The Impact of Ice Loading on Single Point Moored Production Units

Chen Jainsky
Quanxin Xia
Arun Duggal

SOFEC, Inc.

27 June 2012

Overview

- Introduction
- SOFEC Experience with Ice Loads on SPM Production Units
  - Offshore Newfoundland
  - Barents Sea
  - Bohai Bay
- Some General Observations on Model Testing and Mooring Design

Terra Nova FPSO – Grand Banks

Terra Nova Design Environment

	1-Year	100-Year
Waves	Hs = 10.9 m Tp: 12.9 – 16.0 sec	Hs = 16.0 m Tp: 15.7 – 20.2 sec
Wind	Vw = 28.8 m/s	Vw = 39.6 m/s
Current	Vc = 1.0 m/s	Vc = 1.3 m/s
Pack Ice	0 – 30%	> 50 – 70%
Icebergs	<100,000 MT	>100,000 MT

Disconnect Criteria:

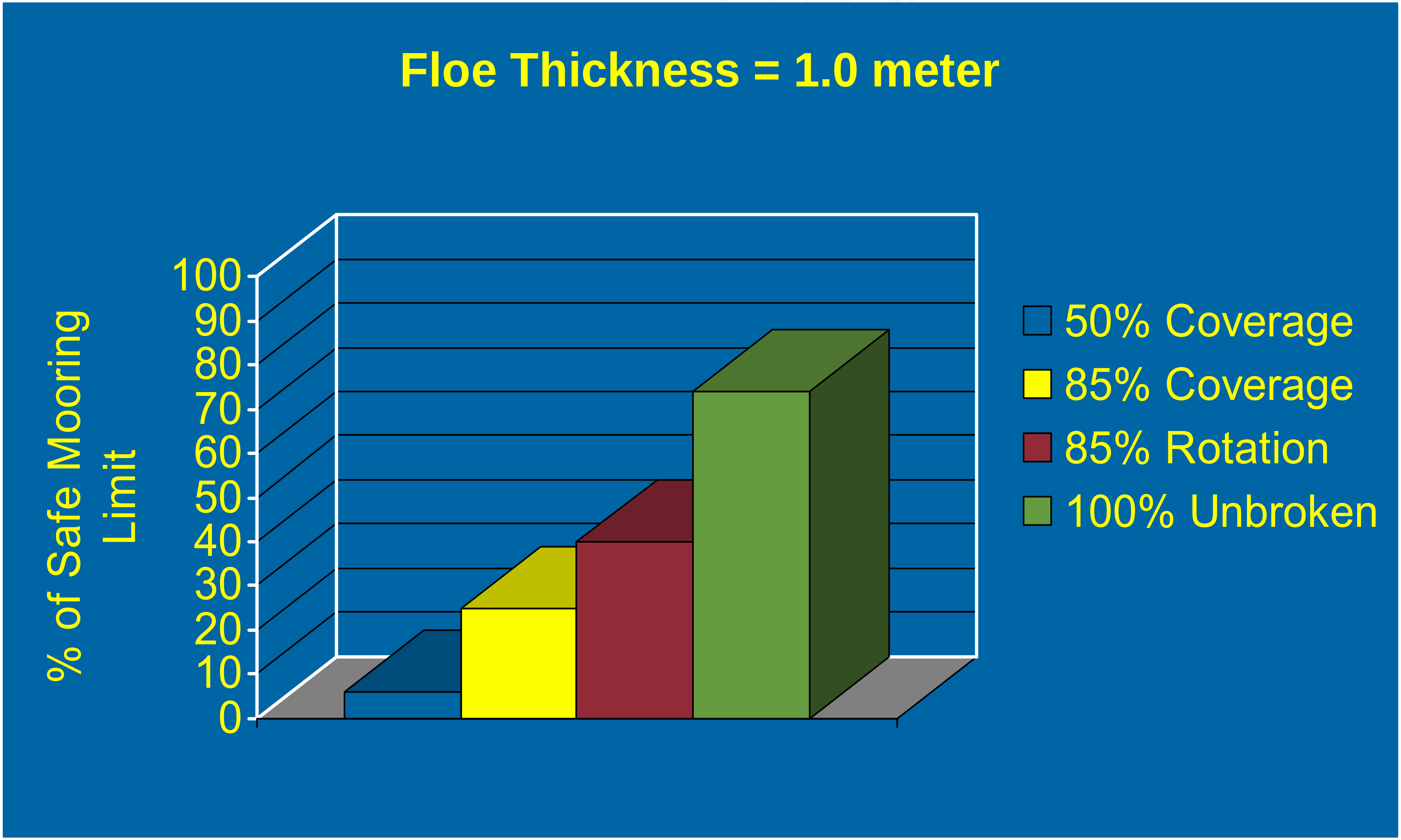
- Approaching Iceberg: >100,000 MT
- Pack Ice Coverage: >50% &/Or >0.3 m thick

Ice Load Tests– NRC-IOT, St John's Newfoundland

- Pack-Ice Tests:
  - Ice Tank (90 m long X 12 m wide)
  - Model Scale 1:27.5
  - 3 level ice thicknesses: 0.3, 0.5 and 1.0m
  - Pack Ice from 100% to 50% coverage with variation in floe size
  - Various Ice Drift Speeds up to 1 m/s
  - Head-on and Rotation Tests
- Iceberg/Bergy Bit Impact Tests
  - Ocean Basin
  - Model Scale 1:44.5
  - Iceberg of 100,000 MT, current only
  - Bergy Bit of 3,500 MT, waves and current

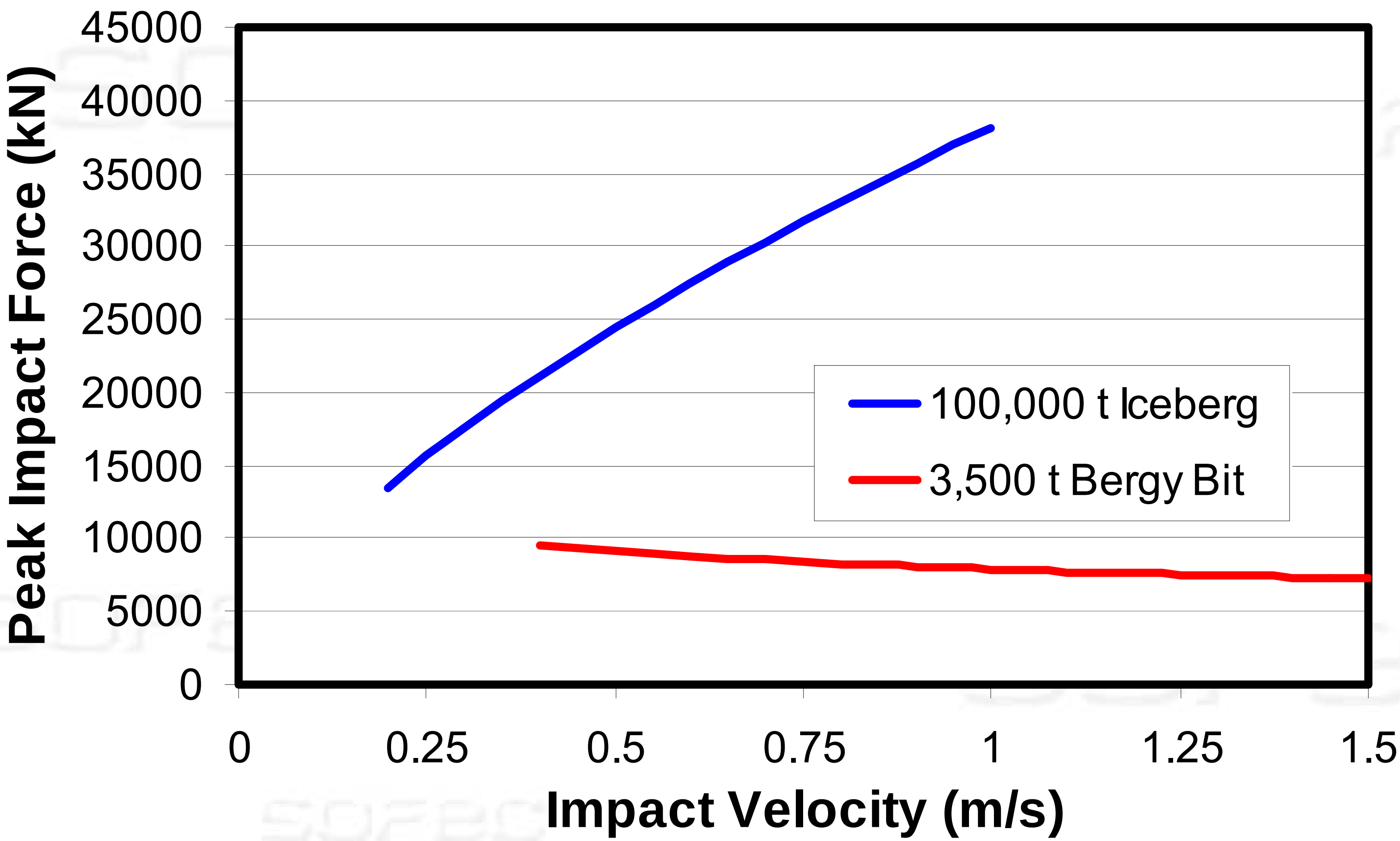
Performance in Pack-Ice

Pack Ice Load on Moored FPSO



Impact of 100,000 MT Iceberg with FPSO

Iceberg & Bergy Bit Impact Loads



sofec

Barents Sea: Project General Information

- Site Condition
  - Ice Condition:
    - Sea ice: Mostly 1st year ice.
      - Level ice (typical 100yr RP ice thickness = 2 m)
      - Ice ridge (typical 100yr RP ice ridge keel depth = 21m)
      - Rubble field (typical 100yr RP consolidated ice rubble field depth = 9m)
    - Iceberg: Occurs on average about every 20 years. Not considered for mooring design
  - Open Sea Condition (100 year RP):
    - Wave: Hs = 12m, Tp = 17s
    - Wind: 31 m/s
    - Current: surface speed = 60 cm/s

- Vessel/Mooring General Particulars
  - Ice-breaker type vessel of about 220 000 Ton Displacement
  - 20 mooring anchor legs
  - Disconnectable buoy

Design Requirement in Ice Condition

- Design Conditions
  - 100 year RP 1st year ice ridge in head-on conditions
  - 100 year RP 1st year level ice conditions coming from any direction, including ice drift reversal

- Design global ice and mooring loads
  - For head-on interactions: calculated values
  - For non-zero heading interactions: model test values

Calculation

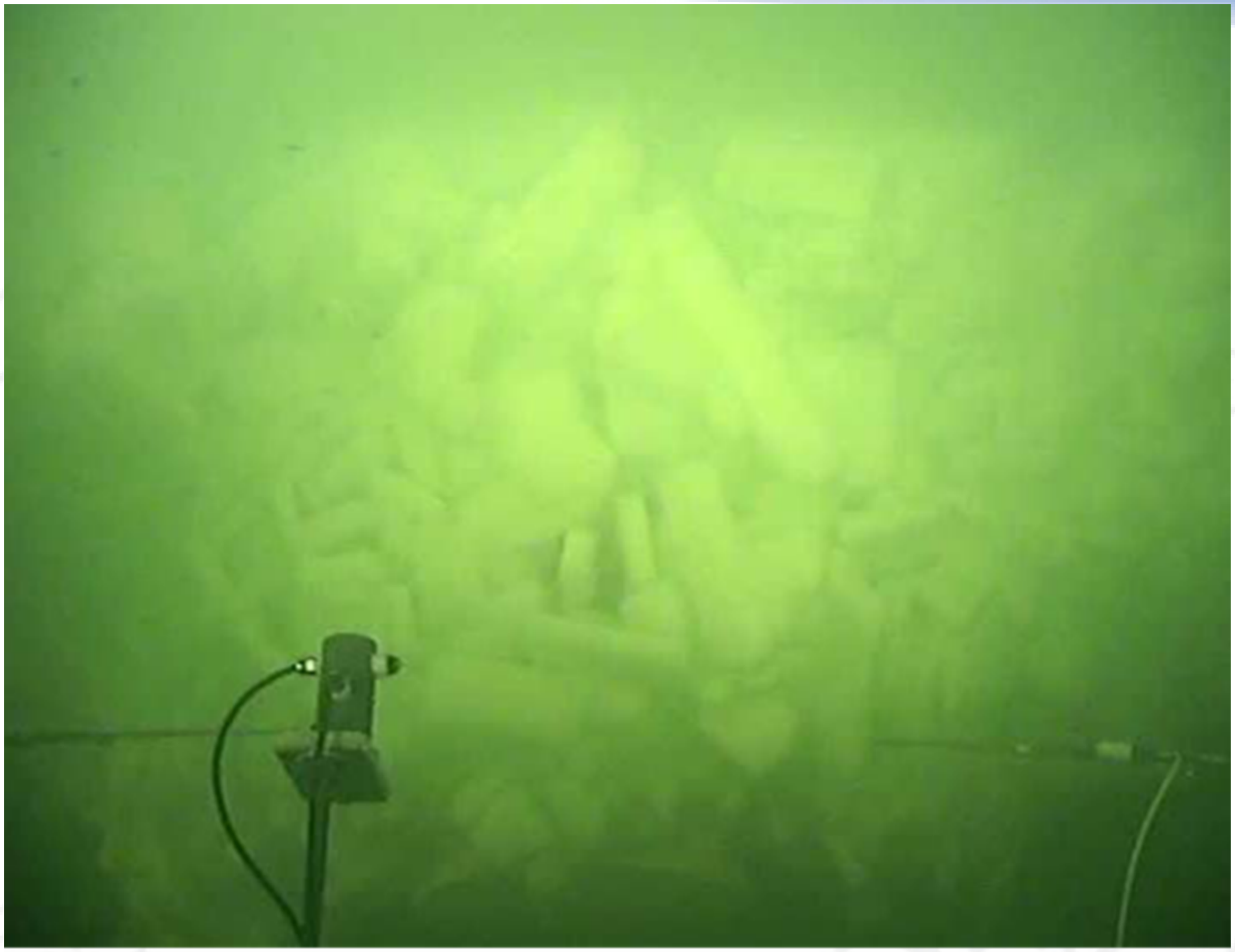
- ISO 19906 (Arctic Offshore Structures)
- Loads due to the consolidated layer are calculated using an elastic beam bending model.
  - Ice breaking on a downward slope
  - Applicable for 20 deg ≤ bow slope ≤ 50 deg (ice-breaker type)
- Loads due to ice ridge keel are calculated based on a semi-empirical method.
  - Loads due to keel failure on the bow
  - Loads due to keel rubble friction along the sides of the vessel
- No analytical model for drift reversal scenarios.

Model Tests

- Ice Tank Facilities: Krylov Institute, St. Petersberg / HVSA, Hamburg
- Scale = 1:70 / 1:45
- Test campaign
  - Level ice, ice ridge, rubble field
  - Head-on, 30-degree attack angle, drift reversal
  - Moored, Moored and thruster assisted, free floating and fixed
  - With / without ice management
- Challenge:
  - Modeling of the ice properties
  - Modeling of the ridge geometry

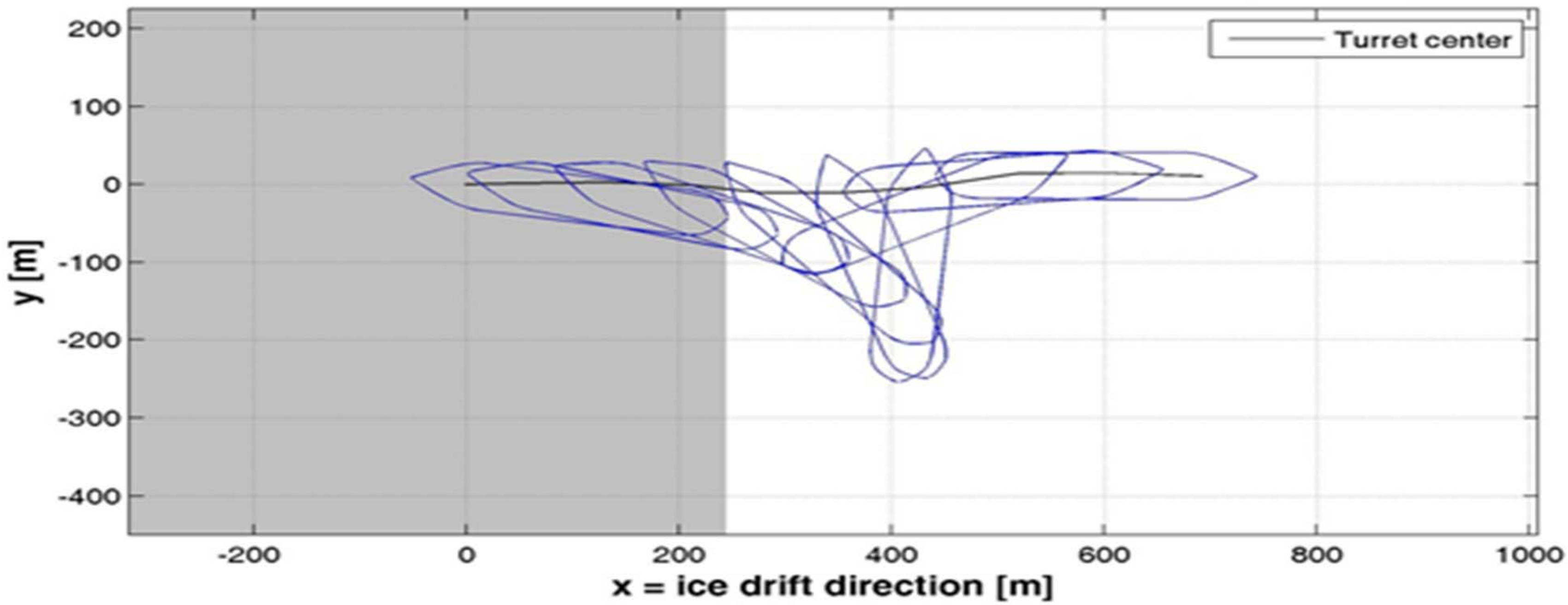
Model Rubble Ice Field

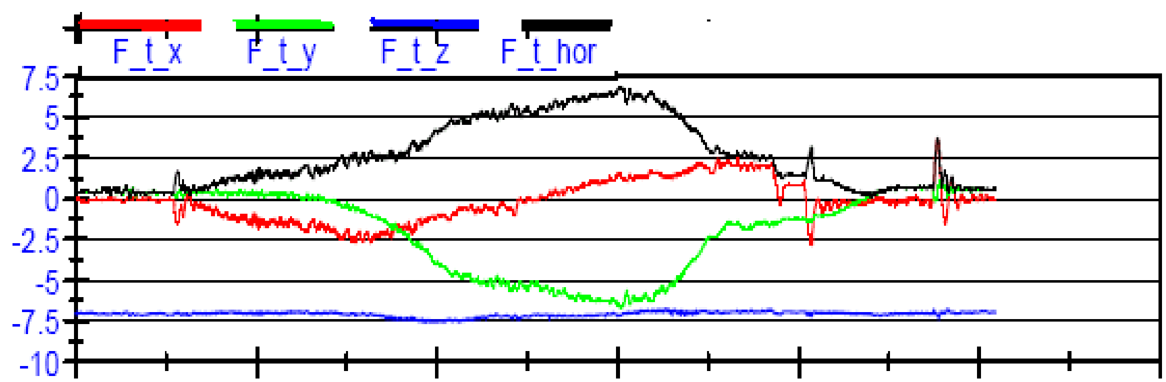
Model Ice Ridge



Buoy Embedded by ice rubbles during drift reversal in 100 year RP ice ridge

Example Results





Model Test Results for Various Scenarios (Mooring Loads due to Ice)

- 100 yr RP Level Ice
  - Approach from 30°: ≈ 20% of Max. Design Load
  - Drift reversal 170°: ≈ 45% of Max. Design Load
- 100 yr RP Ice Ridge
  - Head-on: ≈ 75% of Max. Design Load
  - Approach from 30°: ≈ 120% of Max. Design Load *(not a design case)*
  - Drift reversal 170°: ≈ 160% of Max. Design Load *(not a design case)*
- With Ice Management
  - 30% decrease in loads

Calculated Loads vs. Measured Loads

- Reasonable Comparison
  - Head-on ice ridge: calculated 86% vs. measured 75%
- Difficulty in matching the results well:
  - Approximation in ice properties (e.g. flexible strength)
  - Lack of information on “as built” ice ridge geometry. (Analytical model sensitive to the ice ridge keel depth and angle, based on “perfect” geometry)
- Designed for an upper bound value of 100% (for head-on)
- Ice loads >> Wave loads

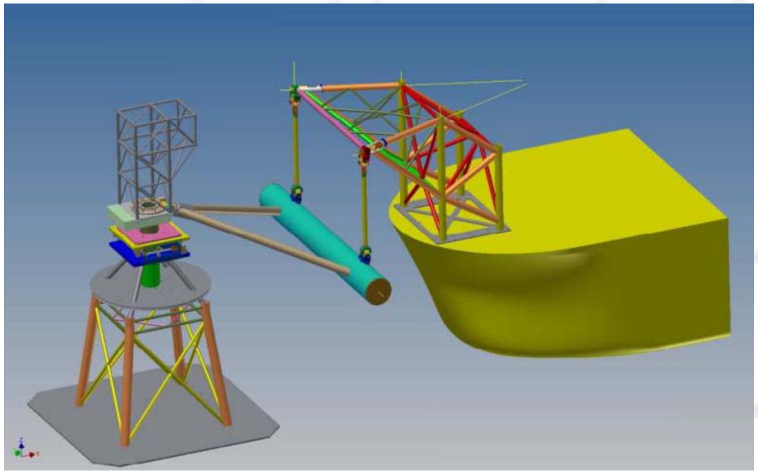
Under Hull Transport

- Assess the risk of riser and potentially mooring damage by ice
- Evaluated based on underwater video recordings
- Conservative results: protected environment without current or waves. Ice management not considered.
- Ice under the buoy observed for 100 year RP level ice, ice ridge and rubble field during drift reversal
- Mooring lines embedded in rubble from all direction in case of 100 year RP ice ridge and rubble field
- The restoring force of the mooring system may results in varying velocity of the ice blocks thus complicates the ice transport mechanism.

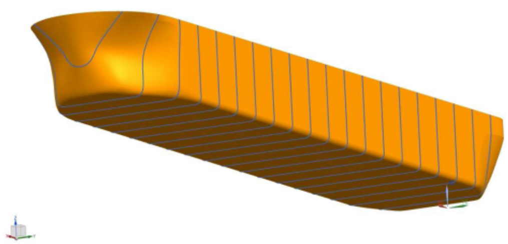
Bohai Bay – Water Depth ~20m

sofec

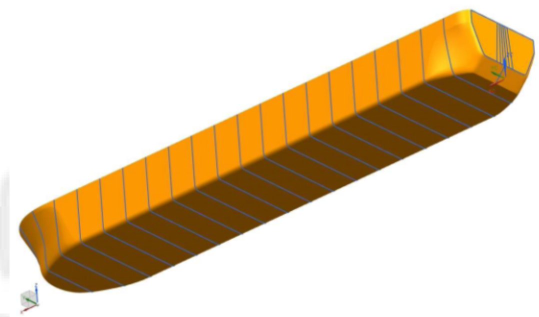
Mooring and Vessel Model



Tower Yoke Mooring



Bow view



Stern view

FPSO Vessel

Ice Model Test

- Model Scale 1:42, HVSA, Hamburg
- Ice thickness in model scale = 6.2 ~ 7.6 mm
- High ice drift speed (1.3m/s)

ENVIRONMENT	25-year Level Ice	50-year Level Ice 1	50-year Level Ice 2	Unit
WATER DEPTH				
Still Water Depth	17.9	17.9	17.9	meters
ICE DATA				
Ice Density	0.89	0.89	0.89	$tonnes/m^3$
Ice Thickness	0.26	0.32	0.32	Meters
Compressive Ice Strength	1.96	1.99	1.99	MPa
Ice Drift Speed	1.3	0.4	1.3	m/s

Ice Environment Conditions

Ice Properties

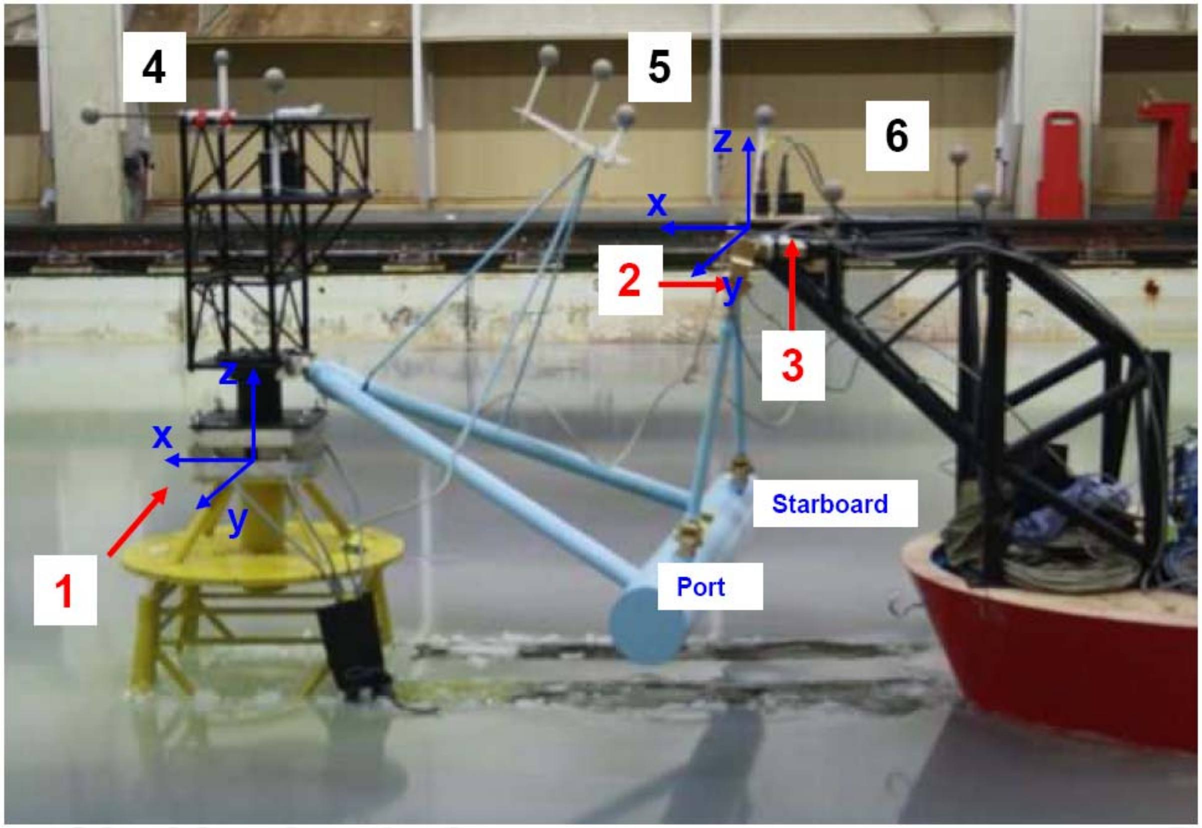
Flexural Strength

Model scale values		
Test Series	HSVA measured $\sigma_{f\,(meas)}$	Bohai Sea target $\sigma_{f\,(target)}$
[-]	kPa	kPa
1015	33.6	14.3
1025	37.0	14.3
2010	31.0	14.3
2020	37.9	14.3
3010	29.7	14.9
3020	36.5	14.9
4010	26.6	14.9
4020	28.0	14.9
5010	41.7	14.3
5020	44.4	14.3
6010	22.5	14.9
6020	25.7	14.9
7010	29.0	14.3
7020	29.1	14.3
8010	31.6	14.9
8020	30.0	14.9

Ice Thickness

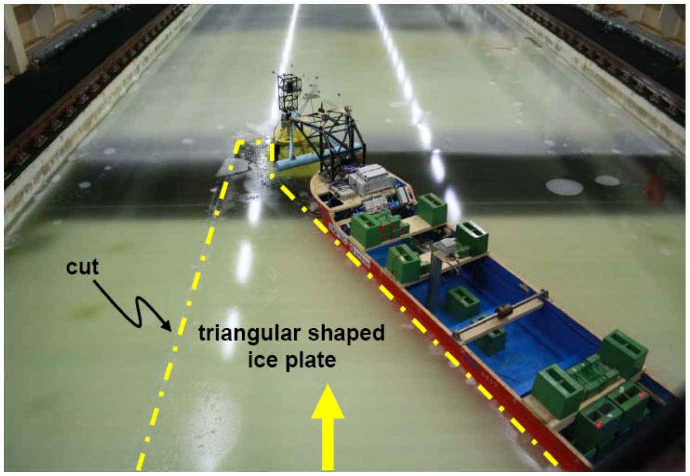
Model scale values		
Test Series	HSVA Measured Hice (meas)	Bohai Sea target Hice (target)
[-]	Mm	mm
1015	7.0	6.19
1025	6.6	6.19
2010	5.9	6.19
2020	5.9	6.19
3010	8.2	7.62
3020	8.2	7.62
4010	8.3	7.62
4020	8.3	7.62
5010	6.3	6.19
5020	6.0	6.19
6010	8.2	7.62
6020	8.2	7.62
7010	6.5	6.19
7020	6.5	6.19
8010	9.3	7.62
8020	9.4	7.62

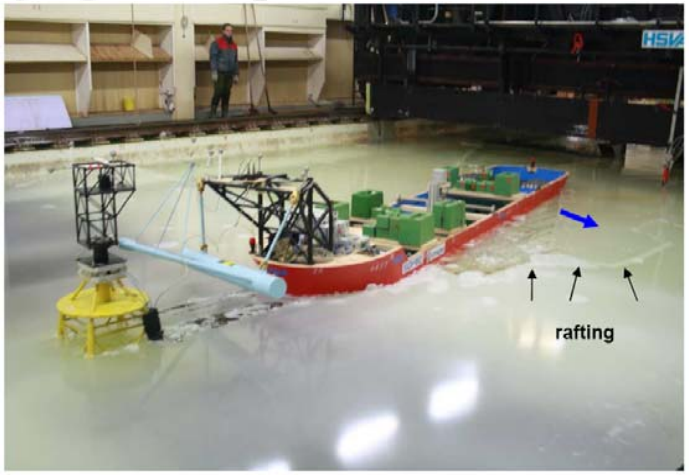
Model Set-up



(1) 6-component scale mounted on the jacket-tower
(2) Load cell at both sides of upper U-Joint
(3) Tree strain gauge load cells at the FPSO
(4) Reflectors at the tower
(5) Reflectors at the yoke
(6) Reflectors at the FPSO

30 Deg Heading Test

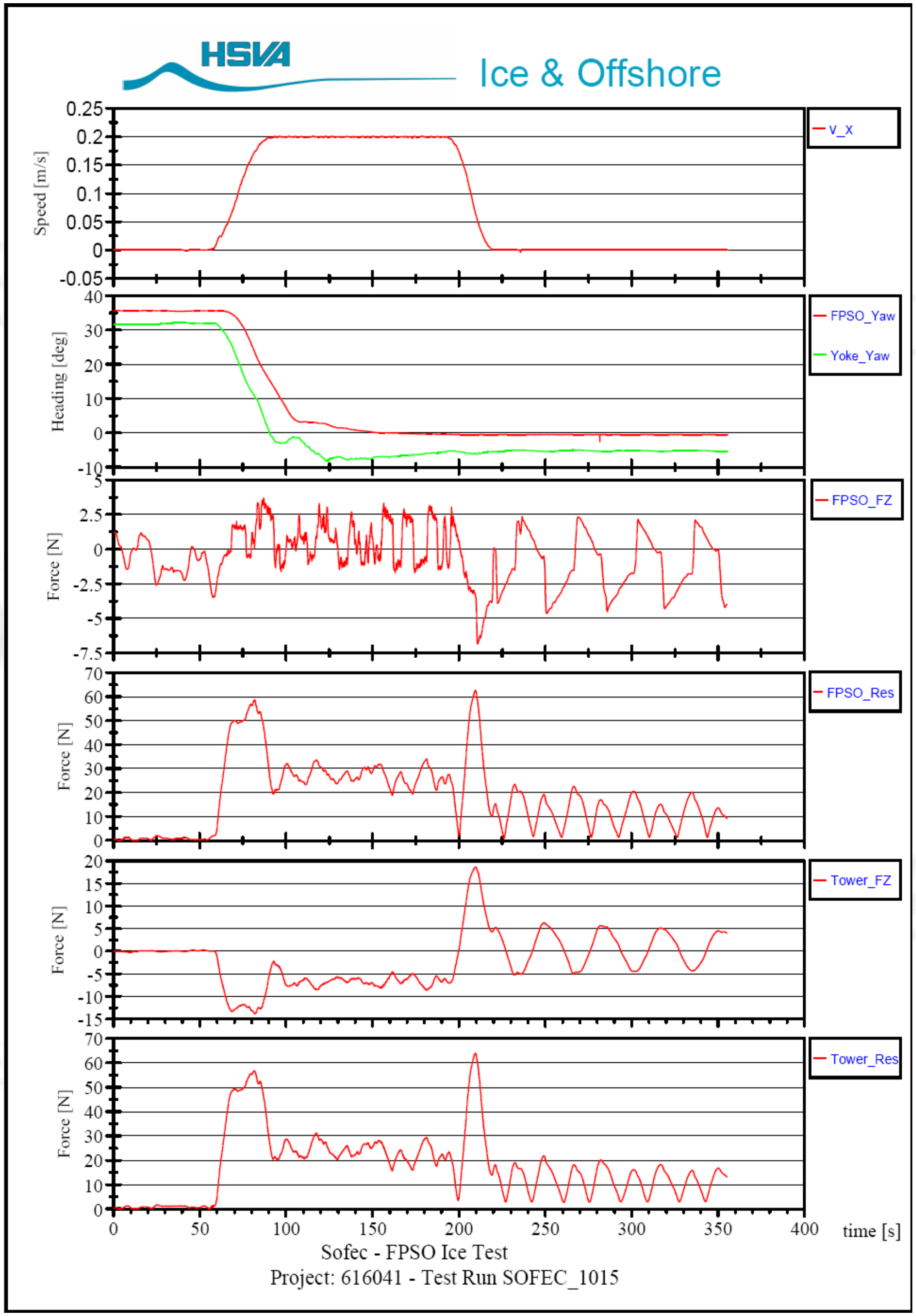




Initial heading: 30 deg

sofec_fpso_4010_cam2.mpg

Time History



SOFEC

170 Deg Reversal Test

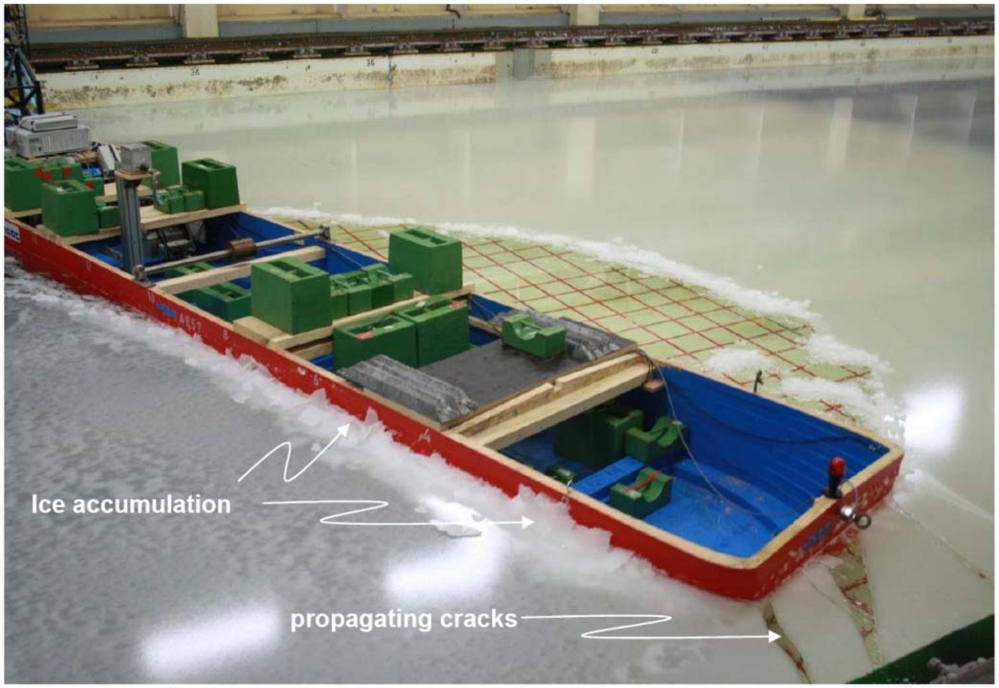
Initial heading:170 deg

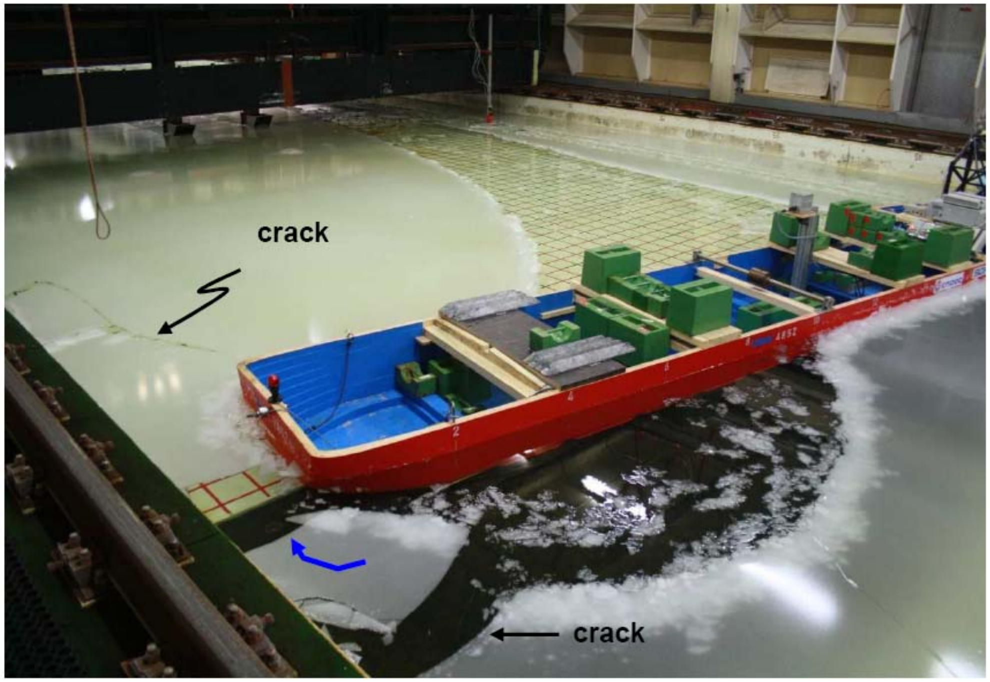
sofec_fpso_2010_cam2.mpg

Ice Failure

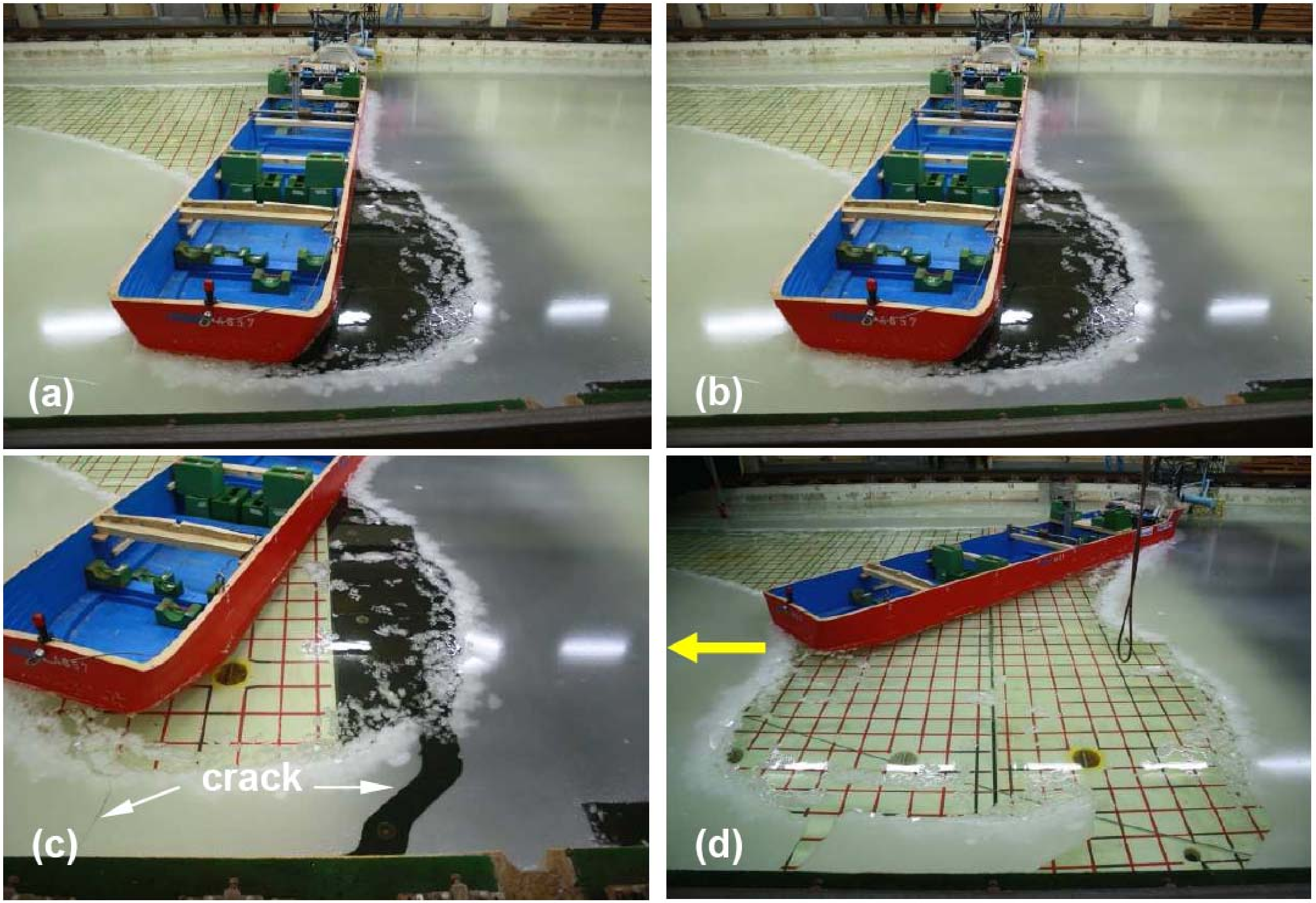
Crushing failure

Cracks





Crack Propagation



General Observations – Model Testing

- Ice characteristics/properties vary by basin due to proprietary (and different) methods for producing model ice.
- Challenges in reproducing all ice characteristics (e.g. flexural strength and compressive strength) at model scale.
- Limited basin lengths/widths results in trade-offs between model scale, ice properties, and set-ups to be tested.
- Ice Sheets may take 1 – 3 days to create; test programs are long duration (several weeks) and test program needs to be focused. Data can end up being qualitative than quantitative if not properly designed and modeled.
- For people without much experience recommend hiring consultants with experience in ice load prediction and tank testing to support model test program and load estimation.
- Requirement for Ice Tank Model Testing Guidelines?

General Observations – Mooring Design

- Ice Management – typically not taken into account for mooring design loads
- Higher uncertainty in estimating design ice loads
  - Limited ice data
  - Large variability in ice characteristics
  - Inaccuracy in load prediction by either design code, numerical models and ice tank tests
  - For dynamic systems may need hybrid model test/simulation to predict extreme loads and responses
  - => higher mooring safety factors or load factors?
- Pay attention to ice accumulation below vessel / around mooring. Can cause damage to instrumentation, sheathed wire, risers, etc.