(Plastic) Design Principles

SAFEICE Dissemination Workshop
25 September 2007
Richard Hayward

Germanischer Lloyd

Content

Presentation of results reported in :

Deliverable 8-4	Principles of Plastic Design
Deliverable 9-2	Assessment of Risk Levels in Ice Class Rules

Deliverable 8-4 Principles of Plastic Design

1. Why Plastic Design?
2. Basic Collapse Mechanism
3. Effect of Brackets
4. Shear-Bending Interaction
5. Shape Factors
6. Energy Methods
7. Acceptable Response Criteria?

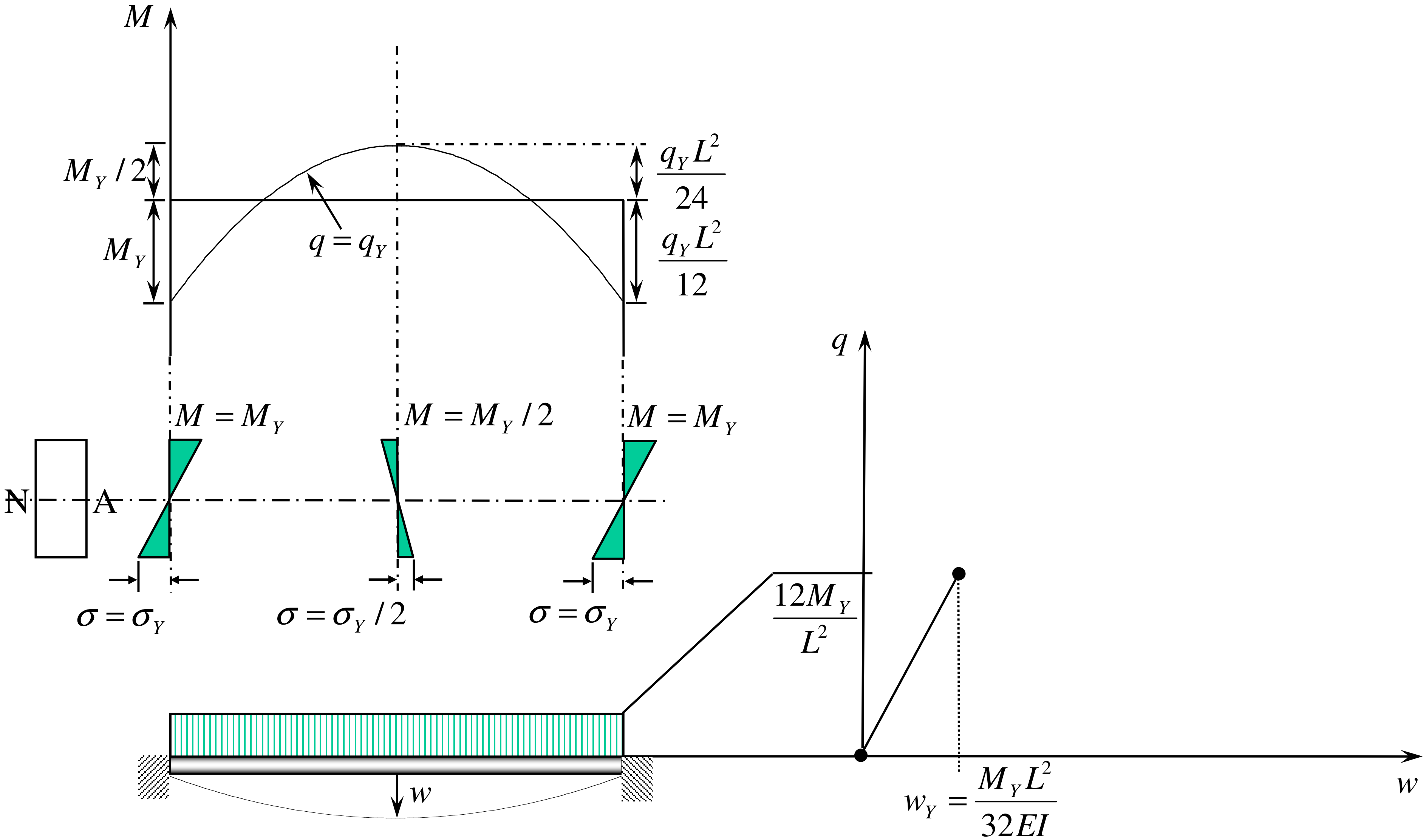
1. Why Plastic Design?

Plastic design refers to design where the structural response of the structure is permitted to exceed the elastic limits of its material.

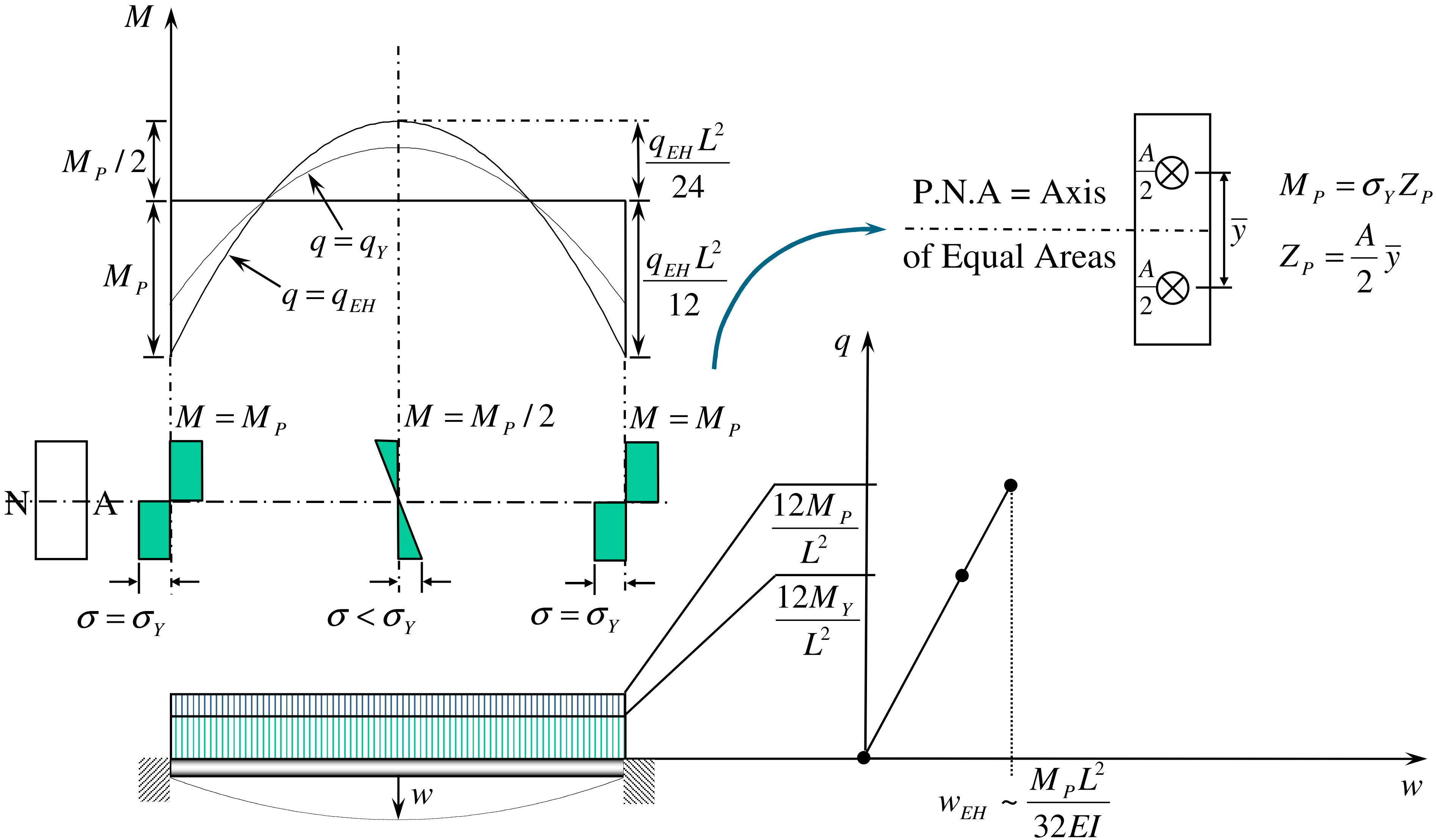
1. Elastic design requires excessively heavy structures to resist design ice loads.

2. An explicit consideration of plastic behaviour is required to determine the true margins of safety associated with extreme ice loads.

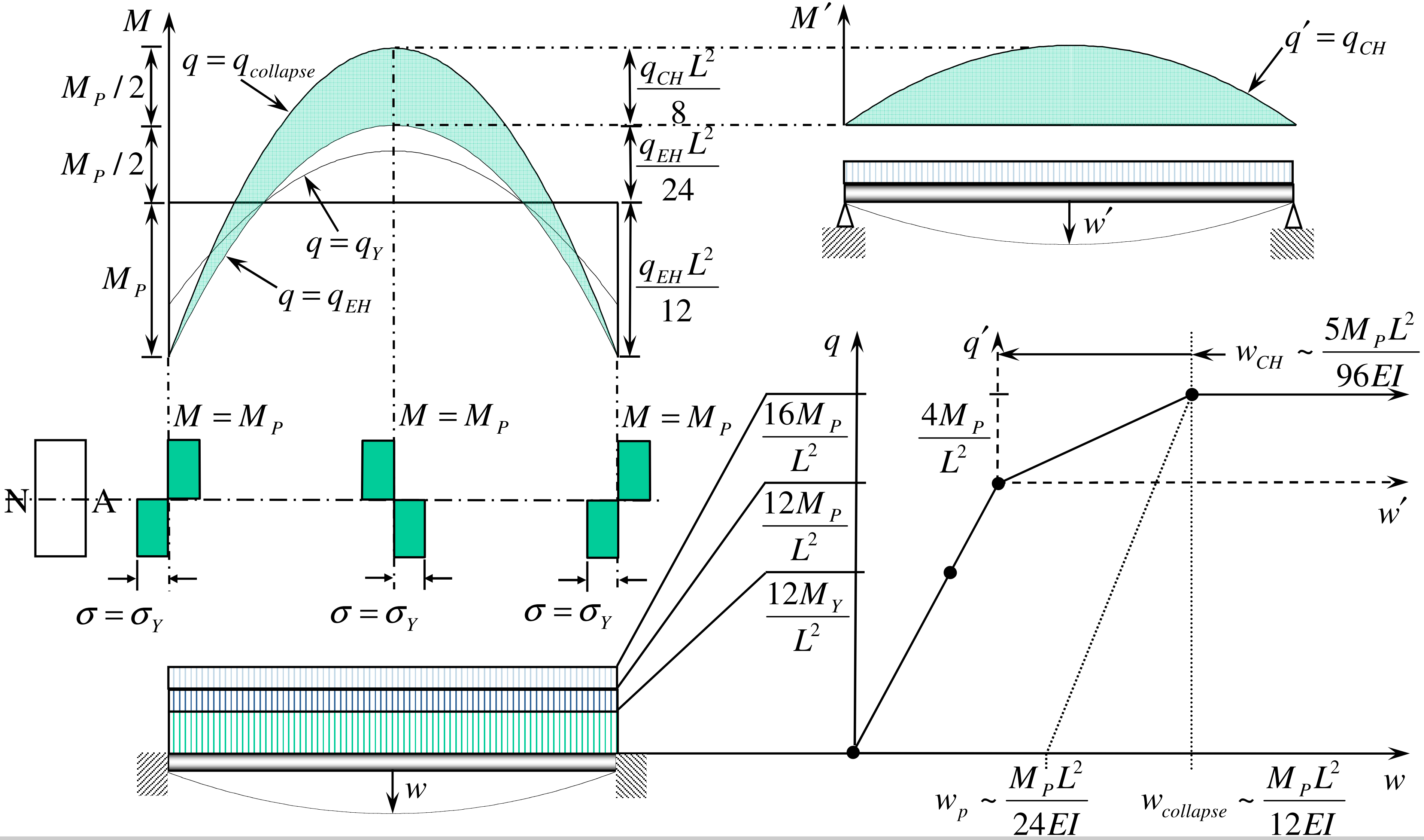
2. Basic Collapse Mechanism : $q = q_Y$



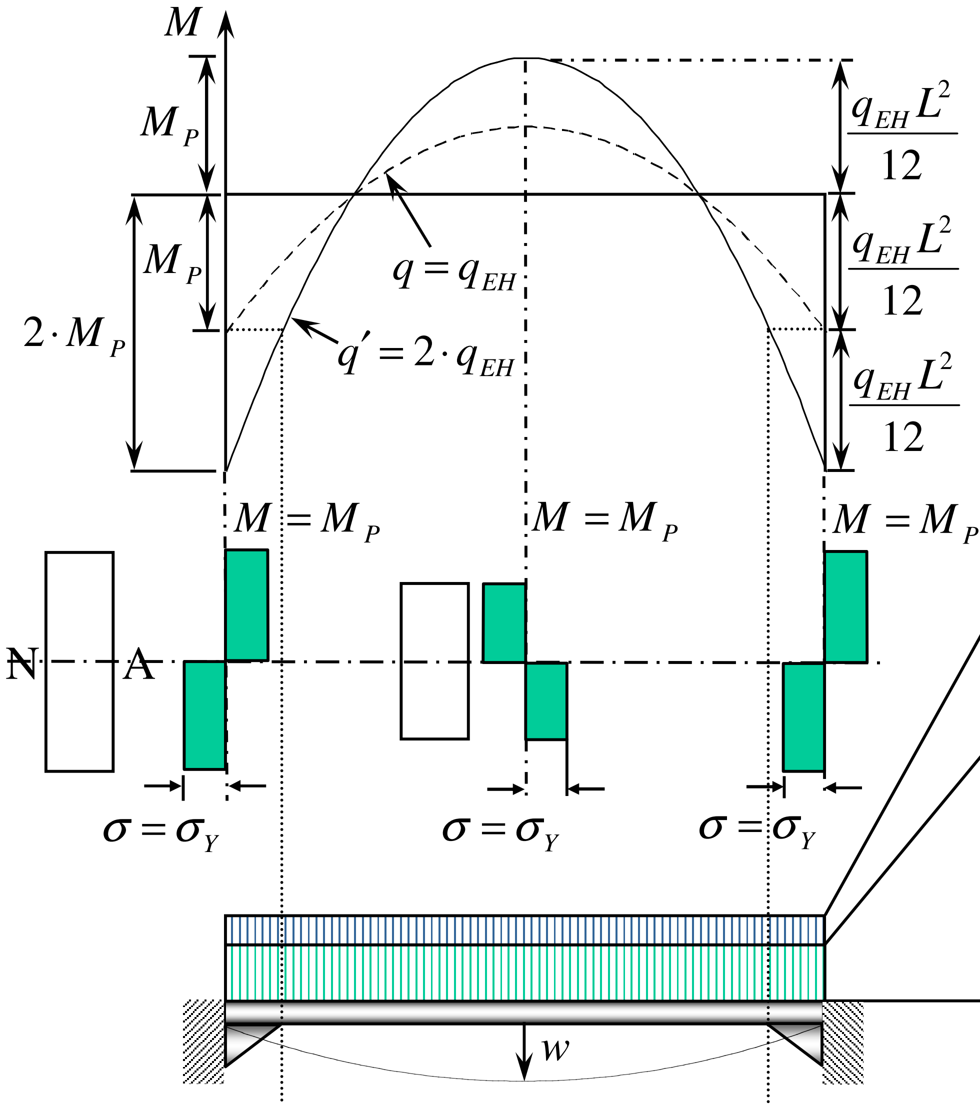
2. Basic Collapse Mechanism : $q = q_{EH}$



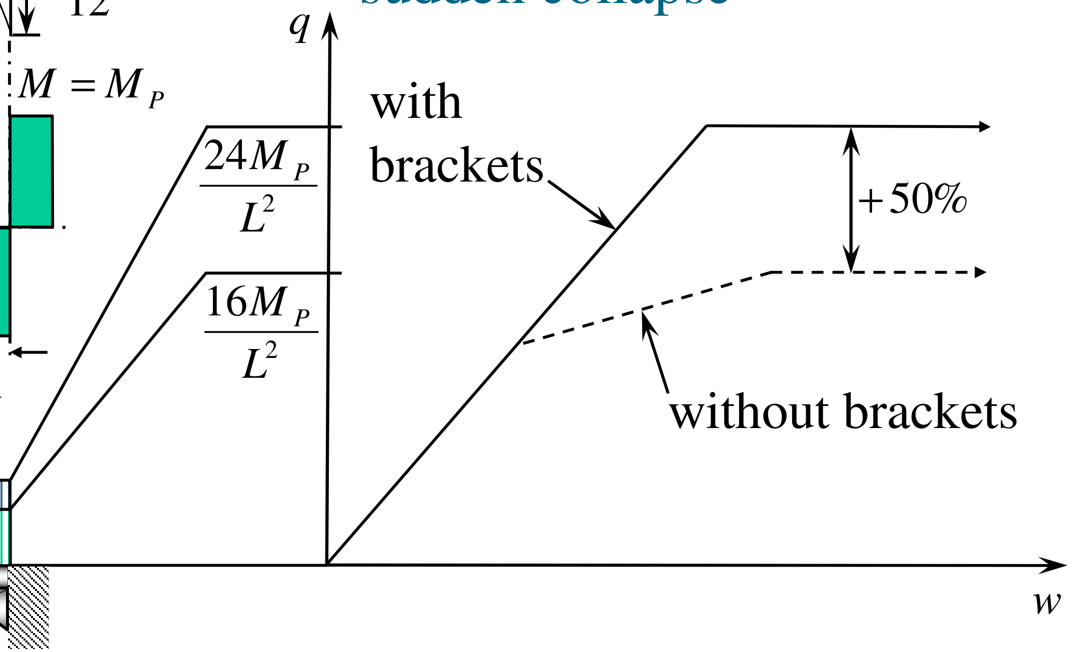
2. Basic Collapse Mechanism : $q = q_{collapse}$



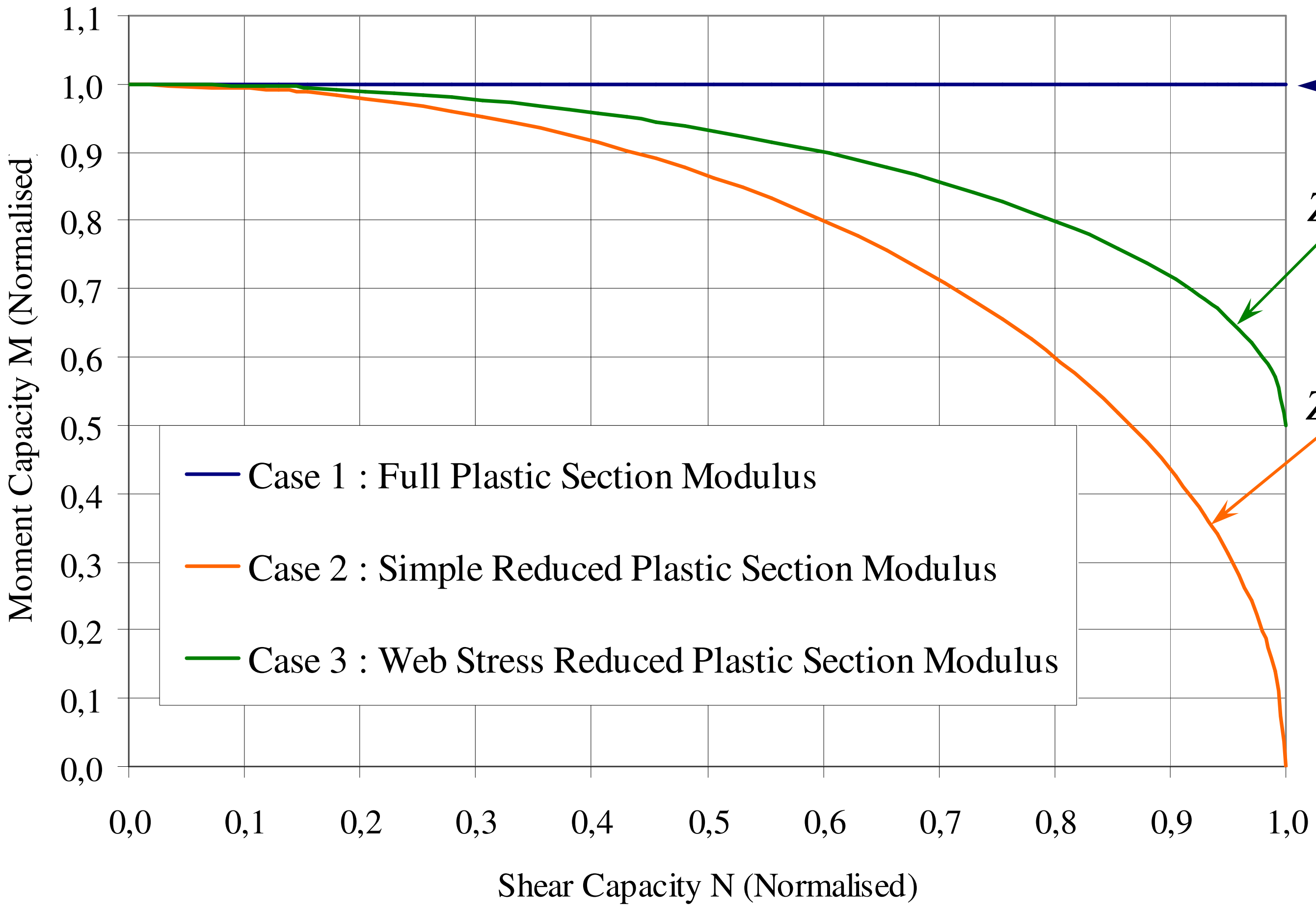
3. Effect of Brackets



- brackets dimensioned such that three hinges form simultaneously
- reduction in effective span (and hence bending moment) ignored
- 50% greater capacity, but more sudden collapse



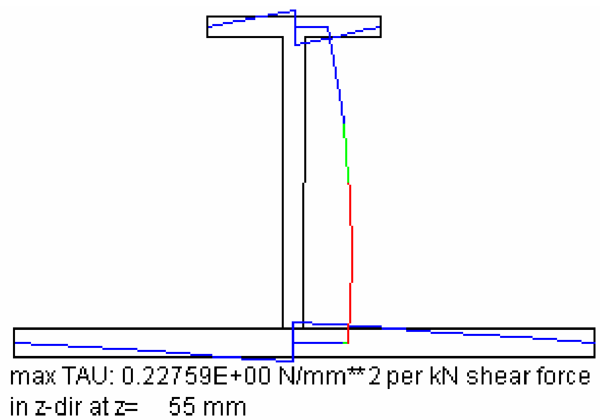
4. Shear-Bending Interaction



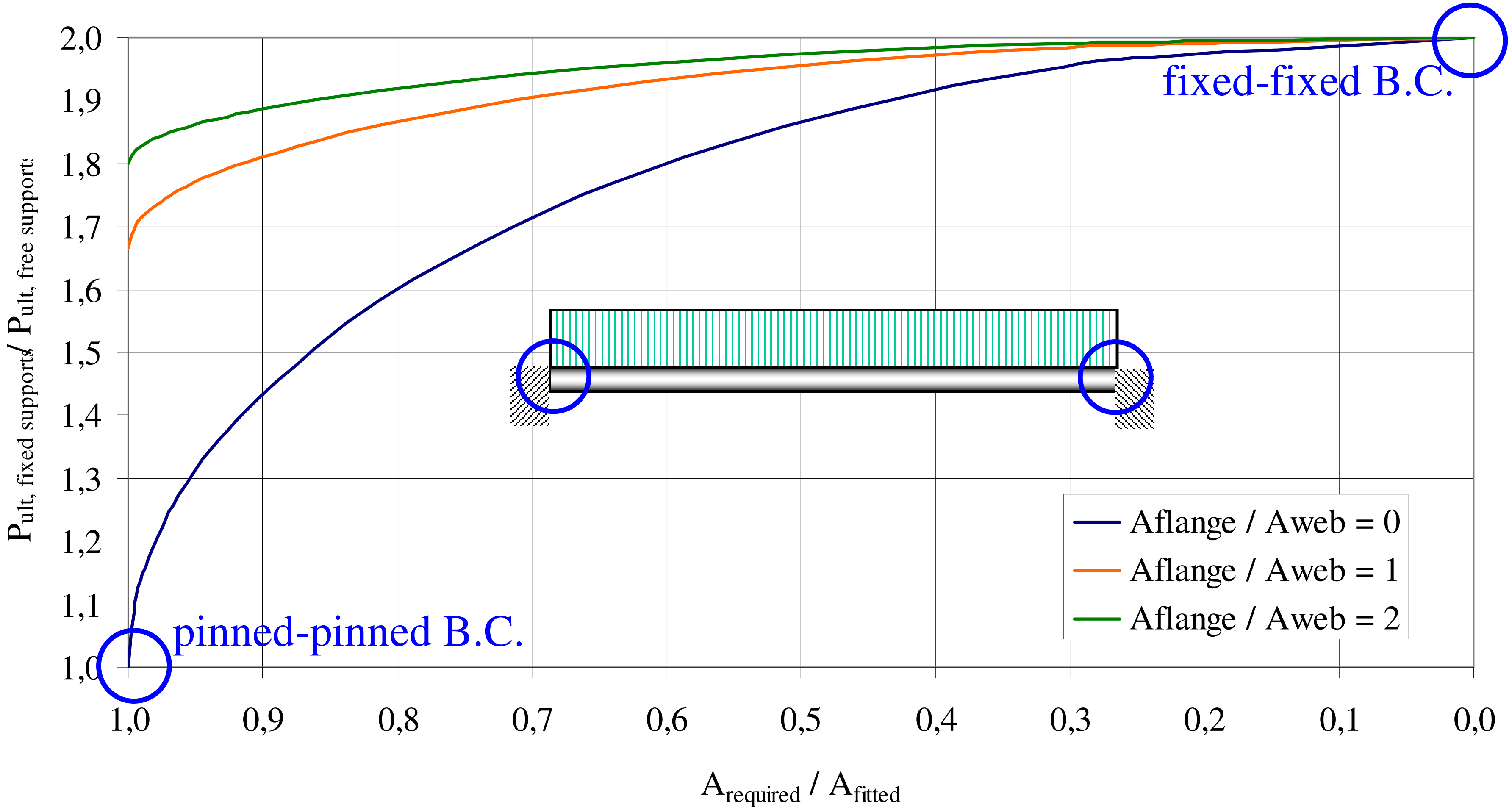
$$Zpr = Zp$$

$$Zpr = Z_{flange} + Z_{web}\sqrt{1-\left(\frac{A_{required}}{A_{fitted}}\right)^2}$$

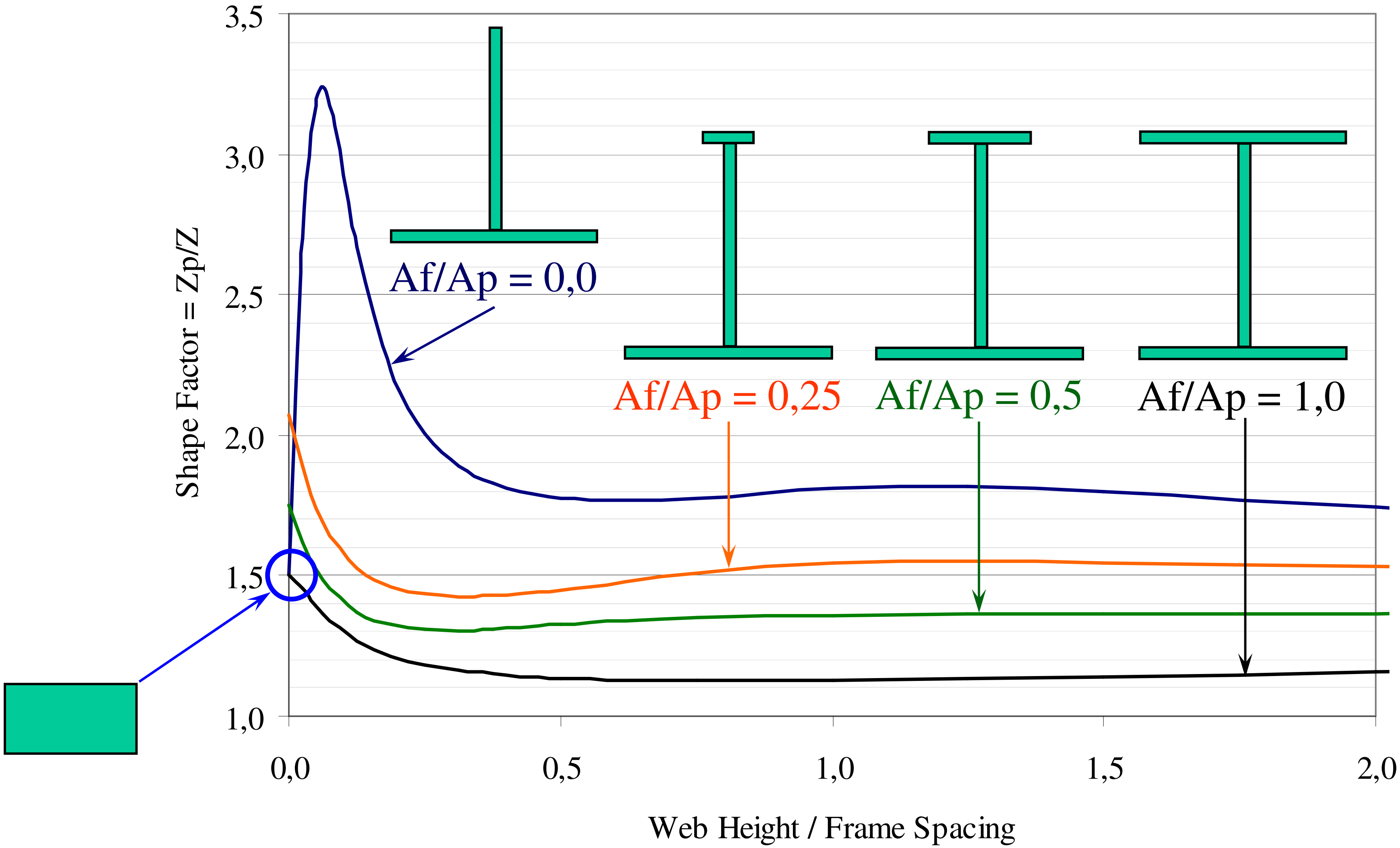
$$Zpr = Zp\sqrt{1-\left(\frac{A_{required}}{A_{fitted}}\right)^2}$$



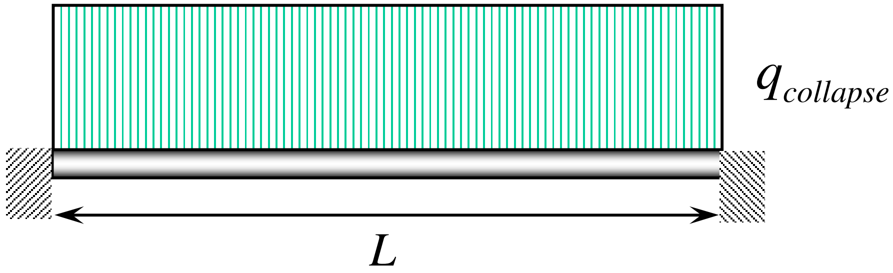
4. Shear-Bending (Symmetric) Interaction
- Effect of Web Stress Reduced Section Modulus -

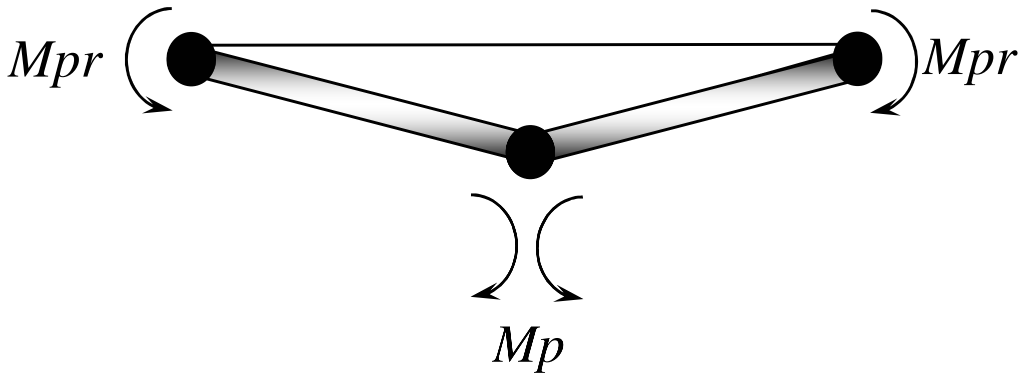


5. Shape Factors



6. Energy Methods
Longitudinal Framing



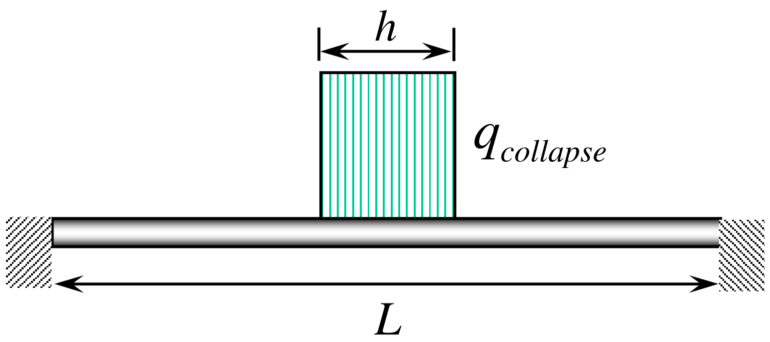


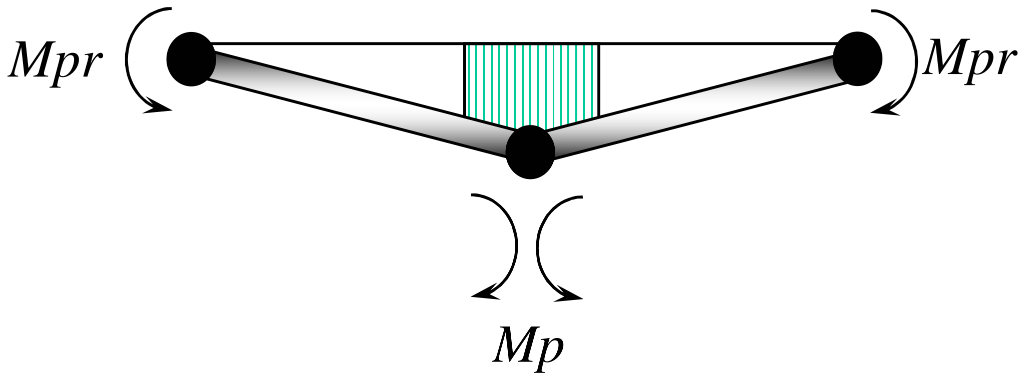
$$External \quad Work \quad = \quad Internal \quad Work$$

$$\frac{q_{collapse} \cdot L}{2} = \frac{4Mp}{L} + 4 \cdot \frac{j}{2} \frac{Mpr}{L}$$

j = number of rotationally-restrained supports

6. Energy Methods
Transverse Framing (Symmetric Load)



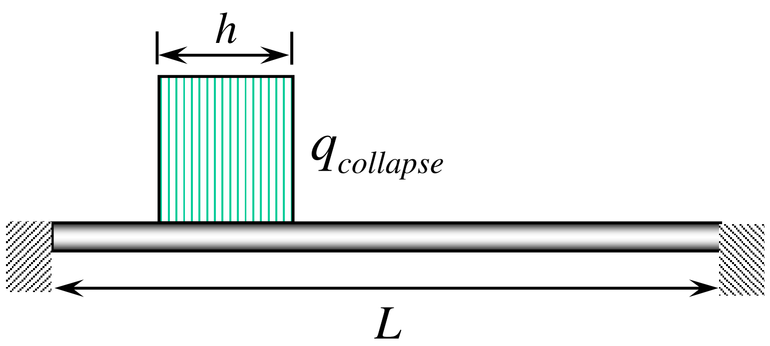


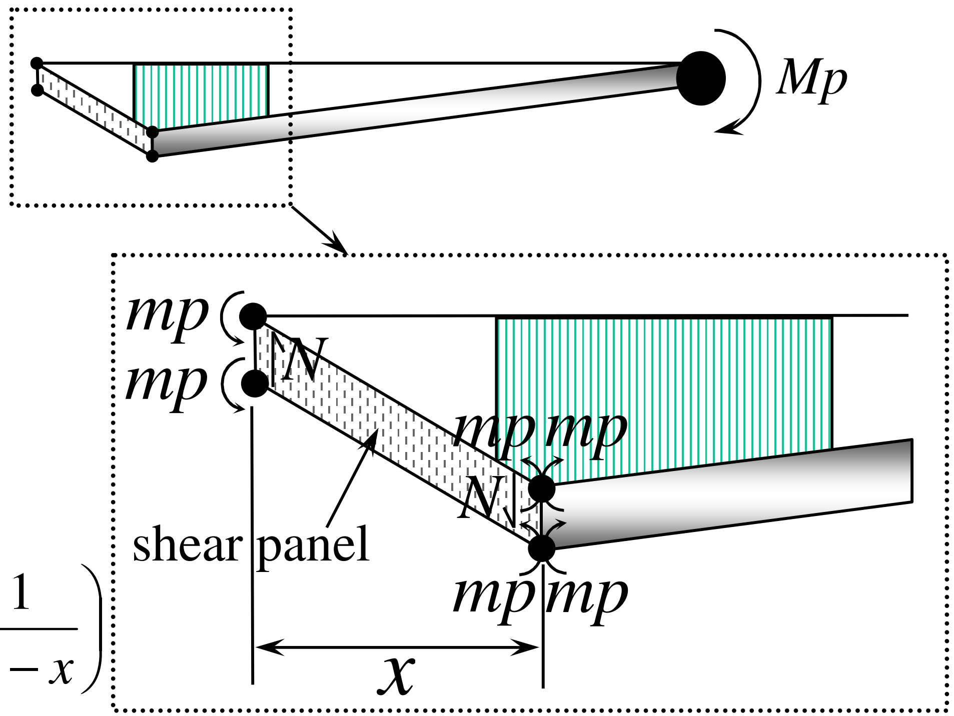
$$External \quad Work \quad = \quad Internal \quad Work$$

$$q_{collapse} \cdot spacing \cdot \left(1 - \frac{h}{2 \cdot L}\right) = \frac{4Mp}{L} + 4 \cdot \frac{j}{2} \frac{Mpr}{L}$$

j = number of rotationally-restrained supports

6. Energy Methods
Transverse Framing (Asymmetric Load)

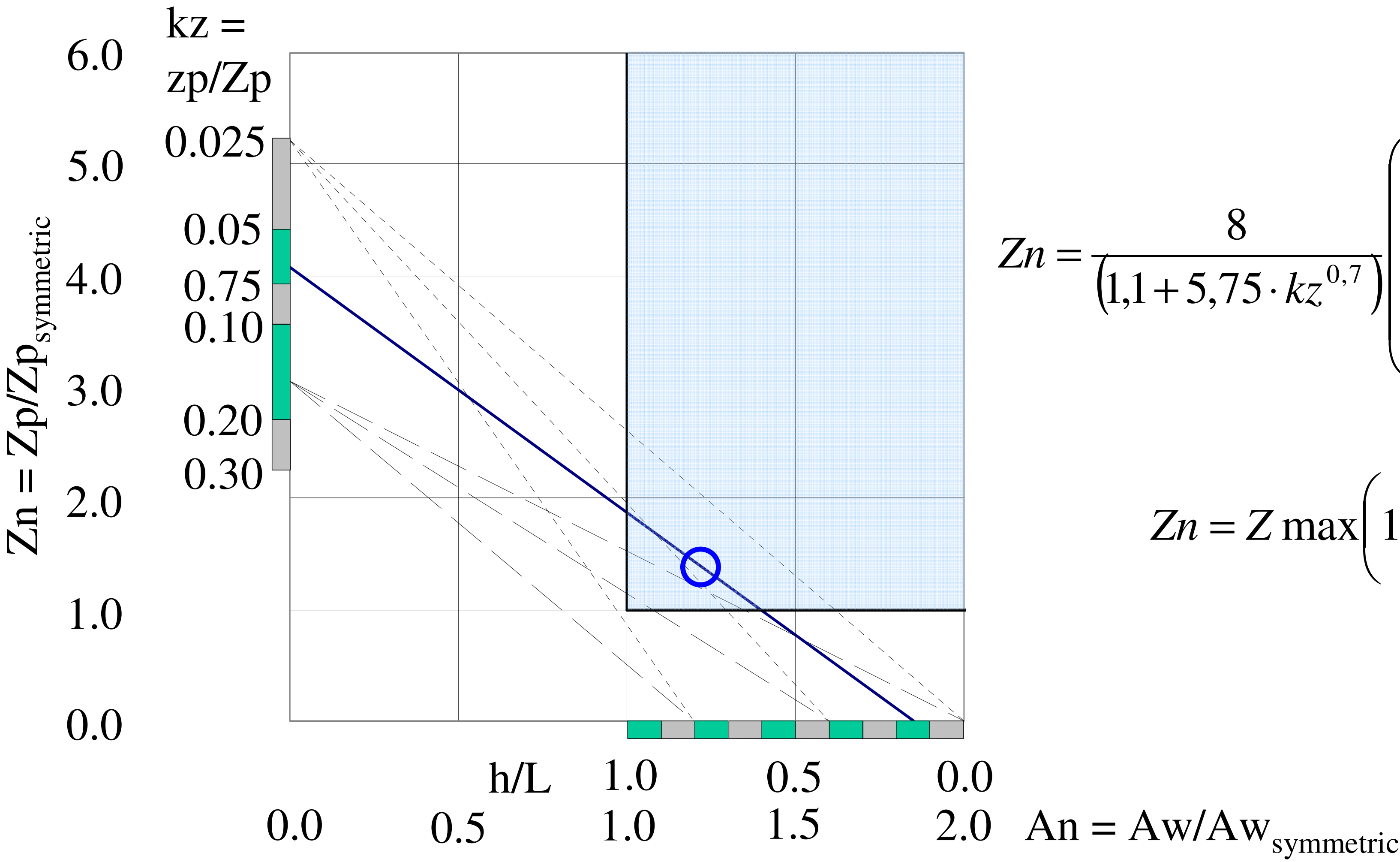




$$External \quad Work \quad = \quad Internal \quad Work$$

$$q_{collapse} \cdot spacing \cdot \left(1 - \frac{h}{2 \cdot L}\right) = N + \frac{Mp}{L - x} + mp\left(\frac{2}{x} + \frac{1}{L - x}\right)$$

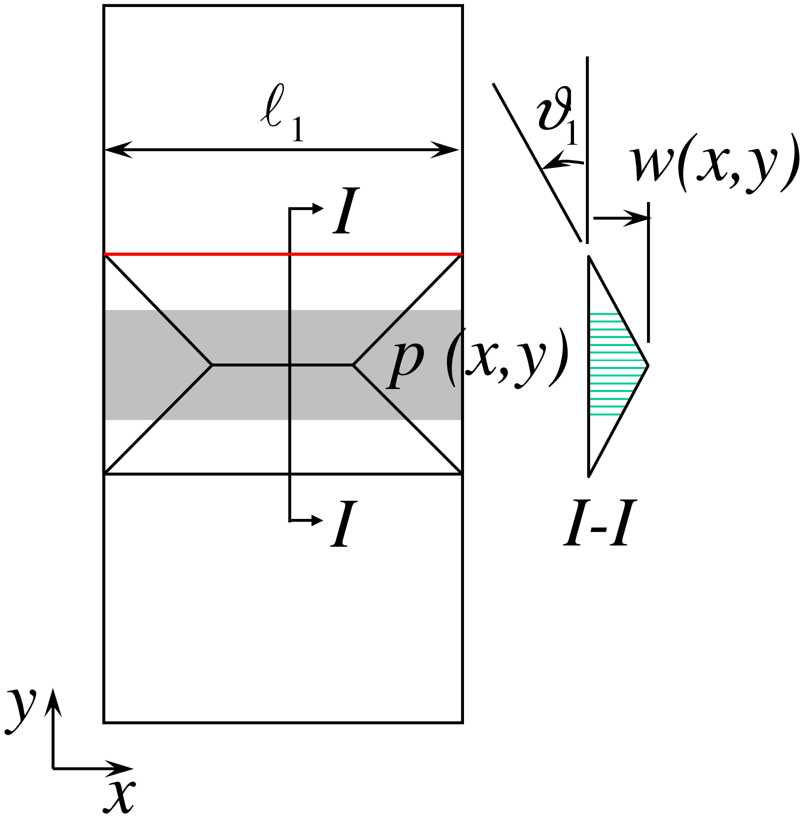
6. Energy Methods
Transverse Framing (Asymmetric Load)



$$Zn = \frac{8}{\left(1{,}1 + 5{,}75 \cdot kz^{0,7}\right)} \left(1 - \frac{An}{2 \cdot \left(1 - \frac{h}{2 \cdot L}\right)}\right)$$

$$Zn = Z\max\left(1 - \frac{An}{A\max}\right)$$

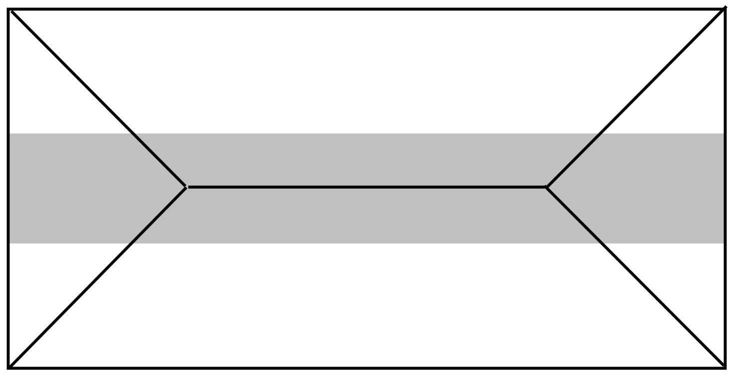
6. Energy Methods
Plating



Transverse Framing

External Work = Internal Work

$$\iint p(x,y)w(x,y)dxdy = \sum_{i=1}^{n} \ell_i M_0 \vartheta_i$$



Longitudinal Framing

7. Acceptable Response Criteria?

1. Ultimate or collapse limit state (ULS)

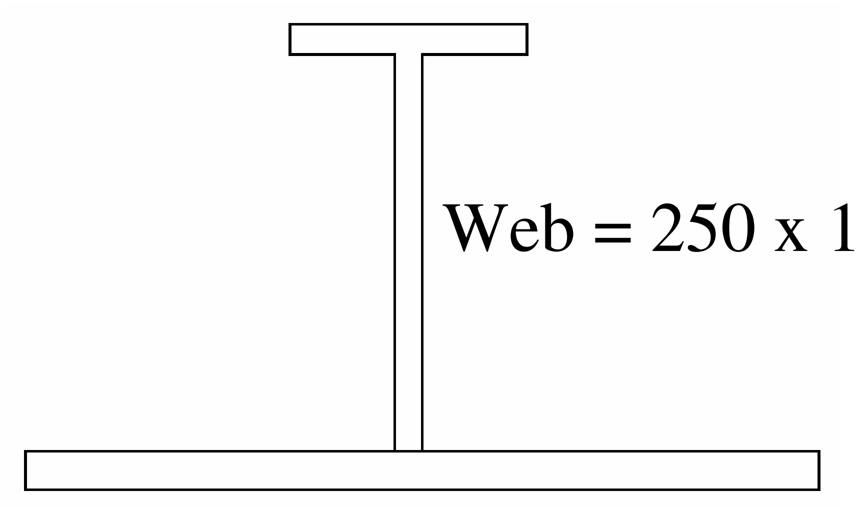
   - based on load carrying capacity or ultimate strength

2. Serviceability limit state (SLS)

   - based on the limits of deflections (or vibration) for normal use

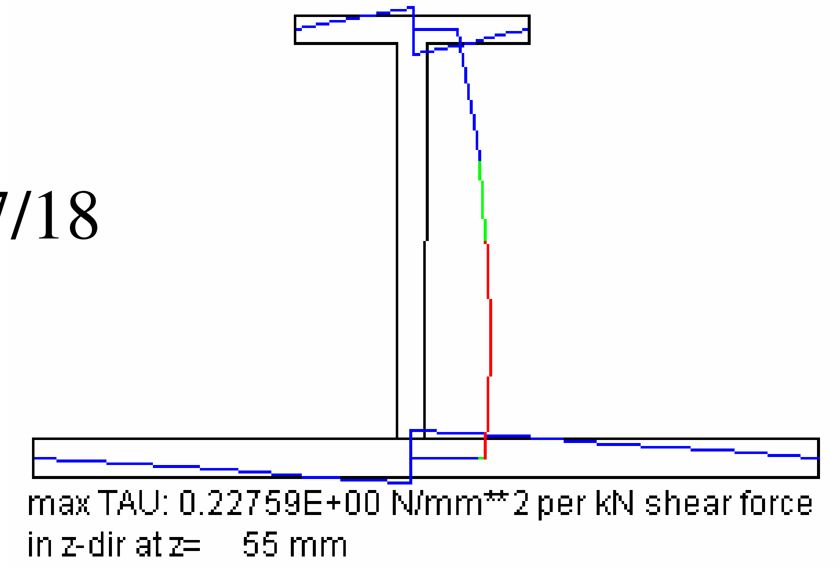
7. Acceptable Response Criteria?
Sample Calculation

Flange = 150 x 17/18



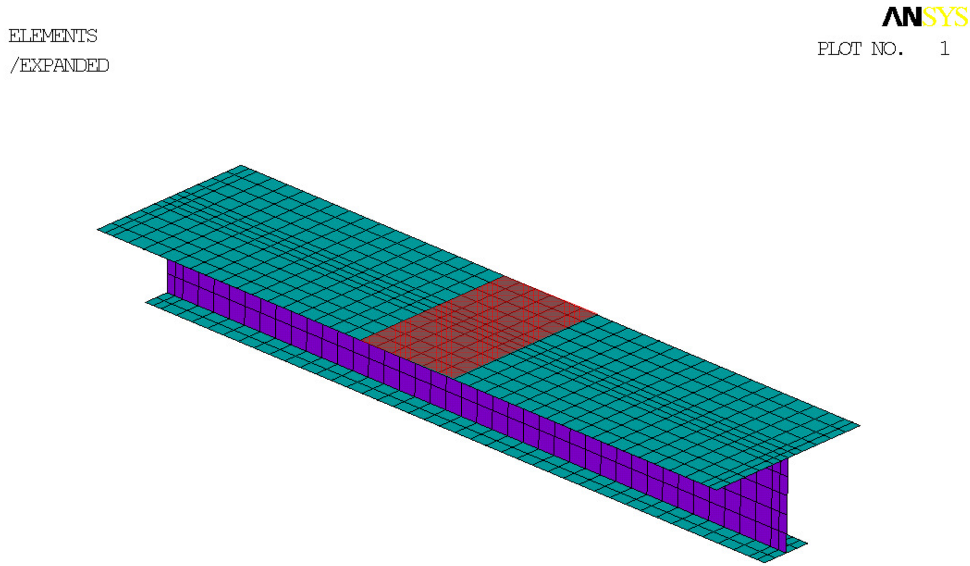
Web = 250 x 17/18

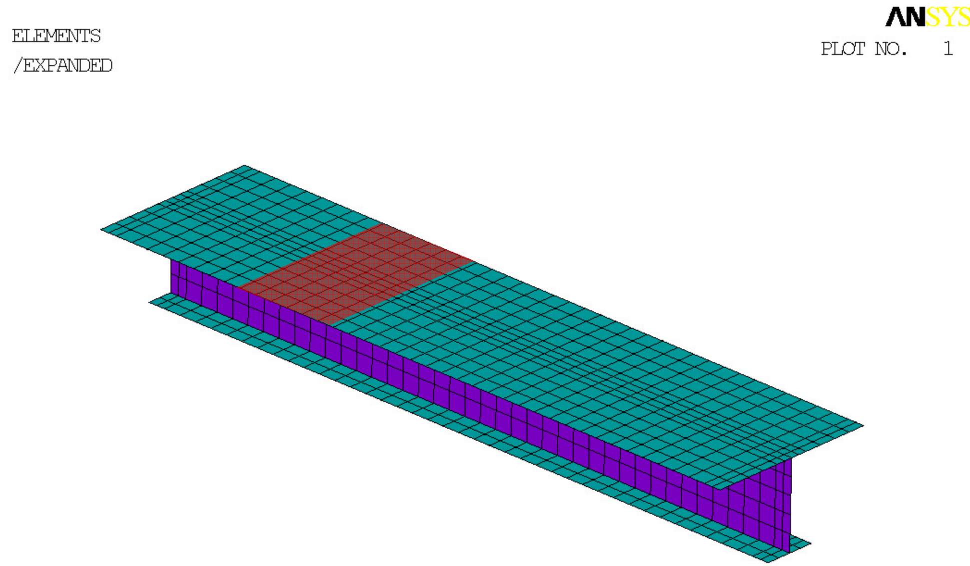
Plate = 500 x 25



Length = 2000 mm, Load Height = 300 mm, R_{eH} = 235 N/mm^2

7. Acceptable Response Criteria?
Finite Element Model





Symmetric Loading

Asymmetric Loading

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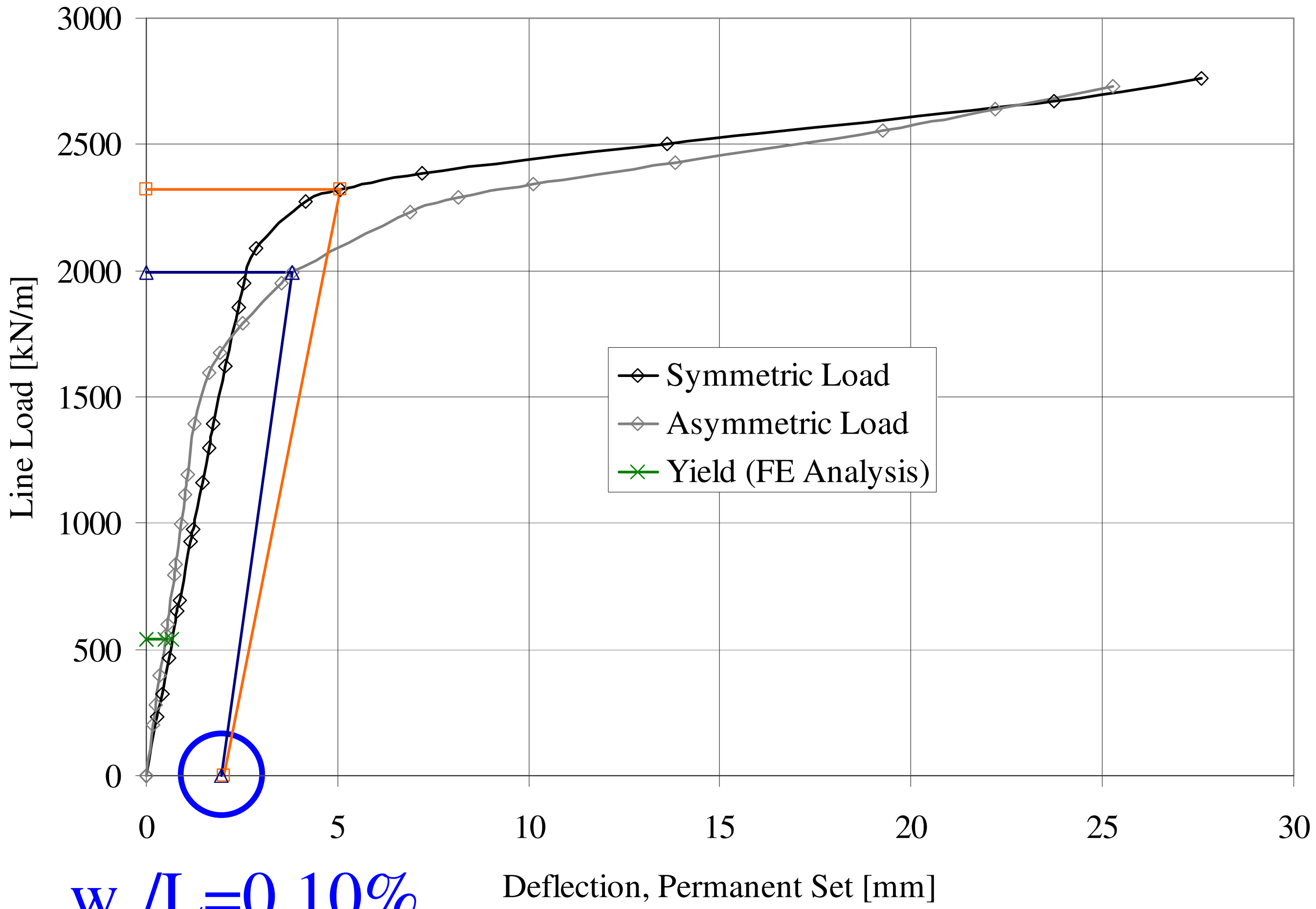
7. Acceptable Response Criteria? Transverse Framing



$w_p/L=0,10\%$

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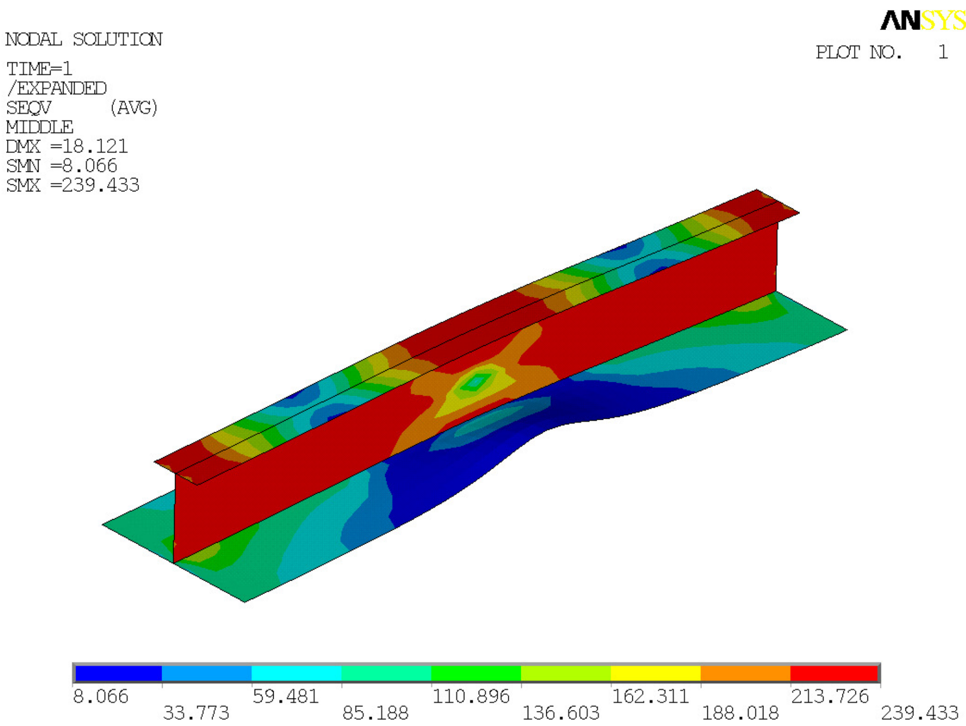
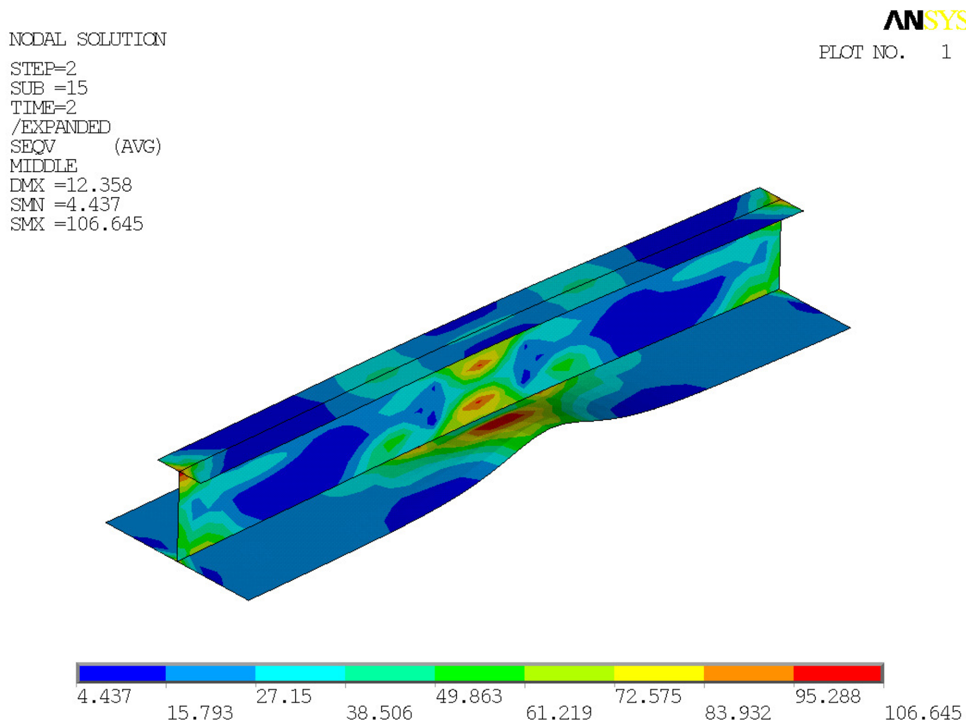
7. Acceptable Response Criteria?
Transverse Framing – Symmetric Loading

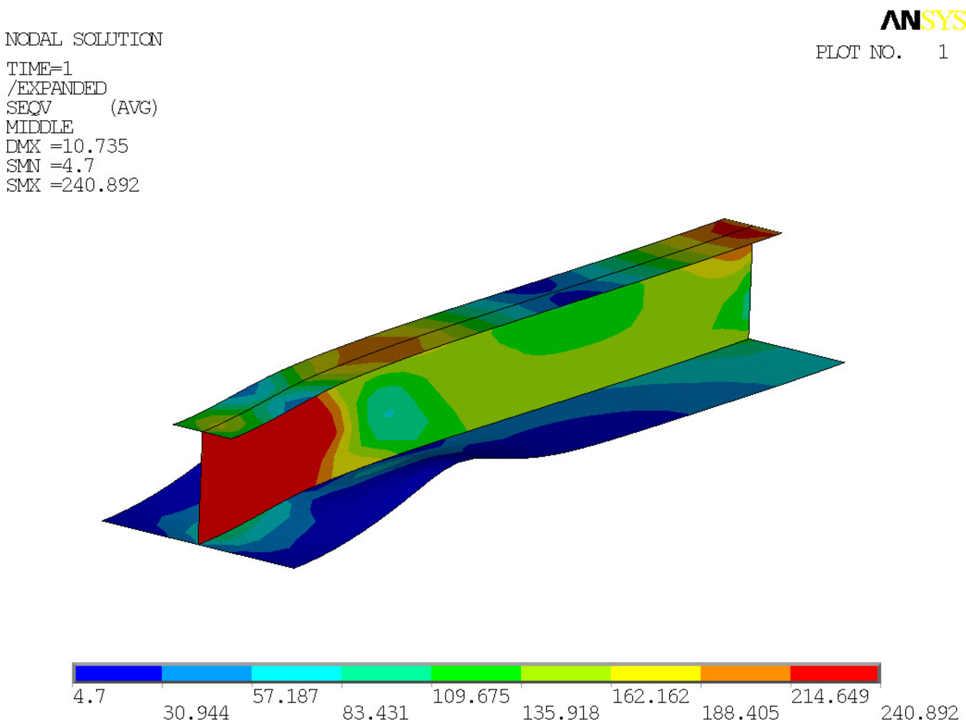


Design (Von Mises) Stresses

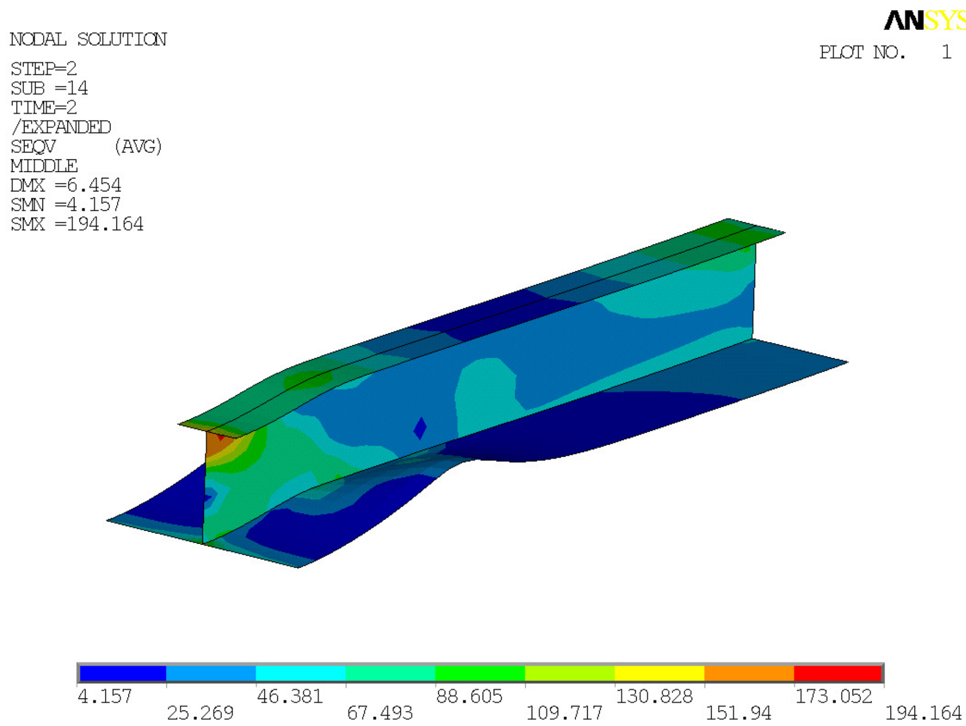


Residual (Von Mises) Stresses

7. Acceptable Response Criteria? Transverse Framing – Asymmetric Loading



Design (Von Mises) Stresses



Residual (Von Mises) Stresses

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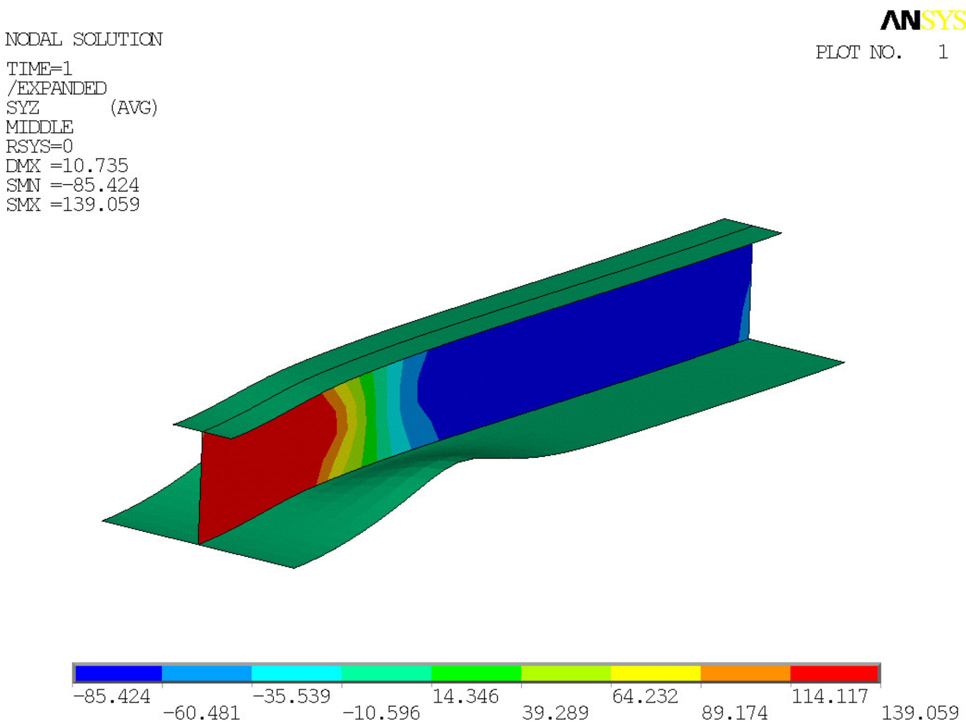
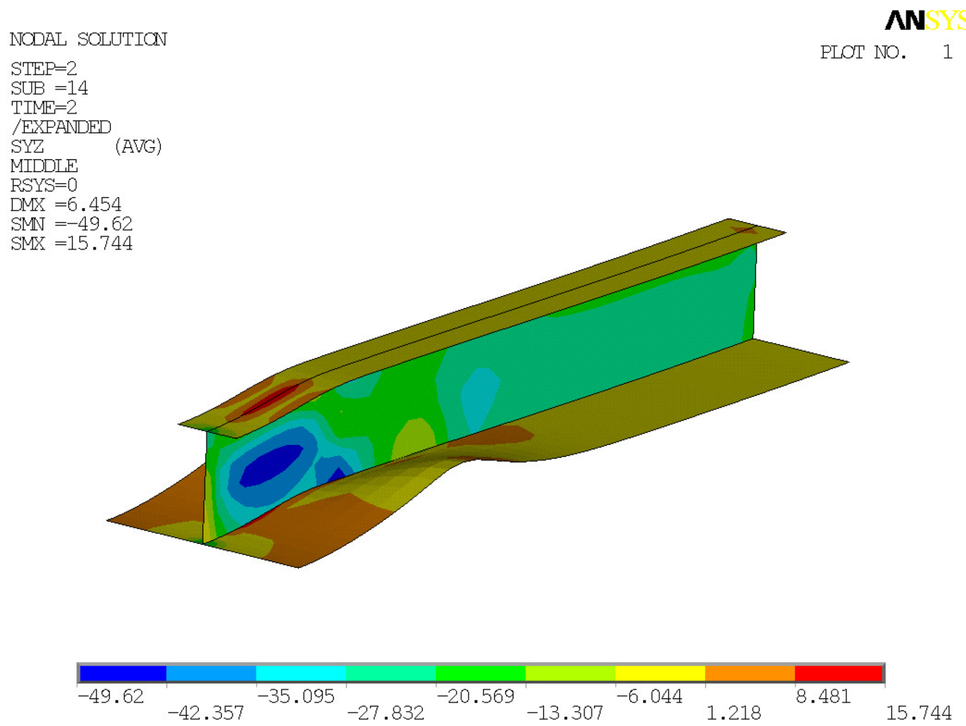
7. Acceptable Response Criteria? Transverse Framing – Asymmetric Loading

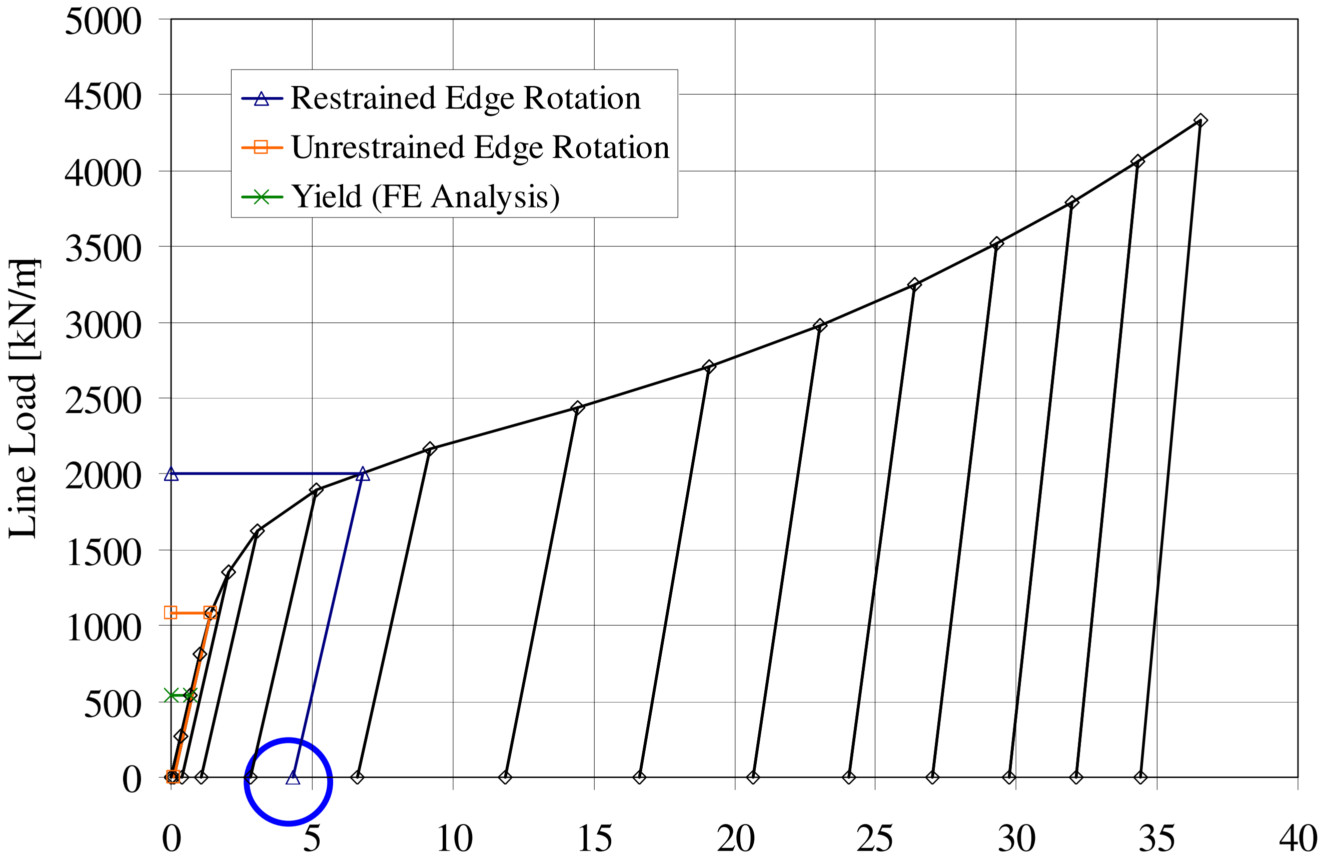


Design (Shear) Stresses



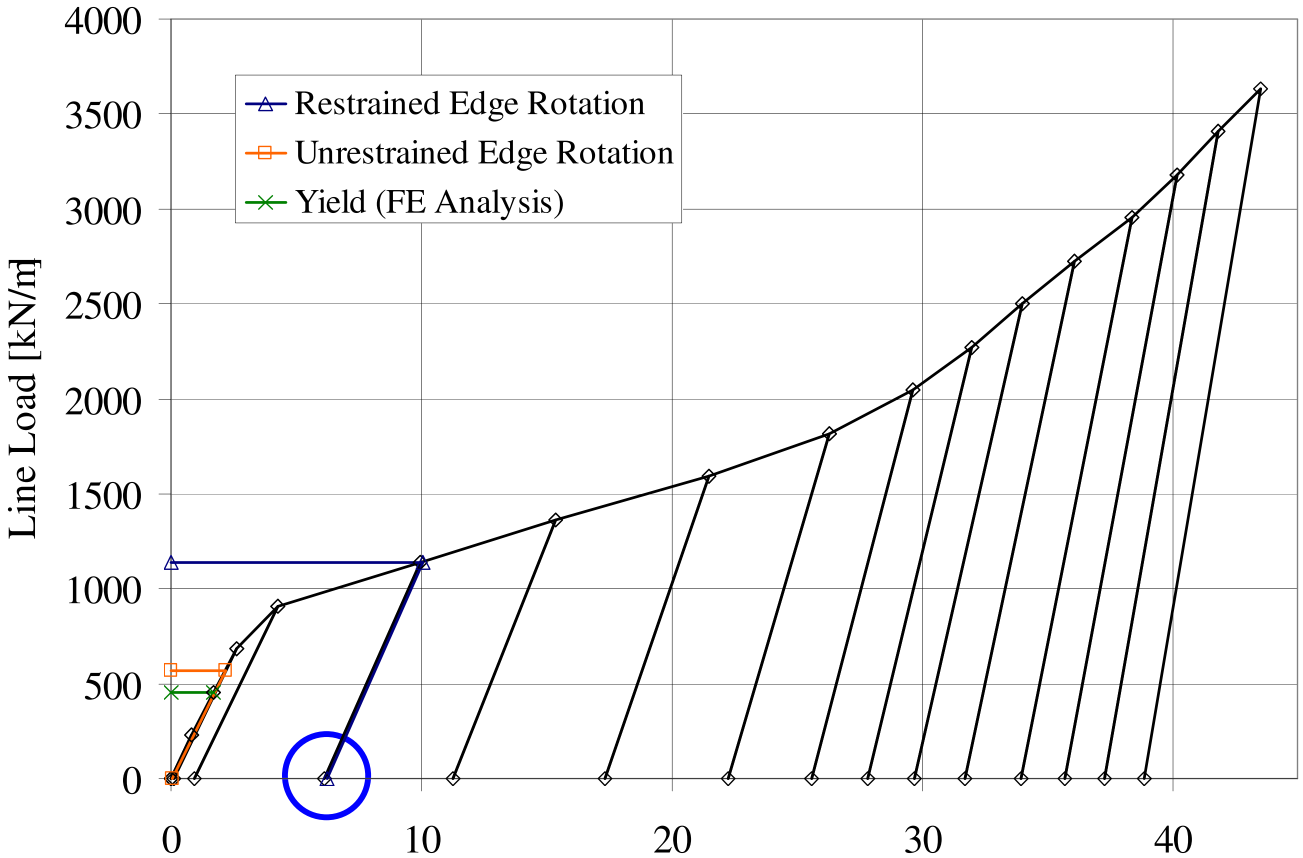
Residual (Shear) Stresses

7. Acceptable Response Criteria? Plating (Transversely-Framed)



$w_p/s=0,86\%$

7. Acceptable Response Criteria? Plating (Longitudinally-Framed)



$w_p/s=1,24\%$

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Deliverable 9-2 Assessment of Risk Levels in Ice Class Rules

1. Main Particulars of Ships Used in Assessment
2. Assessment of Risks – Base Case
3. Assessment of Risks – Influence of Load Height
4. Assessment of Risks – Influence of Frame Orientation
5. A Structural Design Method for Ice Class Ships
6. Recommendations for Further Development of Ice Class Rules

1. Main Particulars of Ships Used in Assessment

	Kemira	Arcturus	Kashira
Type	Chemical Tanker	Ro-Ro	Tanker
Ice Class	IAS	IAS	IAS/UL
Length	113 m	155 m	112 m
Displacement	8250 t	12000 t	9000 t
Power	4119 kW	13200 kW	5000 kW
Operational Profile	57% Bay of Bothnia 21% Bothnian Sea 22% Baltic Proper	88% Gulf of Finland 12% Baltic Proper	100% Gulf of Finland (assumed)
Frame Spacing	370 mm (trans.)	364 mm (trans.)	360 mm (trans.)
Waterline Angle	19,0 °	16,5°	20,0°
Frame Angle	21,3°	27,2°	20,6°

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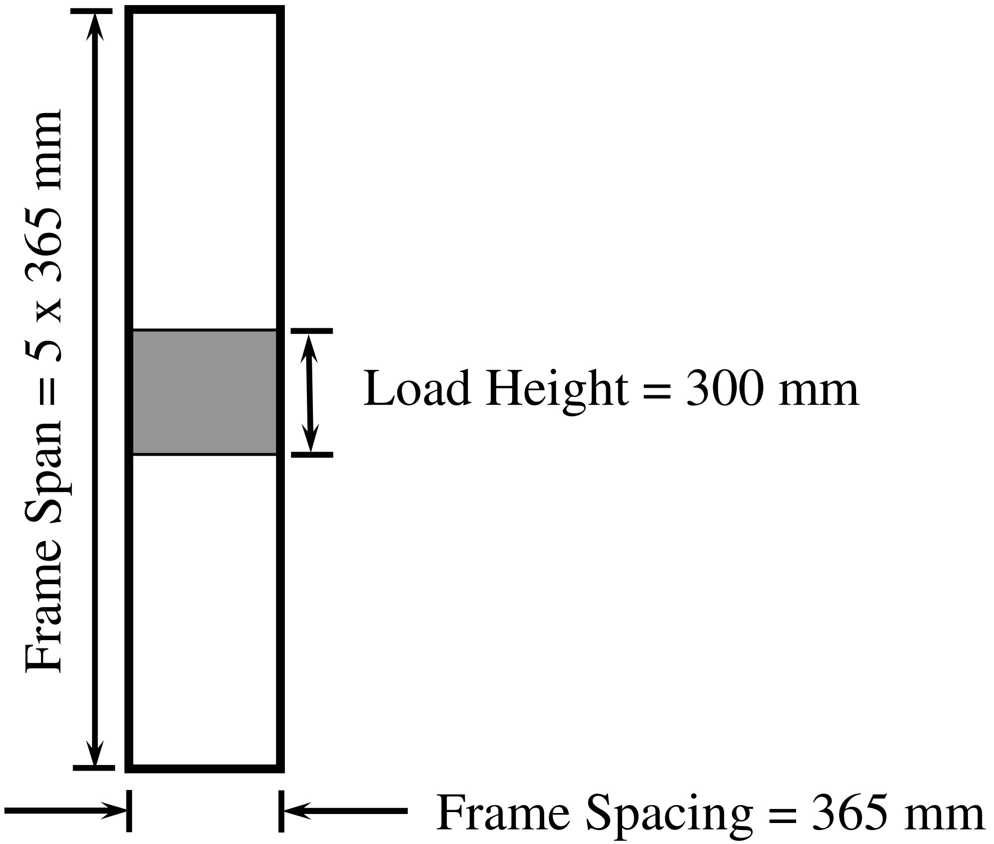
2. Assessment of Risks
Base Case



$\sigma_y = 235\ \mathrm{N/mm^2}$

$A_{flange}/A_{web} = 0{,}50$

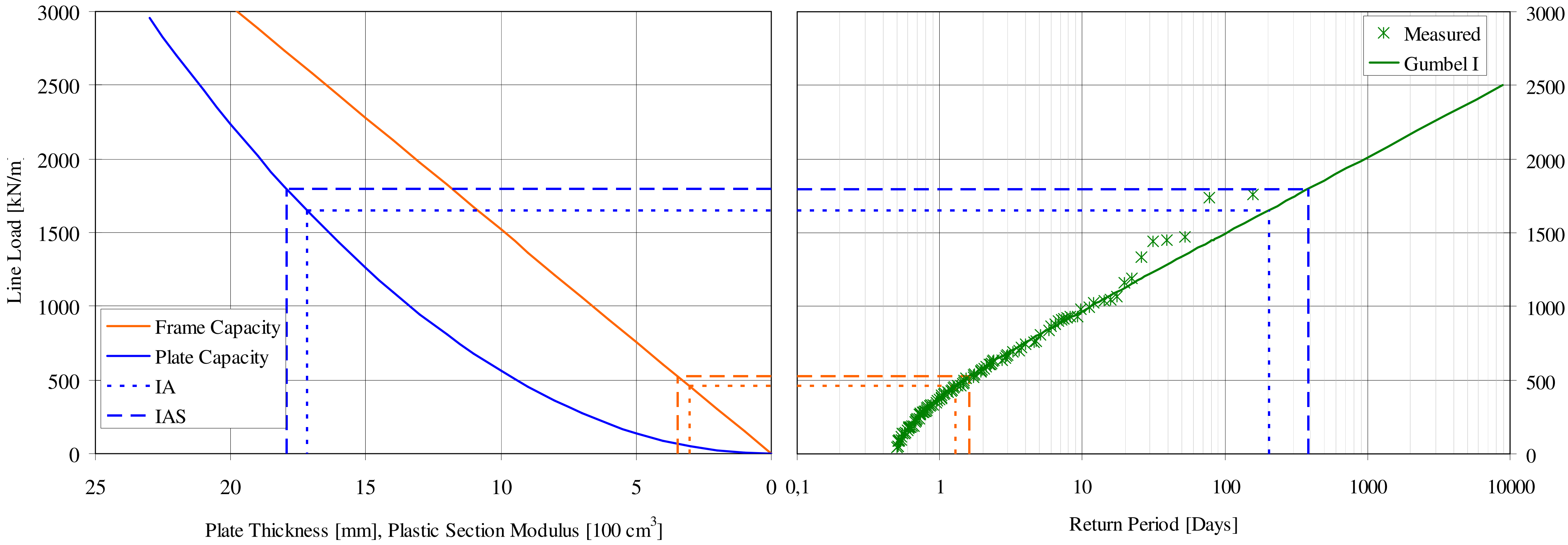
$k_z = z_p/Z_p = 0{,}05$

$A_{fitted}/A_{required} = 1{,}0$

Shape Factor = 1,25 (FSICR)

B.C. = Fixed-Fixed

2. Assessment of Risks
Base Case
FSICR (Kemira)



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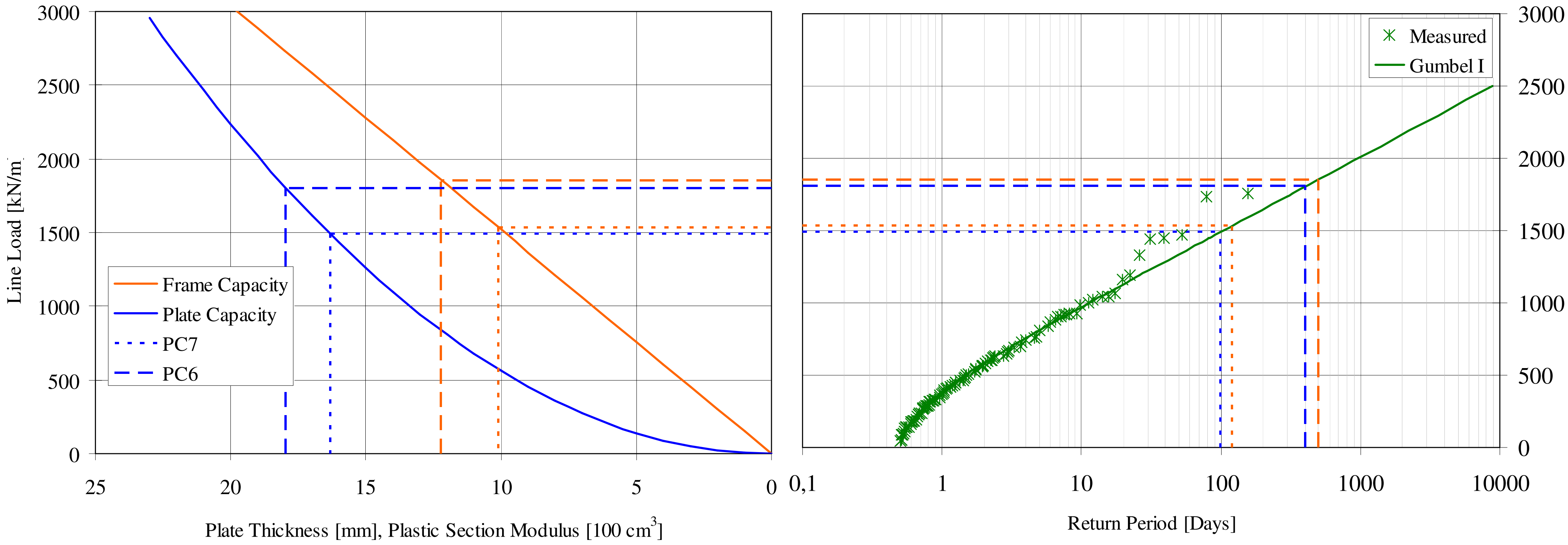
2. Assessment of Risks Base Case IACS (Kemira)



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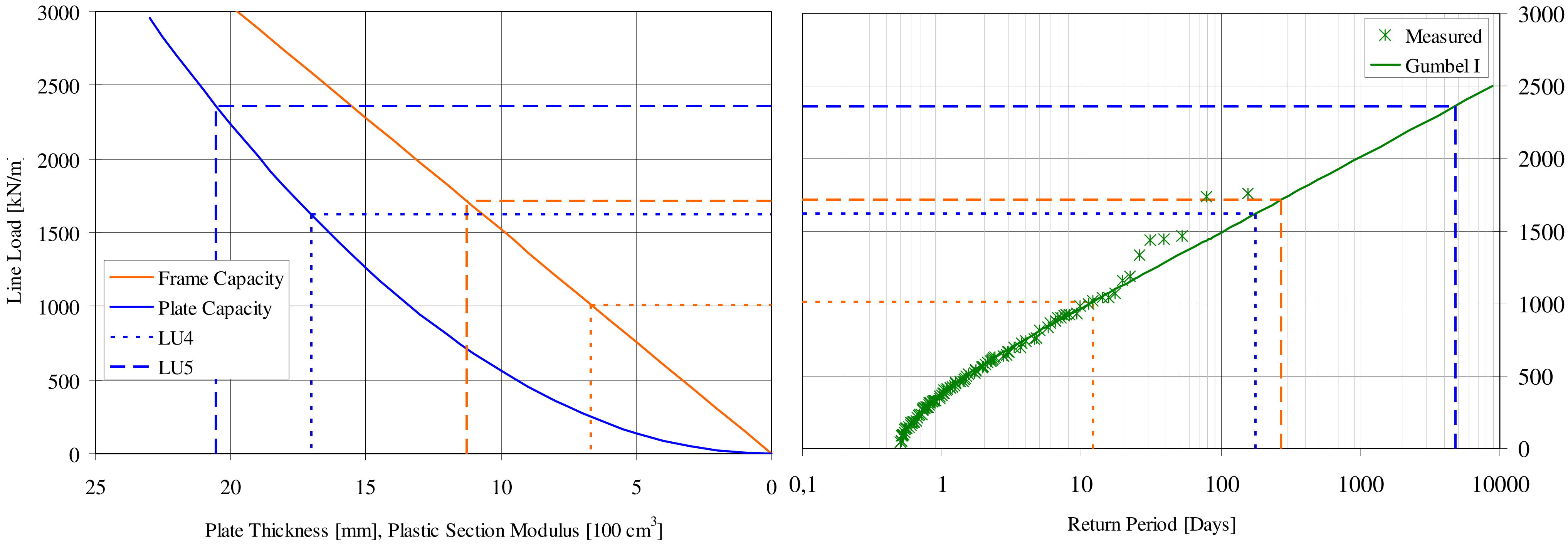
2. Assessment of Risks Base Case RMRS (Kemira)



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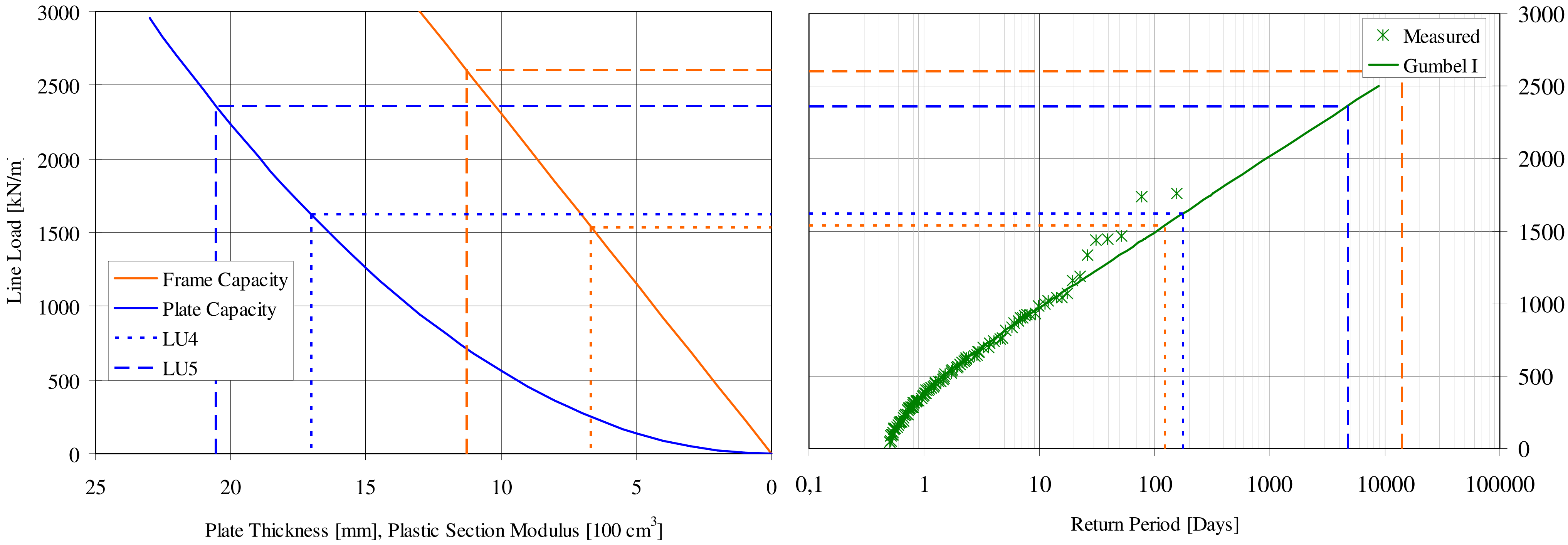
2. Assessment of Risks
Base Case (Symmetric Bending Only)
RMRS (Kemira)



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2. Assessment of Risks
Base Case - Kemira

	Required Scantlings		Collapse Load		Return Period	
	Plate [mm]	Frame [cm³]	Plate [kN/m²]	Frame [kN/m²]	Plate [Days]	Frame [Days]
FSICR (IAS)	17,9	347	1795	526	386	1,6
IACS (PC6)	18,0	1221	1806	1853	405	499
RMRS (LU5)	20,5*	1130	2360	1715	4782	270

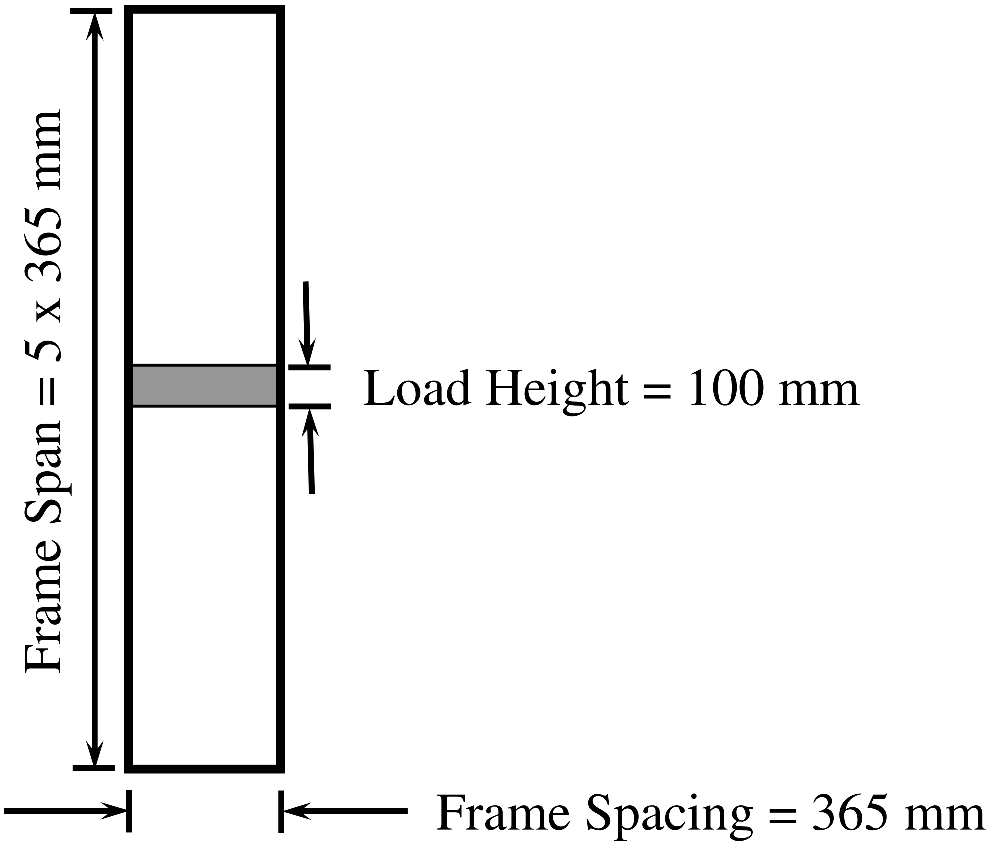
2. Assessment of Risks
Base Case - Arcturus

	Required Scantlings		Collapse Load		Return Period	
	Plate [mm]	Frame [cm³]	Plate [kN/m²]	Frame [kN/m²]	Plate [Days]	Frame [Days]
FSICR (IA)	**20,8**	**445**	**2424**	**676**	**1293985**	**13**
IACS (PC7)	**16,2**	**996**	**1471**	**1512**	**2424**	**3181**
RMRS (LU4)	**16,7***	**626**	**1559**	**950**	**4340**	**79**

2. Assessment of Risks
Base Case - Kashira

	Required Scantlings		Collapse Load		Return Period	
	Plate [mm]	Frame [cm³]	Plate [kN/m²]	Frame [kN/m²]	Plate [Days]	Frame [Days]
FSICR (IA)	17,7	324	1761	491	463	1,4
IACS (PC7)	16,8	1056	1571	1603	189	220
RMRS (LU4)	17,6*	753	1732	1144	404	25

3. Assessment of Risks
Influence of Load Height



$\sigma_y = 235$ N/mm^2

$A_{flange}/A_{web} = 0{,}50$

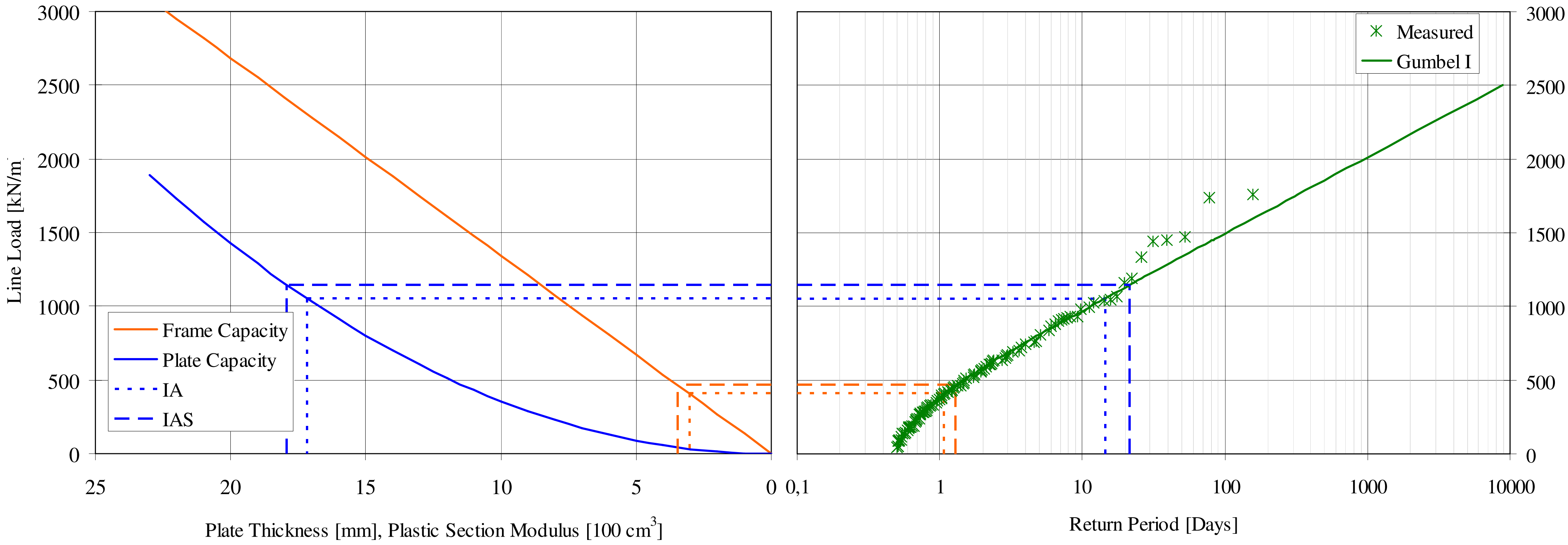
$k_z = z_p/Z_p = 0{,}05$

$A_{fitted}/A_{required} = 1{,}0$

Shape Factor = 1,25 (FSICR)

B.C. = Fixed-Fixed

3. Assessment of Risks
Load Height = 100 mm
FSICR (Kemira)



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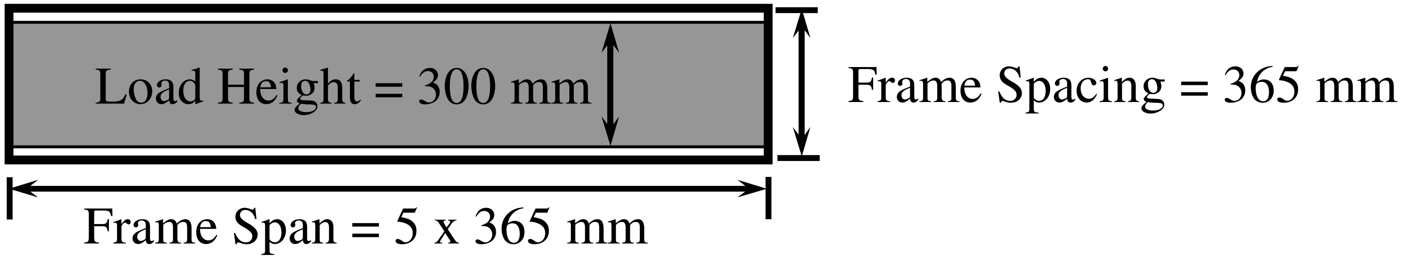
3. Assessment of Risks
Load Height = 100 mm - Kemira

	Required Scantlings		Collapse Load		Return Period	
	Plate [mm]	Frame [cm^3]	Plate [kN/m^2]	Frame [kN/m^2]	Plate [Days]	Frame [Days]
FSICR (IAS)	**17,9**	**347**	**1145 (1795)**	**465 (526)**	**22 (386)**	**1,3 (1,6)**
IACS (PC6)	**18,0**	**1221**	**1152 (1806)**	**1638 (1853)**	**22 (405)**	**192 (499)**
RMRS (LU5)	**20,5***	**1130**	**1506 (2360)**	**1516 (1715)**	**106 (4782)**	**111 (270)**

4. Assessment of Risks
Influence of Frame Orientation



Load adjusted by FSICR c_a factor:

$$c_a = \frac{47 - 5 \cdot FrameSpan}{44}$$

$$\max imum = 1{,}0$$

$$\min imum = 0{,}6$$

$\sigma_y = 235\ \text{N/mm}^2$

$A_{flange}/A_{web} = 0{,}50$

$k_z = z_p/Z_p = 0{,}05$

$A_{fitted}/A_{required} = 1{,}0$

Shape Factor = 1,25 (FSICR)

B.C. = Fixed-Fixed

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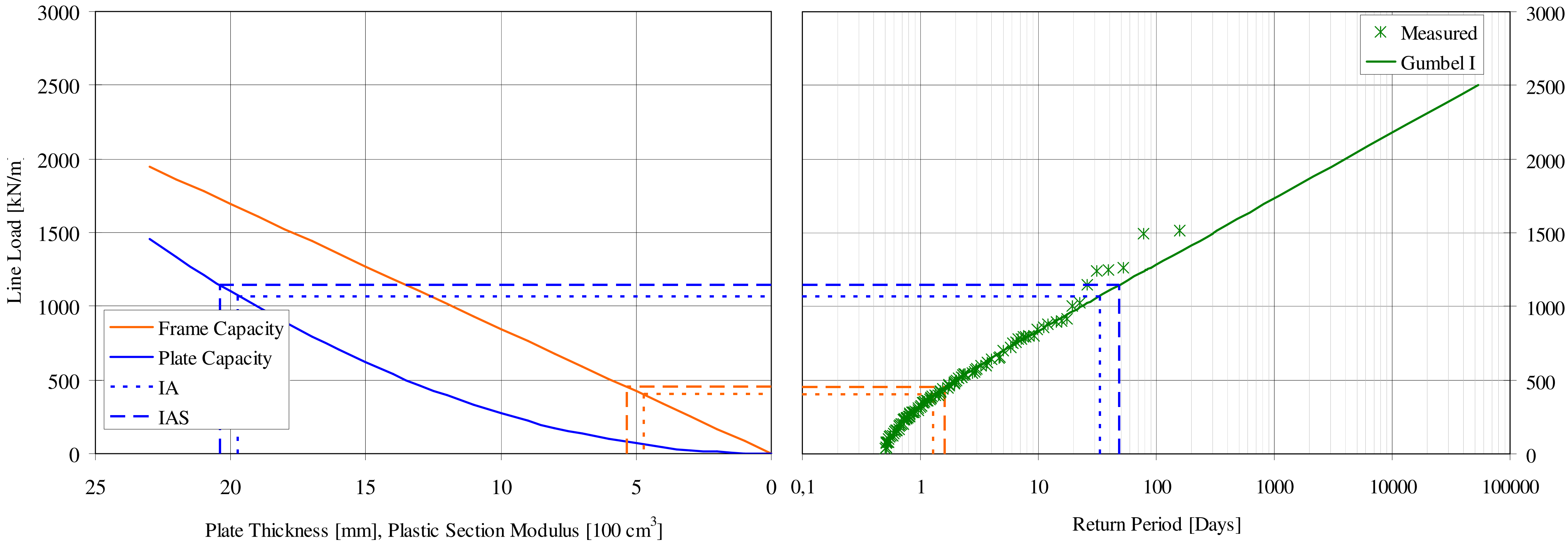
4. Assessment of Risks Longitudinal Framing FSICR (Kemira)



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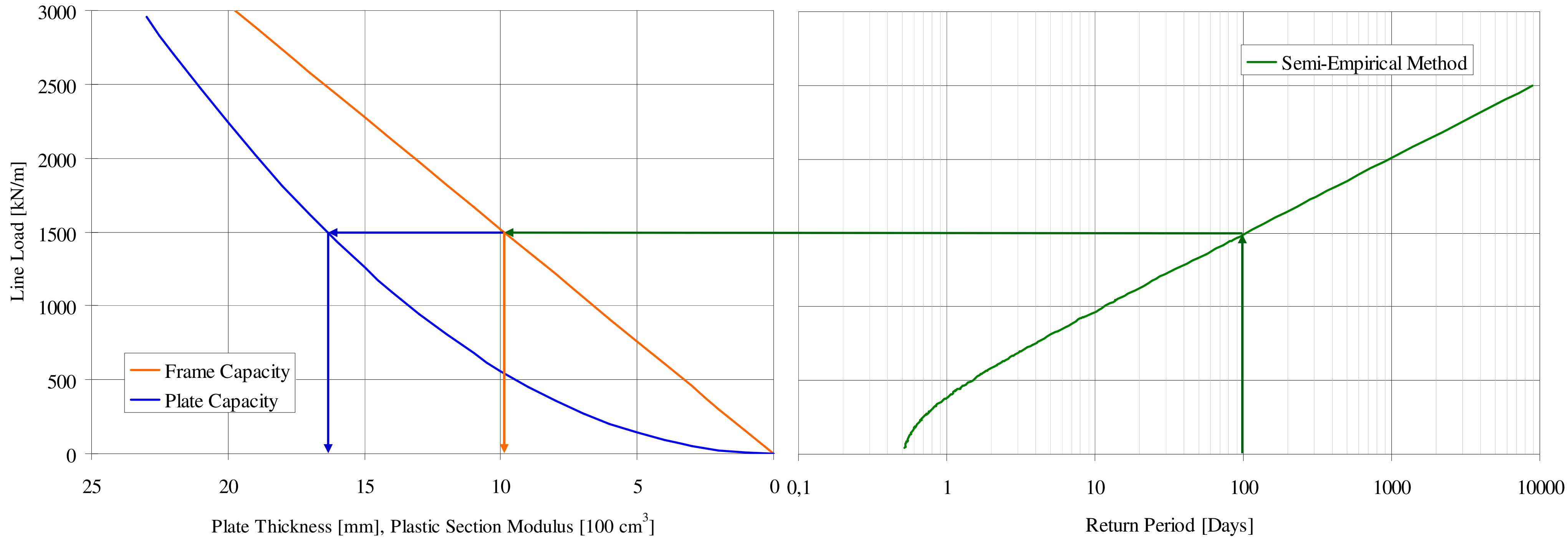
4. Assessment of Risks
Longitudinal Framing - Kemira

	Required Scantlings		Collapse Load		Return Period	
	Plate [mm]	Frame [cm^3]	Plate [kN/m^2]	Frame [kN/m^2]	Plate [Days]	Frame [Days]
FSICR (IAS)	20,4 (17,9)	534 (347)	1143 (1795)	452 (526)	48 (386)	1,6 (1,6)
IACS (PC6)	22,5 (18,0)	905 (1221)	1398 (1806)	766 (1853)	180 (405)	7,1 (499)
RMRS (LU5)	22,3* (20,5*)	1266 (1130)	1364 (2360)	1072 (1715)	151 (4782)	34 (270)

5. A Structural Design Method for Ice Class Ships



6. Recommendations for Further Development of Ice Class Rules

Semi-empirical method needs further development with respect to

•different ice conditions

•different ship characteristics (especially bow shapes and frame spacings/spans, i.e. loaded lengths)

•different design scenarios (i.e. other than continuous icebreaking)

•other hull areas (especially midbody and stern icebelts)

Response criteria needs further development with respect to longitudinal frames (especially influence of adjacent frames)

(Plastic) Design Principles

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