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Ice Research at TUHH

Sören Ehlers

Ship Structural Design & Analysis

Mechanical testing

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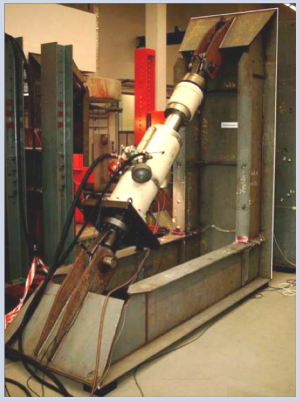
	Impact testing	Static material testing machine	Dynamic material testing machine	Fatigue testing	Variable hyd. test setups
Set up					
Vel max.	750 mm/sec	10 mm/sec	1000 mm/sec	30 Hz	≤ 1000 mm/sec
Forc. max.	160 kN	250 kN	160 kN	180 kN / 600 kN	25 - 4000 kN

Ice-structure interaction testing

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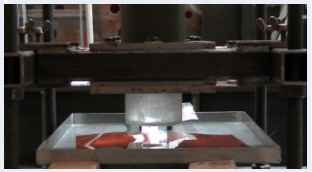
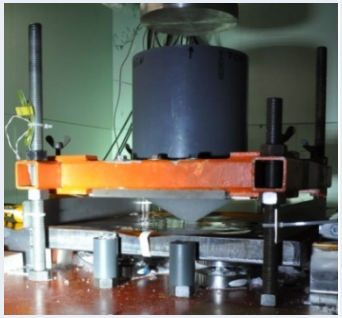
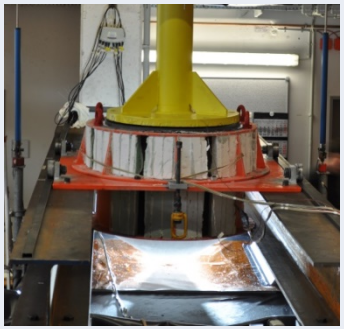
	Friction tests	Small scale	Medium scale	Large scale	Drop tests
Diam.	100 mm	100 mm	200 mm	800 mm	200 mm
Set up					
Vel max.	120 mm/sec	750 mm/sec	750 mm/sec	20 mm/sec	7 m/sec
Forc. max.	100 N	160 kN	160 kN	4000 kN	1.5 t impact mass

Experimental study of ice loads

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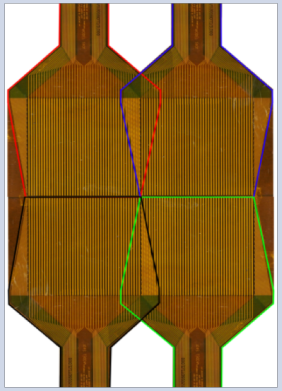
Reefer (Ice laboratory)	Small cold room	Measurement Equipment
		
• Min temp: -40°C • Ice production • Ice preparation • Thin sections	• Max force: 160 kN • Min temp: -15°C • Max velocity: 300 mm/s • Compression and ice structure interaction tests	• TekScan • High speed camera • Laser displacement sensors • Measurement amplifiers with sampling rates until 100 kHz

Background - Requirements

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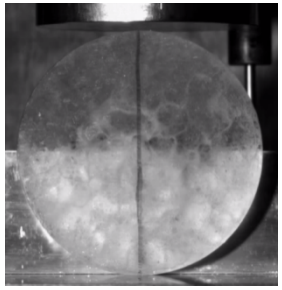
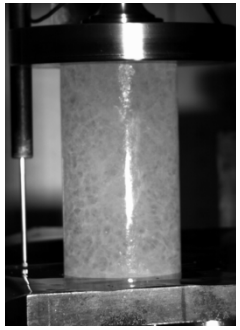
ICE

- Estimation of material properties
- Determination of load-bearing capacity
- Discription of pressure distribution

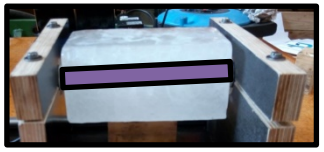
Splitting tests

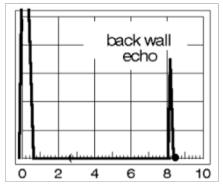


Compression tests



Ultrasonic wave measurements





[J. Krautkrämer und H. Krautkrämer, 1990]

STRUCTURE

Change of material properties due to:

- low temperature
- strain rate effects

Impact testing

Static and dynamic material testing machines

- F_{max}: 250 kN
- v_{max}: 10 mm/s

- F_{max}: 150 kN
- v_{max}: 1 m/s

INTERACTION

- Influence of structural response
- Friction under loading

Ice sample production

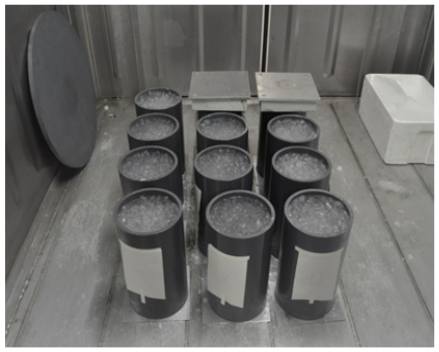
Granular ice samples are used:

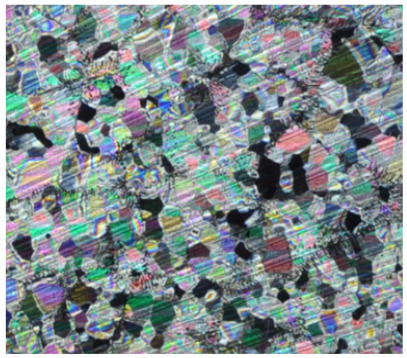
- The samples are produced out of crushed ice and distilled water.
- Advantages:
  - ✓ Fast freezing of the specimens
  - ✓ Uniform grain size
  - ✓ Applicability for different specimen sizes

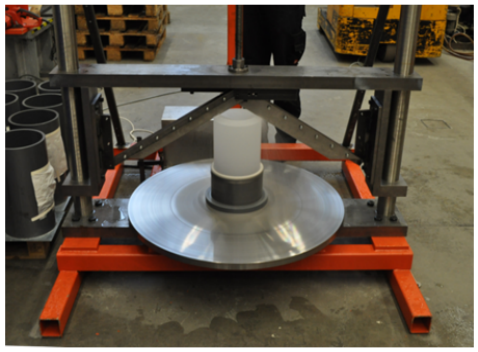
Validation of the material properties was conducted with compression tests:

➔ **6 MPa** $(\dot{\epsilon} = 6E-3)$

Recrushing of crushed ice → Mixing crushed ice and dest. Water in the mould → Freezing of the Specimen → Remove of mould and Shaping of the specimen → Final storage with test temperature







Small scale tests

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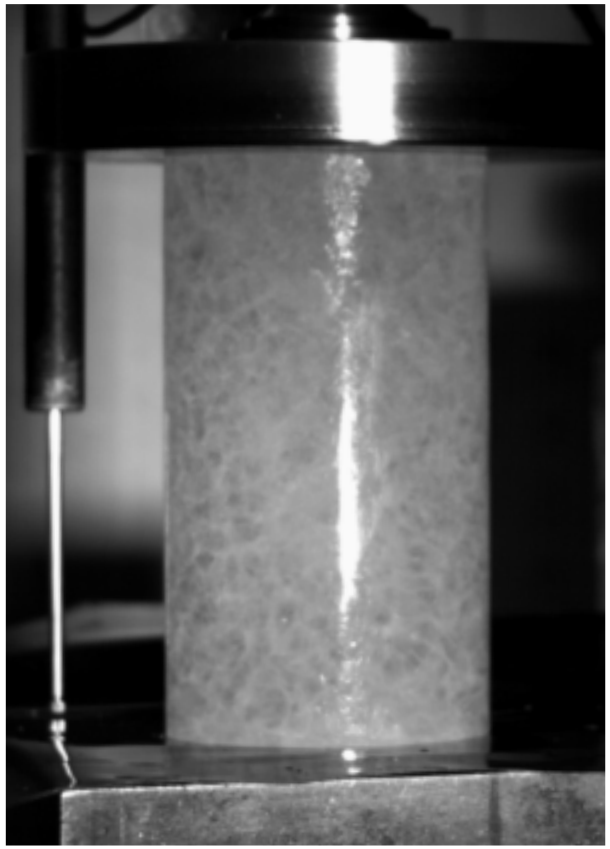
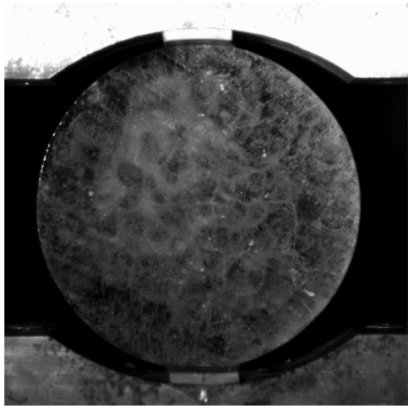
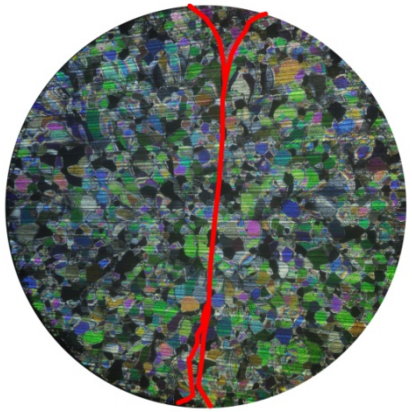
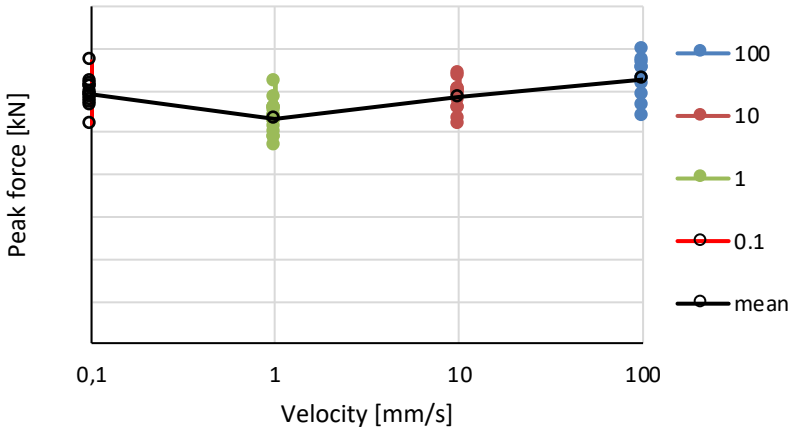
- Compression tests



- Tensile Splitting tests







Ice-structure interaction [ISI] experiments

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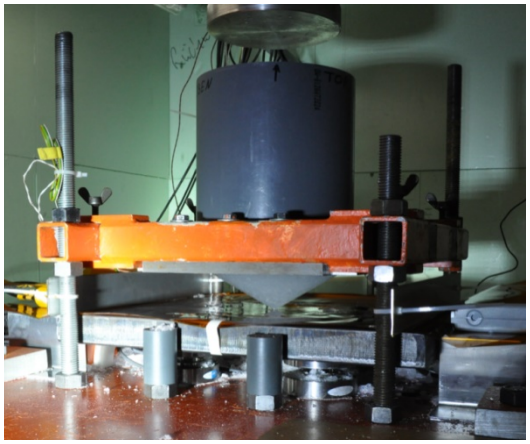
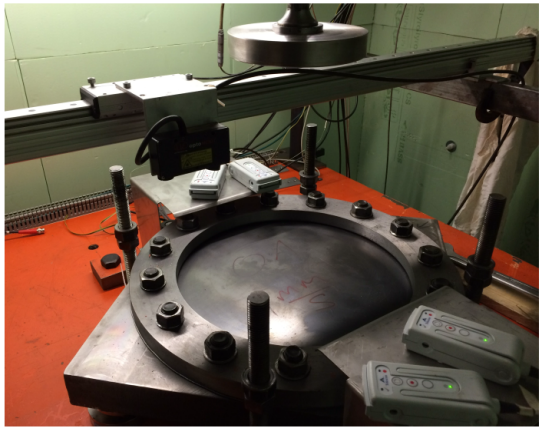
- Medium scale





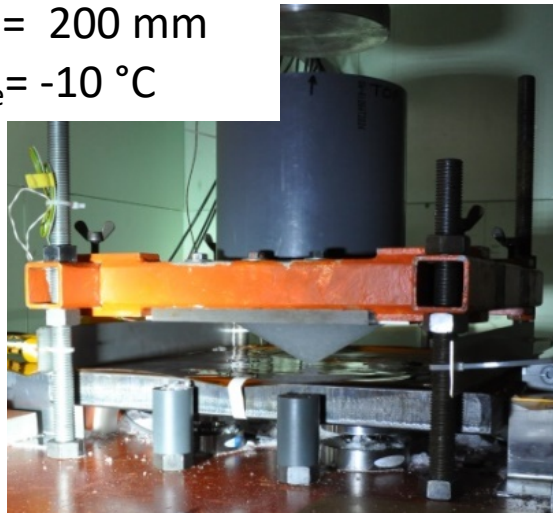
- Large scale

Medium scale results (rigid)

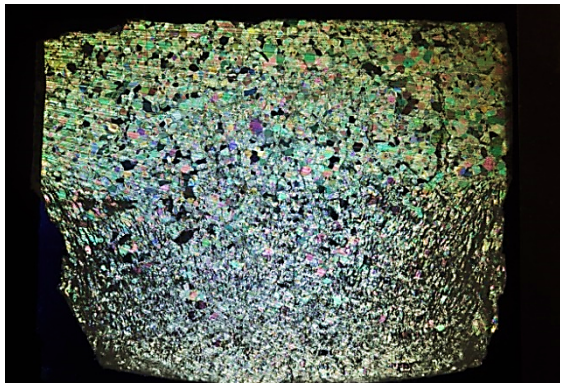
Test Parameter

d = 200 mm

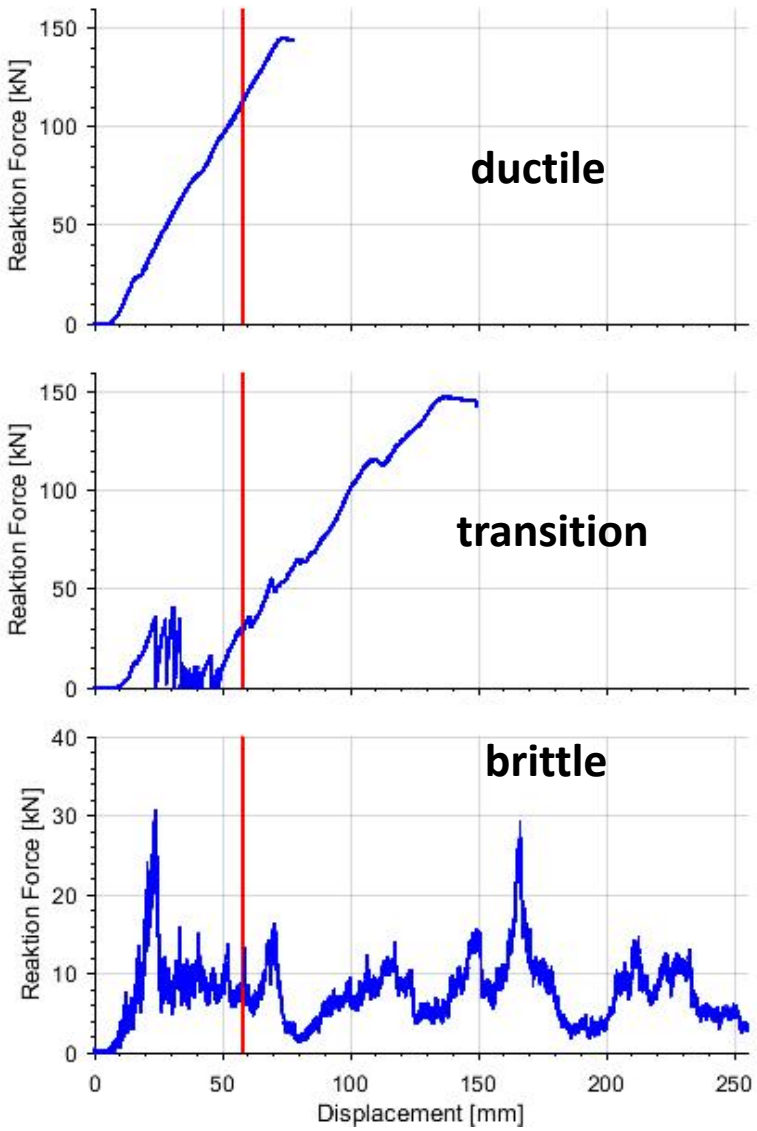
T_{Ice} = -10 °C



Medium scale test setup



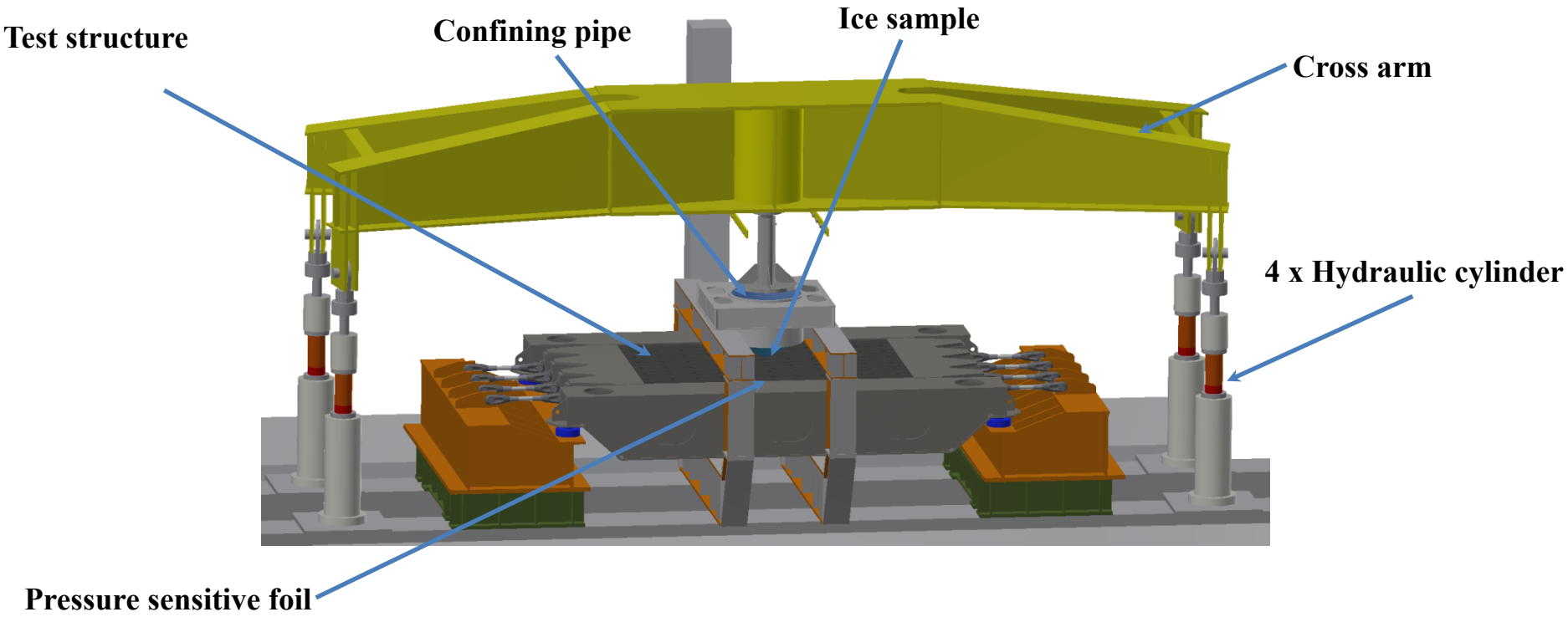
Thin section of a ductile specimen after the experiment



- Offshore structures
- Ships stuck in ice
- Ships at anchor
- FPSOs

- Ships in winter navigation

Test setup of large scale tests



Technical Data	
Max. cross arm speed	max. 20 mm/sec
Max. force	4 MN
Diameter Ice	800 mm
Panel size	3100 mm x 2100 mm

Ongoing large scale ISI experiments

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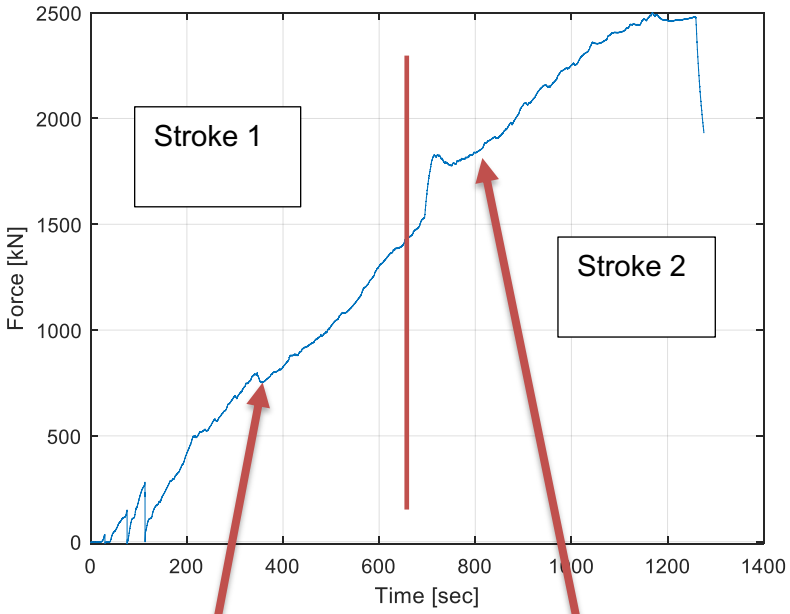
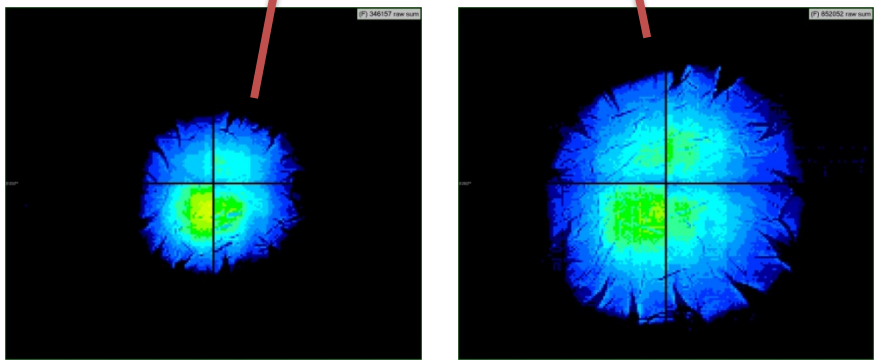
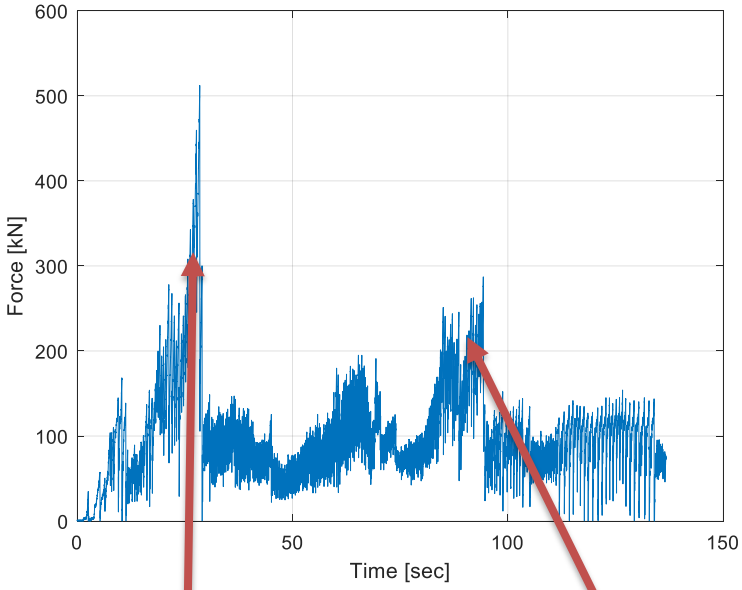
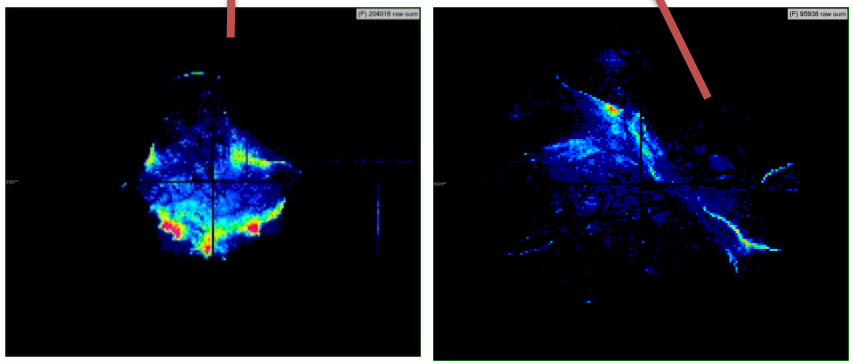
- Ductile





- Brittle





Mission-based load design for arctic waters

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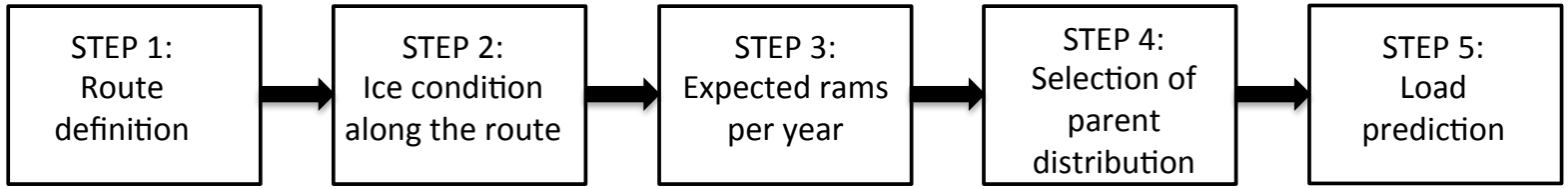
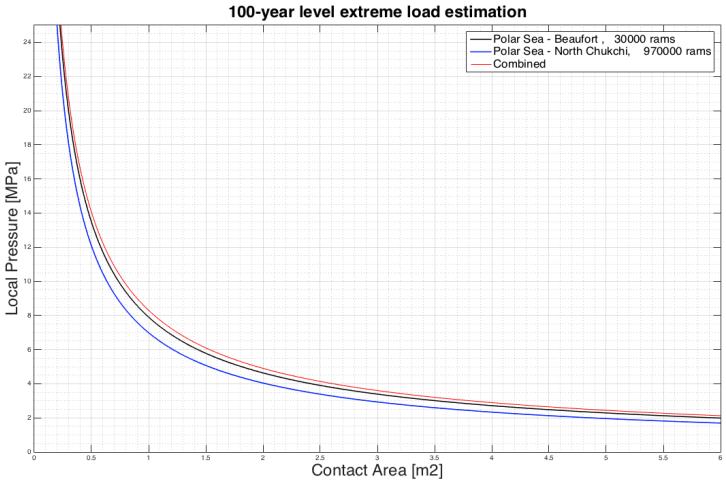
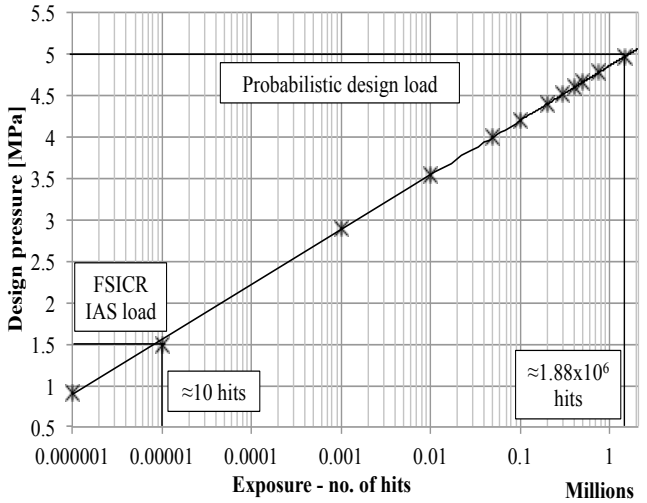
- Mission-based ship design for arctic waters to assess ice loads relevant for the design of a ship operating along a given route

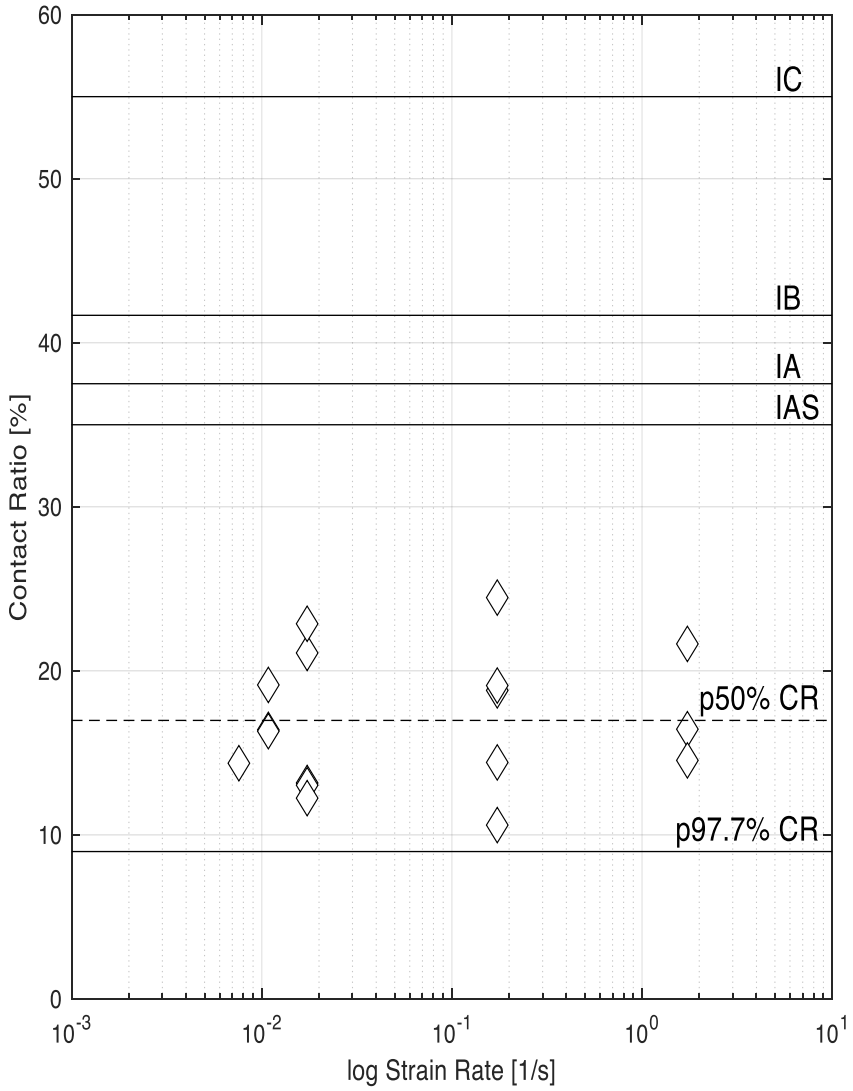


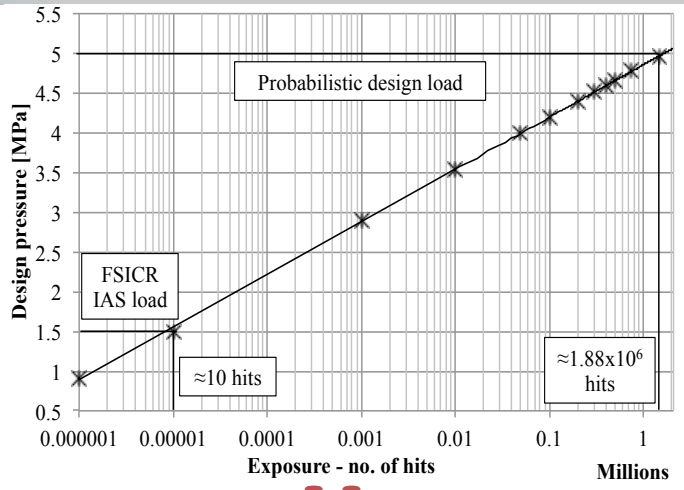
[Collin Knopp-Schwyn and Turkish Flame, CC-BY 4.0]

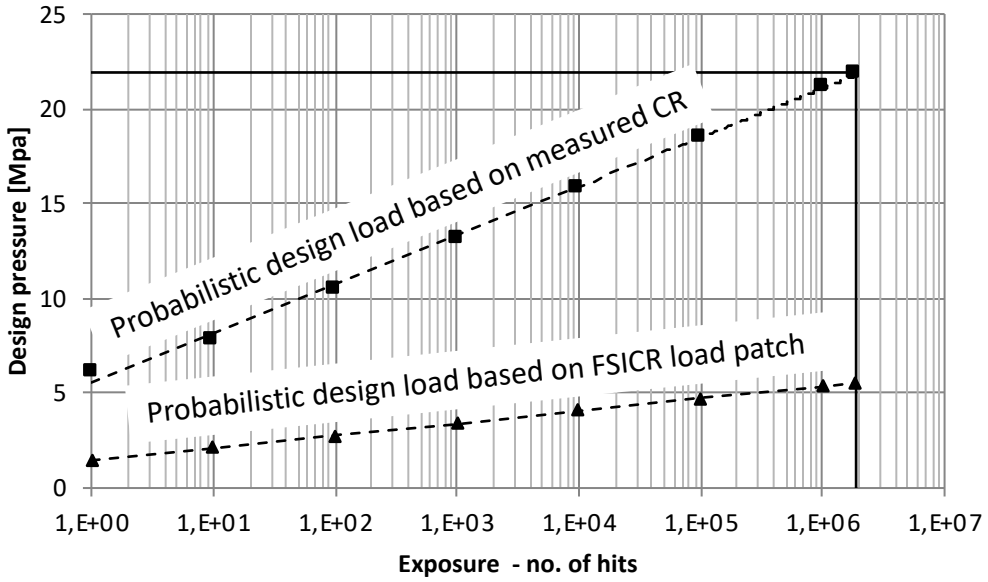




Mission-based load design + measured loaded area

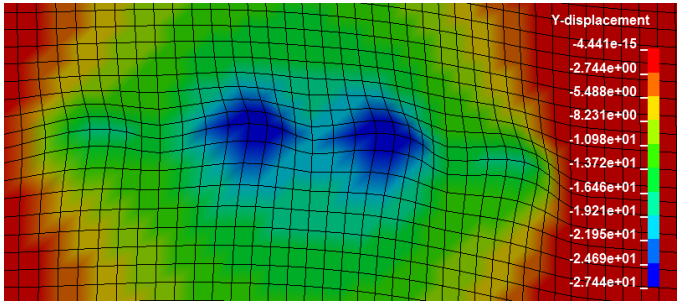


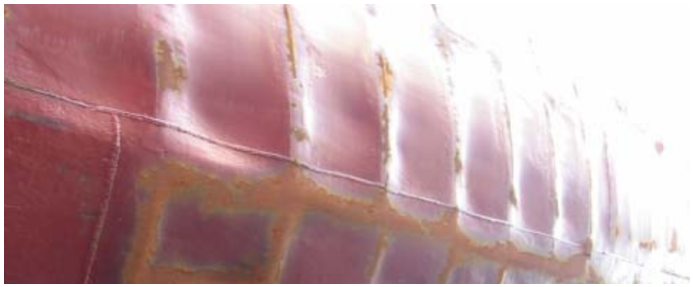




Mission-based load design + measured loaded area

[Collin Knopp-Schwyn and Turkish Flame, CC-BY 4.0]





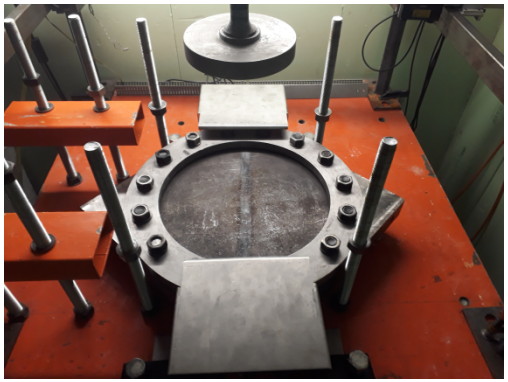
[Hänninen 2015]

Shipdata:

Container ship comparable to ship „FORESIGHT”, that transited the Northern Sea Route in 2009	
Ice class	FSICR IA
Length [m]:	134.4
Beam [m]:	22.5
Draught IA [m]:	8.9
Engine [kW]:	8400.0

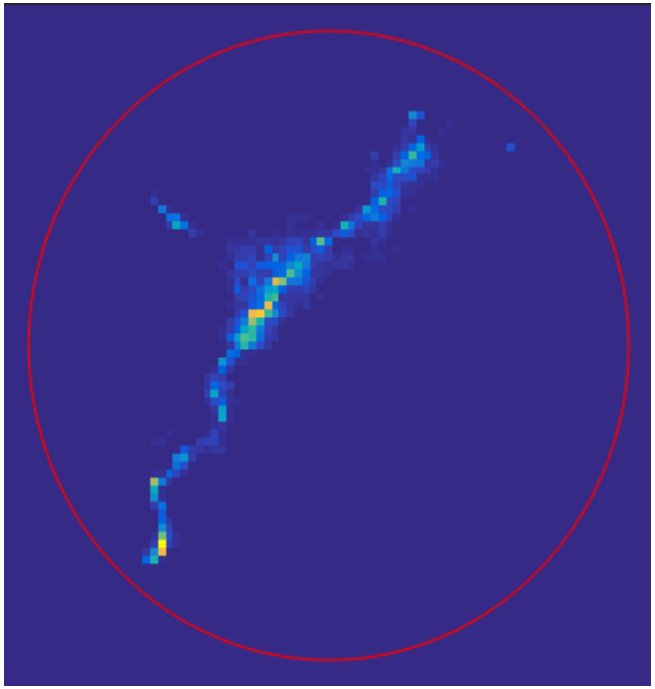
Results:	**max. v. Mises stress [MPa]**		**Resultant displacement [mm]**
	Plate	Frame	
FSICR IA	77	232	≈ 0
Probabilistic with reduced CR	442	520	27

Influence of HPZ



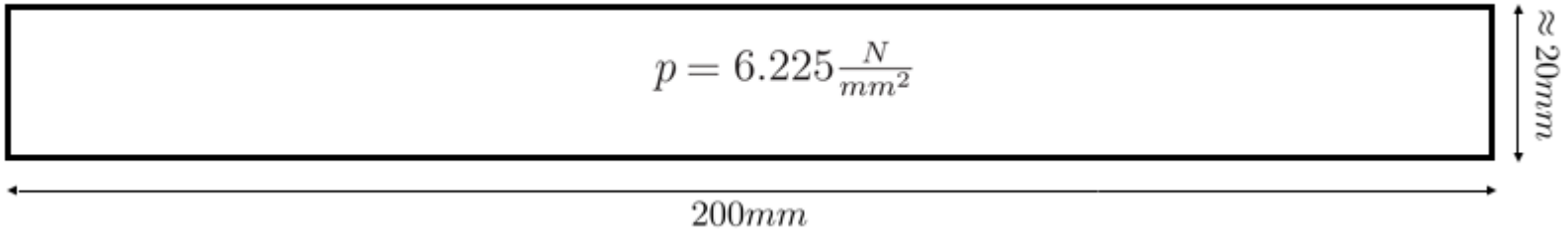
Test setup:

- 200mm diameter (ice)
- 400mm diameter (steel plate)
- 1 mm/sec collision speed



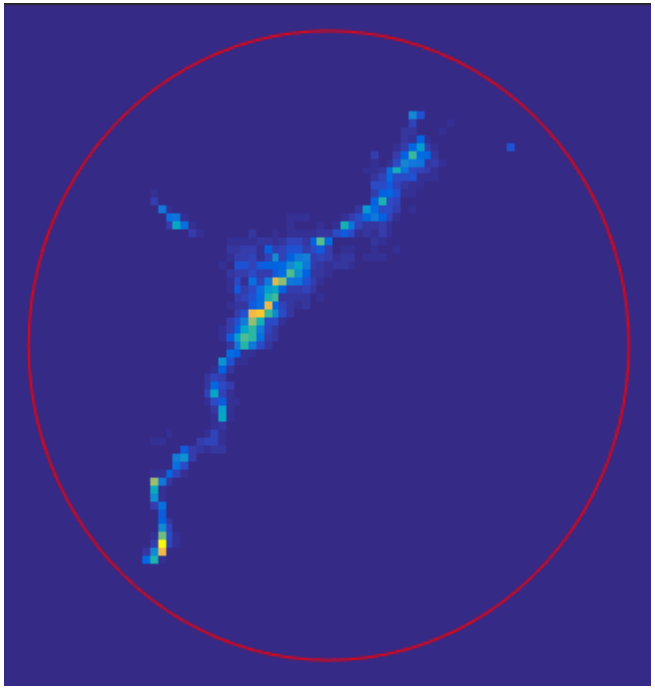
boundary line of the nominal contact area

	Unit	FE-calculation with loadcurves from experiment	FE-calculation with pressure patch	Deviation
Maximum von Mises stress	$[\frac{N}{mm^2}]$	418.4	352.4	15.77%
Permanent deformation	$[mm]$	6.3	3.4	45.49%
Maximum elastic+plastic deformation	$[mm]$	10.0	8.3	17.2%

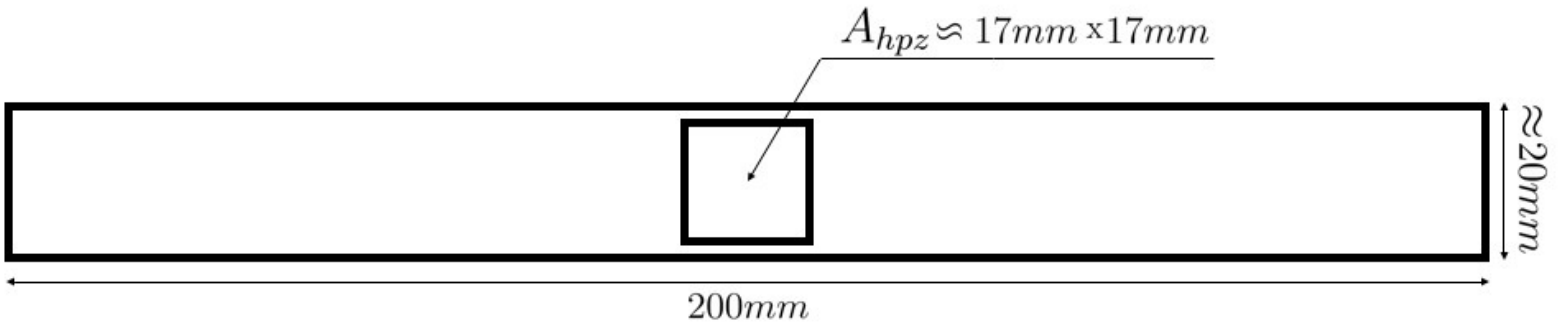


Influence of HPZ

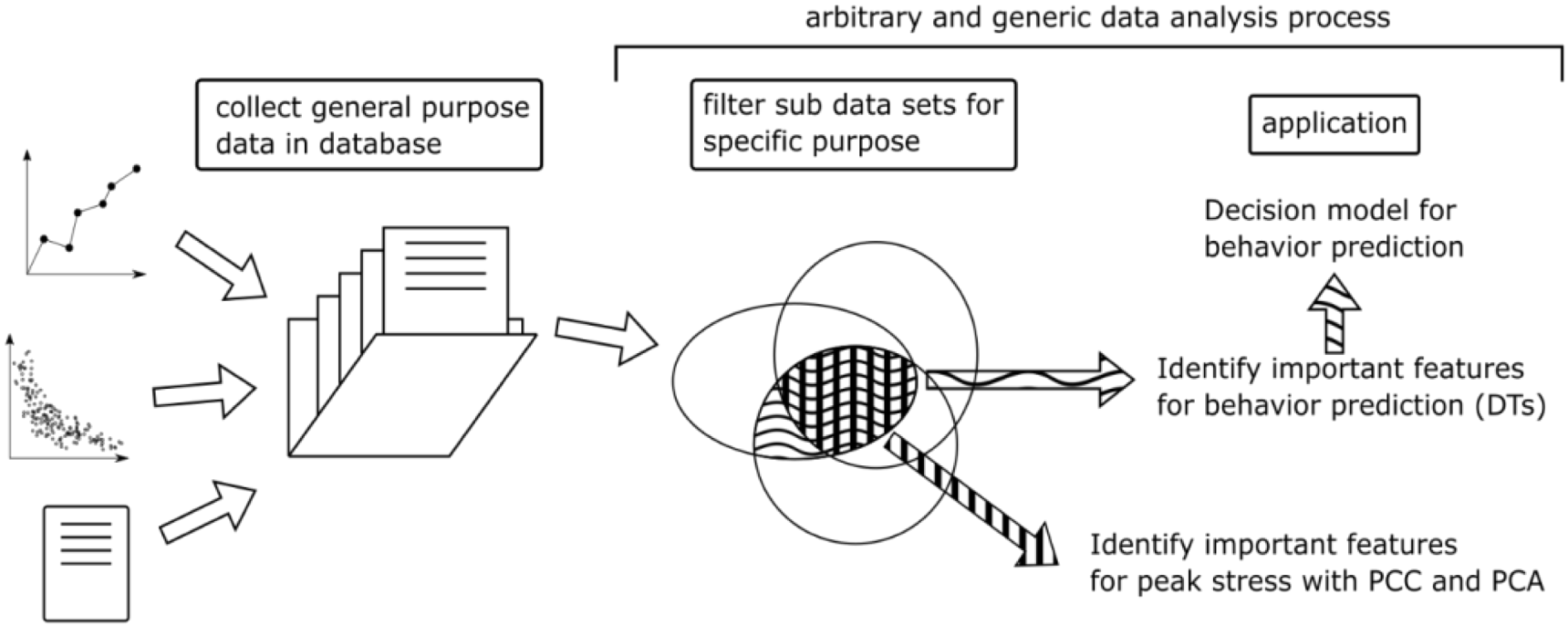
	Unit	FE-calculation with loadcurves from experiment	FE-calculation with developed model	Deviation
Maximum von Mises stress	$[\frac{N}{mm^2}]$	418.4	411.8	1.58%
Permanent deformation	$[mm]$	6.3	5.5	13.66%
Maximum elastic+plastic deformation	$[mm]$	10.0	10.2	-1.59%



boundary line of the nominal contact area



Common data base of ice experiments/Machine Learning



Kellner, Leon, et al. "Establishing a common data base of ice experiments and using machine learning to understand and predict ice behavior." *arXiv preprint arXiv:1812.03994* (2018).

Common data base of ice experiments/Machine Learning

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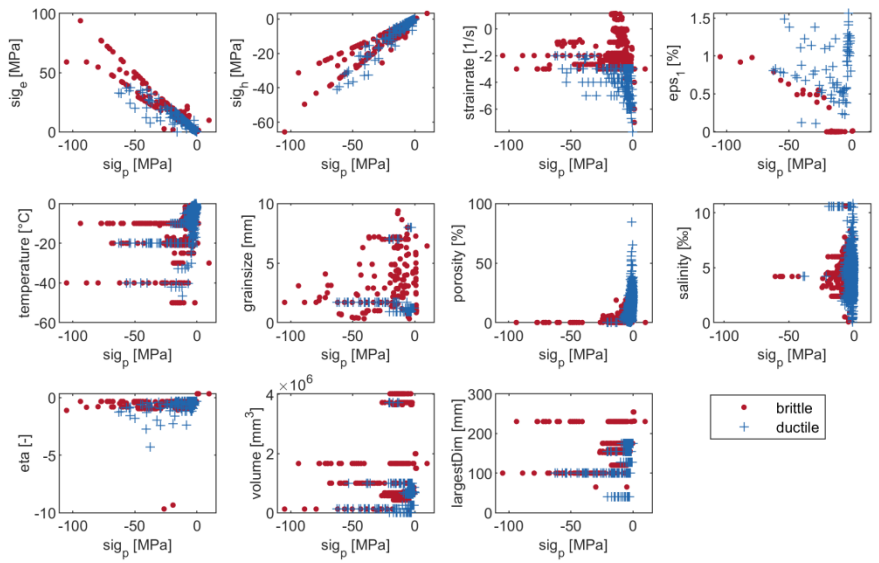
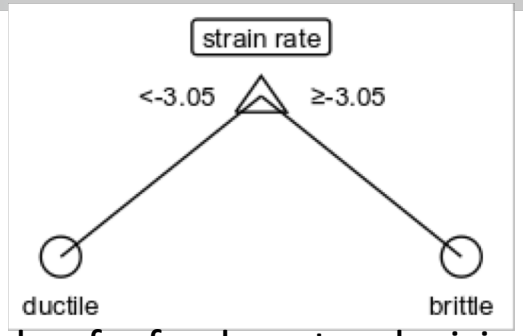
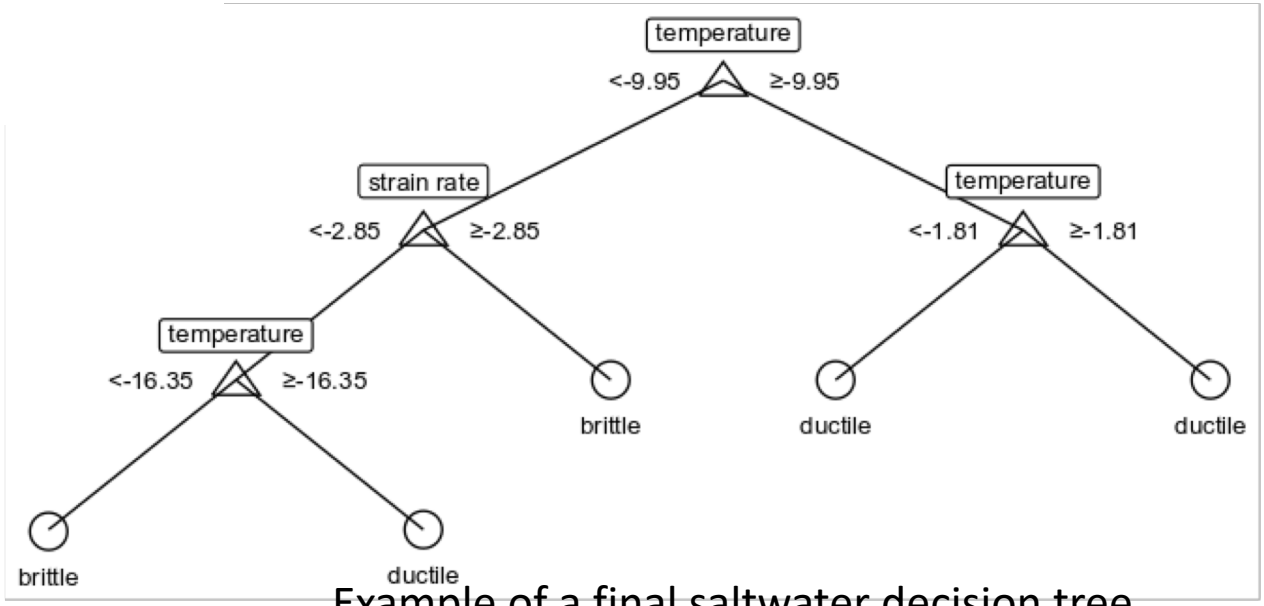




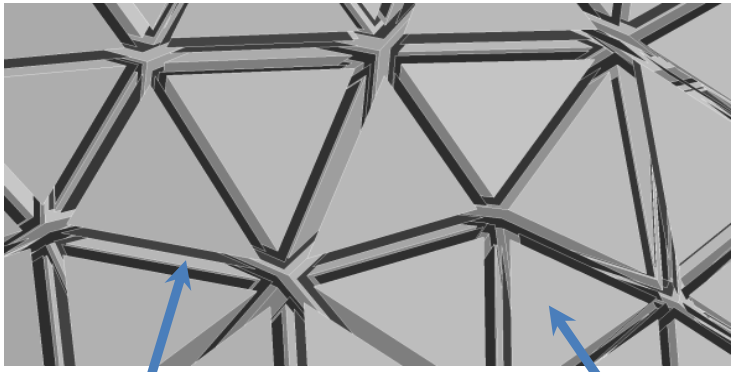
Example of a fresh water decision tree
(Accuracy: 91.4 %)

Machine Learning



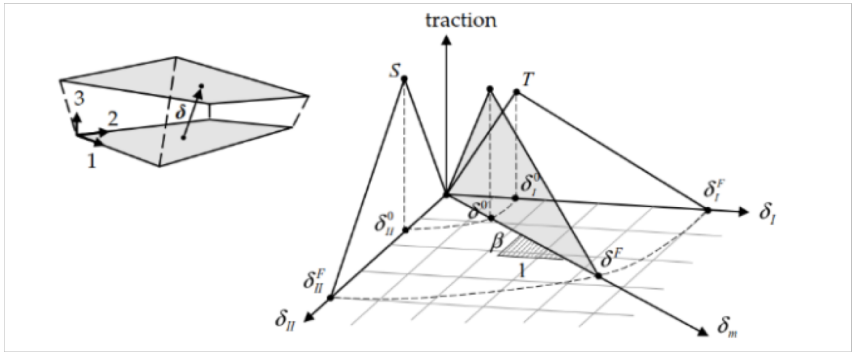
Example of a final saltwater decision tree
(Accuracy: 78.2 %)

Numerical CZM Simulation



CZM Element

Solid Element



Mat138 Mixed mode

Advantages:

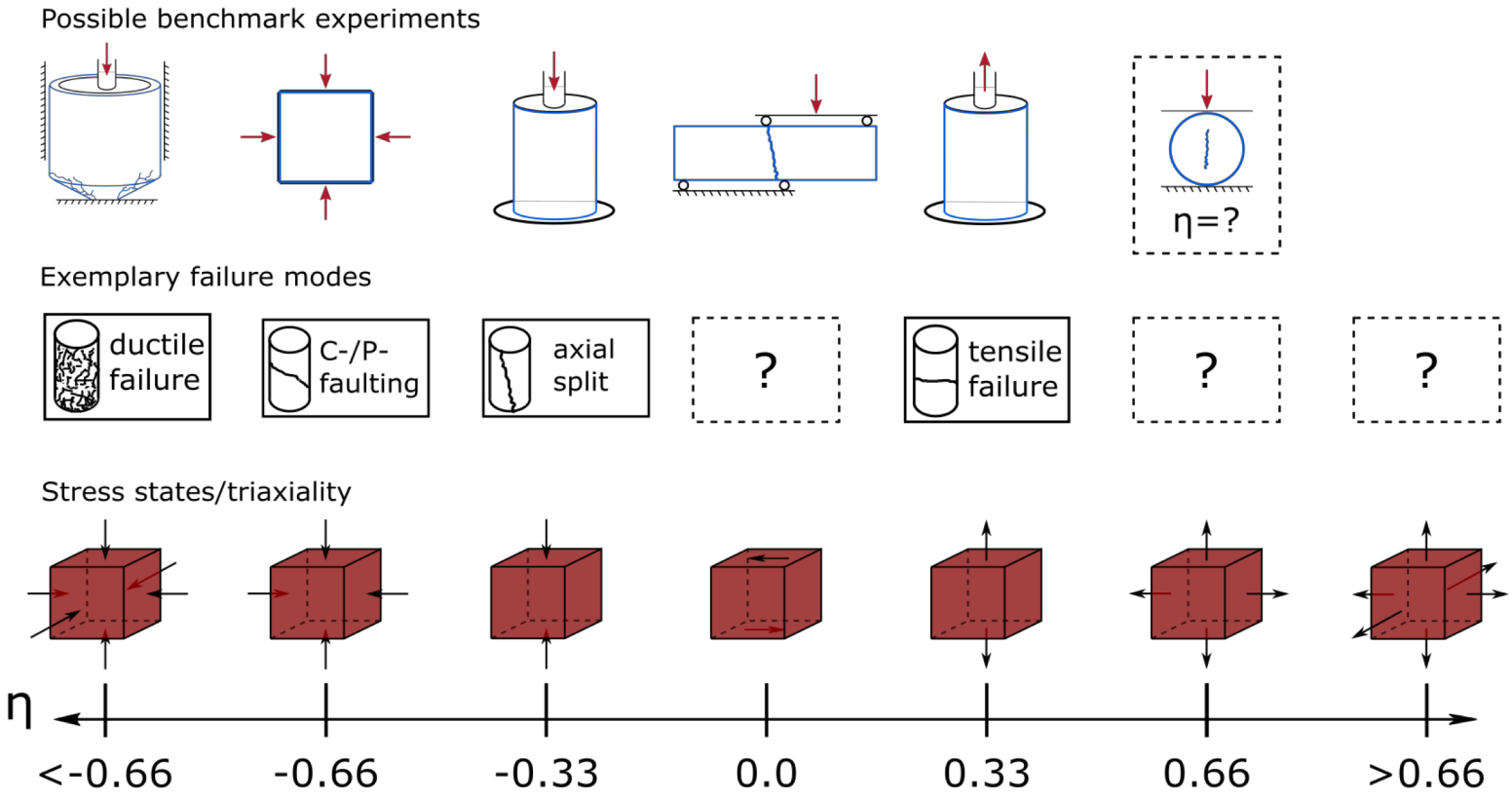
- Volume-preserving
- Arbitrary fracture paths
- Phenomenological model
- Few material parameters required

Disadvantages

- Significant increasing of degrees of freedom
- Small time step necessary
- Artificial compliance of CZM-Elements
- Loss of mass during element erosion

Benchmarking?

Exemplary series of benchmark tests and failure modes for different stress states, where the triaxiality is calculated as η=hydrostatic stress/von Mises stress.



Validating the CZM model

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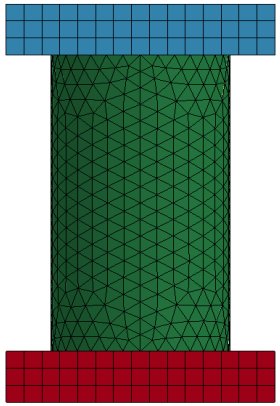
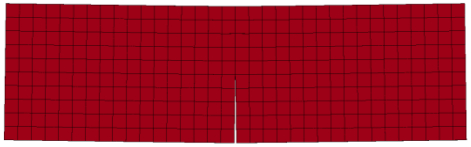
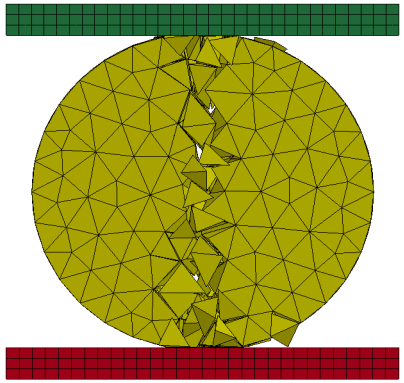
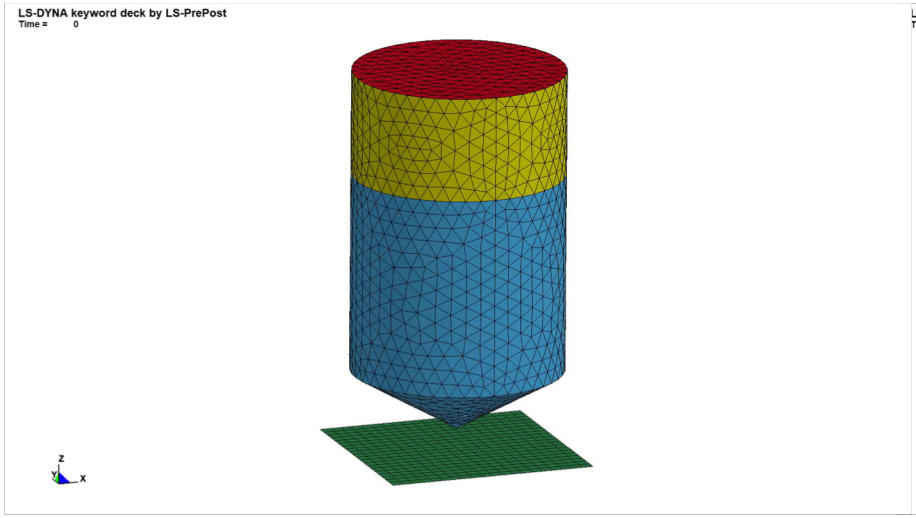
	Compression Test	CTOD Test	Tensile Splitting Test
FE-Model			
Source	Own Measurements	Wei, DeFranco 1991	Own Measurements
Ice-type	Distilled Water/Crushed Ice		Distilled Water/Crushed Ice
Experiment	50 kN	312 N	1.5 kN
Simulation	56 kN	323 N	1.8 kN

Herrnring et al. (2018): Simulation of Ice-Structure Interaction with CZM-Elements. LS-DYNA Forum 2018, Bamberg.

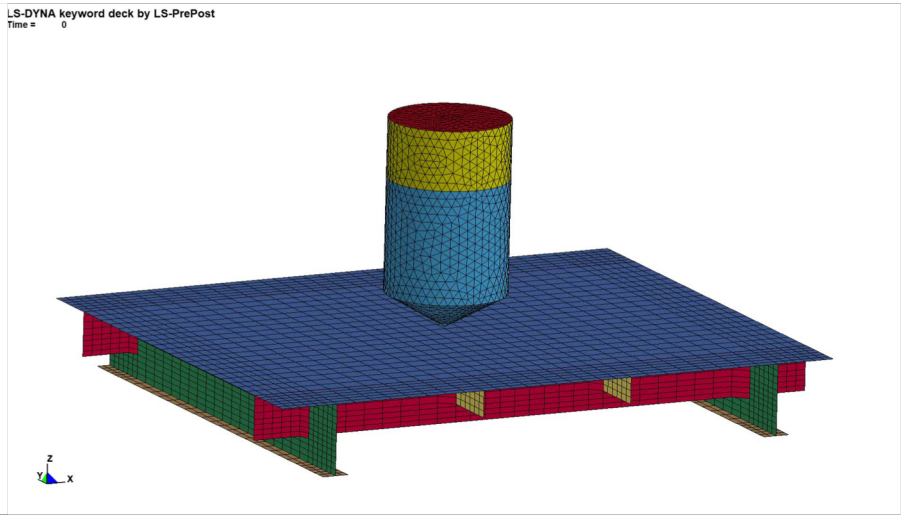
Drop test

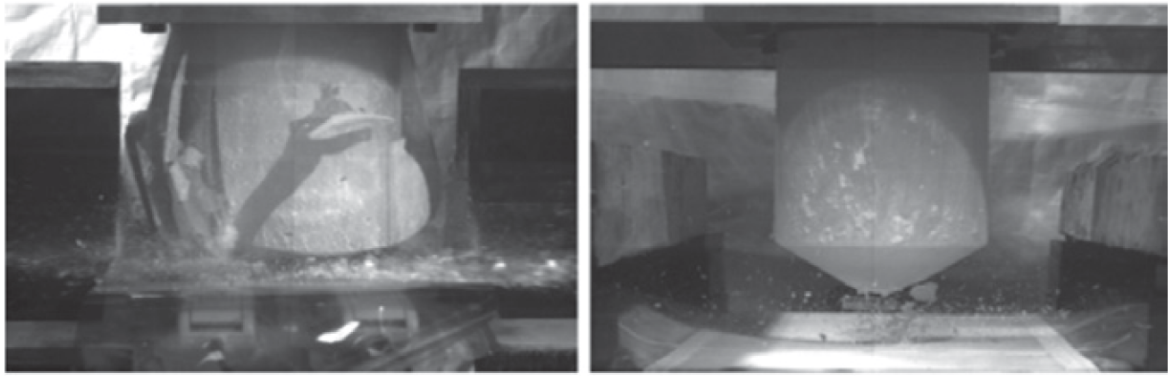
TUHH
Hamburg University of Technology

Drop test with 1,5 m/s against a rigid panel



Drop test with 1,5 m/s against a deformable aluminum panel





Herrnring et al.: Experimental investigation of an accidental ice impact on an aluminium high speed craft. *MARSTRUCT 2017*, pp. 697–704.