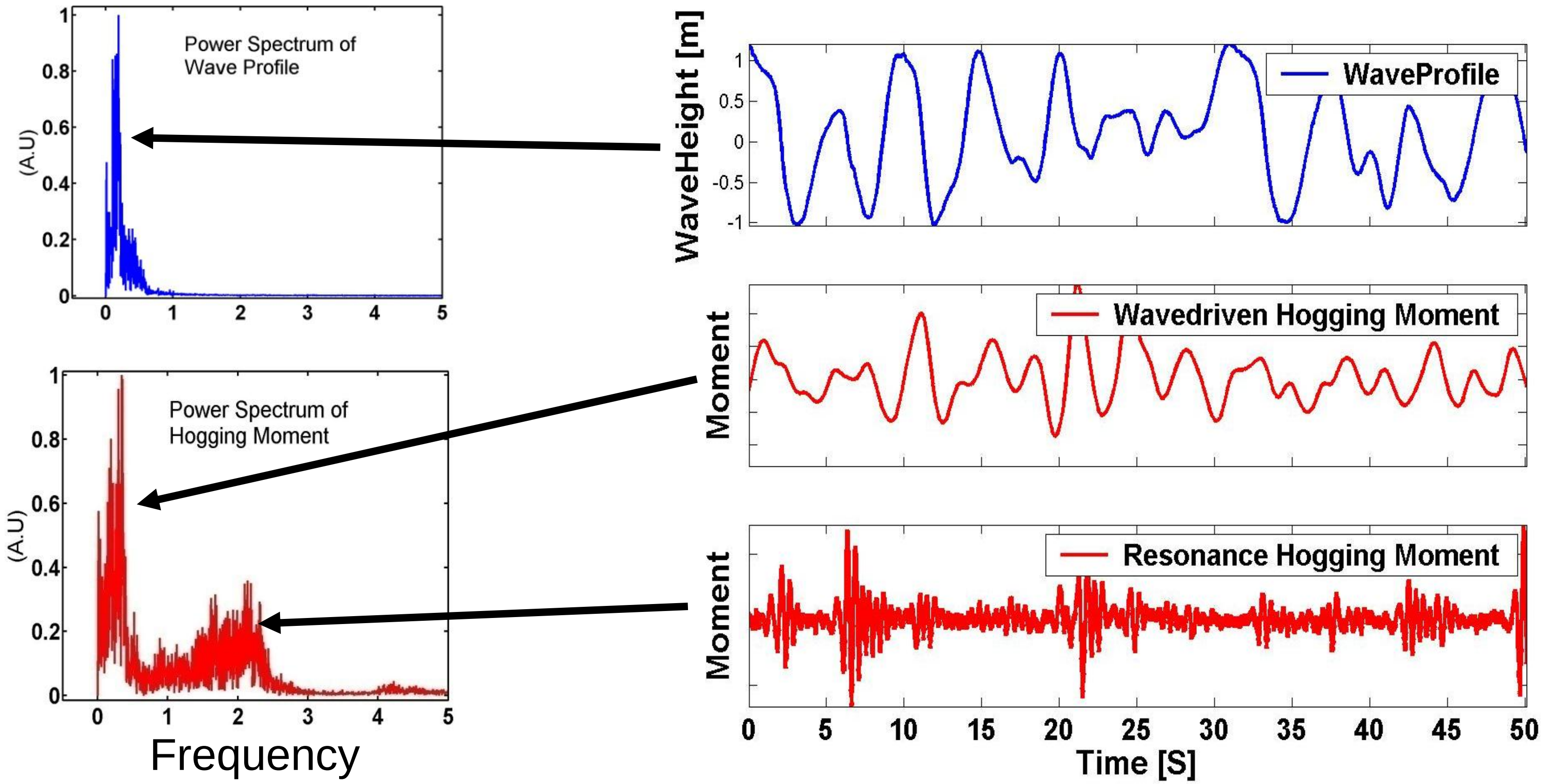
+30knots

Peak Over Threshold (POT) analysis



Peak selection from time series

Frequency analyses of wave and impact loading



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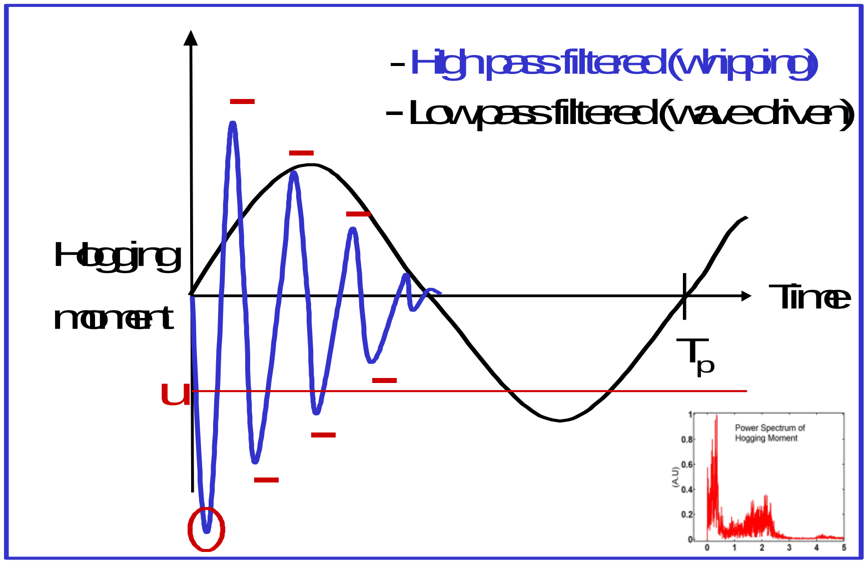
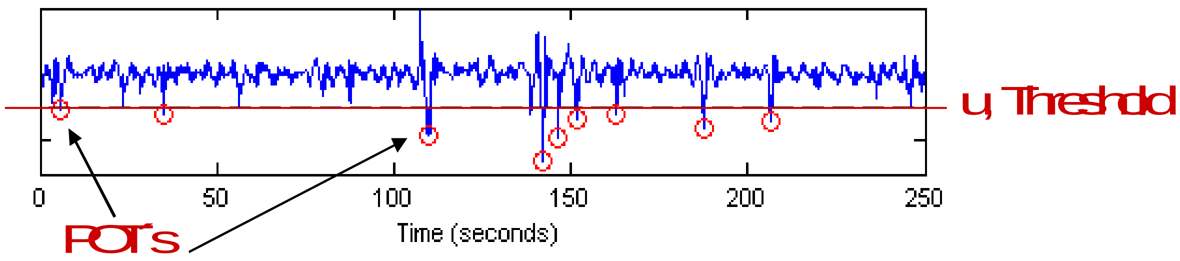
Peak selection from time series

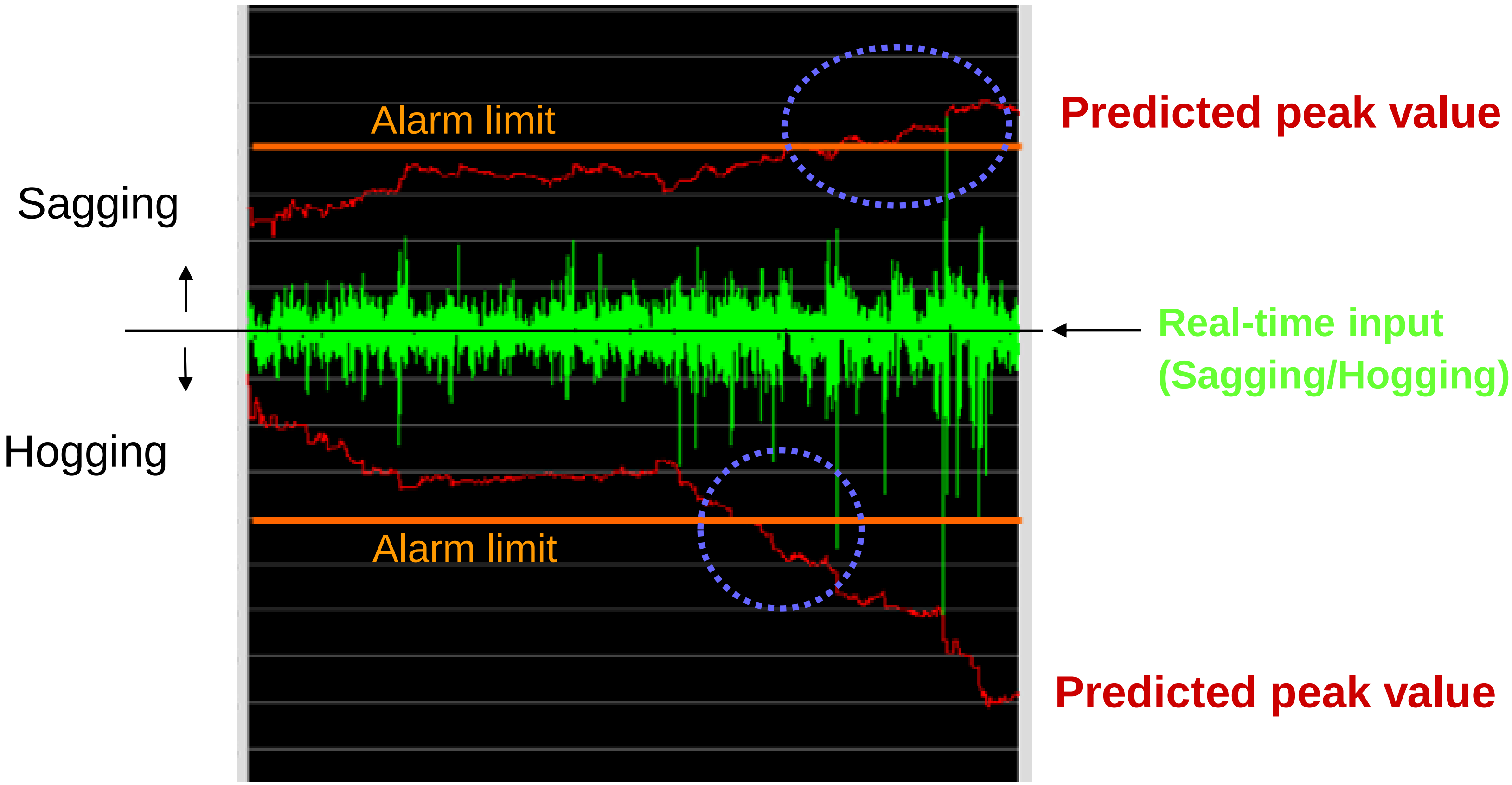


When peak values are found the following checks are performed

- Above/below the threshold u
- Sort all peak over threshold in descending order from the largest peak
- Remove all peaks prior and after within the time period, T_p, the period of incoming wave profile



GUI of the early warning system



Approximately 20min sailing time

2 - Early warning of extreme loading – database

Objective To avoid severe loading by using historical data and real-time measured values (Supplement to the previous module)

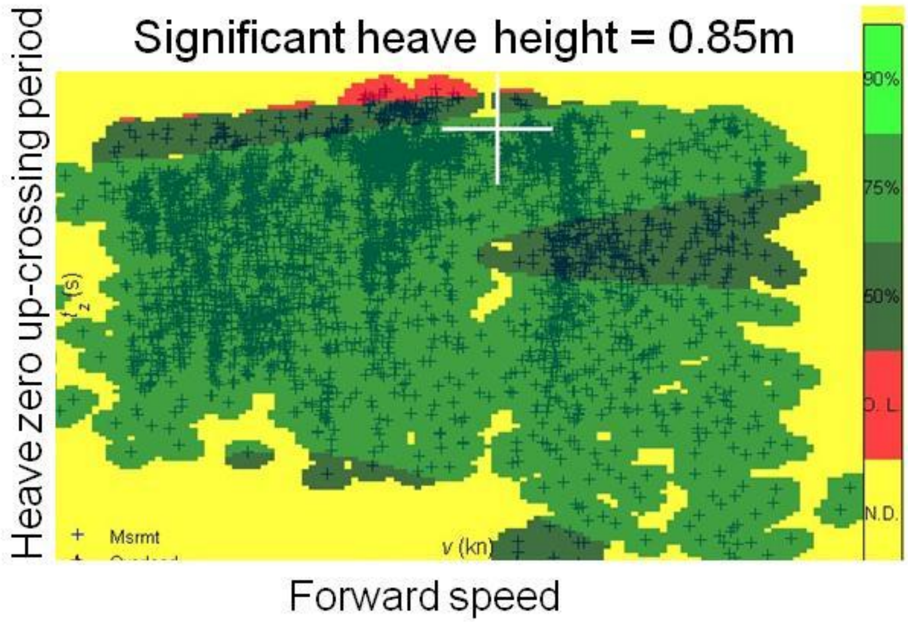
Method Multivariable regression technique

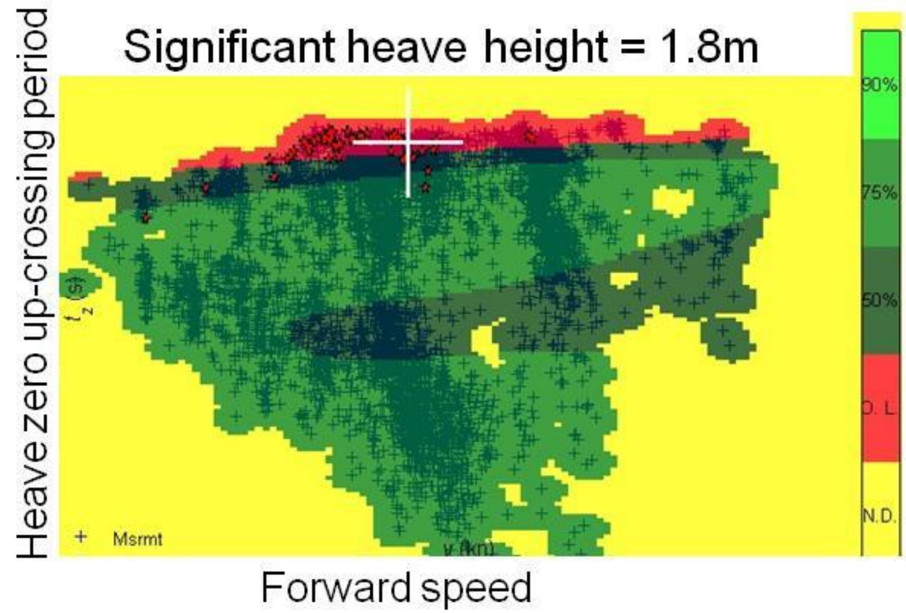
- Measured input parameters: the significant heave height and zero up-crossing period, forward speed, and displacement
- Previous measurements stored in a data base
- When the numbers of data points are sparse it gives better guidance in comparison to a histogram approach.
- Better suited if more parameters are to be included in the model
- Requires less than 10minutes of recorded real-time data

Application

- Extreme high speed vessels
- Sailing in between island and open ocean and/or with variable water depth.

GUI
(Early warning of extreme loading – database)

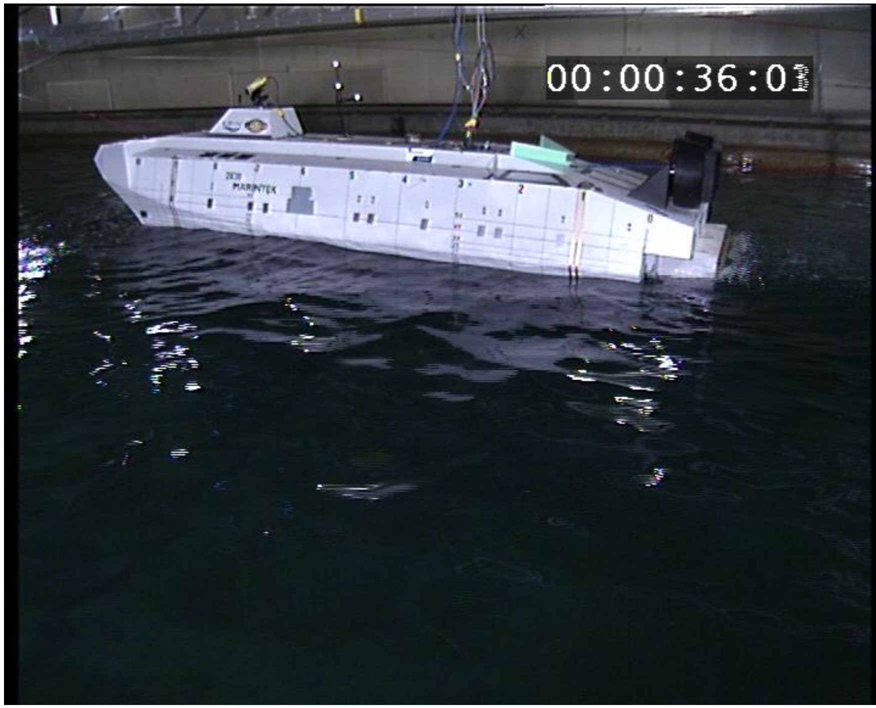


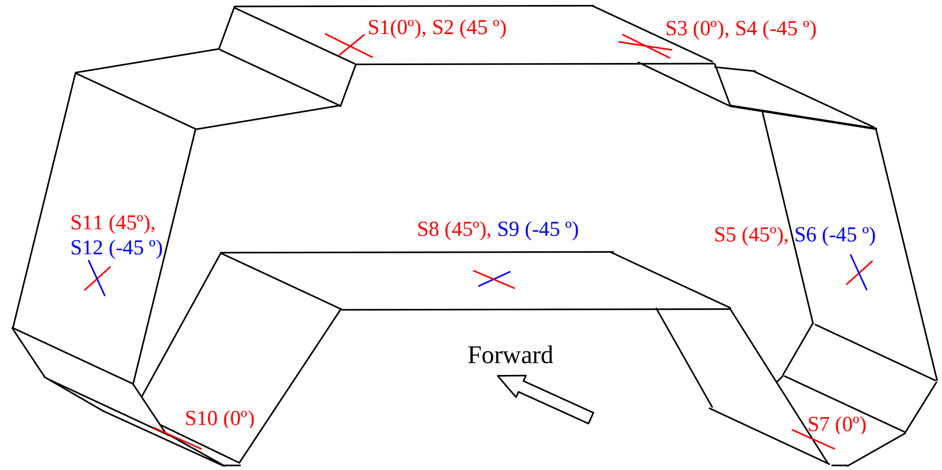


No observations
Overload within 30min
95% confidence for no overload
75% confidence for no overload
50% confidence for no overload

Scaled model testing – Towing tank tests

Global load measurement. (overall weight of instrumentation attached to the scaled model is approx. 1kg)





1:15 scaled model of a 75m and 1250ton SES T-Craft prototype for the US Navy.

The towing tank at MARINTEK, Trondheim in 2009.

Advisory Monitoring System (AMS) / Hull Stress Monitoring Systems (HMS)

Basic module

- Global loads displayed in real-time
- Recording of ship data in a database
- Link for transmitting of data to shore
-Fatigue recorder

Additional modules

Advanced fatigue recorder

Monitoring of local hot spots (steel and FRP structures)

Early warning of possible extreme loading based on:

1) measured global loads
2) measured heave heights/periods and database values

Black-box recorder

AMS/HSMS - Applications

- Verification of design specifications
  - Demo-version, prototypes, pre-series vessels, mock-ups, scaled models, etc…
- Ship manoeuvring assistant
  - Night time operation
  - Operation in areas with wave interference or dangerous waves
  - Training of new crew members
- Present the actual experienced parameters like:
  - Global/local load history
  - Fatigue stress history
  - Fatigue lifetime consumption based on experienced loading
  - Synchronised operational parameters
- Input to maintenance
  - Loading level versus documented failures, cracks, and defects
  - Lifetime loading level and fatigue life predictions.
- Black box recorder

AMS/HSMS - Advantages

A – Optimise the utilisation of the ship platform within sailing restrictions

- Sailing restriction based on measured parameters (load and or acceleration)
- Objective measurement of real-time values instead of relaying on partly subjective sea state assessments
- Instant feedback from voluntarily speed reduction and/or changes in heading
- Improve and correct the foundation for good seamanship
- particularly useful during night time operations, and in areas known to have dangerous waves

B – Safety for crew and passengers

- Early warning of possible near future overloading
- New alarm limits can easily be implemented if hull damages are observed
- The database module can be used for planning and evaluation

C – Reduce maintenance cost

- Damage aviodance
- Track record of experienced loading level and other ship parameters in a data base
- Reduced insurance cost if the ship is classed with an approved hull monitoring system
- Input to the assessment of the cause(s) which lead to damage /failure
- Overloading or design error

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References and contact info

1) **Jensen, A.E., Taby, J., Pran, K., Sagvolden, G. & Wang, G. (2001a).** 'Measurement of global loads on a full scale SES vessel based on strain measurements using networks of fibre optic Bragg sensors and extensive finite element analyses', *Journal of Ship Research* **45**(3), pp.204-214.
2) **Torkildsen, H.E., Brodtkorp, P.A., Wang, G., Jensen, A.E. & Skaugen, A. (2005a).** 'Investigation of wave loads on a surface effect ship with an extended fiber optic ship hull health monitoring system'. *5th International Workshop on Structural Health Monitoring*, San Francisco, CA, USA.
3) **Kaminski, M.L. (2007).** 'Sensing and understanding fatigue lifetime of new and converted FPSOs', *2007 Offshore Technology Conference*, OTC 18913, Houston, Texas, USA.
4) **Jensen A. E., et al. (2009).** "Safe operation of ships using real-time monitoring and statistical predictions", *FAST 2009 vol. 3,* pp. 295-306, Athens, Greece.
5) **Jensen, A.E., Taby, J., Pran, K., Pedersen A. & Jullumstrø E. (sept. 2011),** Global load estimations for a 75 meter FRP composites SES vessel using a scaled model instrumented with a network of fiber optic sensors', *FAST 2011*, Hawaii, USA.

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LIGHT STRUCTURES

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Scaled model testing

The extreme observations with in a 20min real-time run for the SES vessel is few, i.e. the 99% confidence interval becomes too conservative.

The POT analysis is used for estimating the most probable peak value within 3hours in a given sea state.

The extreme value equivalent to the 20 years long term value is defined as follows: (DNV ships rules)

[illegible]

The linear and non-linear response expression above is an approximation for the extreme values with 1% probability of exceedance in a 3 hour sea state.

(The scaled model testing is going to be presented at FAST 2011 conference in September, 2011).