Polar Class Rules

Overview

Claude Daley
Professor
Memorial University
St. John's, CANADA
April 2014

MEMORIAL UNIVERSITY
Faculty of Engineering and Applied Science

Outline

- Main ice class rules and areas of application
- IACS Polar Class Unified Requirements
  - Technical Background
  - Ice load model
  - Class factors
  - Plating strength
  - Framing strength
  - Materials
  - Longitudinal strength
- Equivalency Issues

Brazilian Research Vessel *Mar Sem Fim*, sunk by ice pressure, April 2012, Antarctica,
Source: sometimes-interesting.com

MEMORIAL UNIVERSITY Faculty of Engineering and Applied Science

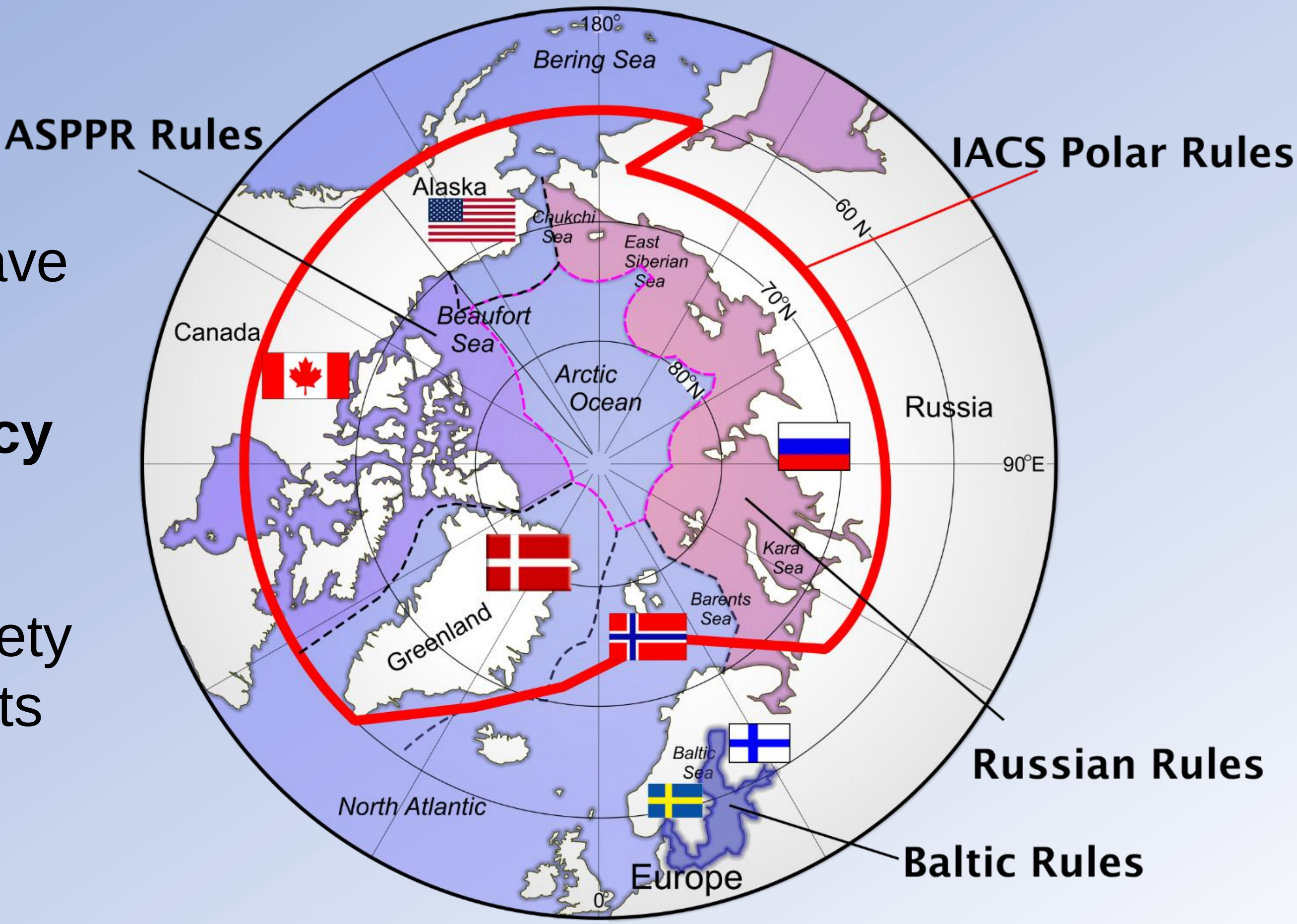
Ice Class Areas

Ice Class Rules have evolved from:

Government Policy

and

Classification Society Response to Clients



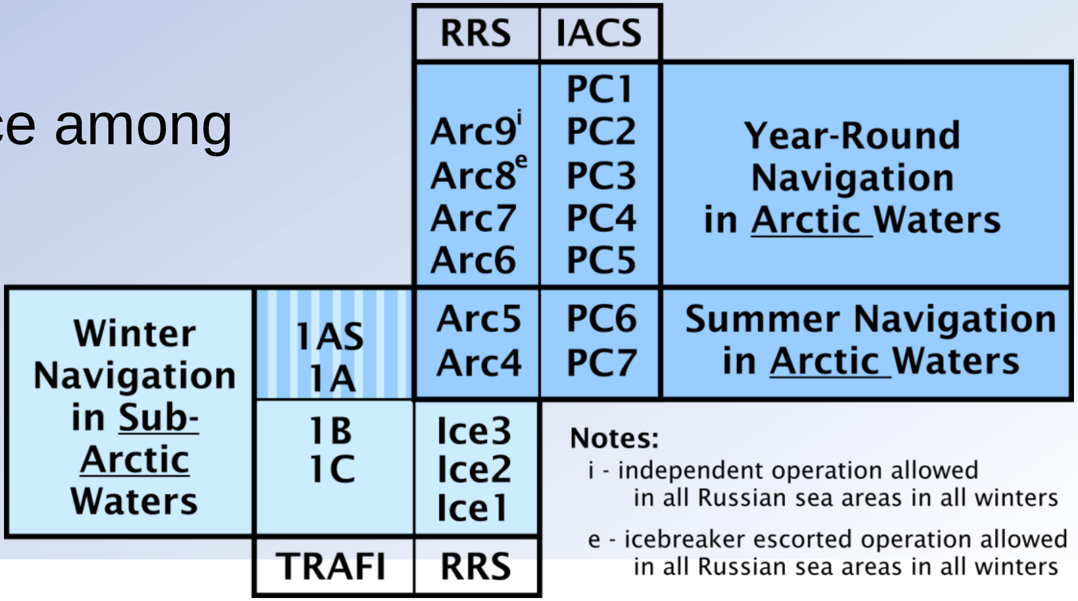
MEMORIAL UNIVERSITY Faculty of Engineering and Applied Science

IACS Polar Class Unified Requirements (UR)

- I1: Polar Class Descriptions and Application
- I2: Structural Requirements for Polar Class Ships
- I3: Machinery Requirements for Polar Class Ships
- Download available from IACS web site www.IACS.org.uk

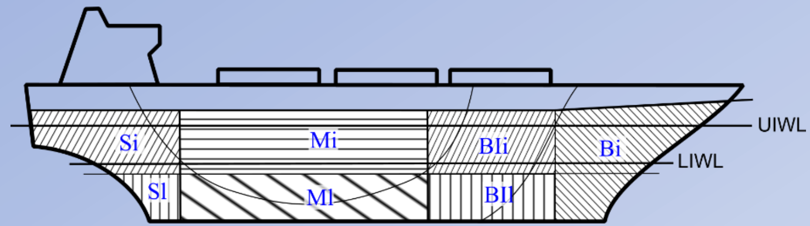
Polar Classes

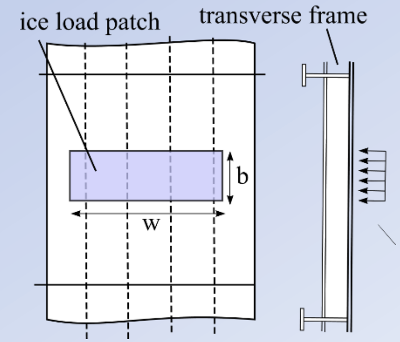
- **Lowest Polar Class (PC7):** should have general levels of strengthening roughly comparable to Baltic 1A
- **Highest Polar Class (PC1):** capable of independent operation without limitations
- The Polar Rules provide a minimum level of ice strengthening. All Polar Classes can encounter ice conditions that could damage the structure
- Class selection is a balance among ice conditions, operational requirements, and cost



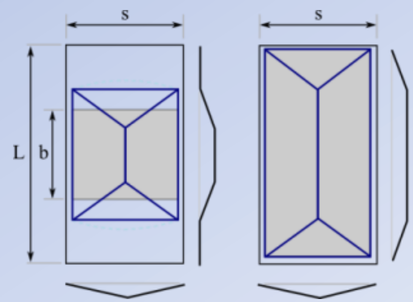
Major Parts of IACS Polar Class: UR I2

- Hull Areas (I2.2)

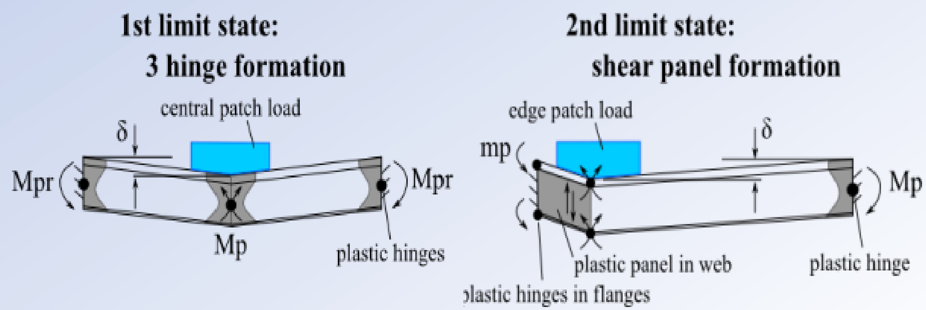




- Design Ice Loads (I2.3)

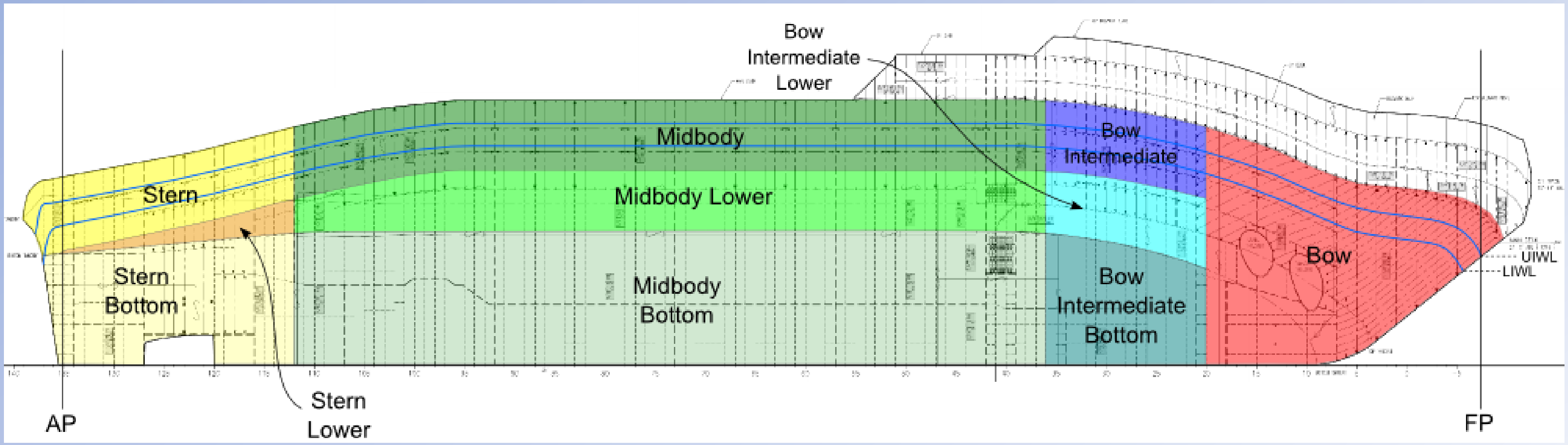


- Shell Plate Requirements (I2.4)
- Frame Requirements (I2.5 - I2.9)
  - Transversely-framed
  - Longitudinally-framed
  - Structural stability



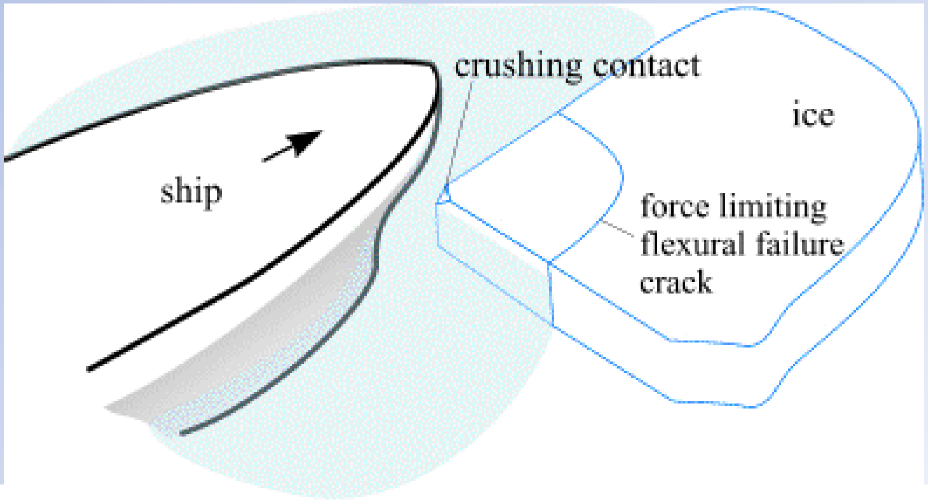
Example of Hull Area Extents

- Shell expansion



Polar Class Concept of Ice Loads

- Design ice loads are rationally linked to a design scenario
- Ice load model is explicit and physics-based
- Glancing collision with an ice edge
  - Valid for both independent and escorted operations (edge of a channel, edge of a floe).
  - Local edge crushing + flexural failure limit

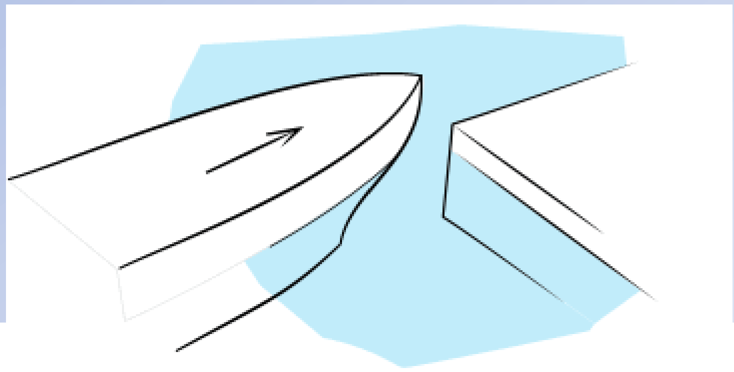


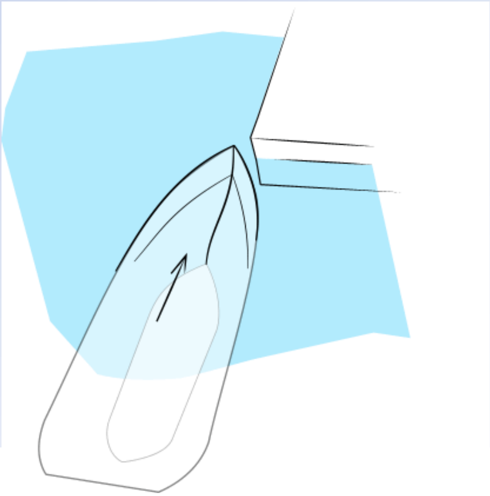
Polar Class Concept of Ice Loads

- The load equation is derived from the solution of a Ship-Ice Collision Model
  - Normal Kinetic Energy = Ice Indentation Energy

$$KE_{normal} = IE_{ice}$$

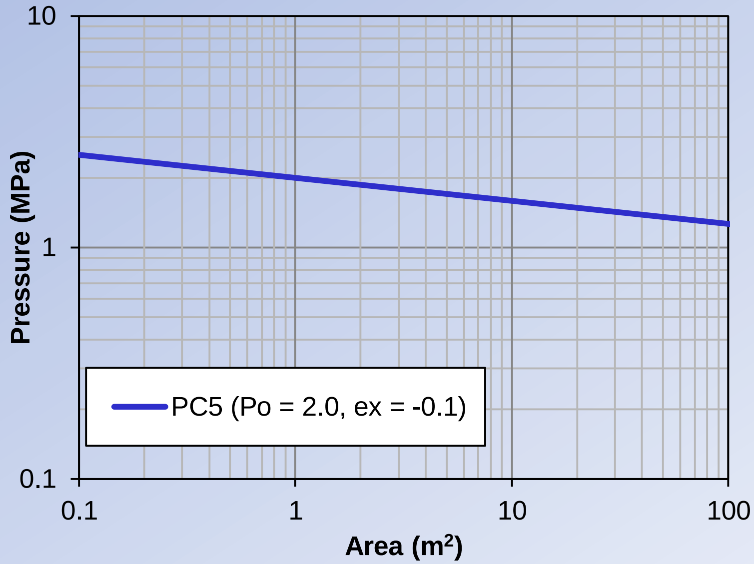
  - Find indentation → Find force, area, pressure
- Model considers ice thickness, ice strength, hull form, ship size and ship speed





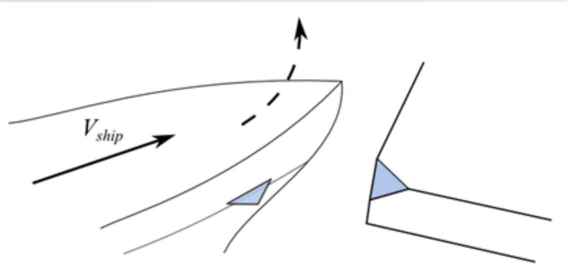
Polar UR Glancing Collision Model

- IACS UR design scenario
  - Physics based
  - f(collision scenario, hull form, ship mass, ice strength terms)
- Popov collision mechanics
  - Local contact pressure defined by pressure-area relationship



- Begins with energy balance

$$KE_n = IE \quad \Rightarrow \quad \frac{1}{2} M_e V_n^2 = \int_0^{\zeta_{max}} F_n(\zeta) d\zeta$$



- Pressure-area model to relate force to indentation

$$p = p_0 A^{ex} \quad \Rightarrow \quad F_n = pA = p_0 A^{1+ex}$$

Indentation Geometry (RHS of Equation)

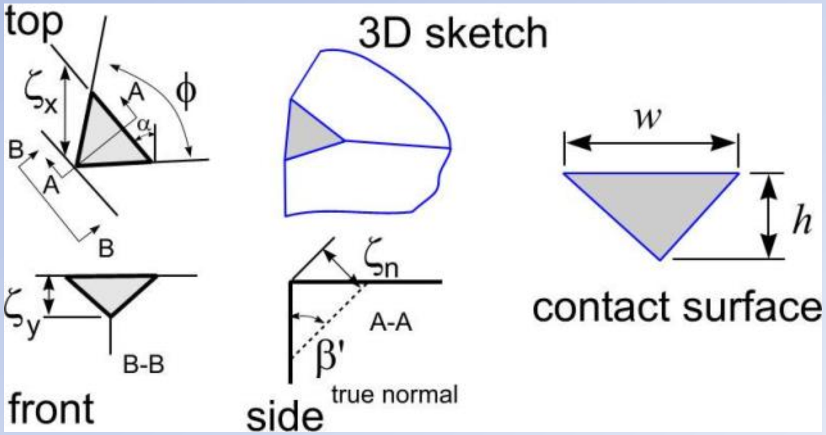
$$\frac{1}{2}M_e V_n^2 = \int_0^{\zeta_{max}} F_n(\zeta)d\zeta$$

$$F_n = pA = p_0 A^{1+ex}$$

- Wedge ice edge geometry

$$A_n = \frac{\zeta_n^2 \tan(\phi/2)}{\sin(\beta')\cos^2(\beta')}$$

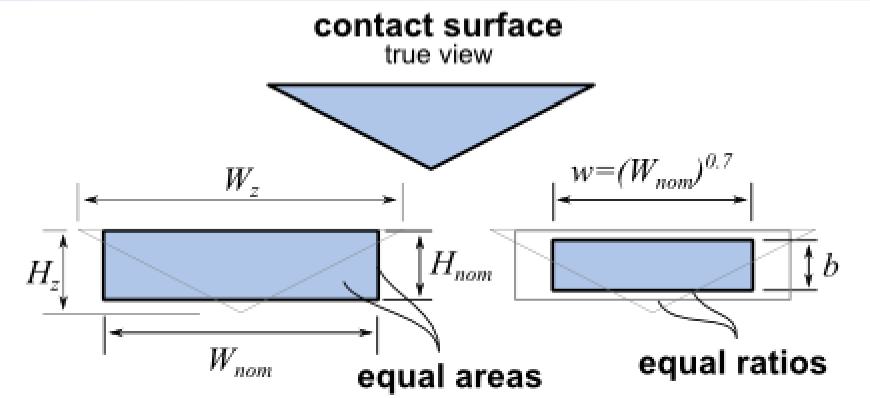
$$F_n = p_0\left(\frac{\tan(\phi/2)}{\sin(\beta')\cos^2(\beta')}\right)^{1+ex} \cdot \zeta_n^{2+2ex}$$



- Contact zoned idealized to rectangular patch

$$w = \left(\frac{2\cdot\zeta_n \tan(\phi/2)}{\sqrt{2}\cos\beta'}\right)^{0.7}$$

$$b = \frac{w}{2\cdot\tan(\phi/2)\sin\beta'}$$



Ice Load Derivation

- Normal force exact solution

$$F_n = (3 + 2 \cdot ex)^{\frac{2+2\cdot ex}{3+2\cdot ex}} \cdot P_o^{\frac{1}{3+2\cdot ex}} \cdot \left(\frac{\tan(\phi/2)}{\sin(\beta') \cdot \cos^2(\beta')}\right)^{\frac{1+ex}{3+2\cdot ex}} \left(\frac{1}{2}\Delta_n {V_n}^2\right)^{\frac{2+2\cdot ex}{3+2\cdot ex}}$$

- Simplified with several assumptions
  - Families of icebreaking hull forms
  - Mass reduction coefficient simplified

$$F_n = f_a \cdot P_o^{0.36} \cdot V_{ship}^{1.28} \cdot M_{ship}^{0.64}$$

- Rule Formulation

$$F_n = f_a \cdot CF_c \cdot D^{0.64}$$

MEMORIAL UNIVERSITY Faculty of Engineering and Applied Science

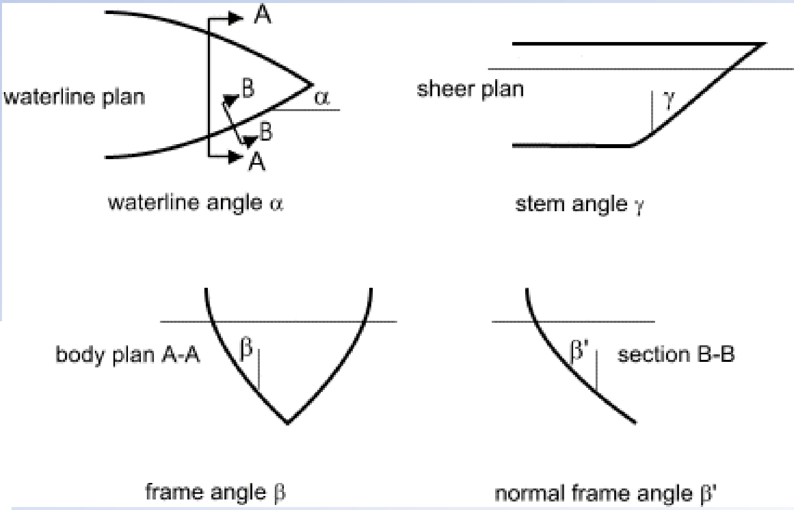
Shape Factor, *fa*

- Pure crushing solution

$$f_a = 1.94 \cdot \left(\frac{\tan(\phi/2)}{\sin(\beta') \cdot \cos^2(\beta')}\right)^{0.32} \left(\frac{1}{2 \cdot Co} l^2\right)^{0.64}$$

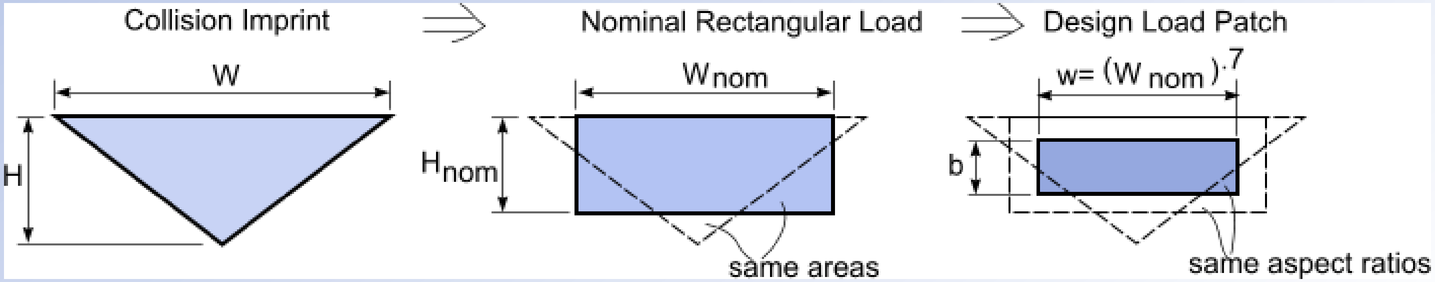
- Simplified formulation
  - One for crushing
  - One for flexural failure
  - Limit to 0.6

$$f_a = min \begin{cases} \left(0.097 - 0.68 \cdot \left(\frac{x}{L} - 0.15\right)^2\right) \cdot \left(\frac{\alpha}{\sqrt{\beta'}}\right) \\ \frac{1.2 \cdot CF_F}{\sin(\beta') \cdot CF_c \cdot D^{0.64}} \\ 0.6 \end{cases}$$



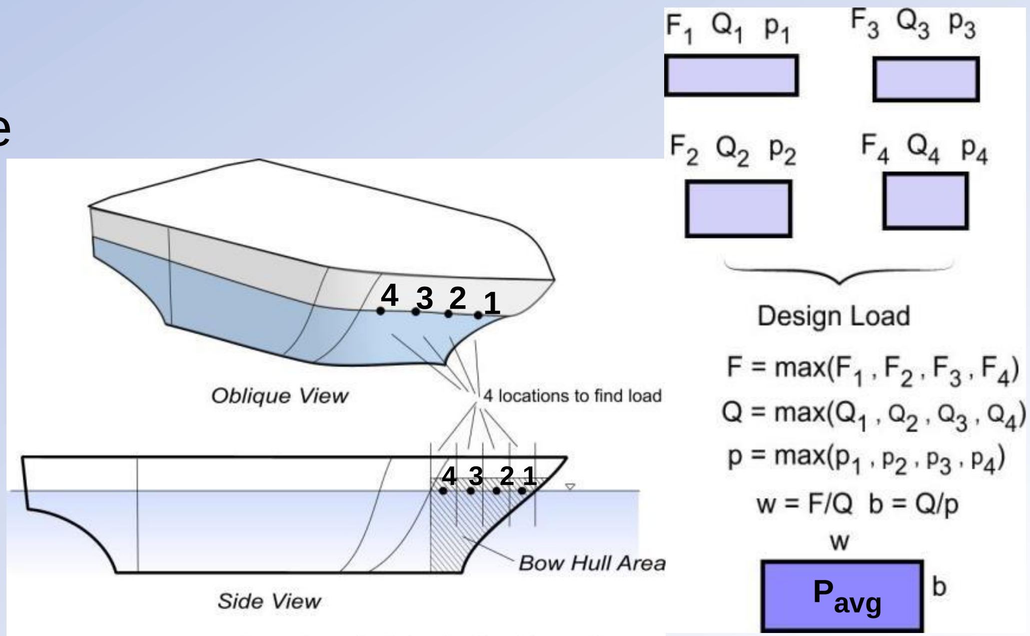
Rule Formulations

- Other rule formulations
  - Pressure $$p = F_n^{0.22} \cdot {CF_D}^2 \cdot AR^{0.3}$$
  - Line load $$Q = F_n^{0.61} \cdot CF_D \cdot AR^{-0.35}$$
  - Width $$w = F/Q$$
  - Height $$b = Q/p$$



Design Ice Loads

- Entire bow area designed with one ice load patch
  - Load parameters calculated at 4 sub-regions
  - Function of the actual bow shape, ship displacement, and ice class
  - Largest F_i, Q_i, and p_i are used in the assembled bow design load
- Non-Bow design ice load
  - Independent of the hull shape
  - Displacement and class dependent
  - Fixed aspect ratio

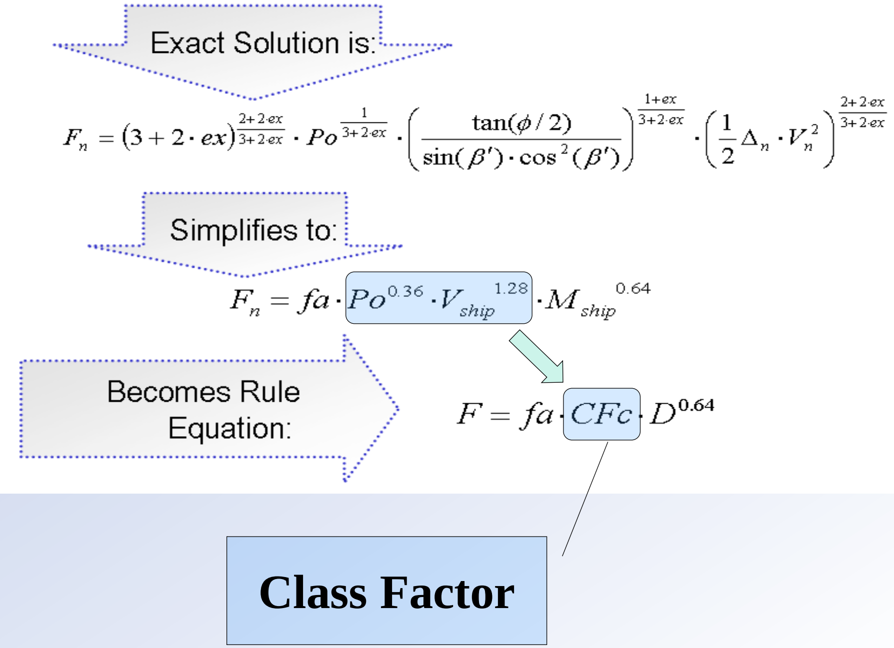


Bow Load Calculation Locations

Class Factors

- The class factors represent the increasingly challenging ice conditions that ice classes are designed for
- In deriving these values, ice thickness, strength and ship speed are all taken into account
- Example of *Crushing Class Factor*

Polar Class	Crushing Failure Class Factor (CFc)
PC1	17.69
PC2	9.89
PC3	6.06
PC4	4.50
PC5	3.10
PC6	2.40
PC7	1.80



Class Factors

- Calibrated to align strength levels with service experience

Polar Class	Crushing Failure Class Factor (CF_C)	Flexural Failure Class Factor (CF_F)	Load Patch Dimensions Class Factor (CF_D)	Displacement Class Factor (CF_{DIS})	Longitudinal Strength Class Factor (CF_L)
PC1	17.69	68.60	2.01	250	7.46
PC2	9.89	46.80	1.75	210	5.46
PC3	6.06	21.17	1.53	180	4.17
PC4	4.50	13.48	1.42	130	3.15
PC5	3.10	9.00	1.31	70	2.50
PC6	2.40	5.49	1.17	40	2.37
PC7	1.80	4.06	1.11	22	1.81

Hull Area Factors (Non-bow)

- The areas other than the bow are designed for a portion of the bow load
- The hull areas are defined based on the shape and waterlines of the vessel

Hull Area		Area	Polar Class						
			PC1	PC2	PC3	PC4	PC5	PC6	PC7
Bow (B)	All	B	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bow Intermediate (BI)	Icebelt	BI_i	0.90	0.85	0.85	0.80	0.80	1.00*	1.00*
	Lower	BI_l	0.70	0.65	0.65	0.60	0.55	0.55	0.50
	Bottom	BI_b	0.55	0.50	0.45	0.40	0.35	0.30	0.25
Midbody (M)	Icebelt	M_i	0.70	0.65	0.55	0.55	0.50	0.45	0.45
	Lower	M_l	0.50	0.45	0.40	0.35	0.30	0.25	0.25
	Bottom	M_b	0.30	0.30	0.25	**	**	**	**
Stern (S)	Icebelt	S_i	0.75	0.70	0.65	0.60	0.50	0.40	0.35
	Lower	S_l	0.45	0.40	0.35	0.30	0.25	0.25	0.25
	Bottom	S_b	0.35	0.30	0.30	0.25	0.15	**	**

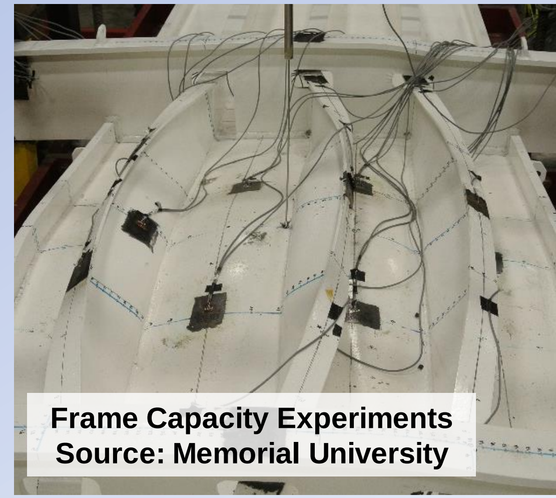
Peak Pressure Factors

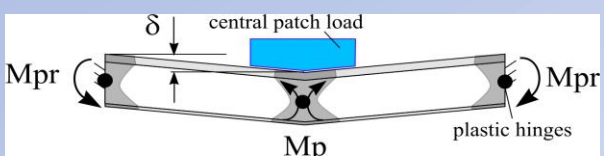
- Areas of higher, concentrated pressure exist within the load patch
  - Full scale and lab observations
- Peak pressure factors are used to account for the pressure concentration on localized structural members

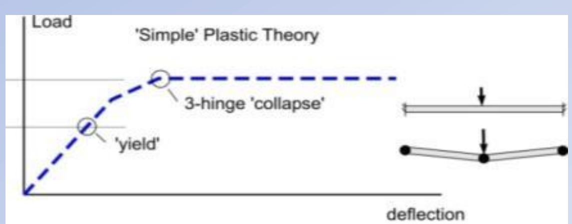
Structural Member		Peak Pressure Factor (PPF_i)
Plating	Transversely-Framed	$PPF_p = (1.8 - s) \geq 1.2$
	Longitudinally-Framed	$PPF_p = (2.2 - 1.2 * s) \geq 1.5$
Frames in Transverse Framing Systems	With Load Distributing Stringers	$PPF_t = (1.6 - s) \geq 1.0$
	With No Load Distributing Stringers	$PPF_t = (1.8 - s) \geq 1.2$
Load Carrying Stringers Side and Bottom Longitudinals Web Frames		$PPF_s = 1$, if $S_w \geq 0.5 * w$ $PPF_s = 2.0 - 2.0 * S_w / w$, if $S_w < (0.5 * w)$
where	s = frame or longitudinal spacing [m] S_w = web frame spacing [m] w = ice load patch width [m]	

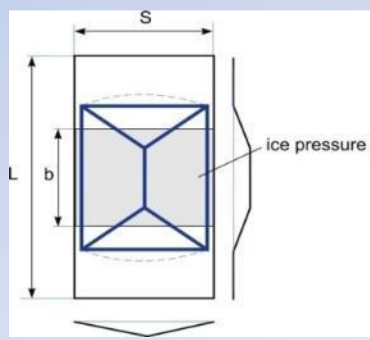
Structural Strength

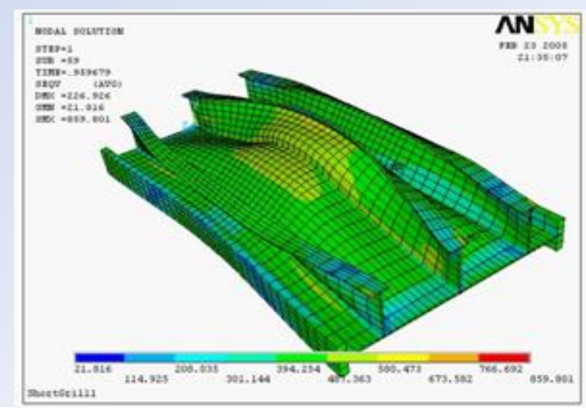
- Design philosophy: realistic plastic response
  - Derived from analytical (energy based) solutions
  - Verified by extensive FEA and lab experiments
- Plastic design
  - design to resist normal and extreme ice load levels
  - Considerable strength reserve
  - Relatively long return period for design loads


Frame Capacity Experiments
Source: Memorial University



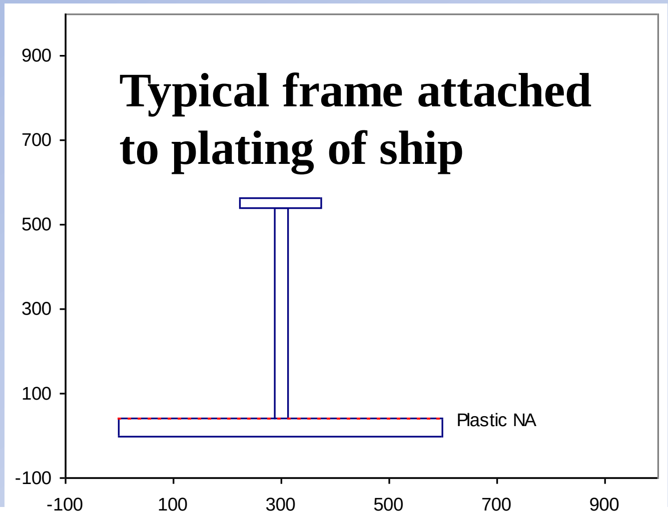


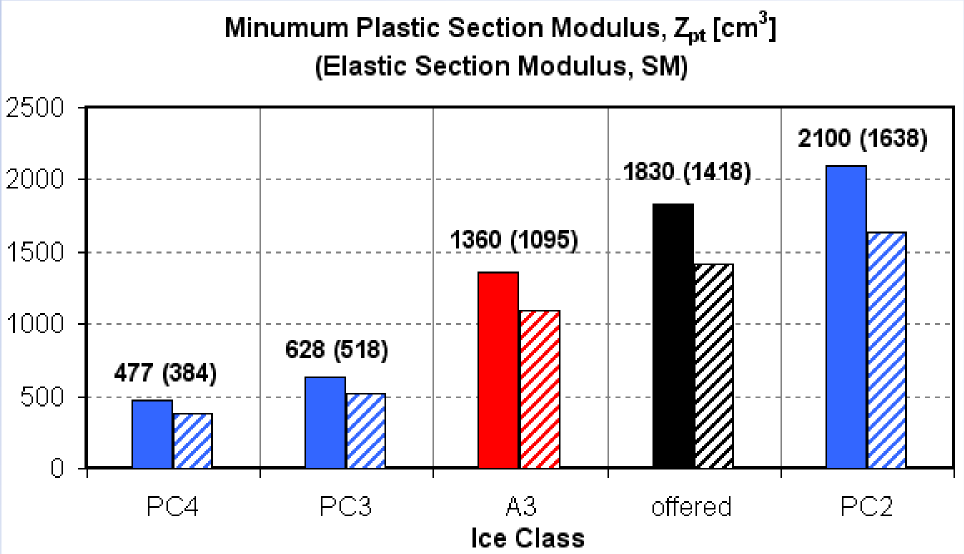




Plastic Section Modulus

- Plastic Section Modulus
  - 1st moment of area about the plastic neutral axis (PNA)
  - PNA is located at the half-area axis, typically assumed at intersection of web and shell
  - Generally 1.25~1.35 x elastic modulus



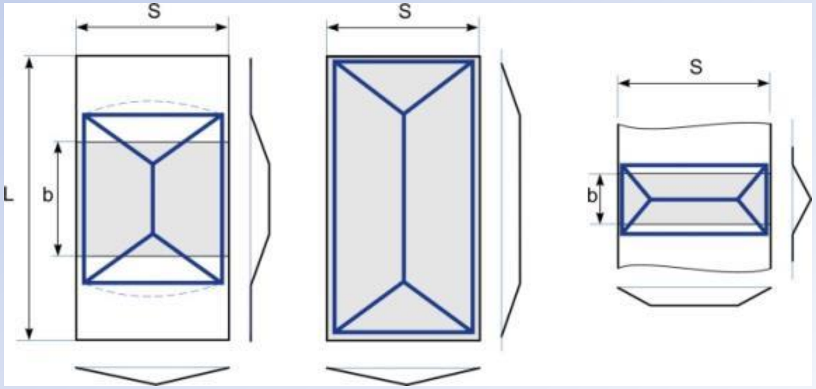


Plating Strength

- Plate folding based on perfectly plastic hinge formation
  - Gives nominal plastic capacity (>2 x yield)
  - Small plastic strains (shown by FE analysis)
  - Substantial membrane & material reserve (little chance of rupture)
- "Net scantling" approach
  - $t = t_{net} + t_s$

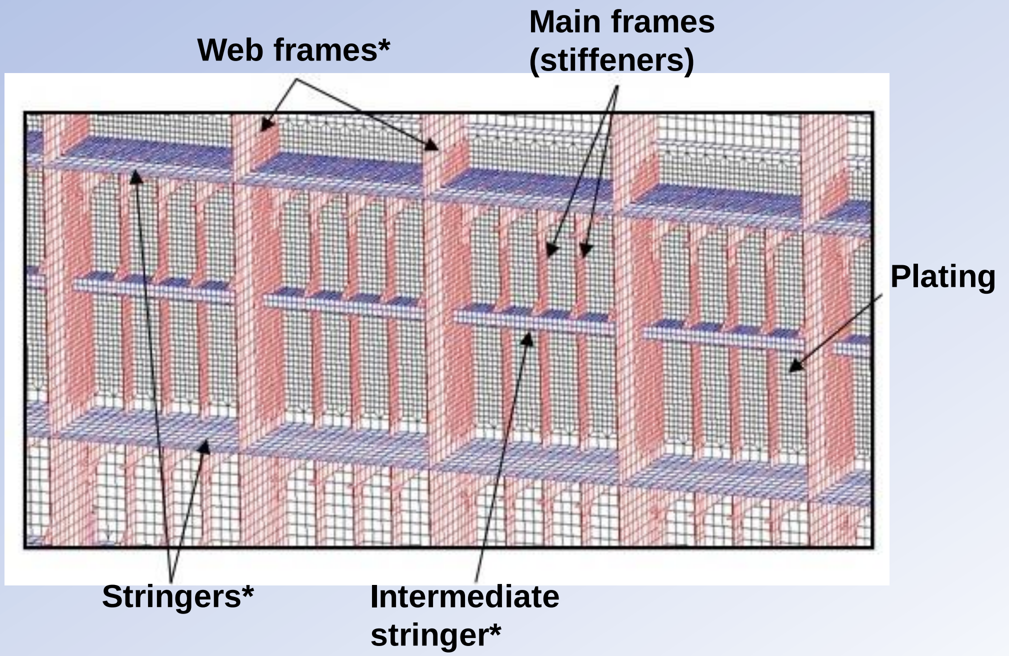
$$t_{net} = 500 * s * ((AF * PPF_p * P_{avg}) / \sigma_y)^{0.5} / (1 + s / (2 * b)) \text{ [mm]}$$

- Framing orientation
  - Transversely framed
  - Longitudinally framed
  - Obliquely framed



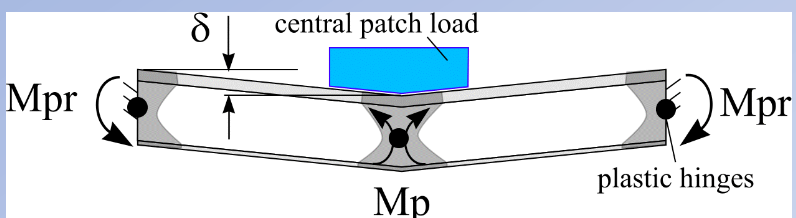
Framing Strength

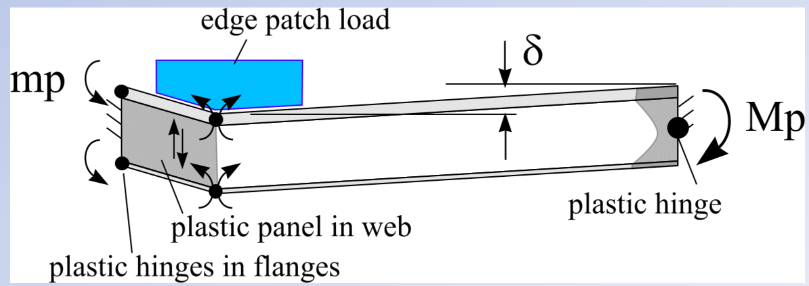
- Framing members
  - Local frames - longitudinal or vertical stiffeners
  - Load carrying stringers*
  - Web frames*
- Local frames
  - Required net shear area
  - Required net plastic section modulus
- Stringers and web frames
  - Scantlings are per class rules
  - Structural stability (buckling) checks

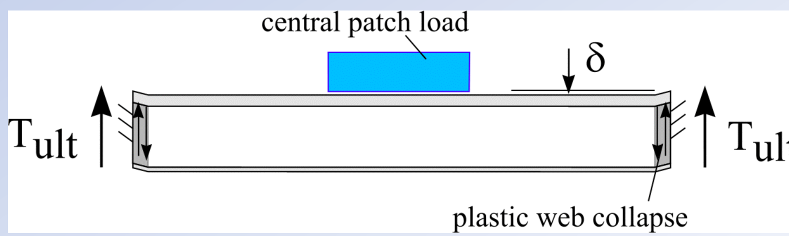


Framing Strength

- 3 limit-states (allowable loads) checked
  - Two involve shear/bending resulting in interaction effects
  - Third is pure shear

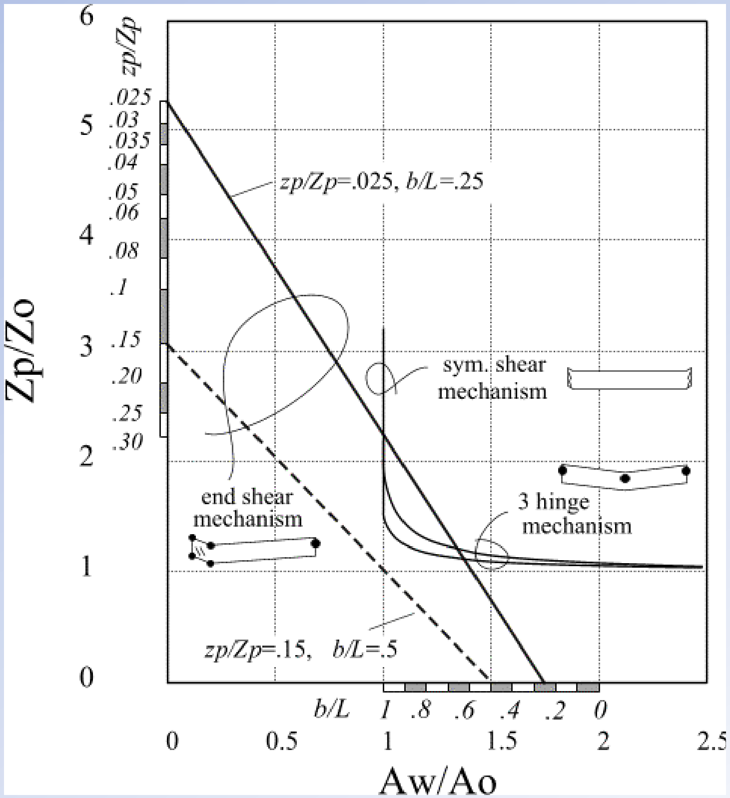






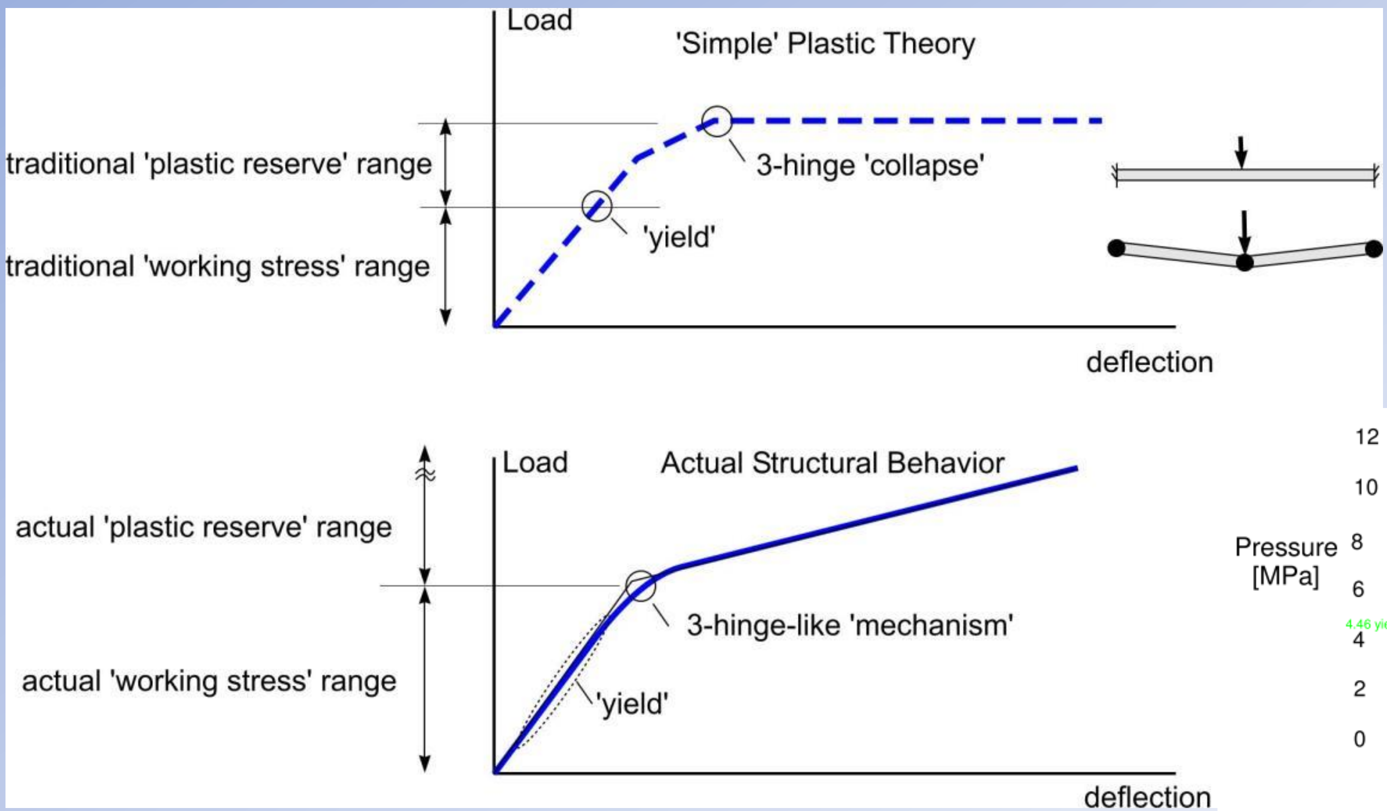
Framing Strength

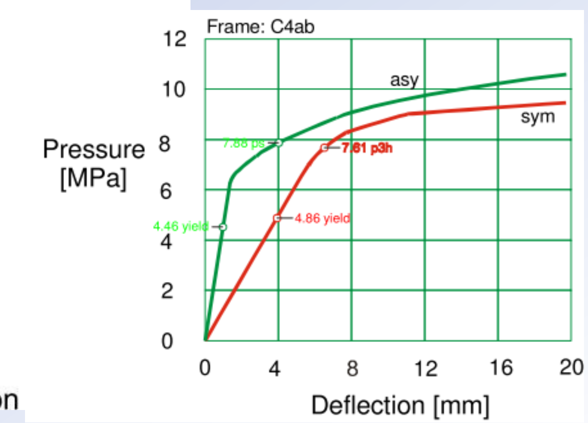
- Frame design allows tradeoffs
  - Over-capacity in web area allows saving in modulus
  - Design point is post-yield, but still quasi-elastic
  - Permanent deflections are ~0, with significant strength reserve



Framing Strength

- Design point is onset of permanent deflections





Framing Requirements

- Required net shear area and plastic modulus
  - Transversely framed arrangements

$$A_t = 100^2 * 0.5 * LL * s * (AF * PPF_t * P_{avg}) / (0.577 * \sigma_y) \ [cm^2]$$

$$Z_{pt} = 100^3 * LL * Y * s * (AF * PPF_t * P_{avg}) * a * A_1 / (4 * \sigma_y) \ [cm^3]$$

  - Longitudinally framed arrangements

$$A_L = 100^2 * (AF * PPF_s * P_{avg}) * 0.5 * b_1 * a / (0.577 * \sigma_y) \ [cm^2]$$

$$Z_{pL} = 100^3 * (AF * PPF_s * P_{avg}) * b_1 * a^2 * A_4 / (8 * \sigma_y) \ [cm^3]$$

Stability Checks

- Frames subjected to compressive loading can be susceptible to buckling
  - Web depth ratios (simple slenderness limits)

For flat bar sections:	$h_w / t_{wn} \leq 282 / (\sigma_y)^{0.5}$
For bulb, tee and angle sections:	$h_w / t_{wn} \leq 805 / (\sigma_y)^{0.5}$

  - Stiffened panels

$$t_{wn} = 2.63 \text{ x } 10^{-3} * c_1 * \sigma_y / (5.34 + 4 * (c_1 / c_2)^2) \text{ [mm]}$$

  - Flange width $w_f \geq 5 \text{ x } t_w$

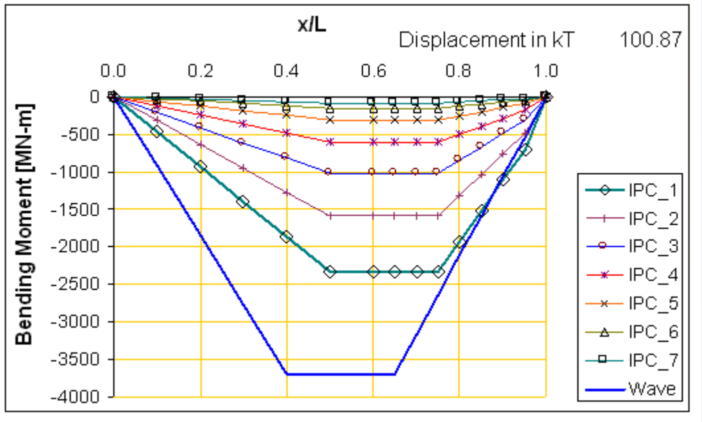
Material Selection

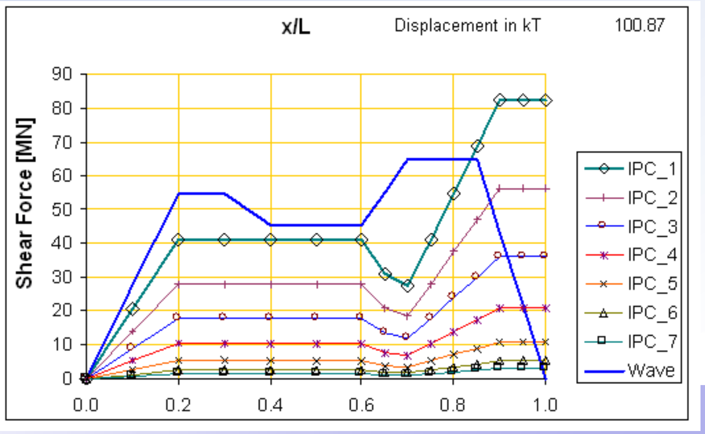
- Fracture toughness of steel in low temperature environments is of concern
- Steel grade requirements provided considering the required fracture toughness / ductility

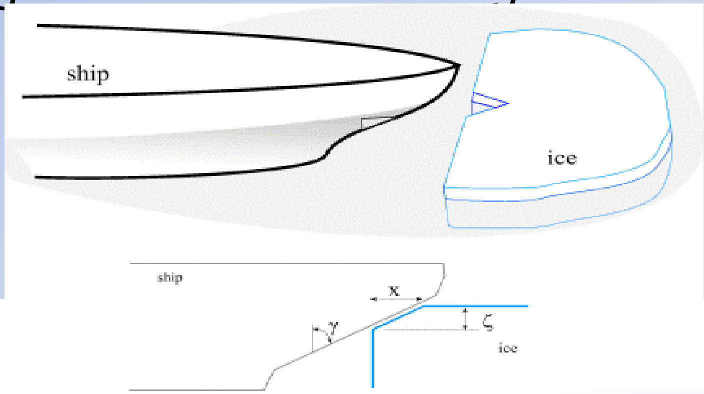
Thickness, t [mm]	Material Class I				Material Class II				Material Class III					
	PC1-5		PC6&7		PC1-5		PC6&7		PC1-3		PC4&5		PC6&7	
	MS	HT	MS	HT	MS	HT	MS	HT	MS	HT	MS	HT	MS	HT
t≤10	B	AH	B	AH	B	AH	B	AH	E	EH	E	EH	B	AH
10<t≤15	B	AH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
15<t≤20	D	DH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
20<t≤25	D	DH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
25<t≤30	D	DH	B	AH	E	EH2	D	DH	E	EH	E	EH	E	EH
30<t≤35	D	DH	B	AH	E	EH	D	DH	E	EH	E	EH	E	EH
35<t≤40	D	DH	D	DH	E	EH	D	DH	F	FH	E	EH	E	EH
40<t≤45	E	EH	D	DH	E	EH	D	DH	F	FH	E	EH	E	EH
45<t≤50	E	EH	D	DH	E	EH	D	DH	F	FH	F	FH	E	EH

Longitudinal Strength

- Scenario: head-on ramming
- Ice induced bending moment and shear forces combined with still water loads (waves ignored) to assess hull girder strength
- Parameters to be considered
  - Design vertical ice force at the bow
  - Design vertical shear force
  - Design vertical ice bending moment





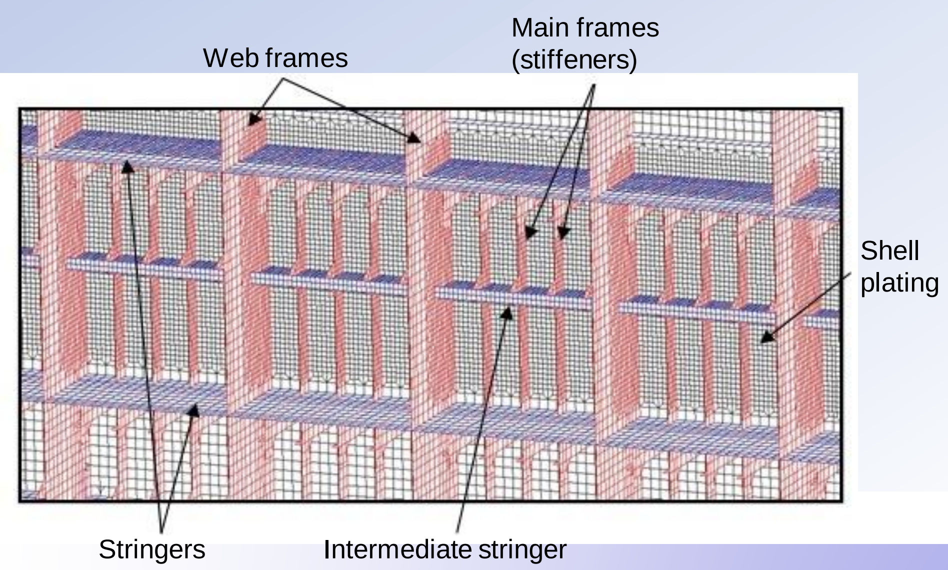


Items under discussion (left to Class)

- Icebreaker notation
- Non-icebreaking hull forms
- Large framing members – girders, stringers, web frames, decks, bulkheads
- Grillage strength assessment
- Stem and stern frames
- Appendages

Reduta Ordona
Source: Transport Canada

Azipod Propulsion Unit
Source: Samsung Heavy Industries



Thank You For Listening

Grounded Icebergs near St. John's