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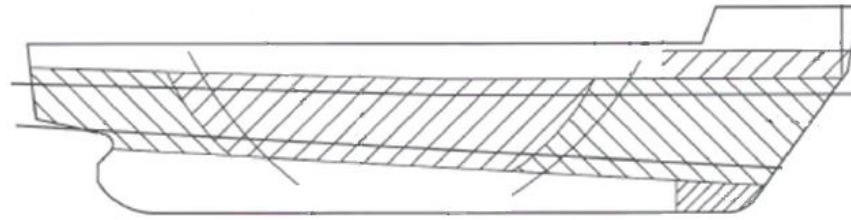
**Development of new
finite element
guidelines for hull
design in the
Finnish-Swedish Ice
Class Rules**

Ville Häyrynen

Background

FSICR structural rules

- ▶ Effective
- ▶ Safe
- ▶ Well established



What could we do better?

- ▶ Offer options
- ▶ Rigid -> Flexible
- ▶ Common -> Novel



HULLFEM Project

Winter Navigation Research Board &
Aker Arctic Technology Oy

Main goal

- ▶ Rule draft for alternative hull design approach

Key focus areas

- ▶ Preserve established safety level
- ▶ Enable direct calculation of any structural arrangement



Approach

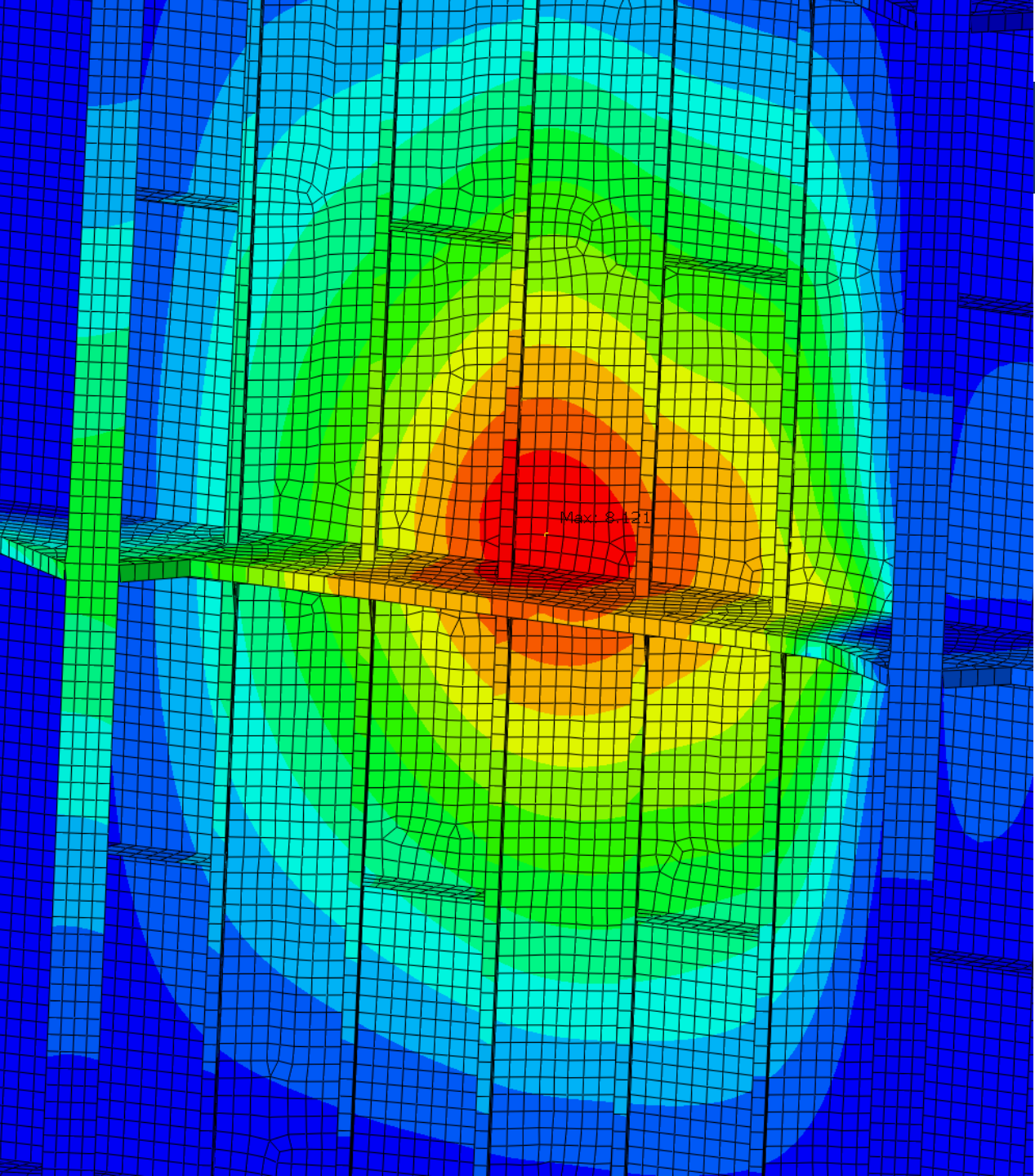
How we addressed the challenge?

Working backwards

1. Start from scantlings according to existing FSICR
2. Choose target acceptance criteria
3. Calculate design loads matching chosen acceptance criteria
4. Formulate new rule around calculated loading and chosen acceptance criteria

And succeeded!





AKER ARCTIC TECHNOLOGY

Development of new finite element guidelines for hull design in the Finnish-Swedish Ice Class Rules

2025-03-06

Ville Valtonen

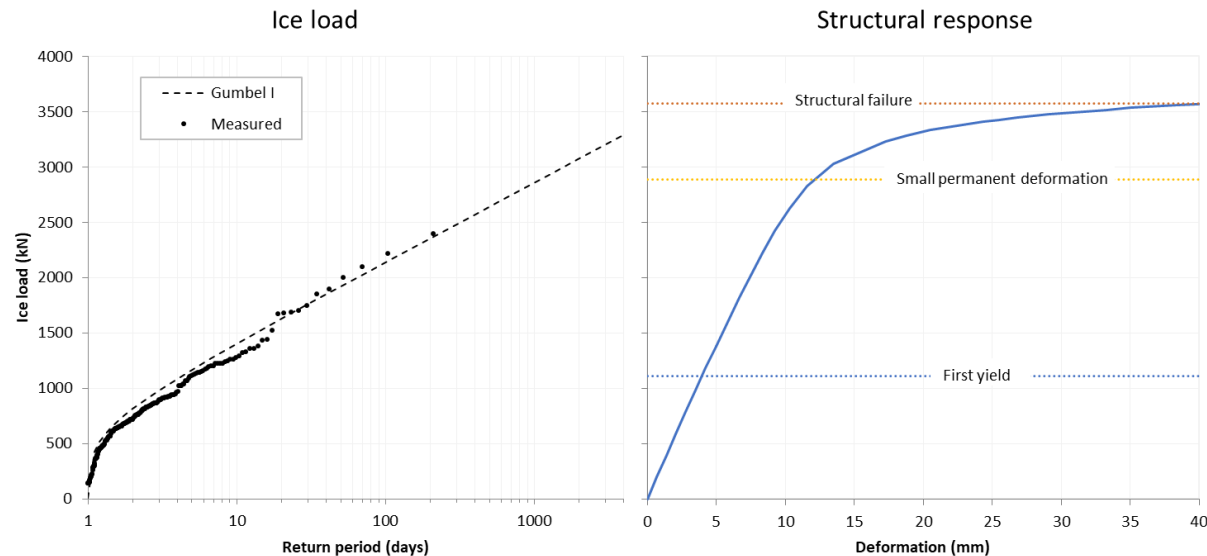
Goals for development of the FSICR hull part

- For a long time, there has been industry wish for relaxing requirements for structural arrangement, especially brackets, lugs, frame spacings, etc.
 - Wish to make ships easier and more economical to build
 - Possibility to assess novel structural solutions
- The Rules should keep up with the development of modern calculation methods and allow those to be used
- Current strength level correct, good service experience – should not be changed



Background – current rule formulas

- Original background in large damage studies made in 1980's and 2003
- Proven by long and favorable service experience – ships designed to FSICR perform well in the Baltic Sea
 - Damages to FSICR ships on Arctic and other regions outside the scope of FSICR - not considered
- Based on linear elastic theory, yield limit
- Design load has relatively small return period (Risk: abt. 10 days), exceeded rather often in service
- Strict requirements for structural arrangement guarantee large plastic reserve -> the structure has sufficient capacity beyond design point for carrying the occasional larger loads



[Development of new finite element guidelines for hull design in the Finnish-Swedish Ice Class Rules](#)

[Ville Valtonen](#)

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Design point

- Ultimately, the goal of ice class hull rules is to ensure safety and minimize repairs, with minimal weight penalty
- In practice, this requires two things:
 - In normal service, significant denting should be avoided, small permanent deformation (couple of mm) is acceptable
 - In accidental scenario, structure may deform locally, but should retain load-carrying capacity and watertightness



Objectives for new method

- Relax requirements for structural arrangement
- Possibility to assess novel structural configurations
 - More design freedom and possibility for new, better solutions
 - Not just some correction factor for leaving out brackets
- Retain current strength level, both at design load and at overload
 - Safety
 - Economics
- Method should be as simple and easy to use as possible
 - Clear criteria for pass / fail
- Method should be robust, so that everyone gets the same results
 - Small variations in modeling practice, meshing, etc. should not result in large variation of result
- More direct connection between design criteria and desired outcome
 - Permanent deformation in service should be small – no or little need for repairs of ice damage
 - Sufficient margin for catastrophic failure (holes, extensive dents or wider damage)

Development of new method

- Finite element method (FEM) is the obvious starting point
 - Has become popular tool for analysing ship structures
 - Currently, lot of ship design is done in 3D models, which allows finite element analysis much easier than 2D drawings
 - Can consider various structural configurations, not limited to one idealization
- IACS Polar Class rules rely on direct calculation (in practice, FE) for design of primary structures
 - Can be either linear or non-linear
- Of course, there would be other tools, for example grillage / 3D-beam analysis available
 - These may be simpler to use
 - But would not address effectively the wish for more freedom for structural arrangement

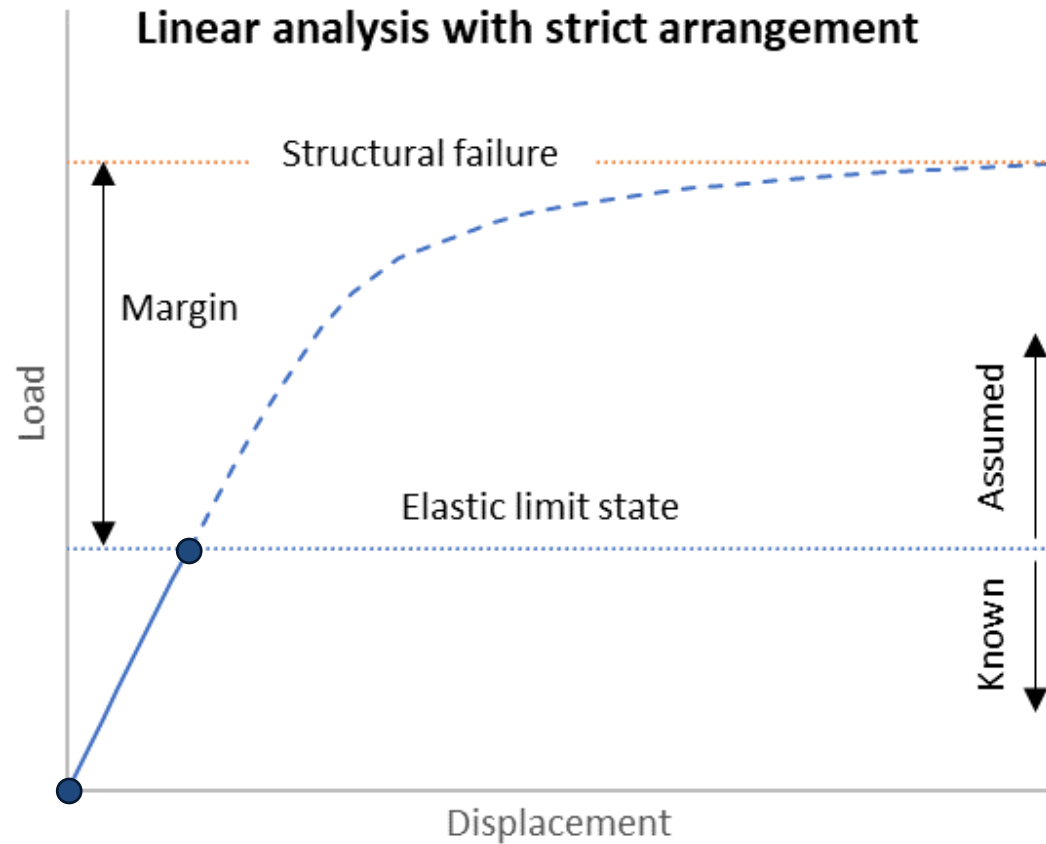
Linear FEM

- Straightforward process
- Widely used
- Well established modelling practices
 - Guidance available in most Classification Society rules
- Yield limit
- Can not predict what happens beyond yield
 - Amount of margin
 - Failure mode – gradual vs. sudden
 - Plastic margin can be guaranteed by strictly controlled structural arrangement
- Can not directly consider buckling and especially post-buckling behaviour
- Local stress concentrations at sharp corners
 - Mesh dependent

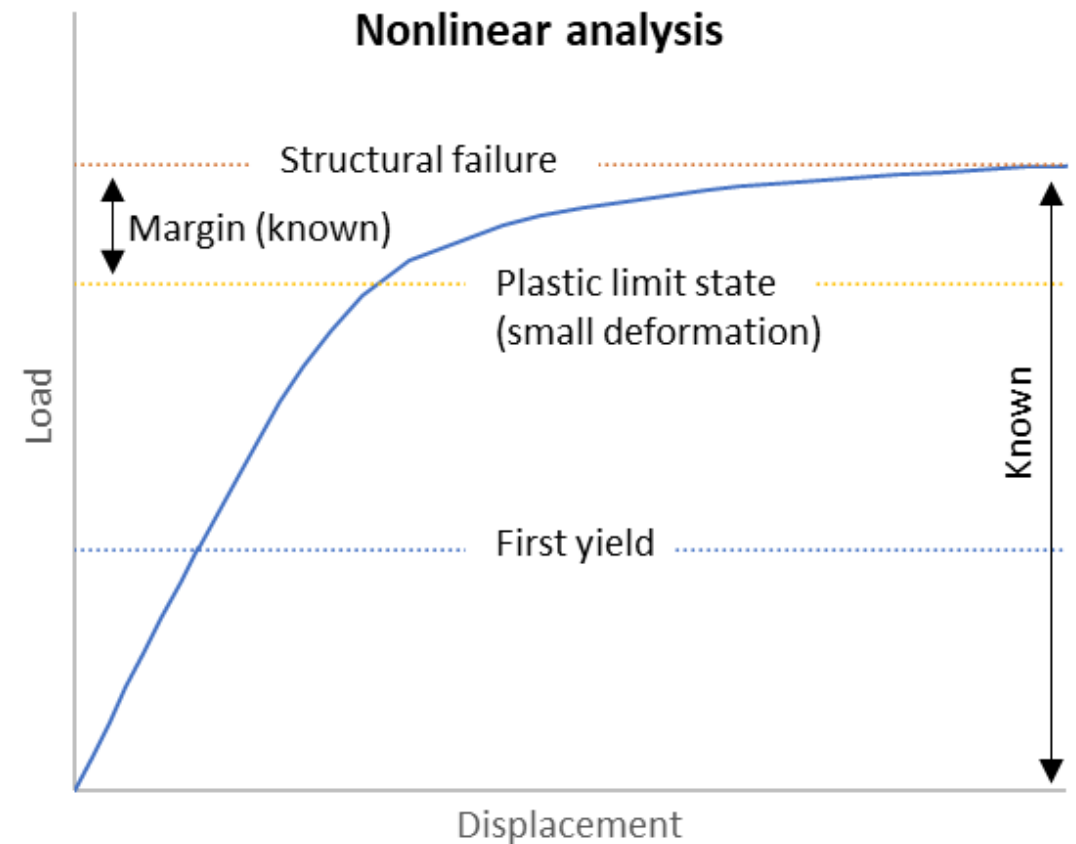
Non-linear FEM

- Some additional things needed for analysis
 - More parameters for material model
 - Load incrementation
 - Large displacement formulations
- Not as widely used (yet)
- Several Classification Societies have guidelines available for PC rules
- Can predict accurately behaviour up to failure
 - Plasticity
 - Buckling, tripping, etc.
 - Tensile failure more complicated to model accurately
 - Margin to failure can be calculated
- Desired outcome (limited permanent deformation) can be directly used as acceptance criteria

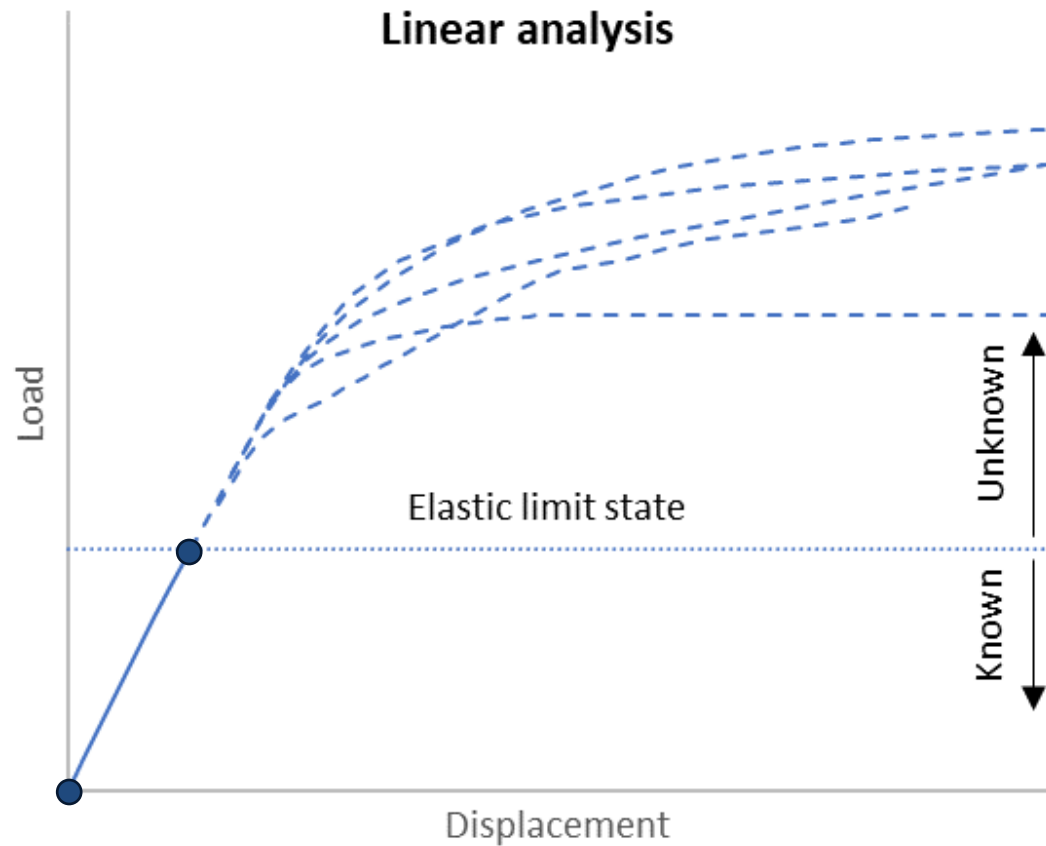
Linear FEM



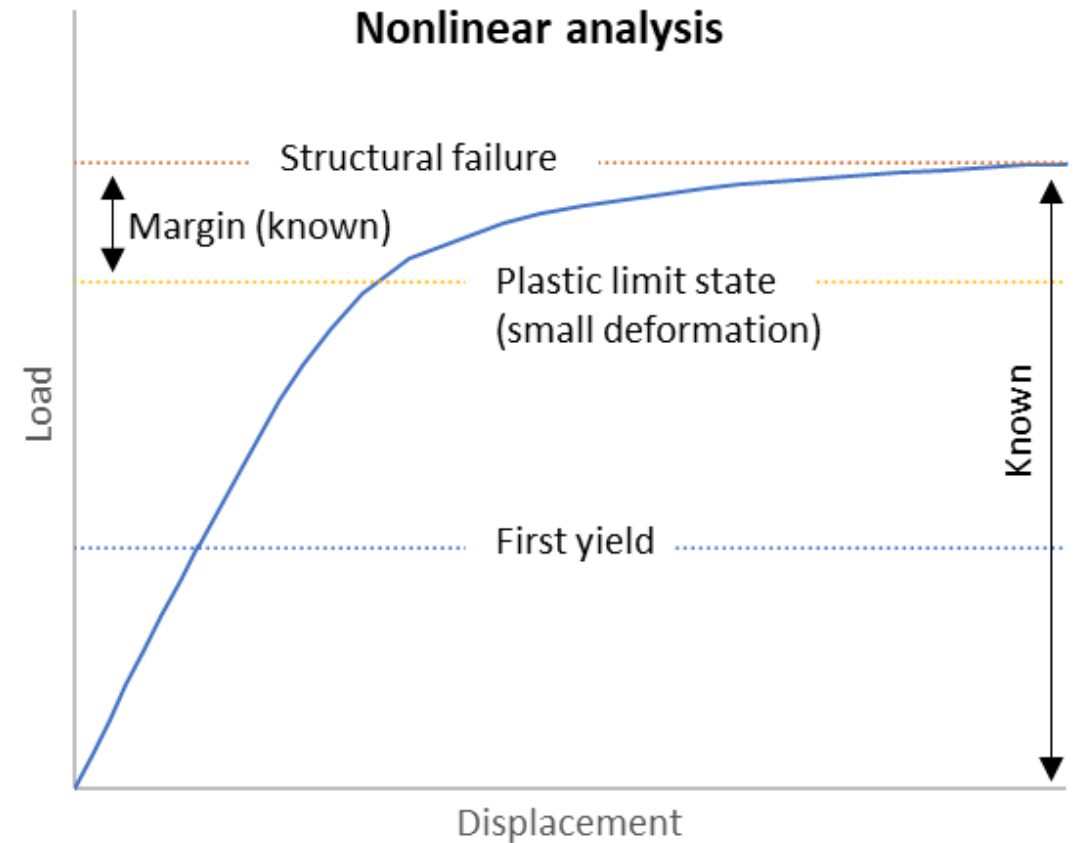
Non-linear FEM



Linear FEM



Non-linear FEM



Selected method for new rules

- Non-linear FE selected
 - Direct link to desired structural response (small permanent deformation)
 - Certainty of margin to failure
 - Allows most design freedom – no need for strict requirements on structural arrangement
- Approach aligned with IACS PC Rules where practical – familiarity for designers and Class Societies
- Allowed permanent deformation linked to IACS Rec. 47 – Shipbuilding and Repair Quality Standard
 - As long as permanent deformation caused by ice is less than allowed (welding) deformation for newbuild:
 - In principle, it is not possible to determine if the deformation is caused by ice or has been there since new
 - Deformed structure retains load-carrying capacity equal to acceptable newbuilt vessel
 - Long list of allowed deformations simplified to 8 mm allowed permanent deformation
 - It is also allowed to use IACS rec. 47 values instead

Practical differences between linear and non-linear FE



Similarities

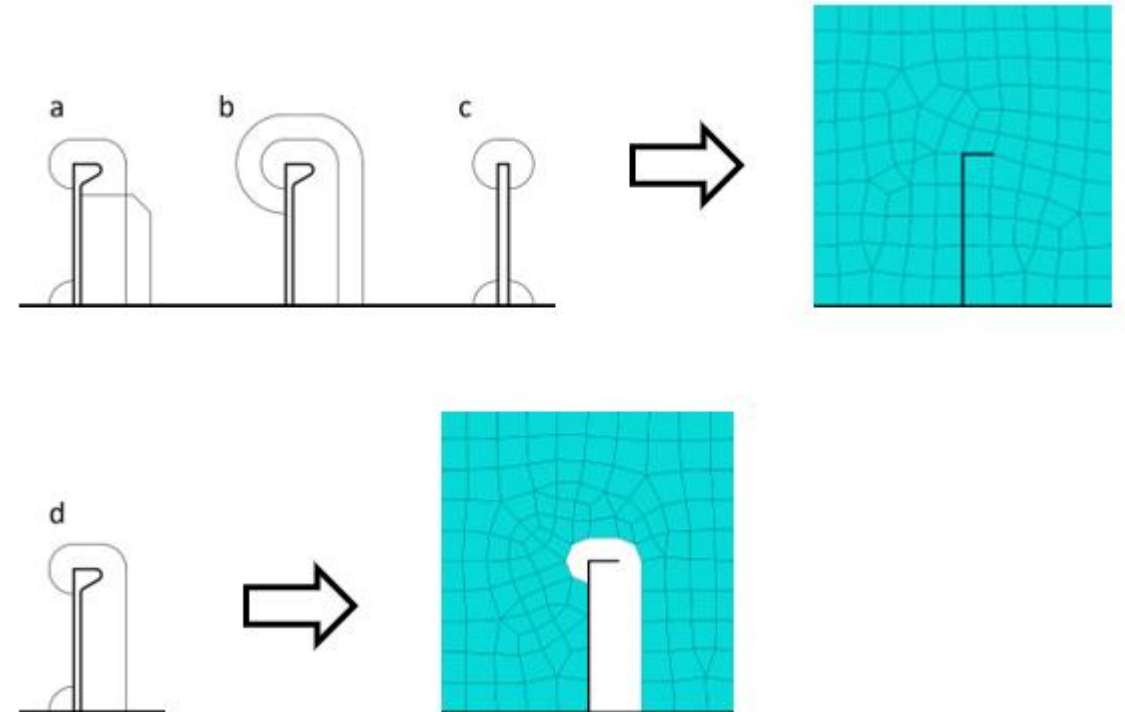
- Geometry modeling
- Meshing
- Boundary conditions
- Load application as pressure patch load
- Checking calculated deformations against allowed

Differences

- Material model – additional parameter for plasticity
- Large deformation formulas – geometric non-linearity
- Incremental load application, release after loading to get permanent deformation

Approach in the new rules – modeling and meshing

- Generally follows Classification Society guidelines for NLFEA for IACS PC classes
- Model size, recommend between two transverse bulkhead, at least two webframe spacings between load and boundaries
- Shell model, element size 8 elements between stiffeners, 3-4 elements on stiffener web
- Gross thicknesses, except shell plate net
- Bulb profiles as equivalent L-profiles
- In general, manholes, end connections etc. should be modeled
- Drain holes, scallops, welds, etc. (small details) need not to be modeled
- In general, sufficient to analyse the most onerous location of hull region, and use same scantling for the rest of the region



Design loads

- Load patch height h and length l_a .
- Load patch parallel to waterline
- Load patches should be applied at UIWL, $0.5 h_i$ below LIWL and at centre of effective span
- Ice load need not to be applied outside vertical extents for shell plate

Table 4-1: Values of h_i and h for the different ice classes

Ice Class	h_i [m]	h [m]
IA Super	1.0	0.35
IA	0.8	0.30
IB	0.6	0.25
IC	0.4	0.22

Table 4-4: Values of l_a for different structural elements.

Structure	Type of framing	l_a [m]
Shell	Transverse	Frame spacing
	Longitudinal	$1.7 \times$ Frame spacing
Frames	Transverse	Frame spacing
	Longitudinal	Span of frame
Ice Stringer		Span of stringer
Web frame		$2 \times$ Web frame spacing

Table 4-10 Suggested load patch locations for transversal framing

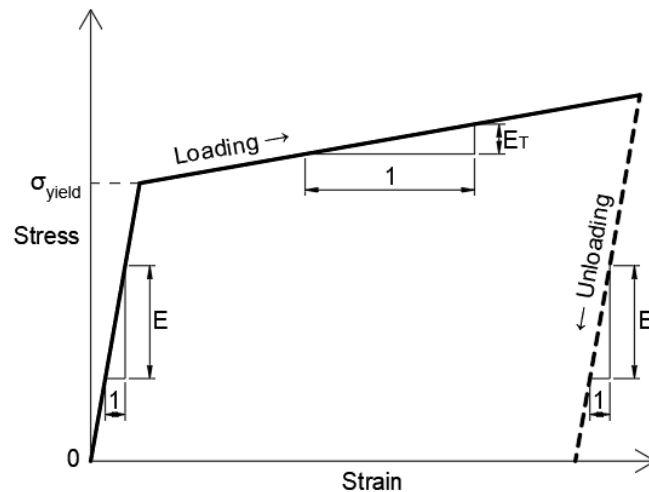
	Vertical	Horizontal
Transverse frame	<ul style="list-style-type: none"> - at UIWL - at $0.5 h_i$ below LIWL - at centre of effective span - at ends of effective span, when end connection not according to 4.4.4 	<ul style="list-style-type: none"> - centred on frame
Stringer	<ul style="list-style-type: none"> - centred on stringer 	<ul style="list-style-type: none"> - at centre of effective span - in way of manholes or large cutouts
Web frame	<ul style="list-style-type: none"> - at UIWL - at $0.5 h_i$ below LIWL - at centre of effective span - at each stringer within ice belt - in way of manholes or large cutouts 	<ul style="list-style-type: none"> - centred on web frame

Table 4-11 Suggested load patch locations for longitudinal framing

	Vertical	Horizontal
Longitudinal frame	<ul style="list-style-type: none"> - centred on frame 	<ul style="list-style-type: none"> - at centre of effective span - at ends of effective span, when end connection not according to 4.4.4
Web frame	<ul style="list-style-type: none"> - at UIWL - at $0.5 h_i$ below LIWL - at centre of effective span - at each end of effective span - in way of manholes or large cutouts 	<ul style="list-style-type: none"> - centred on web frame

Material model

- In general, bilinear plastic model recommended, tangent modulus 1000 MPa
- Approach aligns with IACS PC NLFEA practices of Class Societies
- Possibility to use more sophisticated models
- In studies made, at the relevant load levels, differences between material models small



Development of new finite element guidelines for hull design in the Finnish-Swedish Ice Class Rules

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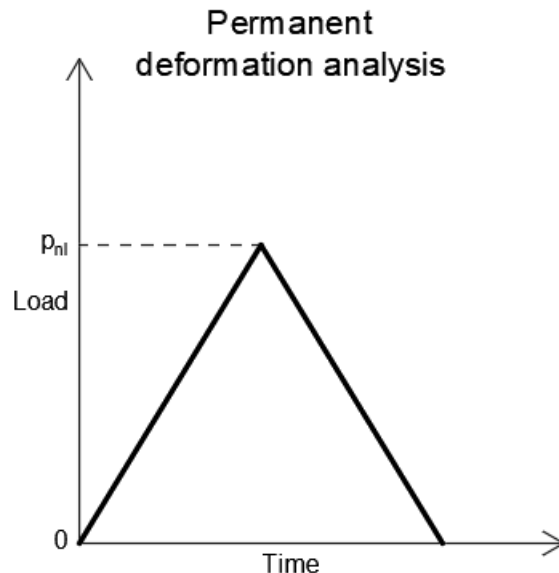
Solution

- Can use implicit or explicit
- Geometric nonlinearities and buckling shall be considered – large displacement formulations
- Load shall be applied incrementally
 - For structure which behavior is governed by plastic hinge mechanism or gradual buckling, automatic incrementation and relatively big increments work well
 - For structure which behavior is governed by sudden buckling, may need to use smaller increments to obtain accurate solution
 - Stabilization / damping should generally be avoided – can overestimate capacity

Acceptance criteria for the new rules

Permanent deformation analysis

- Way to make the structure sufficiently strong for regular service, but no stronger (heavier) than necessary
- Ensures that the permanent deformations in normal service do not exceed newbuilding tolerances (IACS rec. 47)
 - 8 mm in any direction (total deformation)



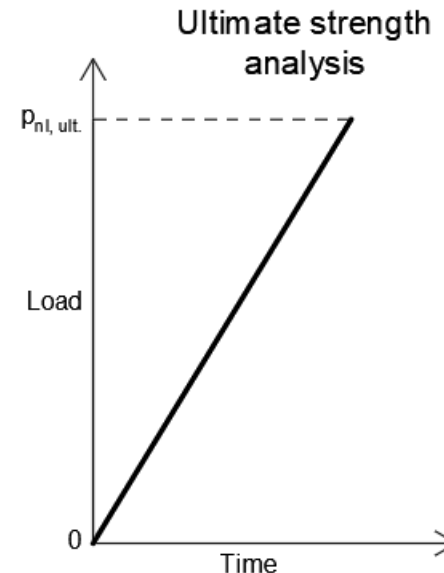
Development of new finite element guidelines for hull design in the Finnish-Swedish Ice Class Rules

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2025-03-06

Ultimate strength analysis

- Ensures that the analyzed structure has the reserve strength that was earlier achieved by strict structural arrangement
- Typical maximum ice loads encountered on the Baltic Sea should not lead to loss of load-carrying capacity, i.e. major damage
- The load-deformation curve shall have a continuously positive slope up to the ultimate ice load.



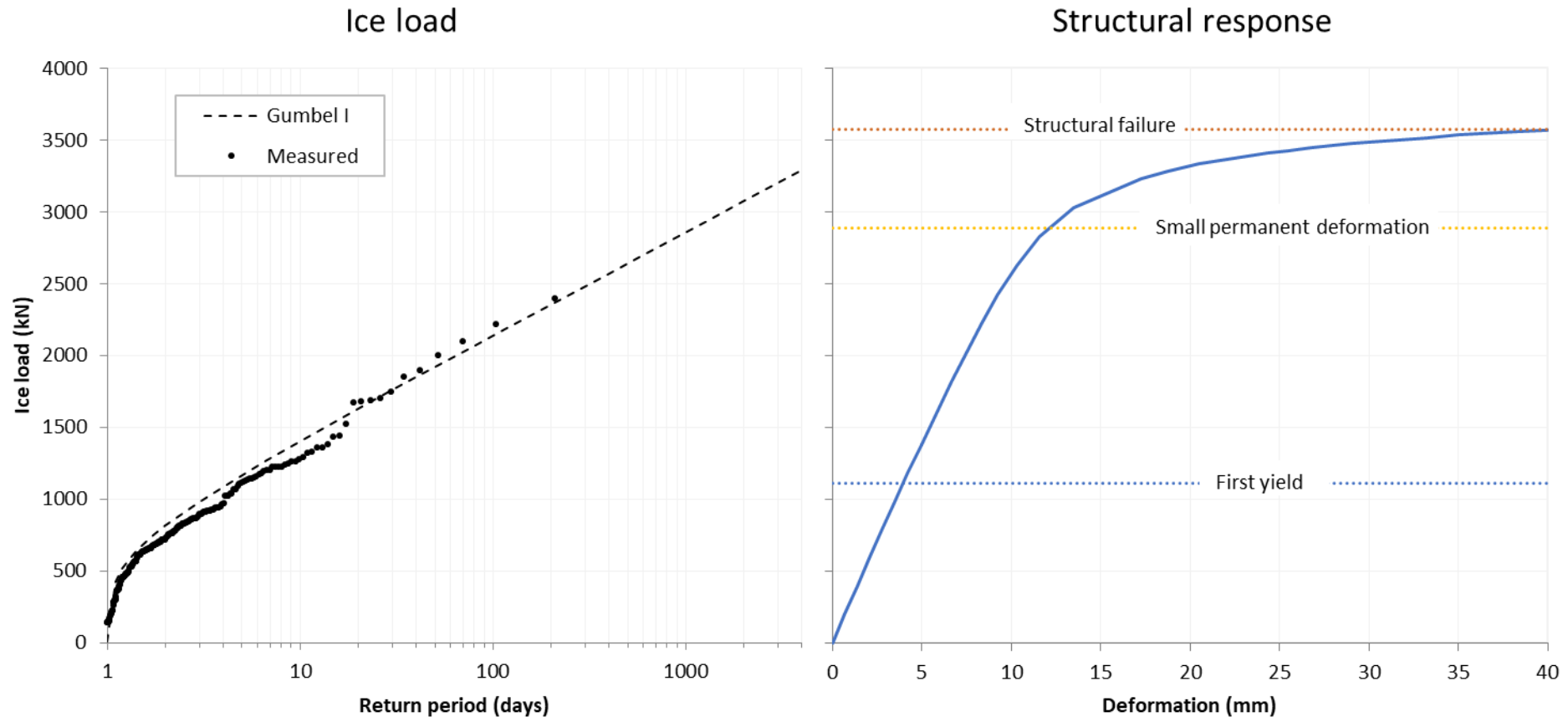
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HULLFEM I, II & III studies to set equivalent strength level

- Target to keep same level of strength, acceptance criteria changed → How should we modify the design load to achieve this?

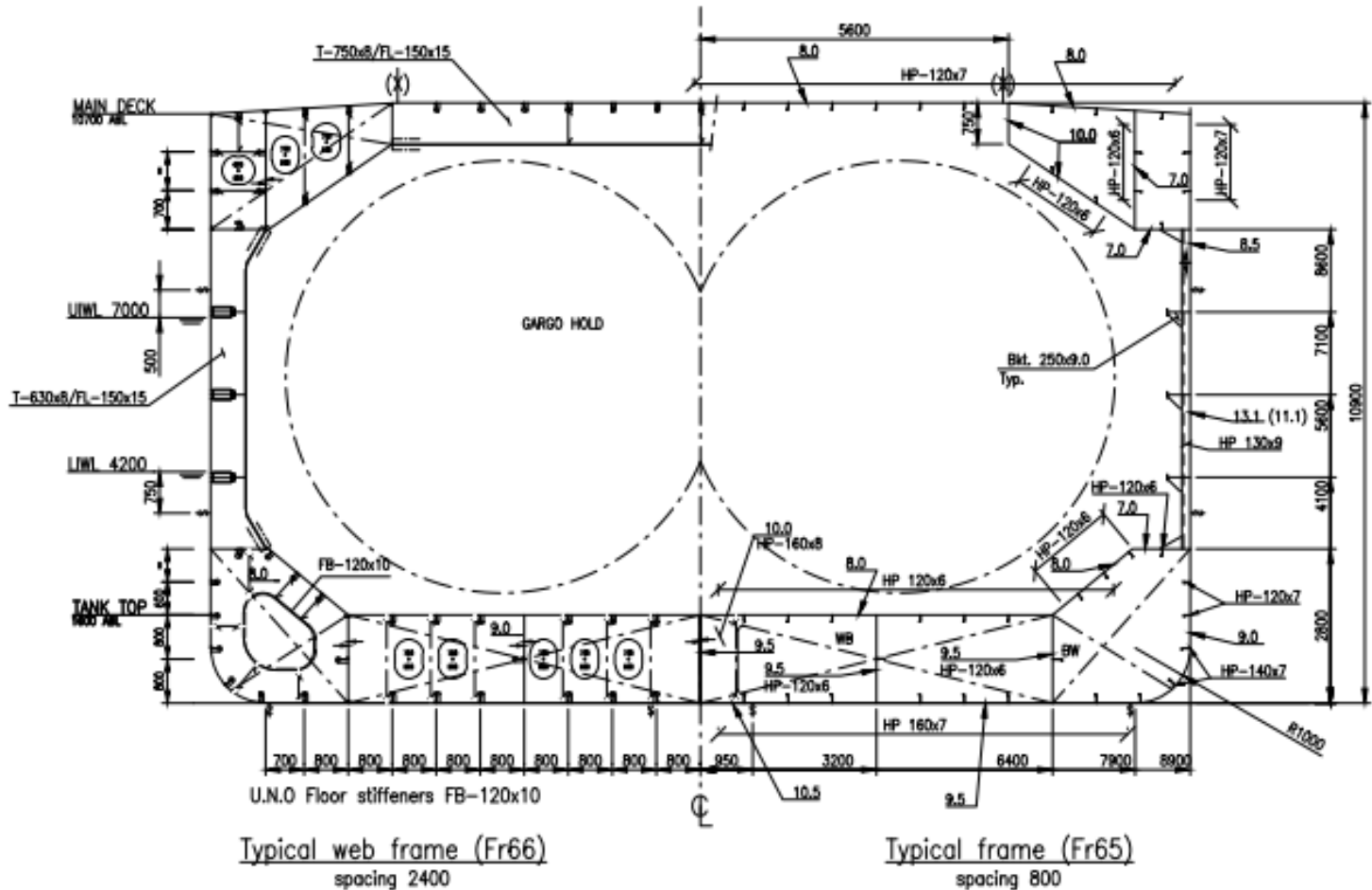


HULLFEM I, II & III studies to set equivalent strength level

- To obtain correct design load, representative sample of example vessels designed to minimum scantlings of current rules
 - In total, 15 vessels / configurations modeled and analysed
- Each example vessel analysed to obtain the load at which the selected limit states are reached
- Vessels chosen:
 - General cargo vessels, small (3000 DWT), medium (10000 DWT) and large (58500 DWT)
 - Medium bulk carrier (single skin version of medium general cargo vessel)
 - RoPax (typical Tallinn / Stockholm ferry)
 - Small-medium LNG tanker
 - Large oil tanker (Aframax)
 - For each of these, midbody modeled and analysed
 - Small ships (archipelago ferries, tugs, etc.) not covered
- In addition:
 - Medium general cargo vessel analysed with three ice classes, IC, IA and IAsuper
 - Medium bulk carrier analysed with several different framing configurations (transverse, $s = 400/600/800$ and longitudinal, $s = 400/600$)
 - Bow of medium general cargo / bulk carrier modeled and analysed

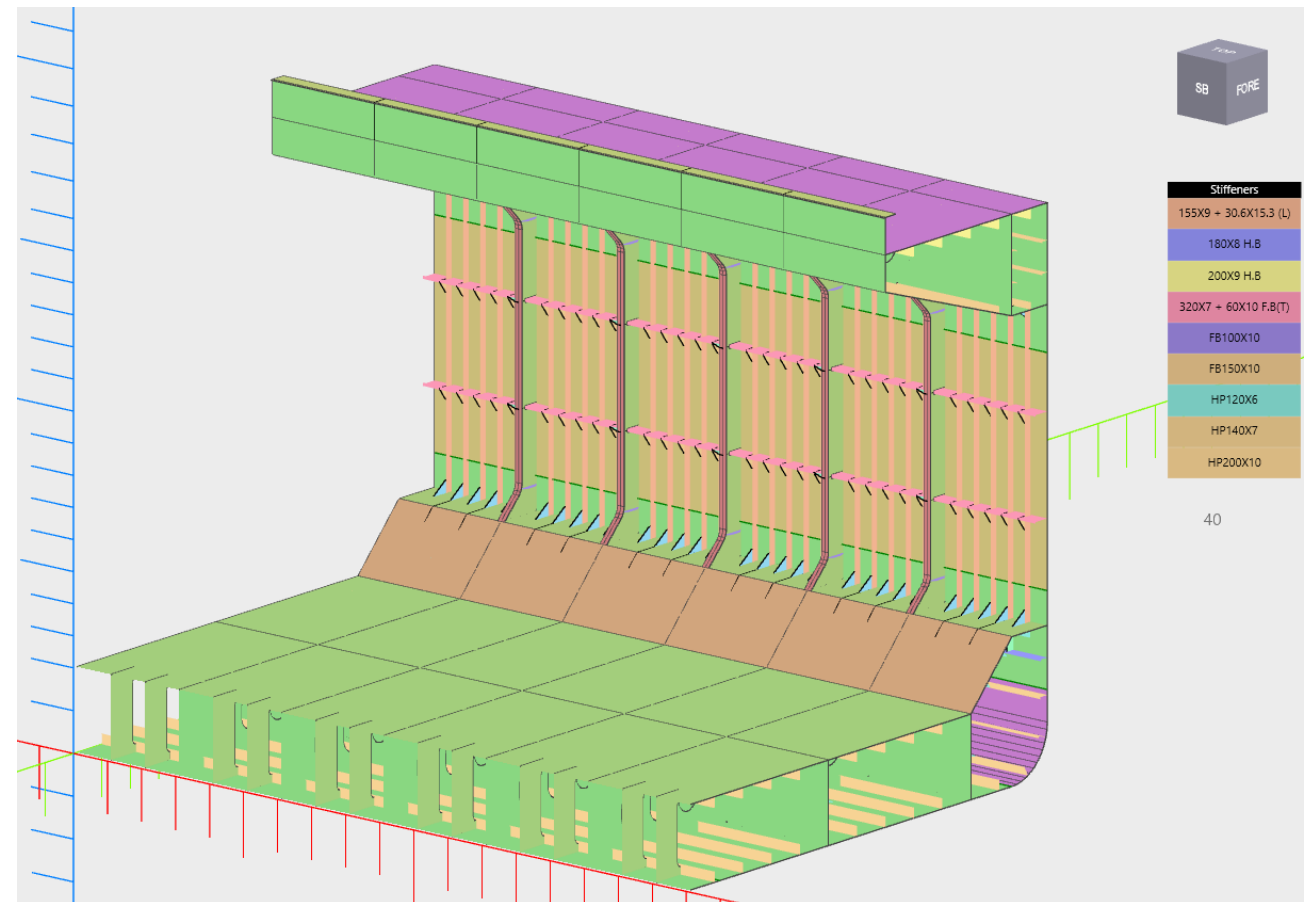
HULLFEM I, II & III studies to set equivalent strength level

- Each vessel designed to Class and FSICR minimum scantlings



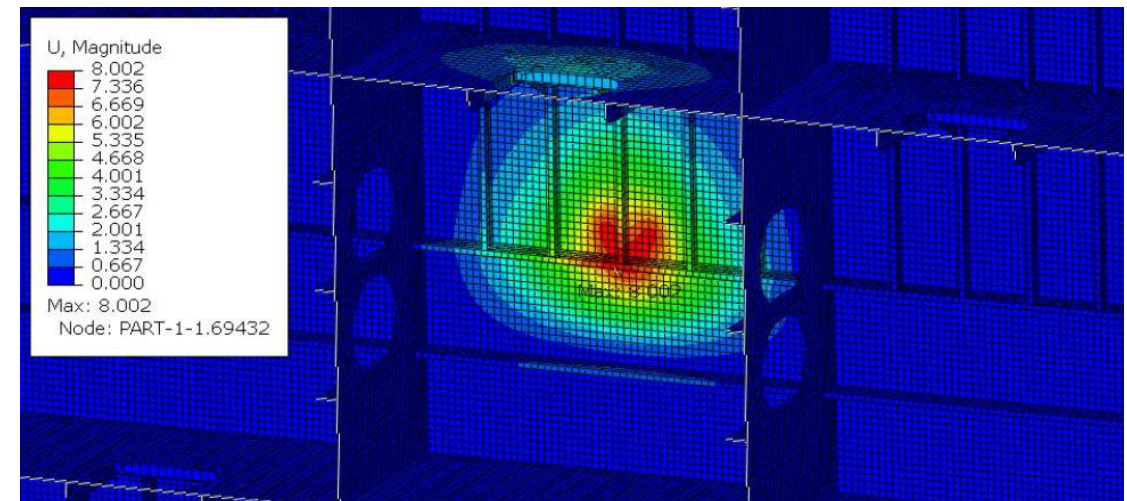
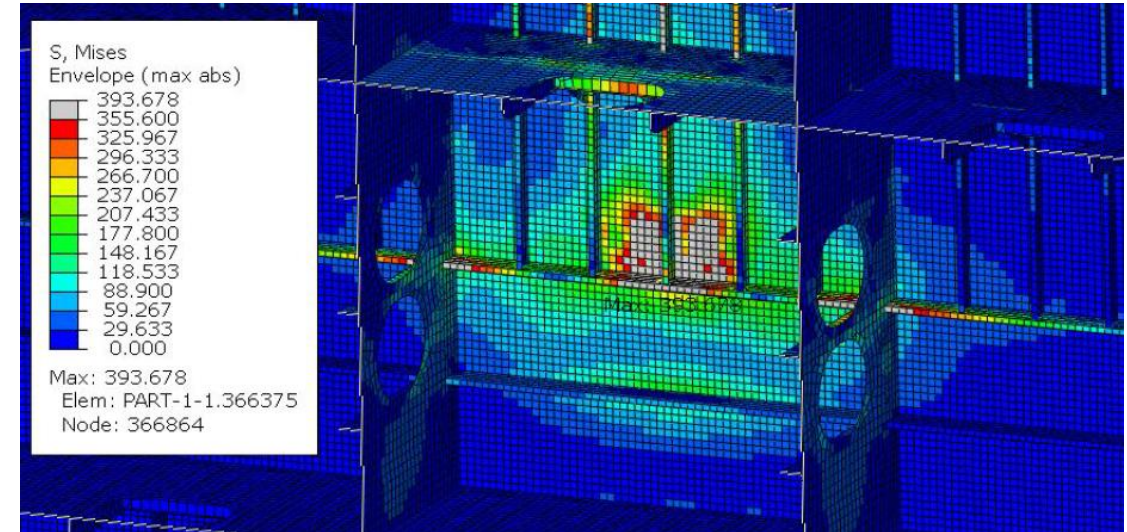
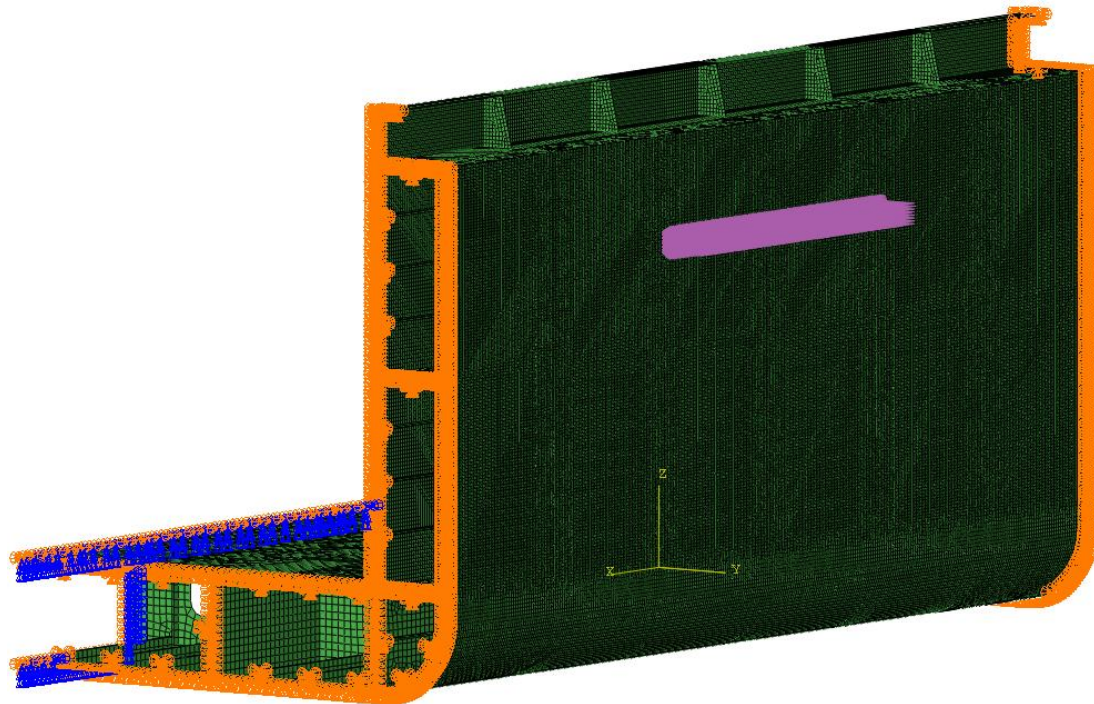
HULLFEM I, II & III studies to set equivalent strength level

- Each vessel designed to Class and FSICR minimum scantlings
- Modeled and meshed in NAPA Designer



HULLFEM I, II & III studies to set equivalent strength level

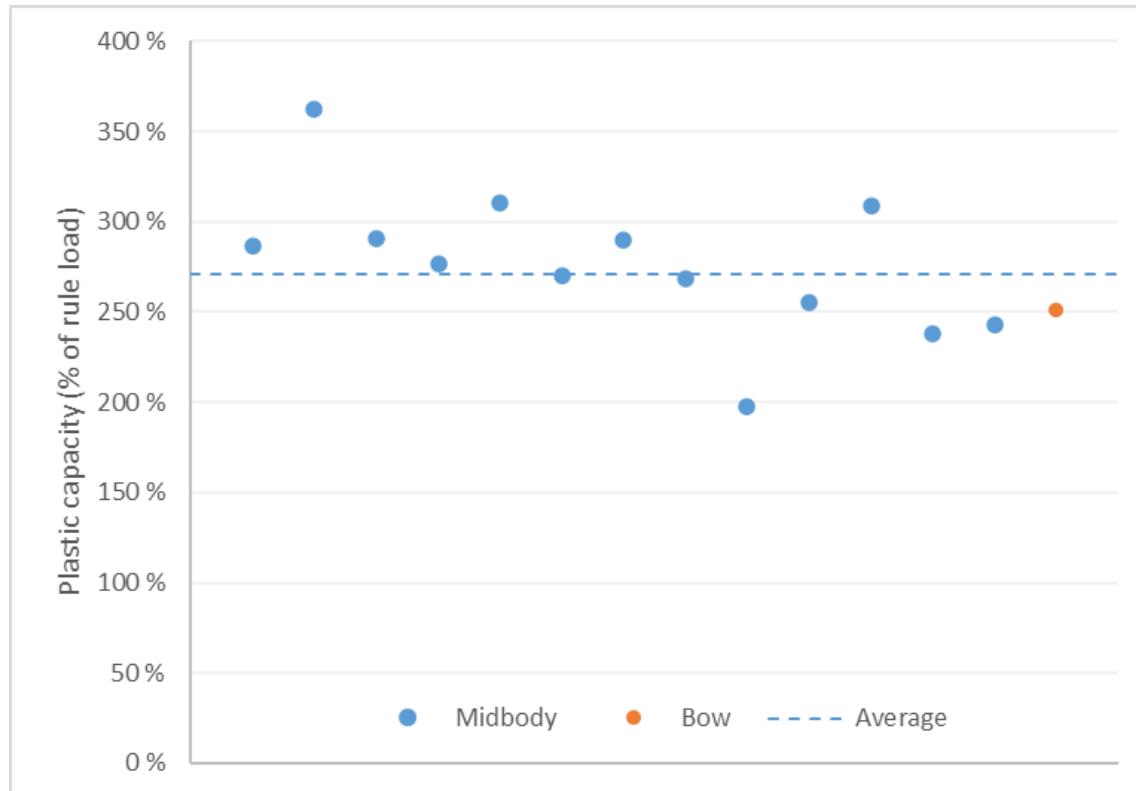
- Each vessel designed to Class and FSICR minimum scantlings
- Modeled and meshed in NAPA Designer
- Analysed with Abaqus
 - Script to iterate load level to find load at which limit state reached



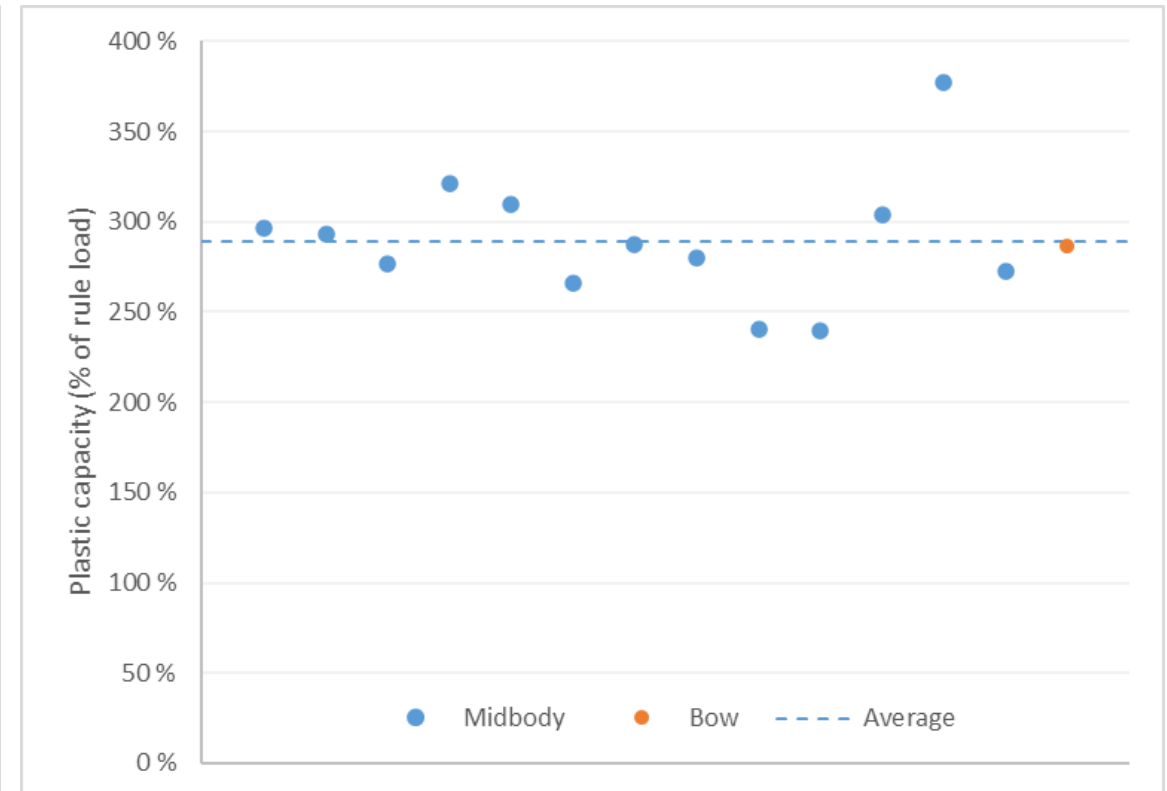
HULLFEM I, II & III studies to set equivalent strength level



Shell plate – design load with 8 mm perm. def.



Frames – design load with 8 mm perm. def.

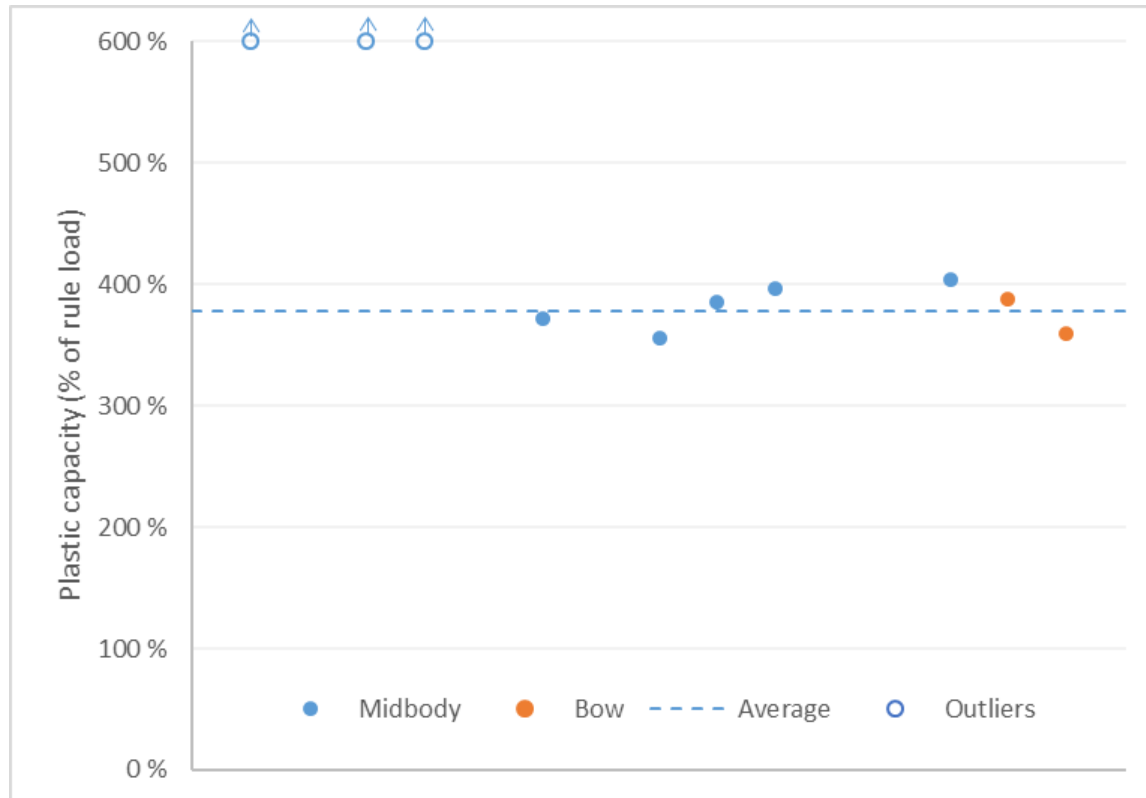


Average $\approx 2.90 \cdot$ rule design load

HULLFEM I, II & III studies to set equivalent strength level

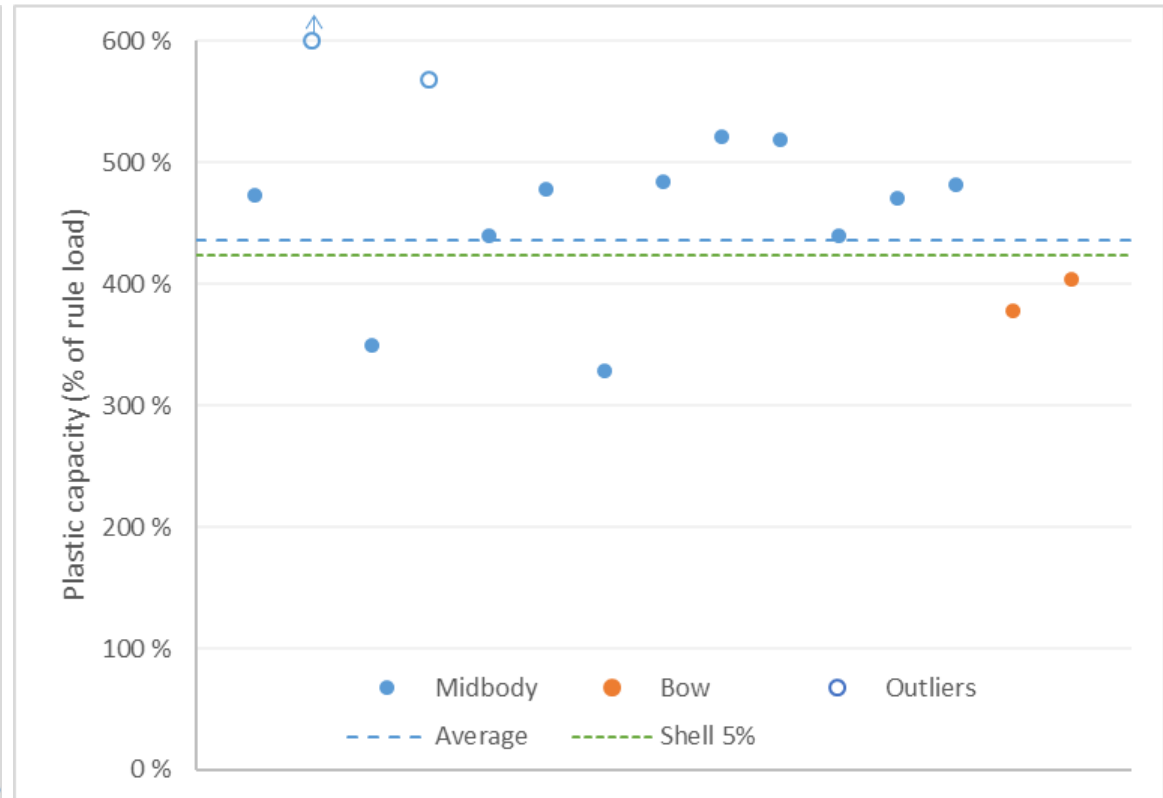


Stringers – design load with 8 mm perm. def.



Average \approx 3.80 • rule design load

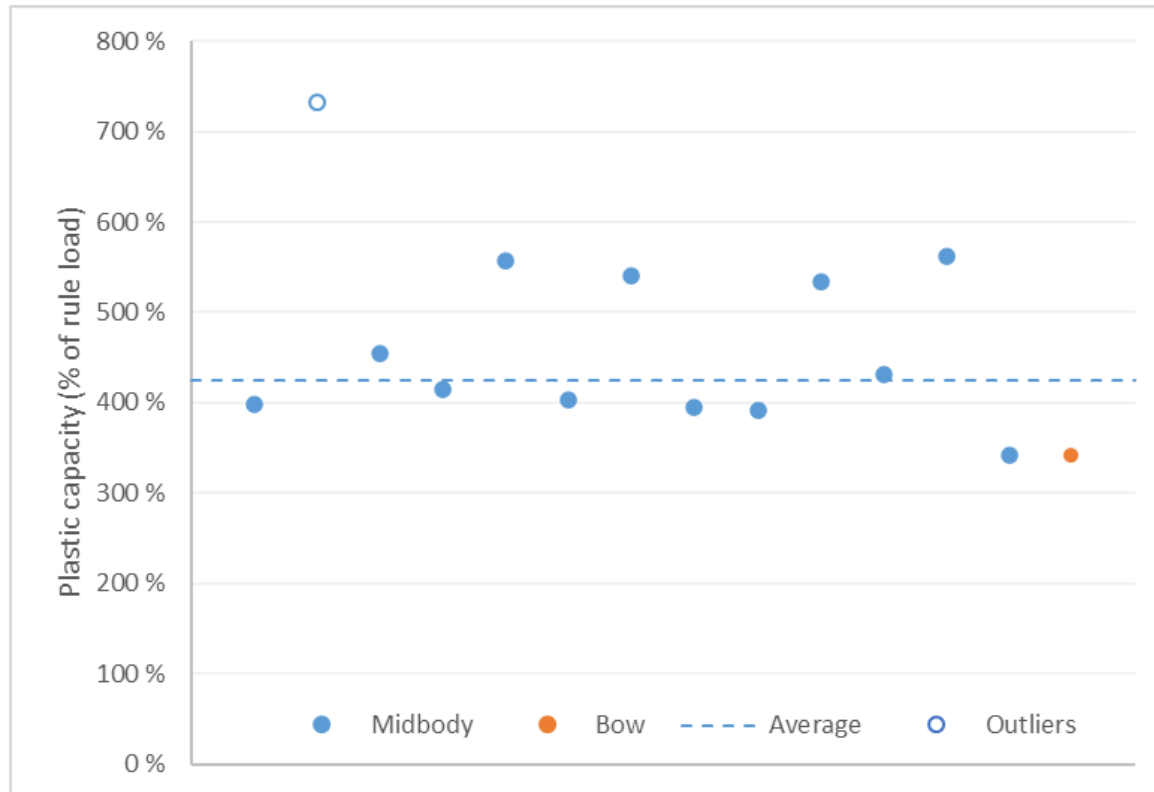
Web frames – design load with 8 mm perm. def.



Average \approx 4.55 • rule design load

HULLFEM I, II & III studies to set equivalent strength level

Shell plate, to 5% of frame spacing permanent deformation – the largest measured typical ice damages on the Baltic Sea i.e. the expected ultimate ice load



Average \approx 4.25 • rule design load

HULLFEM I, II & III studies to set equivalent strength level

- For frames, permanent deformation should be below newbuilding limits at 2.90 times rule load. Equivalent strength to current rules (average 289%).
- For stringers, permanent deformation should be below newbuilding limits at 3.80 times rule load. Equivalent strength to current rules (average 379 %).
- For web frames, permanent deformation should be below newbuilding limits at 4.25 times rule load. Typical reasonable web frames designed to current rules are slightly above this, around 4.55 (average 456 %). Since ice damages suggest that loads in service have not exceeded 4.25 even for the damaged vessels, that is set as the required strength.
- For all structures, there should be positive slope on load-deformation curve up to 4.25 times rule load. This corresponds to typical maximum of measured ice damages (average 424 %). In essence, would be very rare to have loads that exceed this level.

$$\text{Design load } p_{nl} = f_{13} \frac{h l_a}{h_m l_m} p$$

$$\text{Ultimate load } p_{nl,ult.} = f_{14} \frac{h l_a}{h_m l_{a,m}} p$$

Structural member	f_{13}	f_{14}
Frames (section 4.4)	2.90	4.25
Ice stringers (section 4.5)	3.80	4.25
Web frames (section 4.6)	4.25	4.25

- All background studies are published as Winter Navigation Research Board reports (No. 125, 128 and 132), can be found at <https://www.traficom.fi/fi/ajankohtaista/julkaisut/talvimerenkulun-tutkimusraportit>

How to design ships to FSICR in future?

- Prescriptive method kept in the rules
 - Can be used just like before
 - Simple and efficient
 - Limited to traditional structural configuration
- Alternatively, can use the new non-linear FE method
 - Equal level of strength
 - Same or improved safety
 - Same weight
 - Freedom for structural configuration
 - Ability to assess novel structural configurations





THANK YOU

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