Better Tools for Designing Primary Structures

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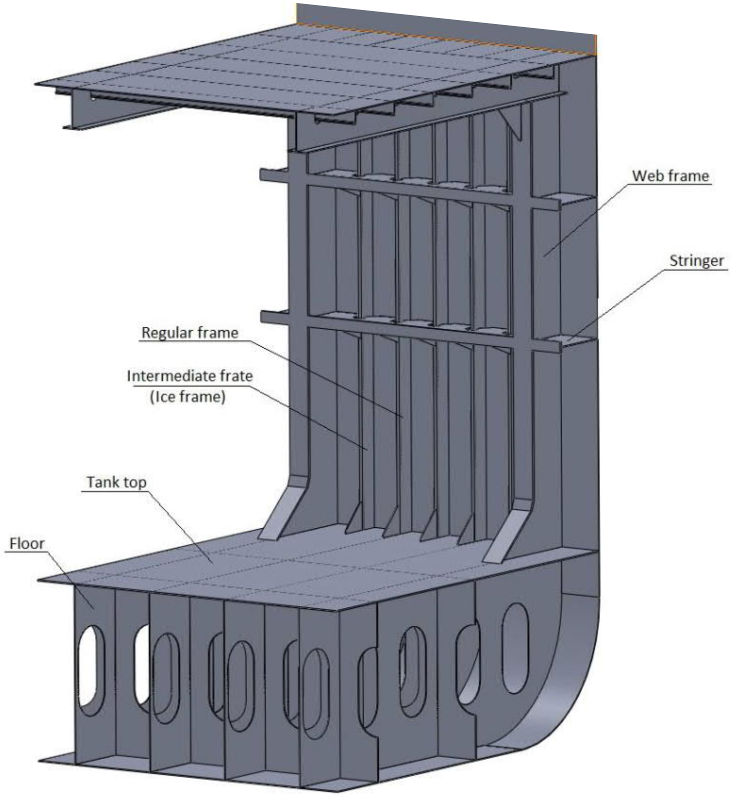
Arctic Passion Seminar 5.3.2020

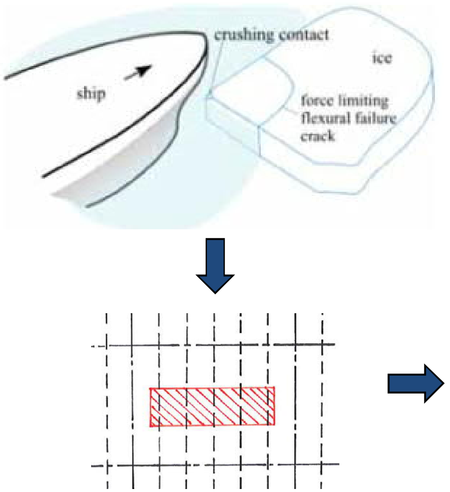
Content

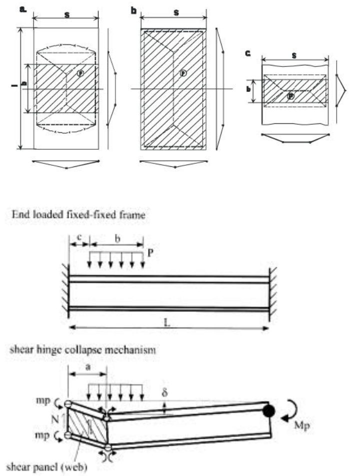
- A new methodology to design primary structure in a way that is consistent with IACS Polar Class Rules and aligns with service experience from existing vessel

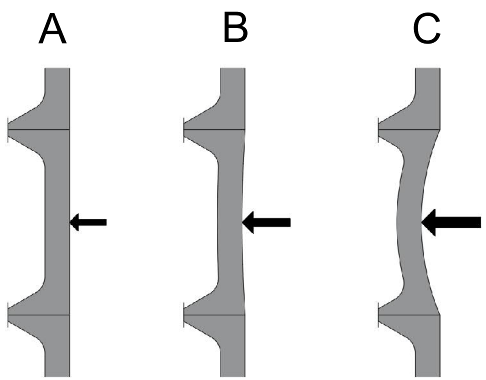


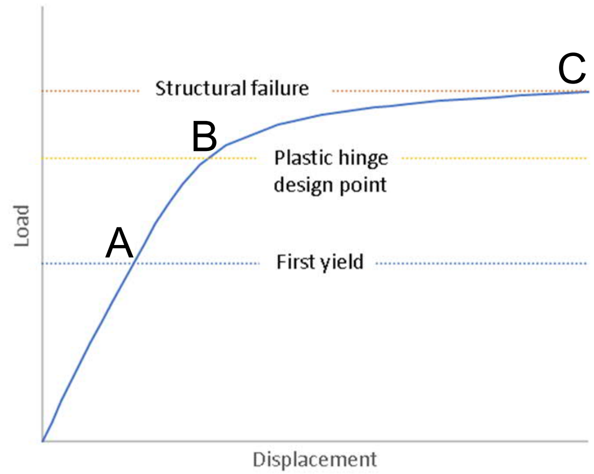
Introduction / background

- Polar Class design load is derived from glancing impact scenario
- Shell plate and frames dimensioned to onset of plastic hinge formation with rule formulas
  - Exceeding yield stress is allowed for plate and frames, as long as permanent deformation is small
- Primary structures are designed with direct calculation - in practice finite element analysis, either linear or non-linear



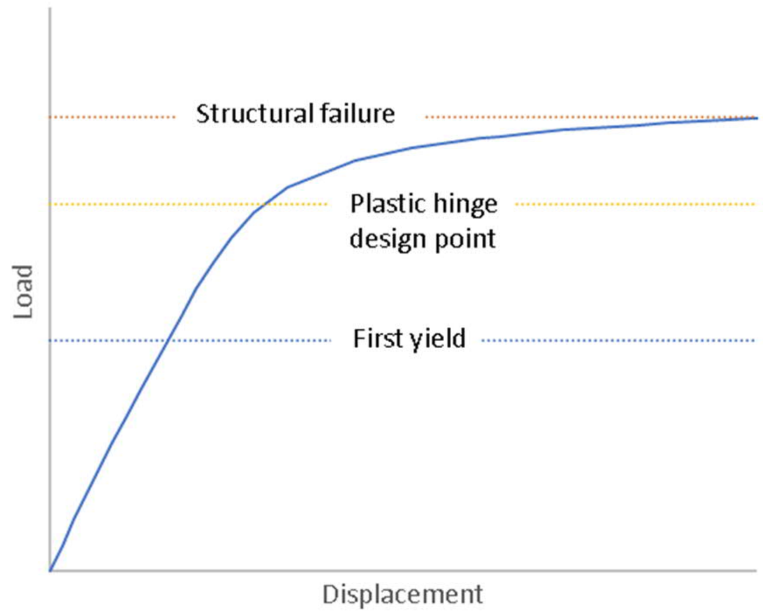






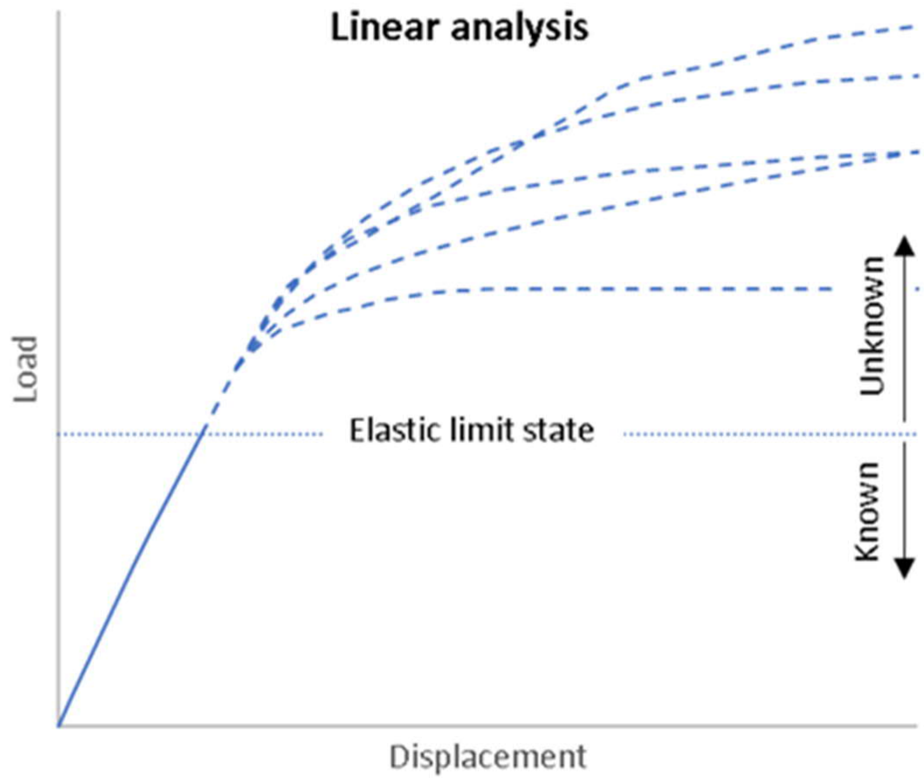
Linear FE analysis

- Currently used by practically everybody
  - Well established methodology
- Limit state yield of the material
  - Maximum allowed shear stress $\tau_{all} = \sigma_y / \sqrt{3}$
  - Maximum von Mises stress in member flanges 1.15 σ_y
    - Gives some allowance for local stress concentrations
- Secondary structure is designed to plastic limit state while primary is designed to elastic limit state



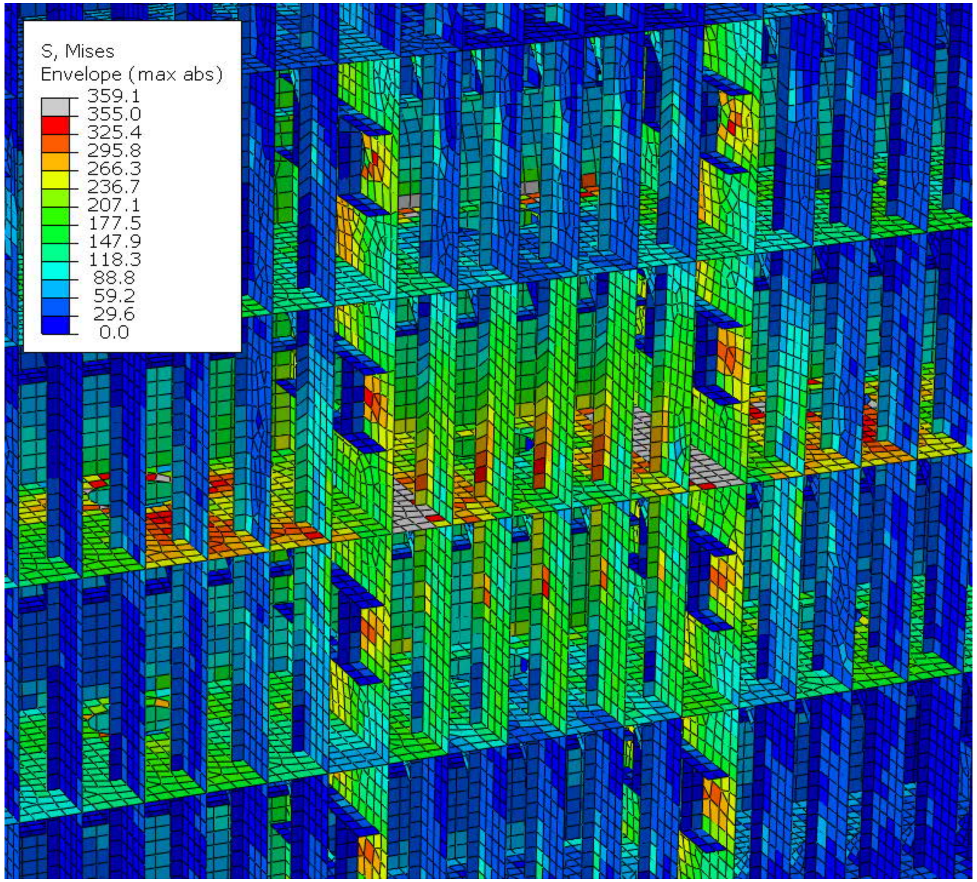
The issues with linear analysis

- Linear analysis gives insight only into what happens before yield
- No info beyond yield → no idea of:
  - Amount of margin
  - Failure mechanism
- Primary structure of many old successful designs would not pass linear analysis
  - No damage observed, even over long service history on harsh Arctic conditions
  - Effect of different limit states?
  - Effect of pressure-area curve?
  - Rarity of impacts with ice features large enough to cause high forces?
  - Some other reason?

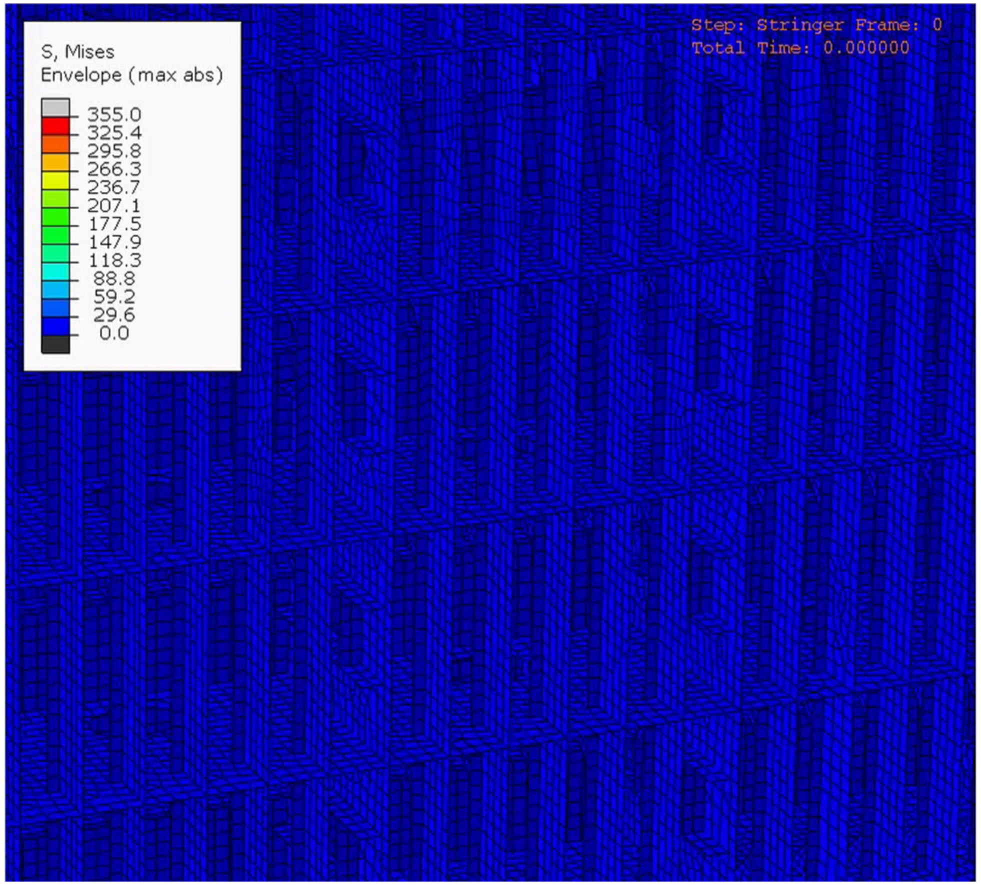


Benefit of moving to non-linear analysis

- Linear analysis



- Non-linear analysis



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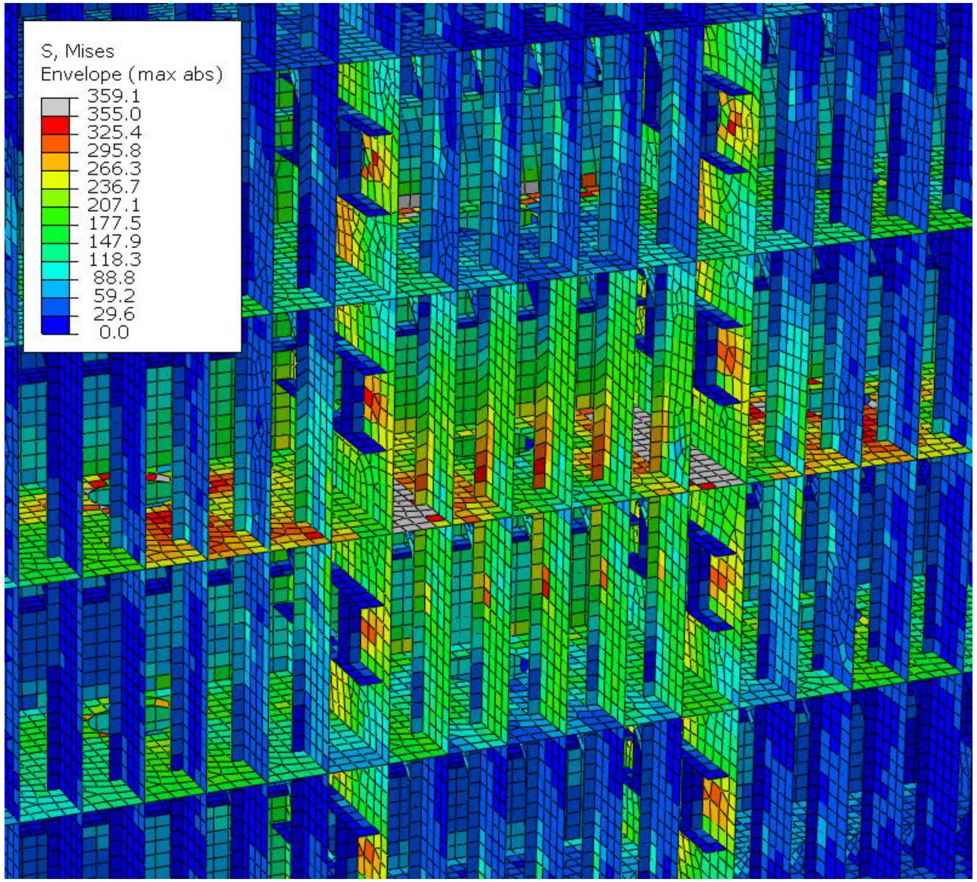
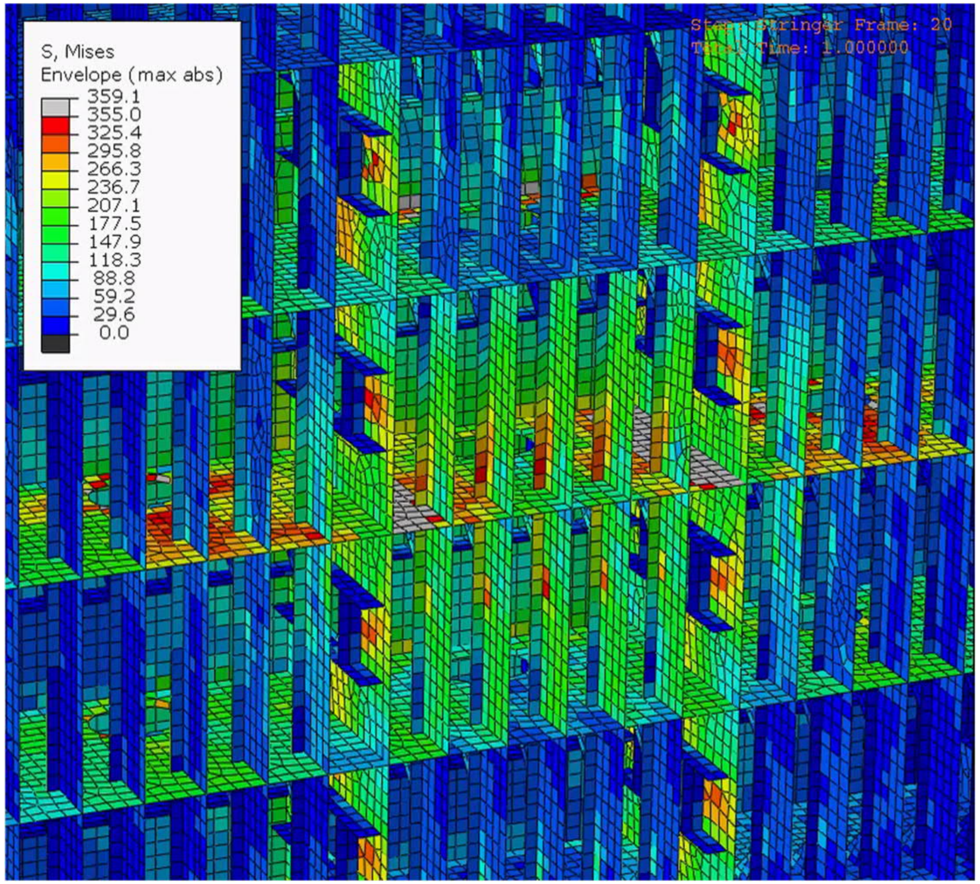


- Non-linear analysis



Benefit of moving to non-linear analysis

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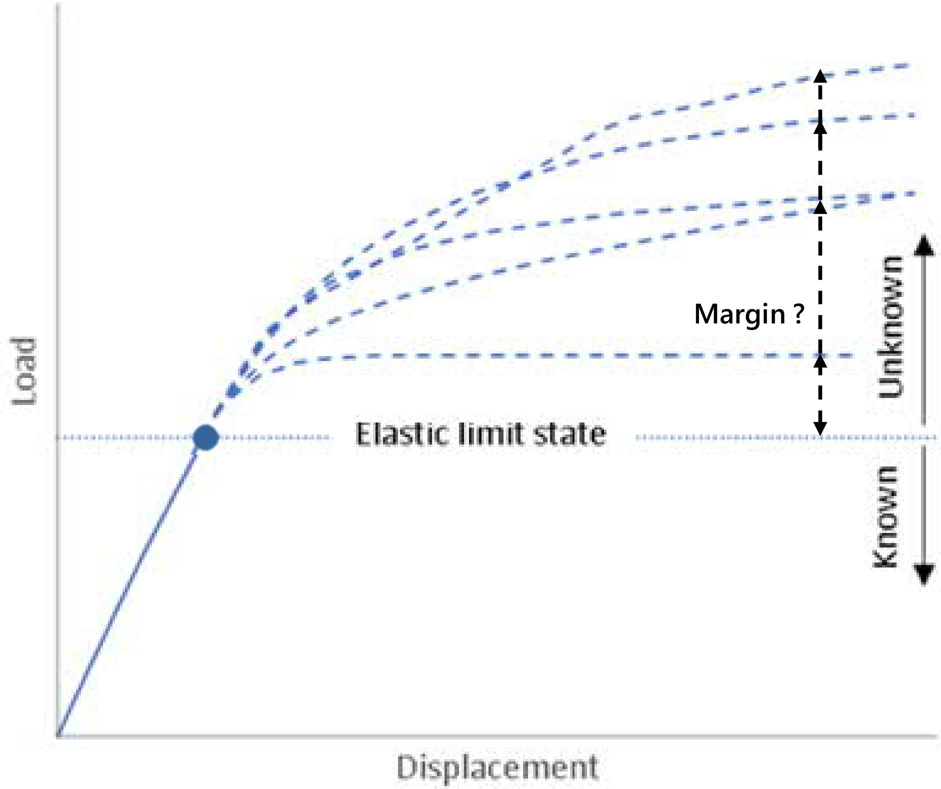
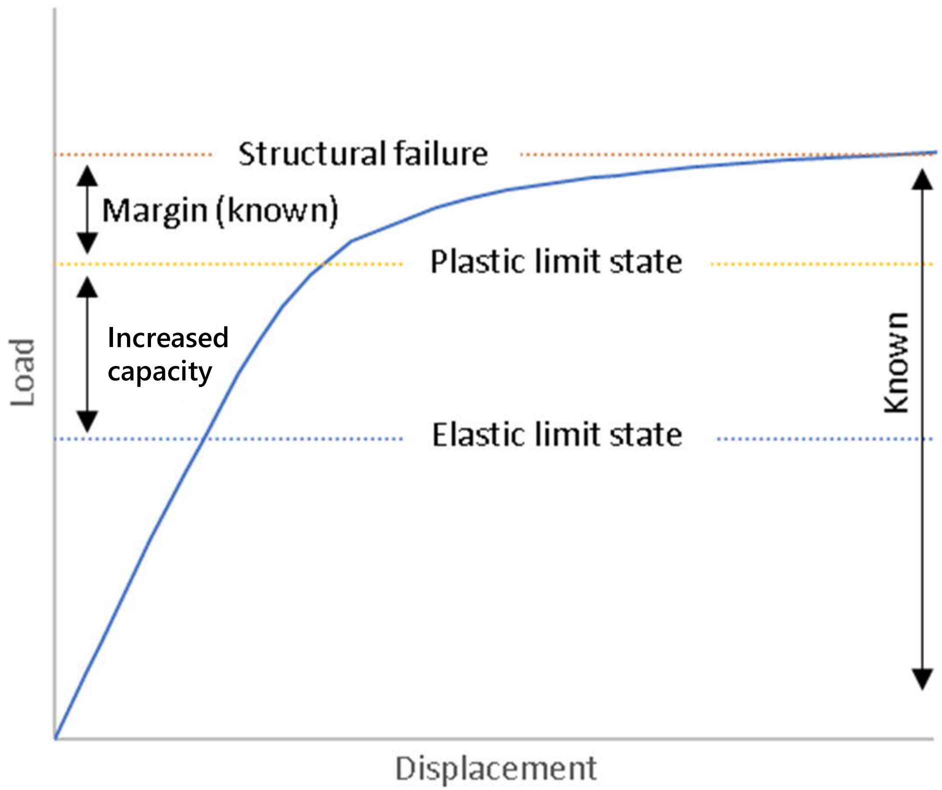
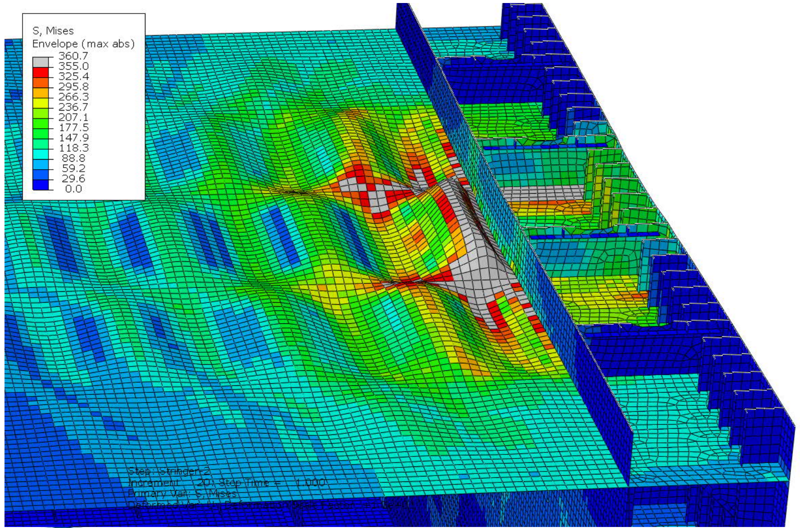


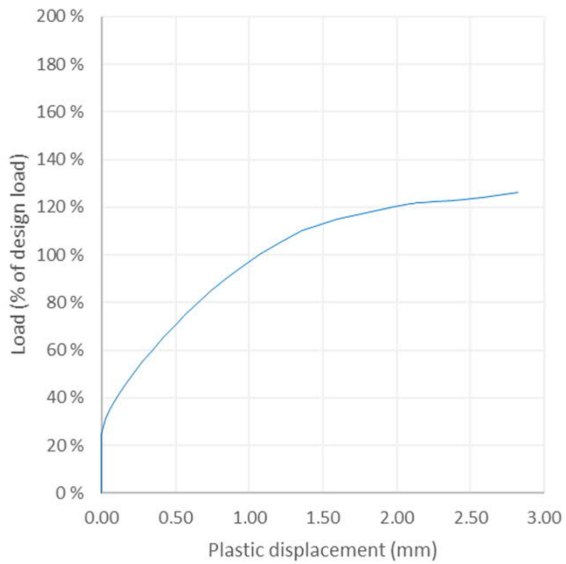
- Non-linear analysis



Benefit of moving to non-linear analysis and importance of model extent

- If model extent is limited to double side, capacity of supporting structures is not checked
- Linear analysis only tells if the deck buckles elastically or not
- Nonlinear analysis tells is buckling elastic or plastic, how it progresses and how the load is shared in structure
- Example, PC 2 vessel designed with linear analysis and model limited to double side, large permanent buckling under design load





IACS PC Rules – nonlinear analysis

I2.17.6 If the structure is evaluated based on non-linear calculation methods, the following are to be considered:

(1) The analysis is to reliably capture buckling and plastic deformation of the structure

(2) The acceptance criteria are to ensure a suitable margin against fracture and major buckling and yielding causing significant loss of stiffness

(3) Permanent lateral and out-of plane deformation of considered member are to be minor relative to the relevant structural dimensions

(4) Detailed acceptance criteria to be decided by the Classification Society

- Very good goals, but how to do this in practice?

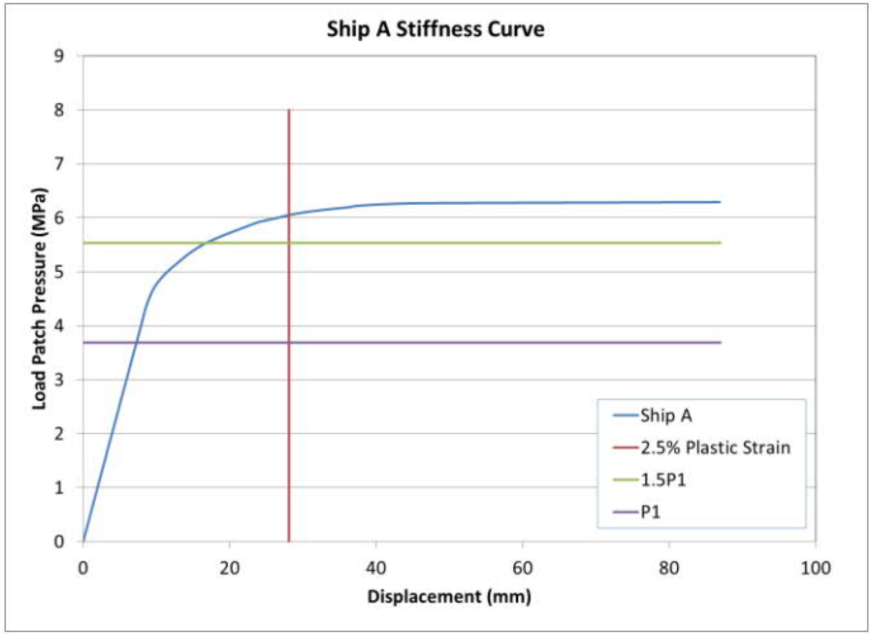
Hull design in IACS PC Rules – nonlinear analysis

- No unified acceptance criteria from IACS or Classification Socities

  → How to design in practice?

Pearson, Hindley & Crocker

Criteria: $\varepsilon_{plastic} < 2.5\ \%$ at $F = 1.5\ F_{design}$



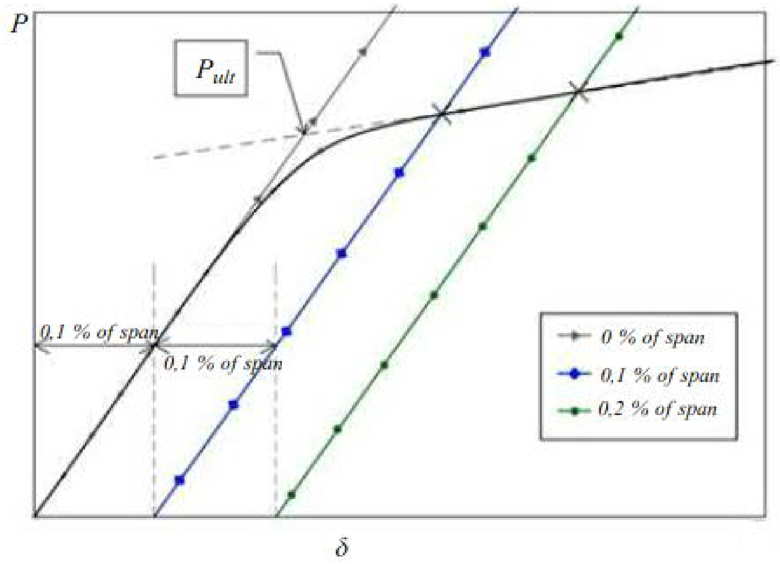
Hull design in IACS PC Rules – nonlinear analysis

- No unified acceptance criteria from IACS or Classification Socities

  → How to design in practice?

RS Rules: tangent intersection method

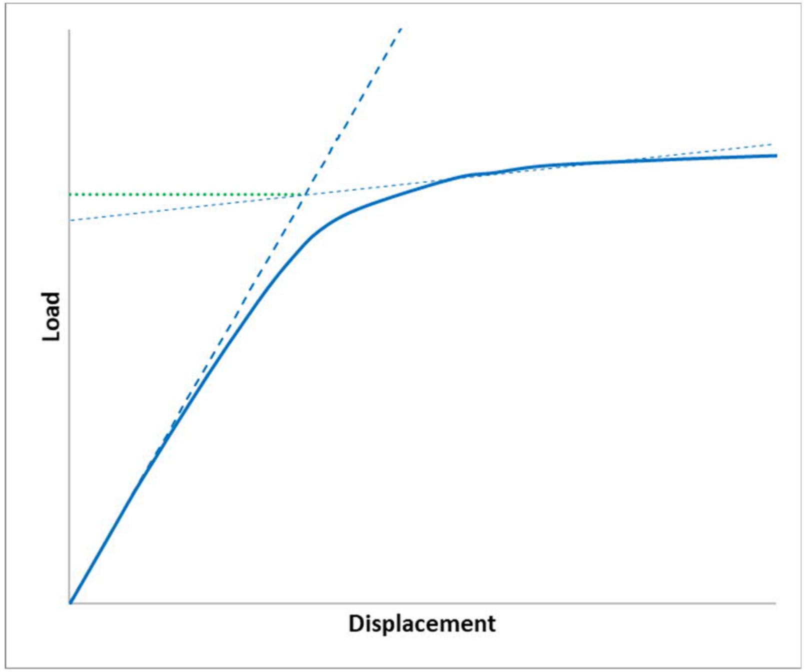
Criteria: $P_{ult} > P_{design}$



Several unpublished methods of similar type

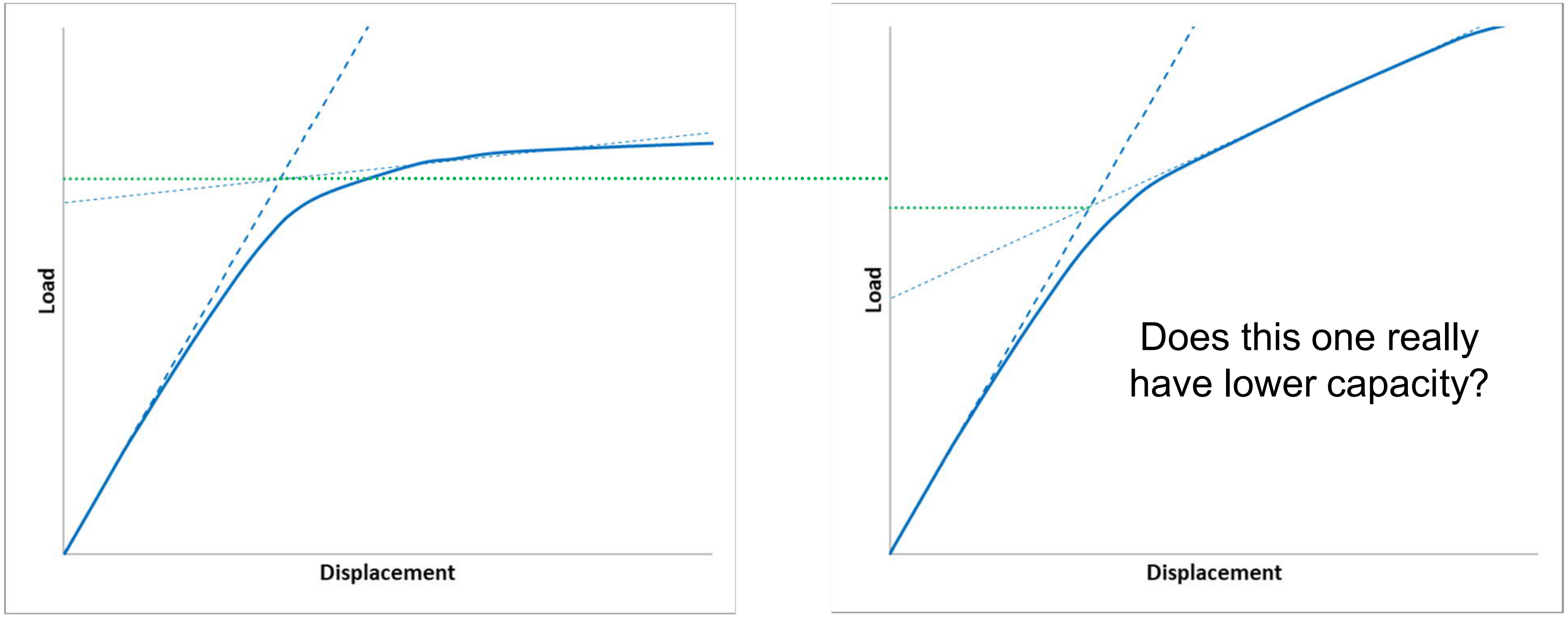
Examples of load-displacement curve

- Methods based on shape of load-displacement curve work very nicely for this kind of ideal curve:



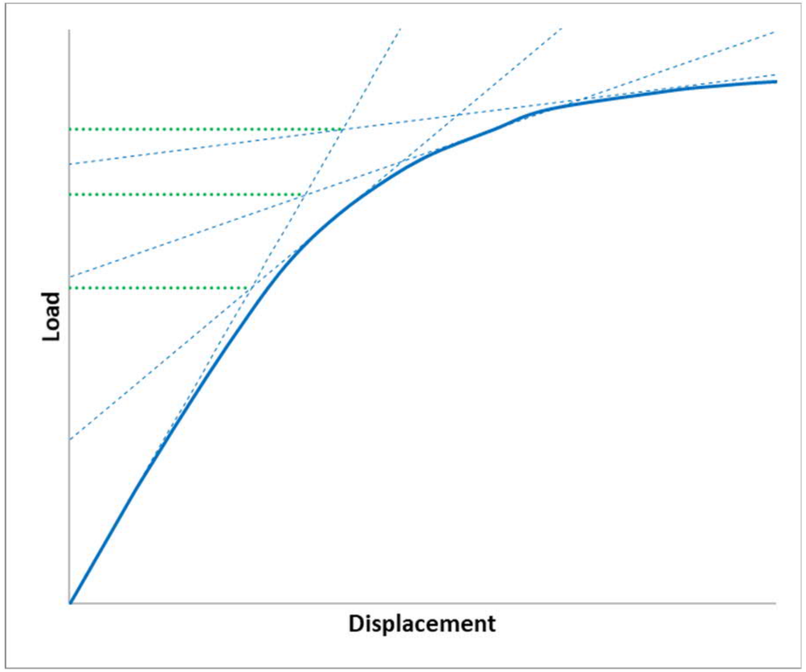
Examples of load-displacement curve

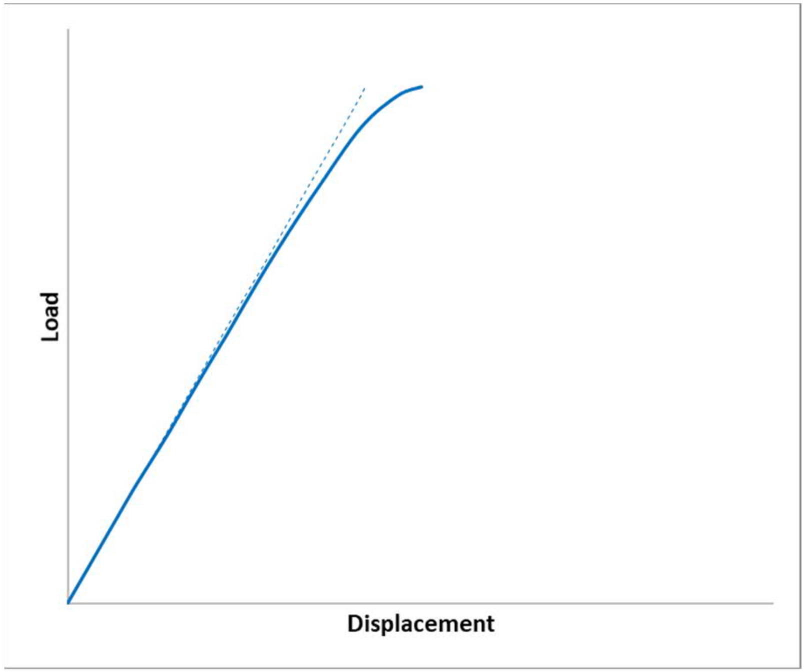
- However, if the load-displacement curve differs from the ideal one, some issues arise:
  - Same elastic capacity, different plastic capacity



Examples of load-displacement curve

- However, if the load-displacement curve differs from the ideal one, some issues arise:
  - What to do with these?





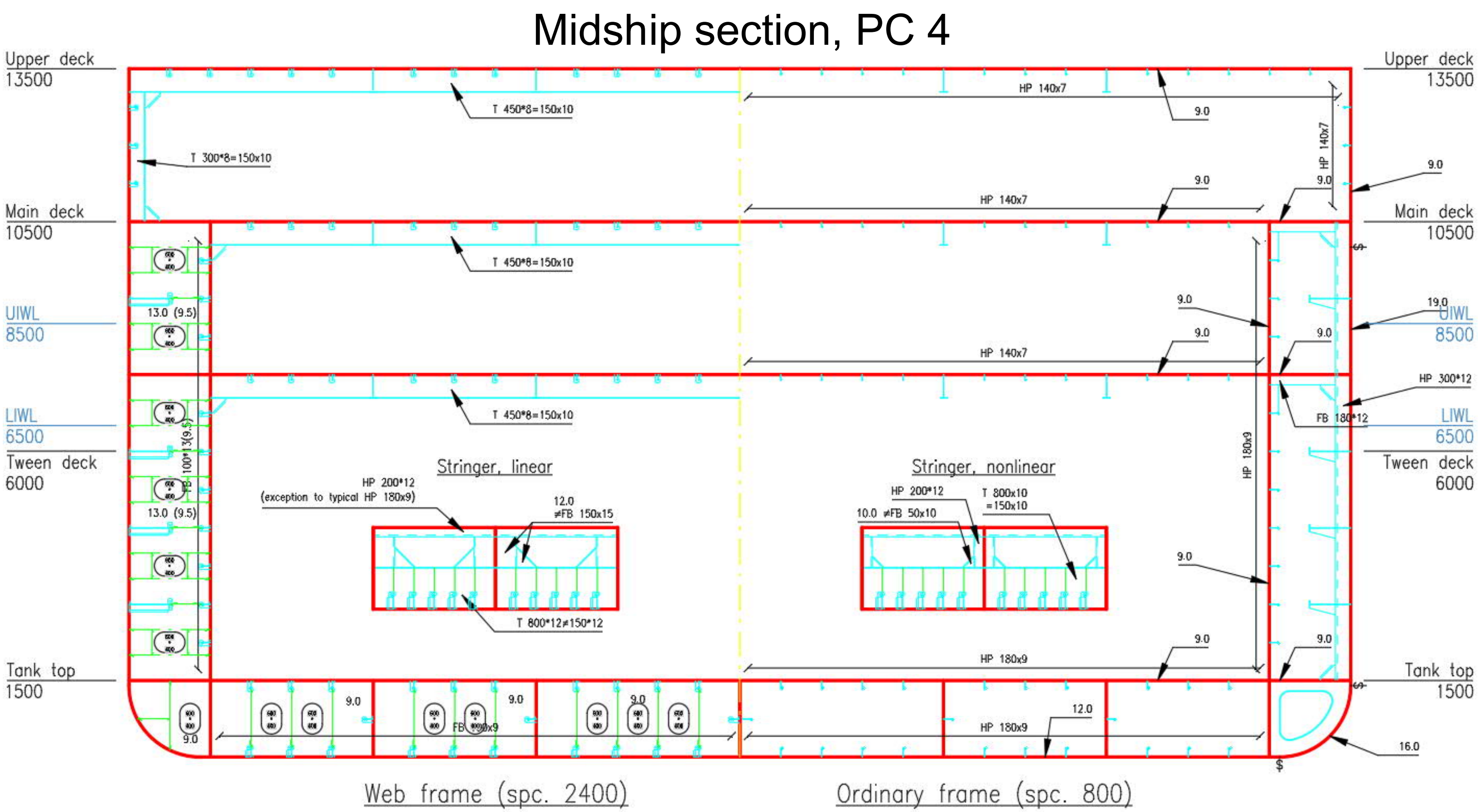
Acceptance criteria

- Clearly, a better acceptance criteria is needed
  - Should not be based on shape of load-displacement curve
  - Plastic hinge would be ideal, but hard to determine reliably from FE model → not practical
- Good acceptance criteria should have following qualities:
  - Robust
    - Will fail structures that are too weak
    - Will rate stronger structure as stronger
    - Small variations in modeling practice, meshing, etc. should not result in large variation of result
  - Simple to apply
    - Preferably as little need for judgement as possible, i.e. clear pass / fail
    - Everyone will do the analysis the same way → simple approval process
  - Ensure that IACS criteria are met
    - Permanent deflections to be minor compared to structural member dimensions
    - Margin against fracture, major buckling and loss of stiffness
  - Ensure proper strength hierarchy, i.e. plate and frames fail before primaries

Example

- Typical polar vessel
  - Δ 25000 t
  - L abt. 175 m
  - B 24 m
  - T 8.5 m
- Double side, width 1.6 m
- Transverse framing
- Frame spacing 400 mm, stringer spacing 1500 mm, webframe spacing 2400 mm, longitudinal spacing 800 mm
- Material HT-36
- Midbody of three ice classes studied, PC 2, PC 4 and PC 6

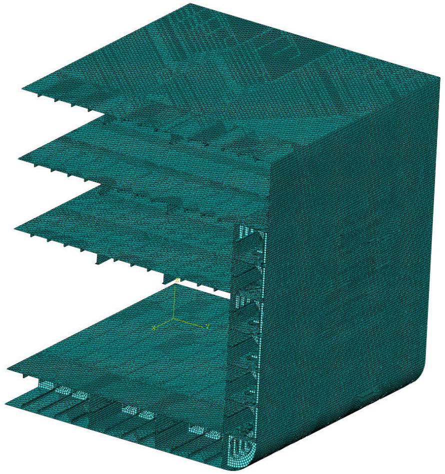
Example – structural arrangement

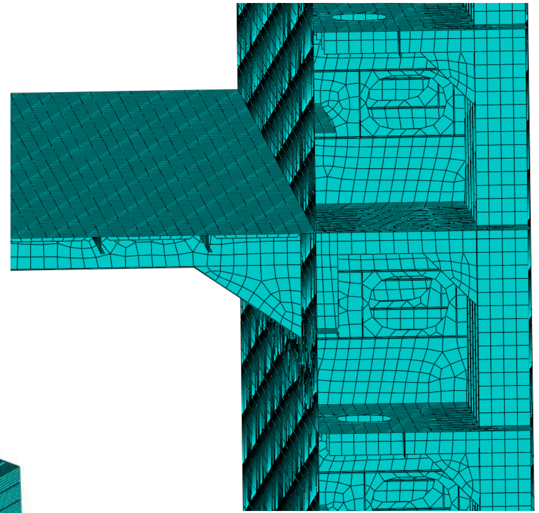


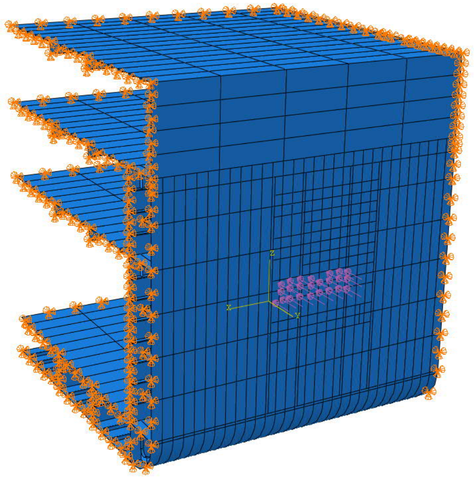
Aker Arctic
The Ice Technology Partner

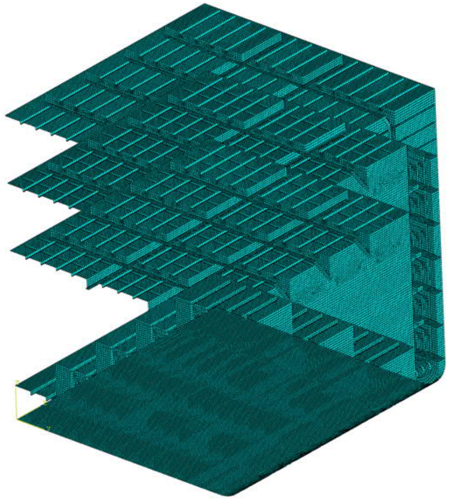
Example – FE model

- Non-linear analysis requires relatively fine mesh and careful modeling to ensure accuracy

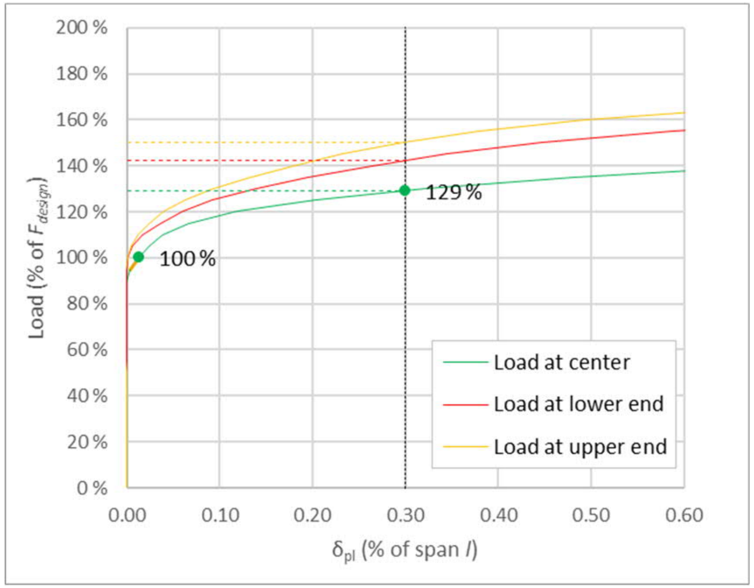




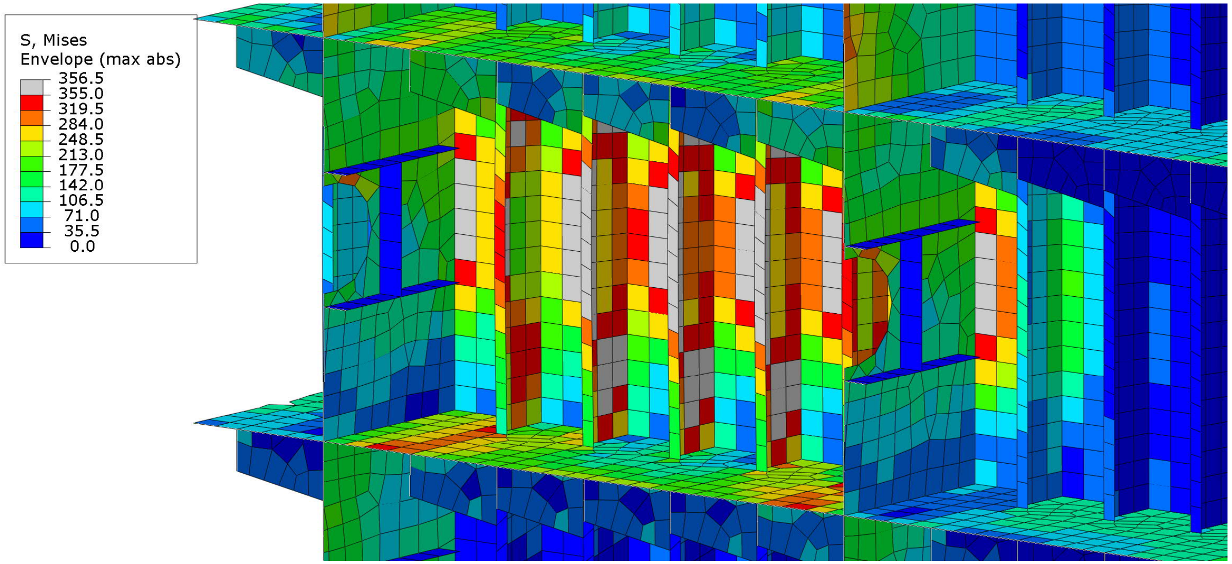




Example – Frame (PC 4)

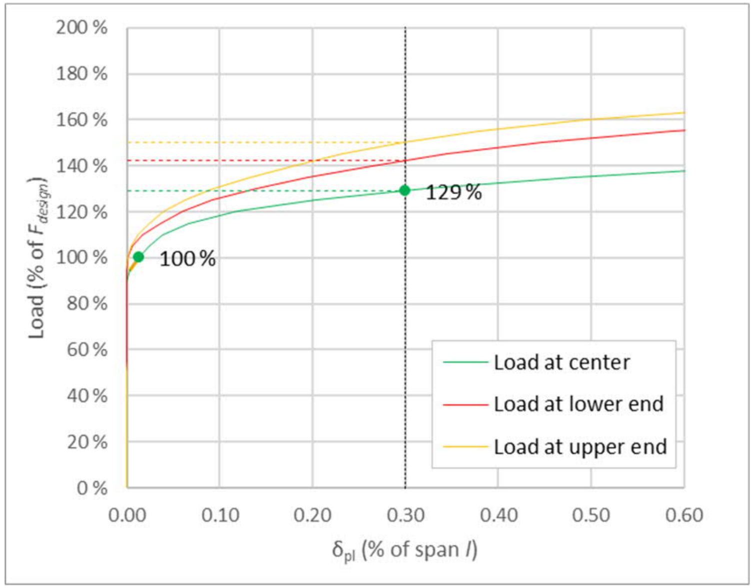


F = 100 % of design load

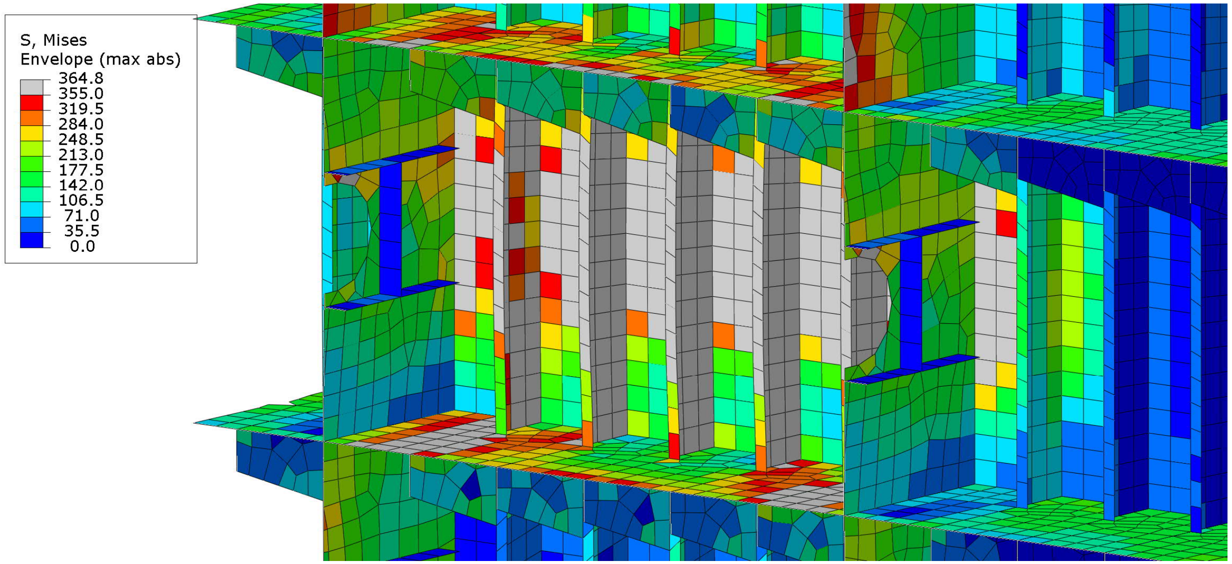


Example – Frame (PC 4)

$$C_{frame} = F(\delta_{pl} = 0.003\ l) = 1.29\ F_{design}$$



F = 129 % of design load



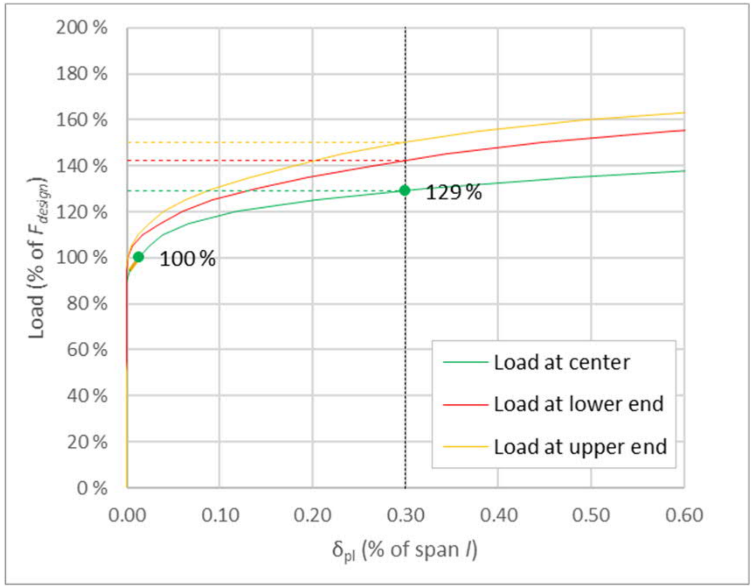
Example – Frame (PC 4)

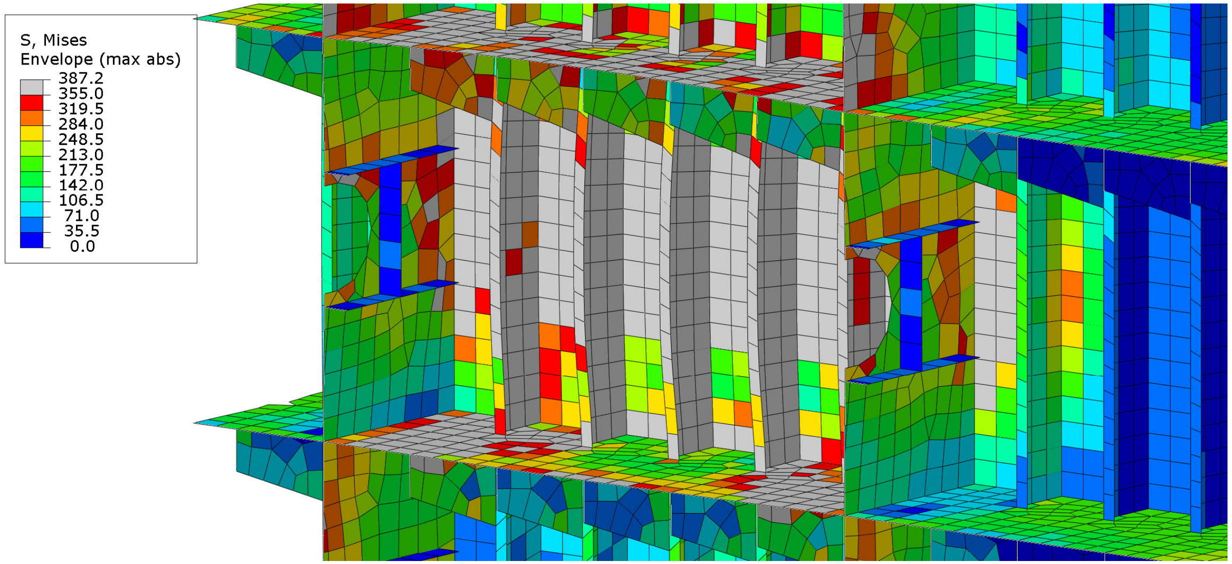
$$C_{frame} = F(\delta_{pl} = 0.003\ l) = 1.29\ F_{design}$$

For PC 4, $CF_0 = 1.15$

$$C_{primary} \geq F_{limit} = 1.15 \cdot 1.29 = 1.48$$

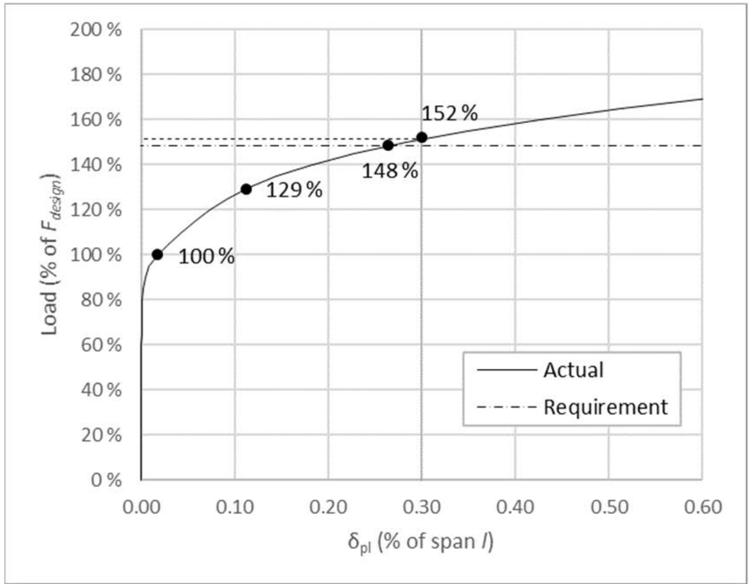
F = 148 % of design load



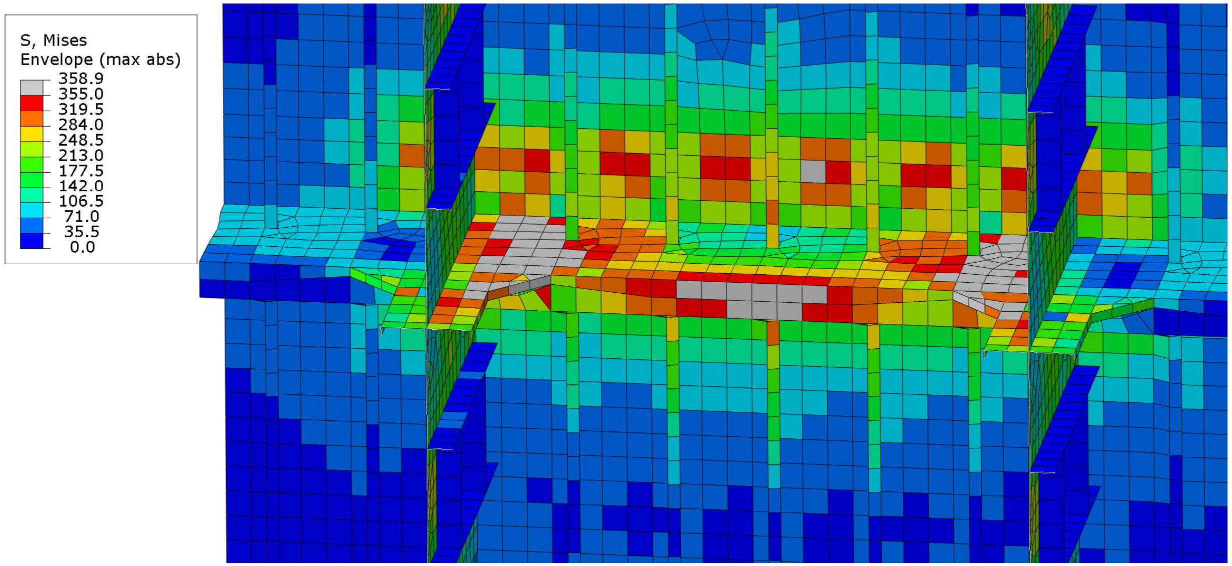


Example – Stringer (PC 4)

$$F_{limit} = 1.48$$



F = 100 % of design load



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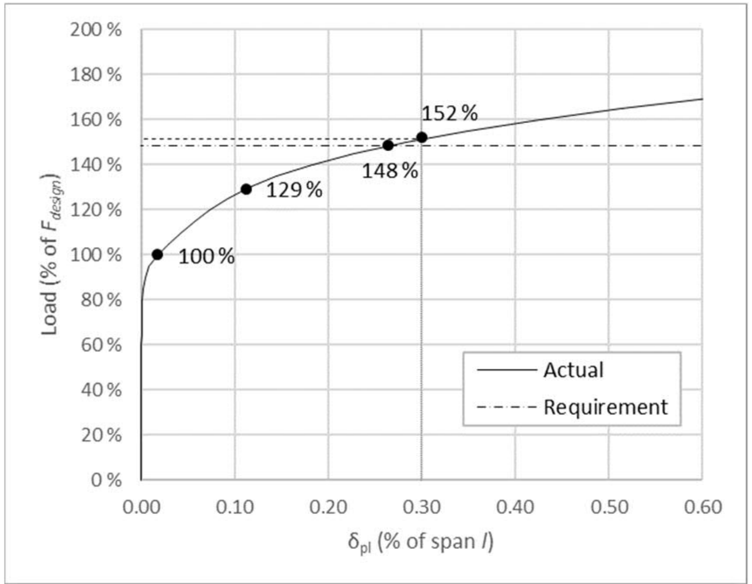

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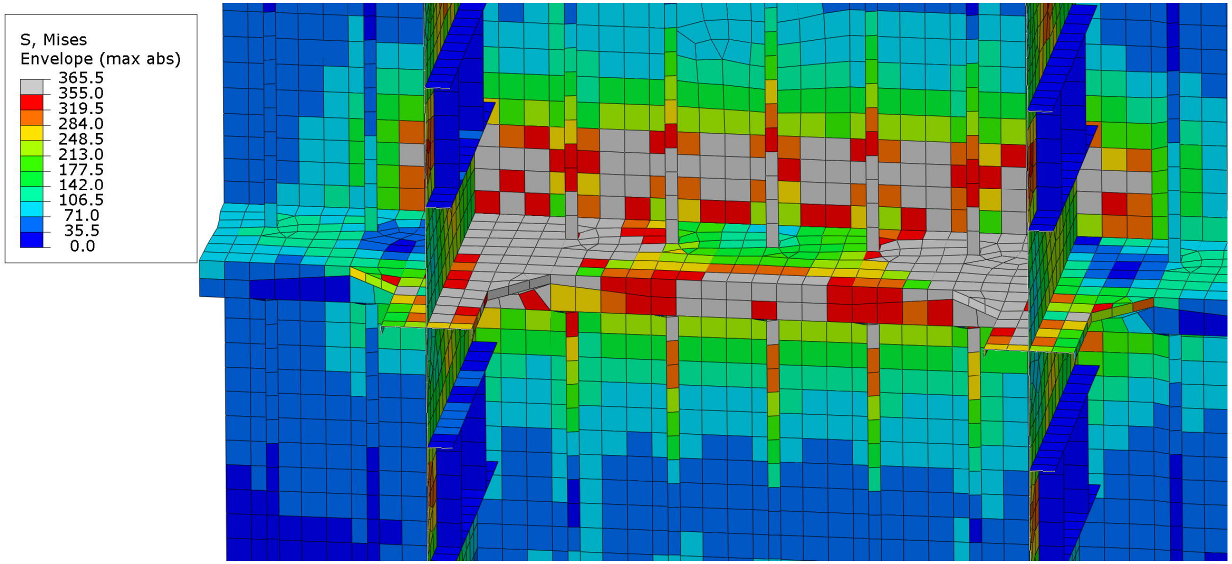

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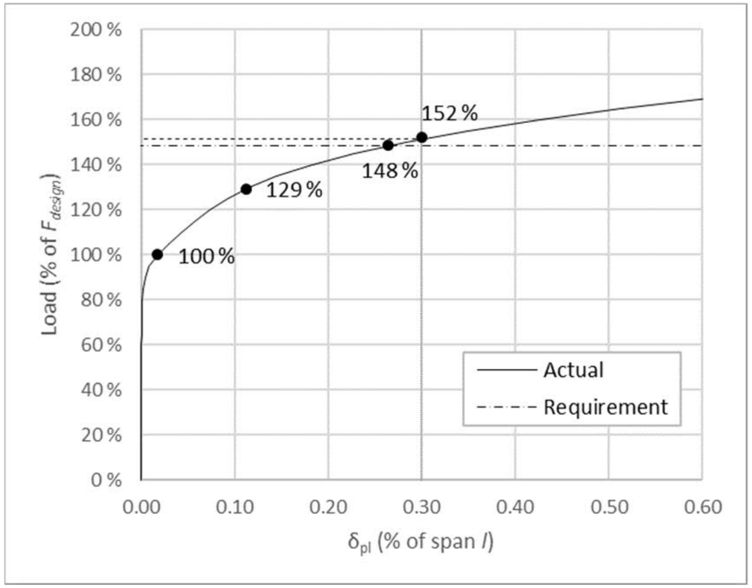
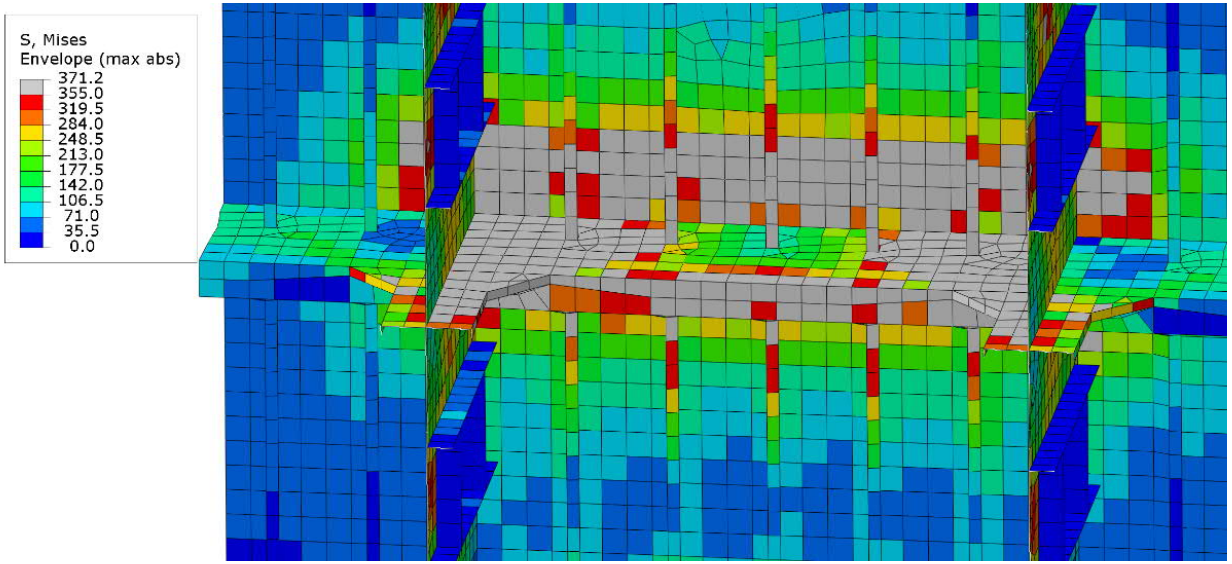


F = 148 % of design load

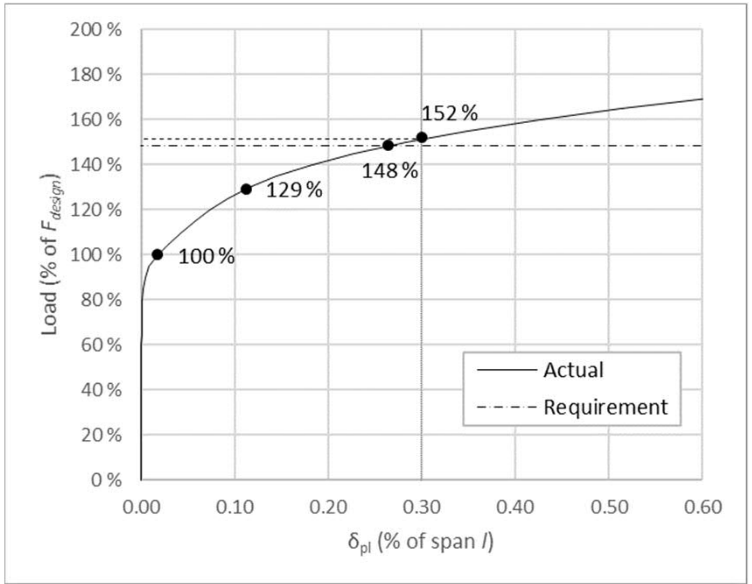


Example – Stringer (PC 4)

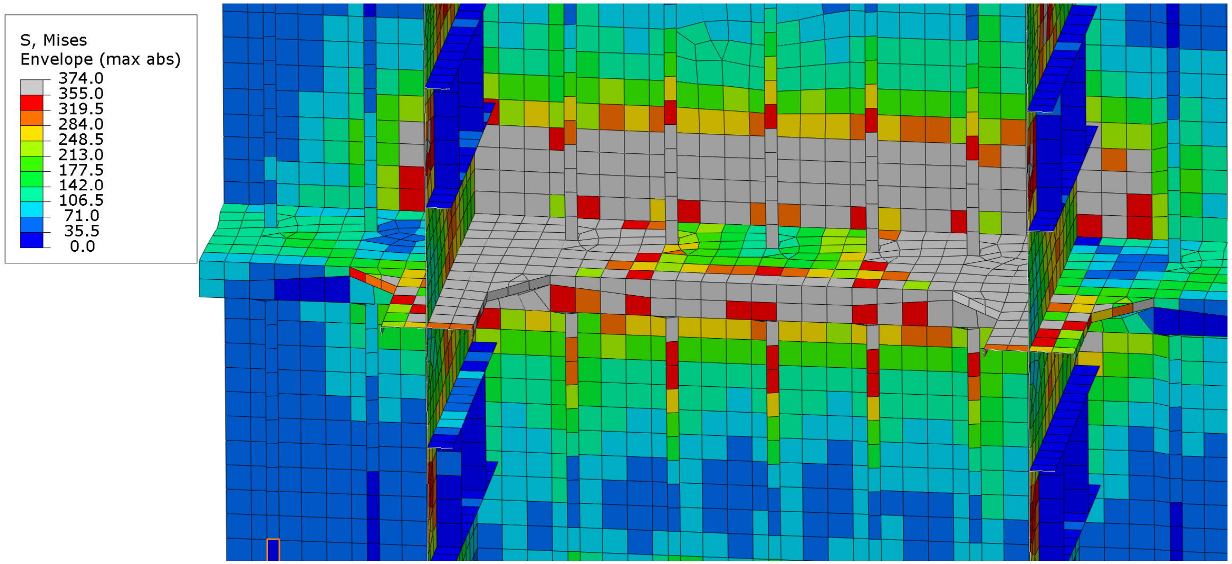
$$F_{limit} = 1.48$$

$$C_{primary} = 1.52$$

$$C_{primary} \geq F_{limit} \quad \longrightarrow \text{OK}$$



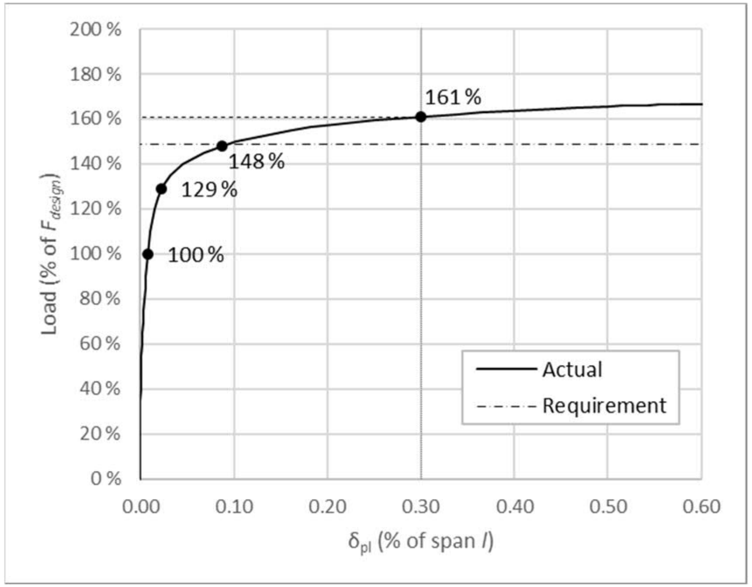
F = 152 % of design load

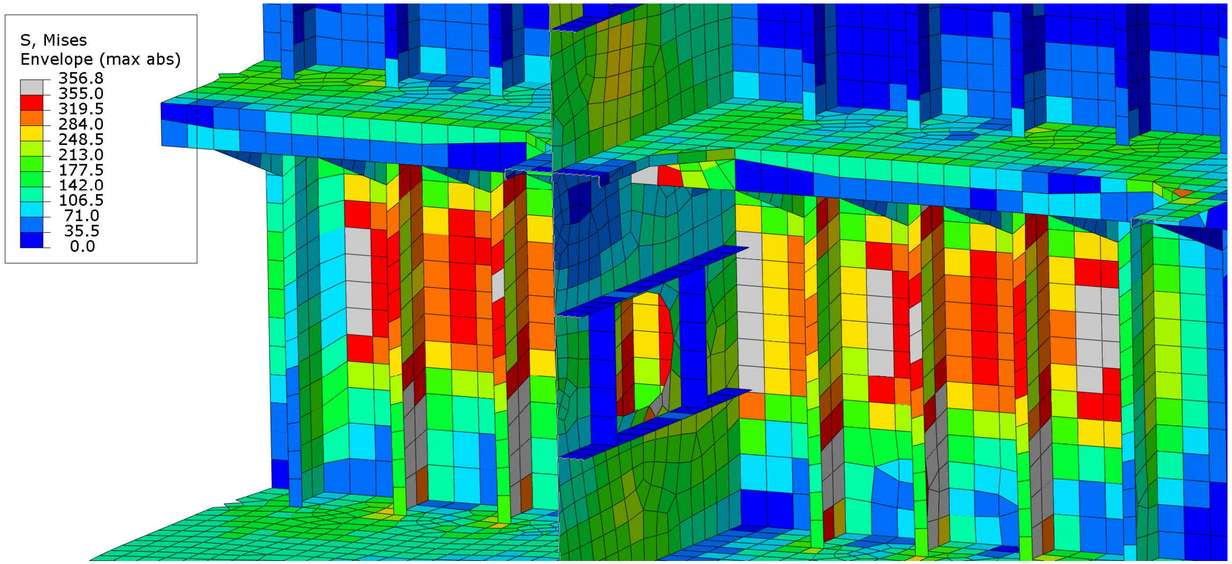


Example – Webframe (PC 4)

$$F_{limit} = 1.48$$

F = 100 % of design load





Example – Webframe (PC 4)

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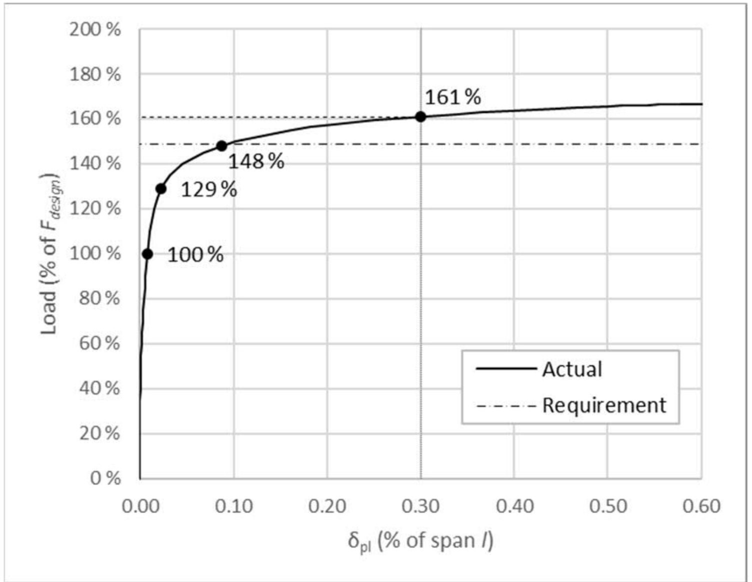
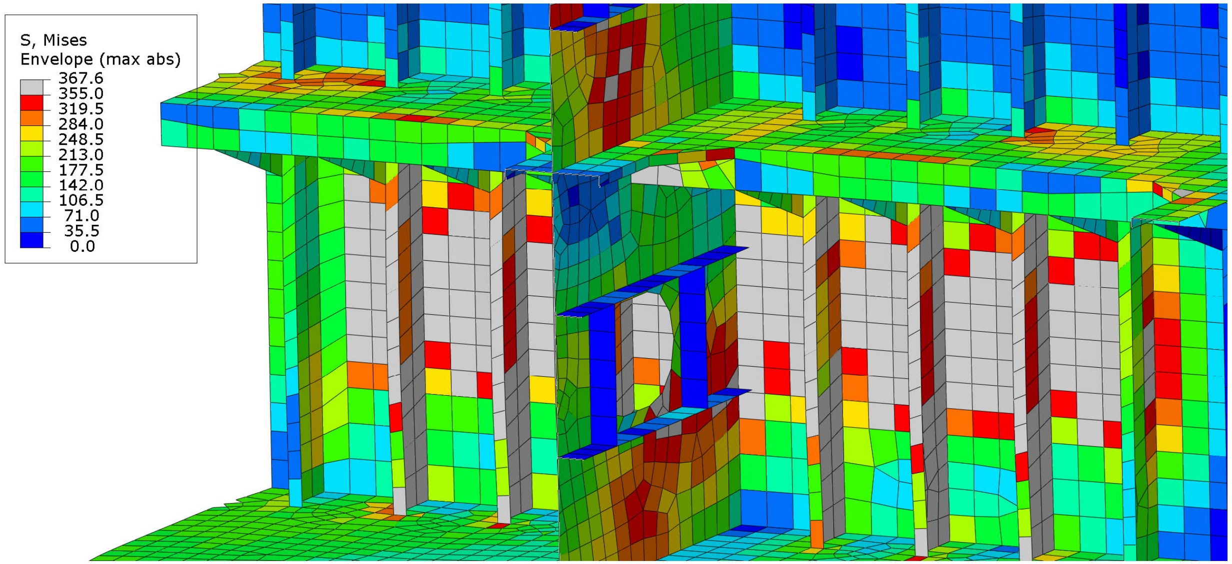
F = 129 % of design load

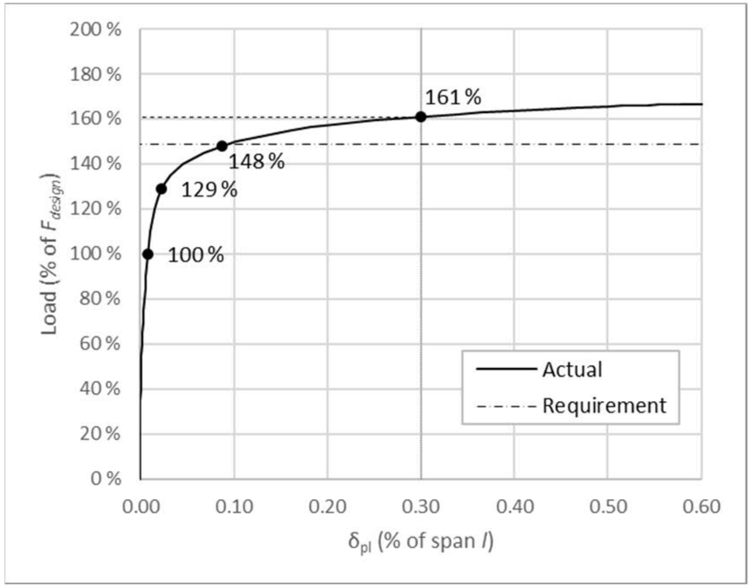


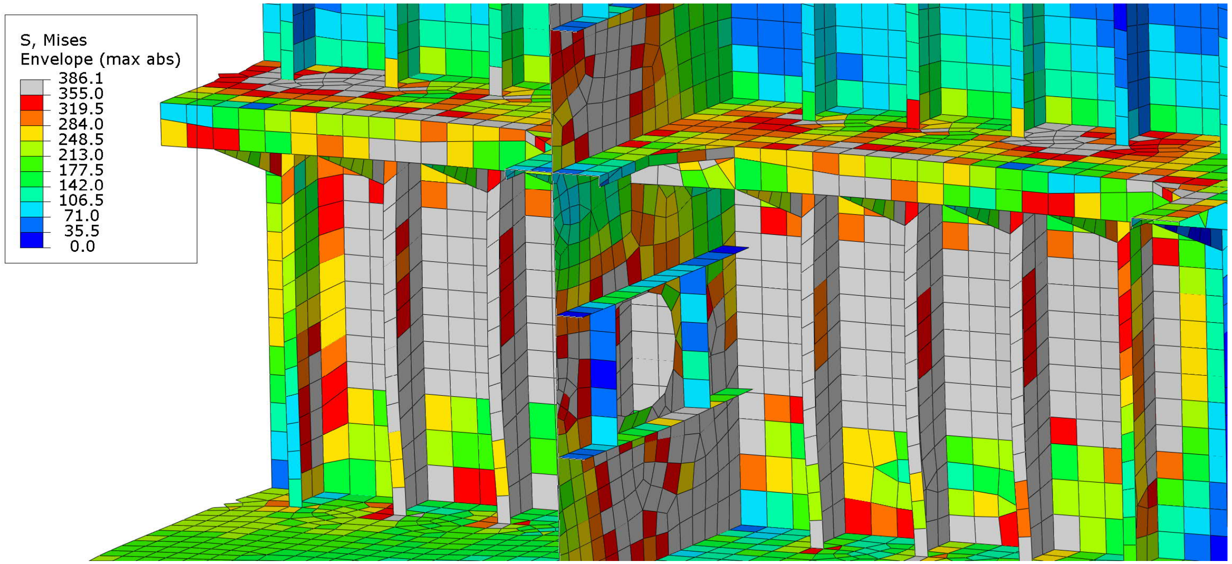


Example – Webframe (PC 4)

$$F_{limit} = 1.48$$

F = 148 % of design load



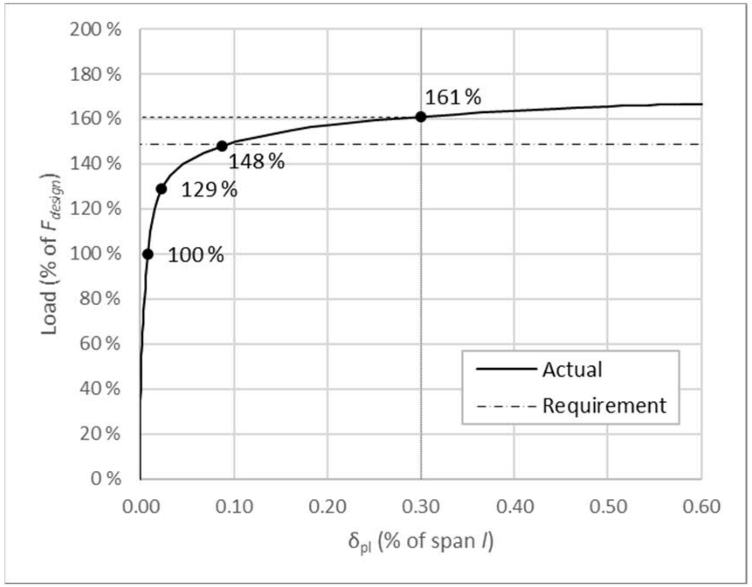


Example – Webframe (PC 4)

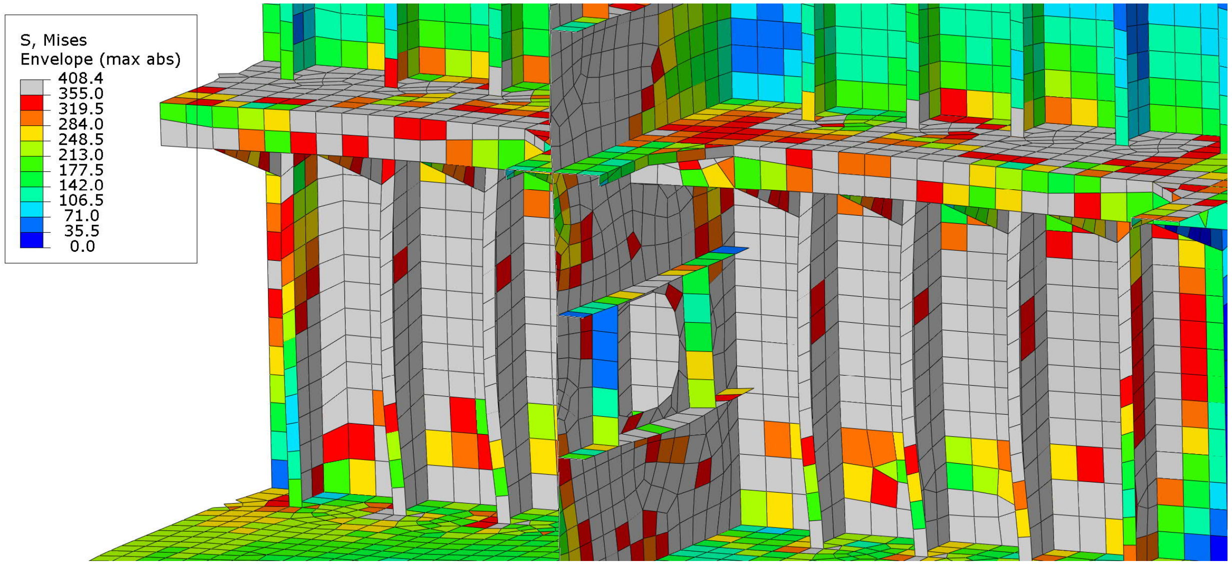
$$F_{limit} = 1.48$$

$$C_{primary} = 1.61$$

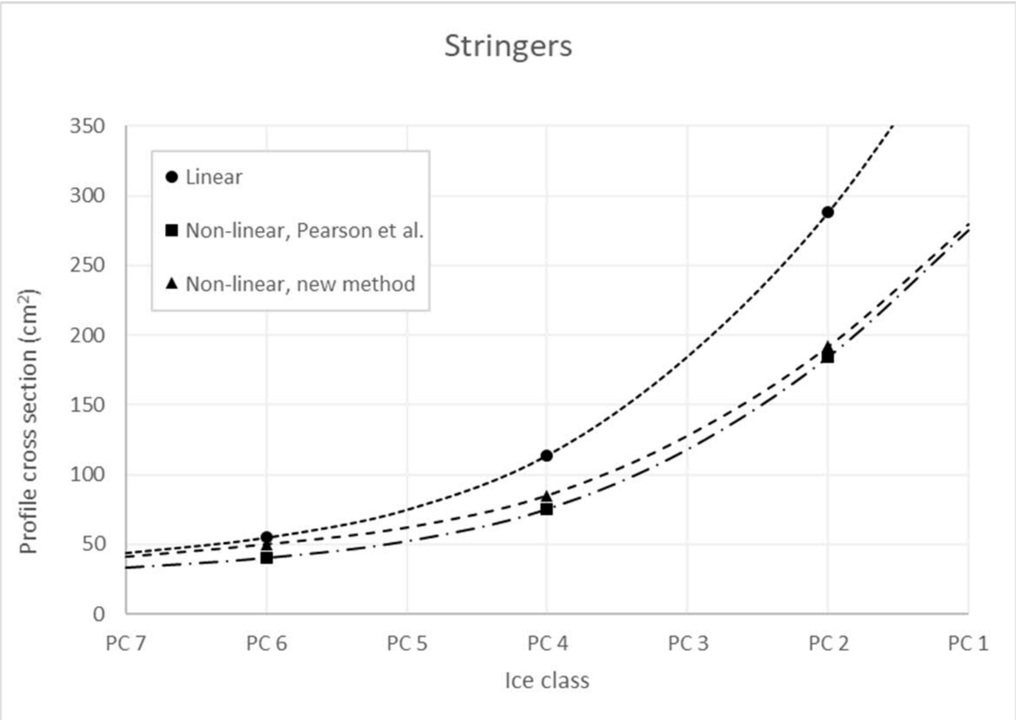
$$C_{primary} \geq F_{limit} \quad \rightarrow \text{OK}$$

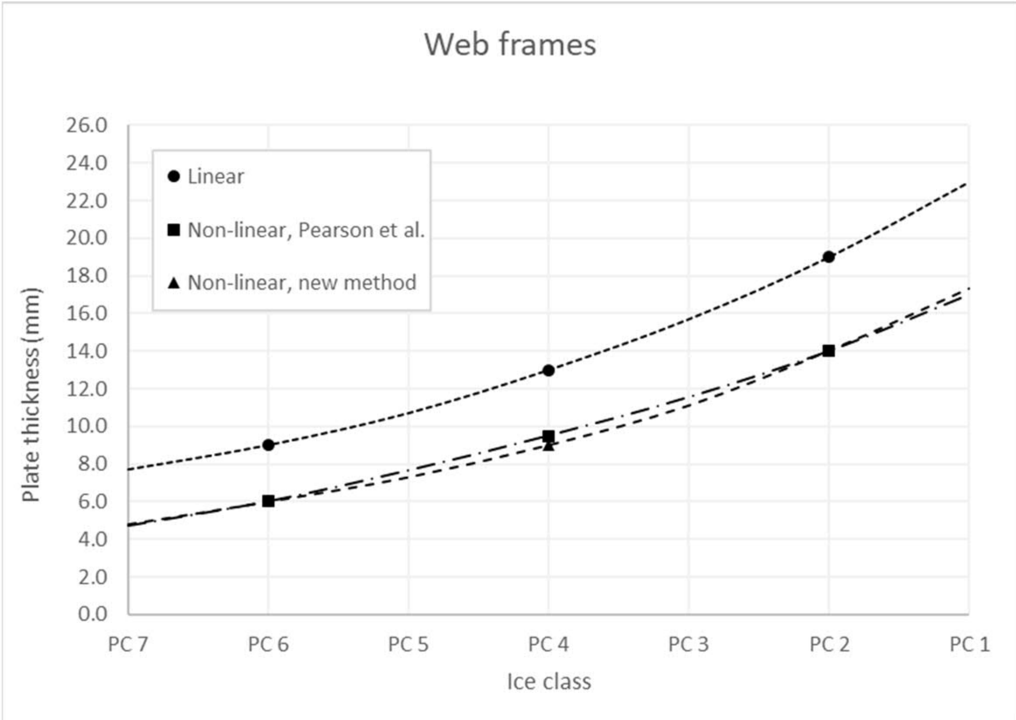


F = 161 % of design load



Example - Results





Conclusions

- Aker Arctic acceptance criteria provides straightforward and robust way to make non-linear analysis of primary structures for Polar Class vessels
- Will be published this summer
- Will be discussed with Classification Societies

Conclusions

- Non-linear analysis of primary structures provides a way to improve structural design of Polar Class vessels
  - Increased safety
    - Better insight into behavior of the structure, actual margins and failure modes
    - Structures supporting the primaries taken into account
  - Reduced weight
    - Especially for high ice classes
  - Scantlings from non-linear analysis align much better with old successful designs