Damage Assessment of Reinforced Concrete Offshore Structures

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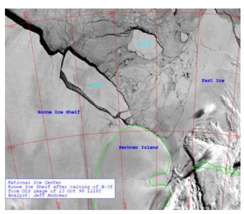
Challenges in Arctic Waters

- When offshore structures are located in shallow arctic water with their topsides exposed, they are vulnerable to impact from sea ice
- Elastic design feasible for impact with smaller icebergs; may not be feasible in impact with multiyear ridges or ice islands



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Objective

- Develop design strategies to enhance post-ultimate performance of reinforced concrete structural components
- Perform a-priori damage assessment using High-Fidelity Physics-Based (HFPB) analyses
- Assess post-collision damage based on developed damage-deflection relationship

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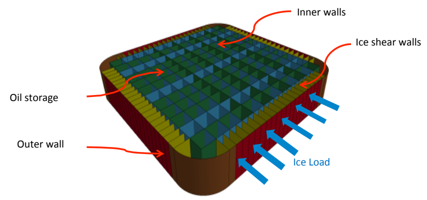
Photo source: www.seatrade-maritime.com

Prototype Gravity-Based Structure



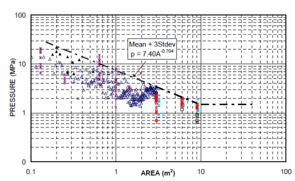
Ice Pressure-Area Relationship

—Assume ice applies uniform load over the outer wall

ISO 19906:

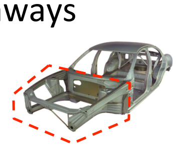
$$p_L = 7.40\,A^{-0.70}, \quad \text{for } A \le 10\text{ m}^2$$
$$= 1.48, \quad \text{for } A > 10\text{ m}^2$$

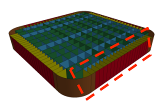
where:
p_L = pressure (MPa)
A = area (m^2)



Vehicle Design Takeaways

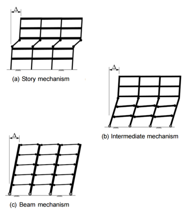
- Absorb energy of impact by detailing "non-essential" components for predictable, nonlinear behavior (fuses)
- Protect critical components by designing for expected capacity of fuses (strongbacks)



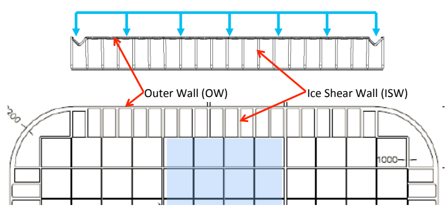


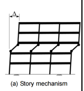
Seismic Design Takeaways

- Absorb energy of dynamic loads through controlled structural yielding
- Maximize amount of energy absorbed by applying bounding and capacity-based design to form multiple “hinges” prior to:
  - Forming an unstable mechanism
  - The onset of brittle element failures
- Tune structure to load

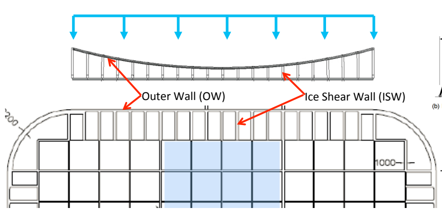


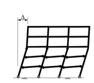
Story Mechanism Analogy



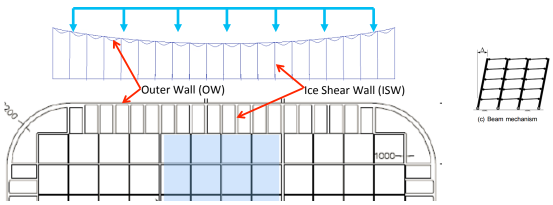


Intermediate Mechanism Analogy



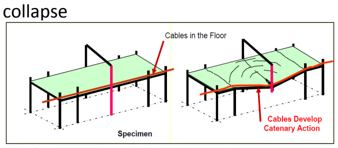


Tuned Wall Properties



Progressive Collapse Takeaways

- The use of unbonded reinforcement (mild steel rebar or high strength post-tensioning strands/bars) with low initial stress has been used in seismic- and blast-resistant design to prevent progressive collapse



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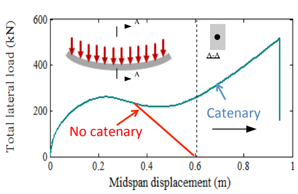
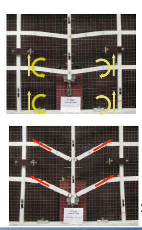
Catenary Action





Sagiroglu (2012)

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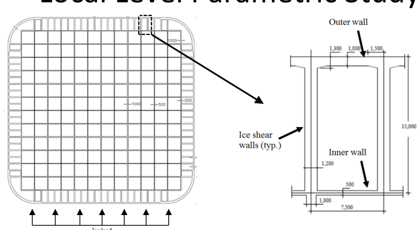
Strategies for Ductile Design

The design of ductile structures requires two tiers of focus:

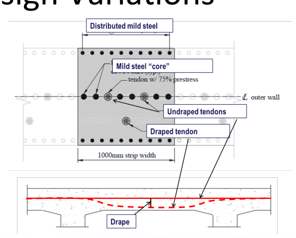
- Individual structural elements that are expected to be pushed significantly beyond yield must be detailed for adequate strength and displacement capacity so that they do not undergo a sudden, drastic loss of strength
- Individual elements must then be assembled in such a way that the structure, as a whole, does not become unstable and suffer from a premature collapse before the design load has been resisted

Local Level Parametric Study



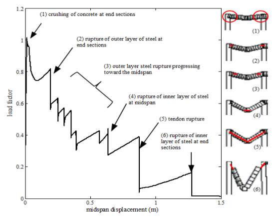
Outer Wall Design Variations

- f'c = 38 MPa
- 2% area of distributed steel
- 26.6 cm^2 tendons with 75% prestress, with/without drape



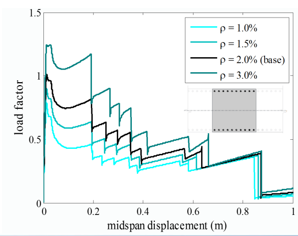
Typical Outer Wall Pushdown Curve

- various stages are directly related to displacement of outer wall



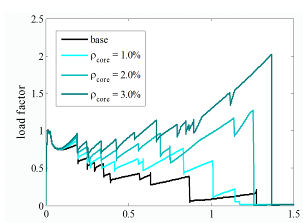
Longitudinal Reinforcement Variation

- Increasing longitudinal reinforcement increases capacity at small displacements but not at larger displacements



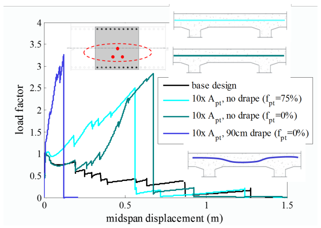
Bonded Core Variation

- Increasing bonded core reinforcement increases capacity significantly at larger displacements

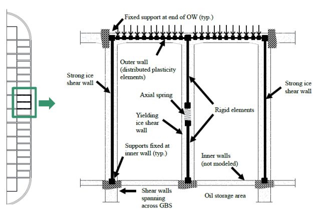


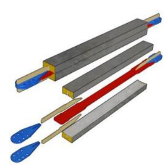
Unbonded Core Variation

- Increasing unbonded core reinforcement increases capacity significantly but does not provide ductility



Global Design Study Model



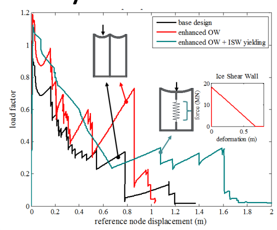


Global Design Study Model

Input Parameter	Description	Base design	Enhanced OW	Enhanced OW + ISW yielding
ρ	Distributed flexural reinforcement ratio	0.02	0.025	0.025
ρ_{core}	Bonded core reinforcement ratio	-	0.015	0.015
f_{pt}	Yield stress of tendons (MPa)	1723	1723	1723
-	Tendon prestress and spacing	75%, 80cm	75%, 80cm	75%, 80cm
f_y	Yield strength of distributed steel and core (MPa)	413	413	413
f'_c	Unconfined concrete strength (MPa)	38	52	52
f'_{cc}	Confined concrete strength (MPa)	44	60	60
F_{ISW}	Peak strength of central ice shear wall axial spring (MN)	-	-	18.4
$D_{ISW,u}$	Ultimate displacement of central ice shear wall axial spring (m)	-	-	0.67

Global Design Study Model

– ISW yielding increases ductility while moderately increasing capacity



Concluding Remarks

– Baseline design exhibits limited toughness
– Use of core steel and unbonded tendons can greatly increase toughness of the outer walls; varying ductility, strength based on the combination of the two
– Significantly improved ductility and energy absorption may be realized by using capacity-based design techniques and ductile fuse elements

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Concluding Remarks

– Displacement at impacted wall can be directly related to damage of components
– Strengthening and repair strategies can be tailored with focus on these components

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Thank you

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