MODELLING STRUCTURE-ICE CONTACT

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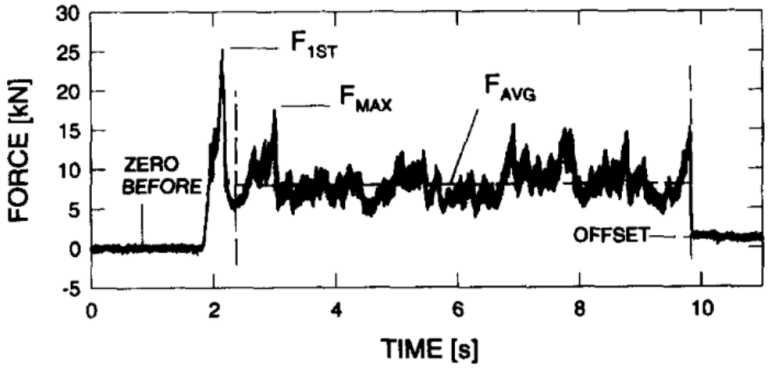
TU Delft, Delft, THE NETHERLANDS



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STRUCTURE – ICE CONTACT;

How do we perceive the contact?

- Descriptive modelling of the contact;
- Modelling ice pressure;
- Modelling ice deformations at contact;
- Questions
- Summary

MODELLING STRUCTURE – ICE CONTACT

What are the aims?

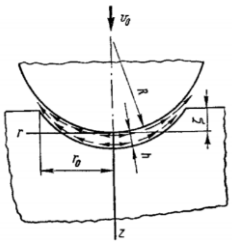
- Understanding the processes at contact;
- Obtaining the force versus indentation relationship for numerical simulations
- Obtaining ice pressure and ice force values for design.

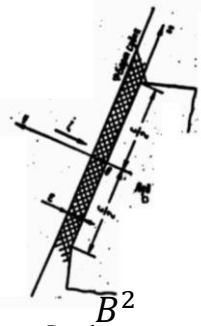
The controlling variable is the normal relative velocity between ice and the structure. When this is positive, ice is failing; when zero, only elastic deformations exist and when negative, damping terms are zero.

DESCRIPTIVE MODELS FOR CONTACT

Squeeze film of crushed ice

Model was derived with drop ball tests (Kurdjumov & Kheisin 1976) and used also in deriving ice pressure on ships (Popov 1965)



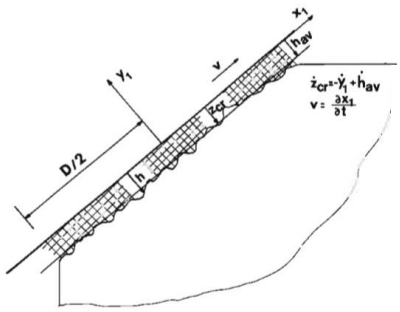


$$p = Cv^{1/4}(r_0{}^2 - r^2)^{1/4} \qquad p = Cv(\frac{B^2}{4} - x^2)$$

C empirical strength parameter and v indentation speed

DESCRIPTIVE MODELS FOR CONTACT

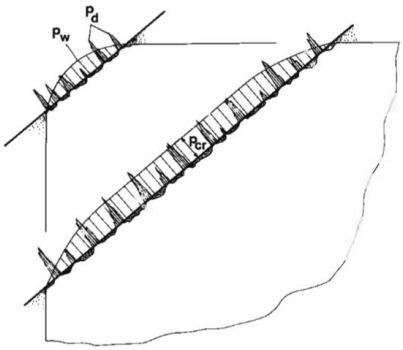
The Russian model included an empirical strength constant and did not taken into account the film thickness variation due to sources of crushed ice. These were included in a slightly improved model (Riska 1987)



$$p_w = -6\eta \frac{\dot{h}_{av} - \dot{z}_{cr}}{h_{av}^3}\left(\frac{D^2}{4} - x_1^2\right)$$

DESCRIPTIVE MODELS FOR CONTACT

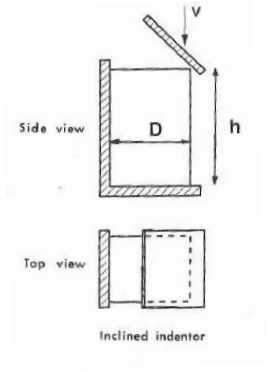
Division of contact into direct contact and contact through a layer of crushed ice (Varsta 1983, Riska 1987)

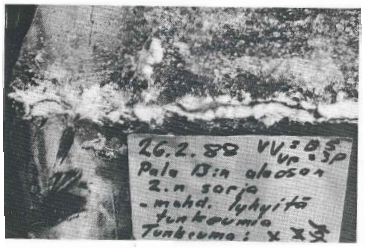


Both p_w and p_d empirical

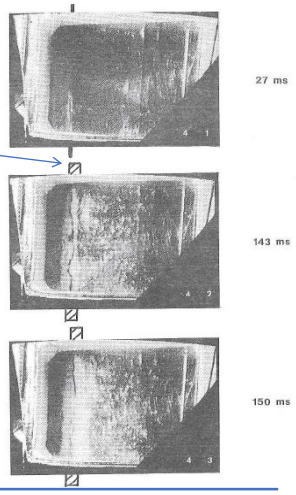
DESCRIPTIVE MODELS FOR CONTACT

Observation of concentrated – line-like – contact (Riska & Joensuu 1988) and its modelling...



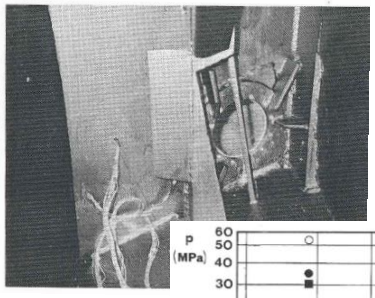


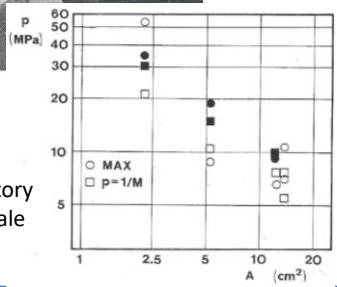
Nominal contact area



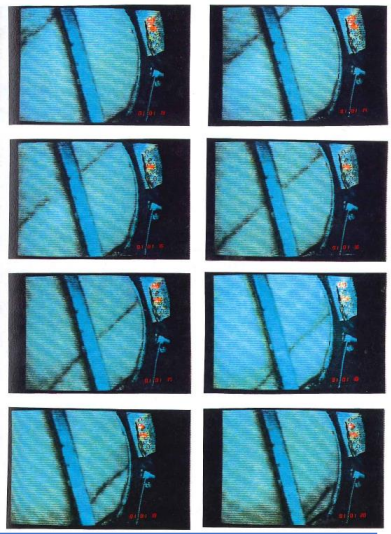
DESCRIPTIVE MODELS FOR CONTACT

Full scale verification



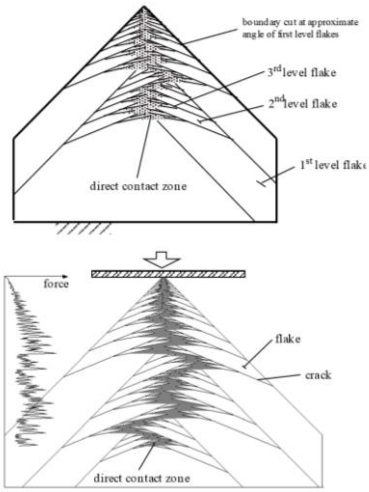


Black – laboratory
White – full scale



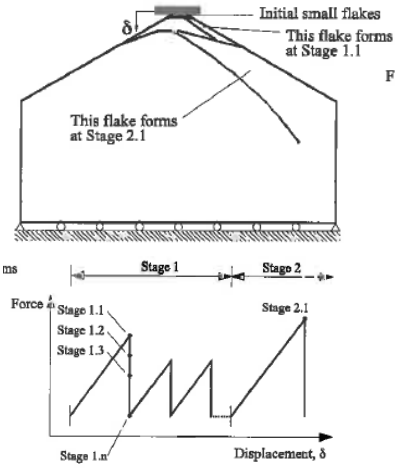
DESCRIPTIVE MODELS FOR CONTACT

...and its modelling (Daley 1991) and...



Cracks based on shear force and shear strength

DESCRIPTIVE MODELS FOR CONTACT



...Tuhkuri (1996)

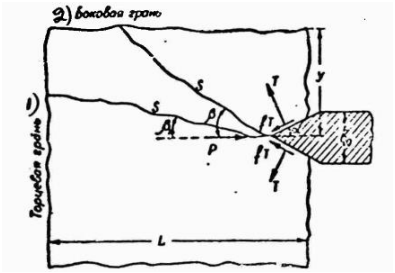
Cracks based on fracture mechanics

Still the question of pressure is open – even if pressure – melting has been suggested (Gagnon)

MODELS FOR ICE PRESSURE

- The aim of the models is to give the ice pressure for ice force calculation;
- Models are empirical.

ICE PRESSURE PROPORTIONAL TO COMPRESSIVE STRENGTH OF ICE R_{cr} (Korzhavin 1962)

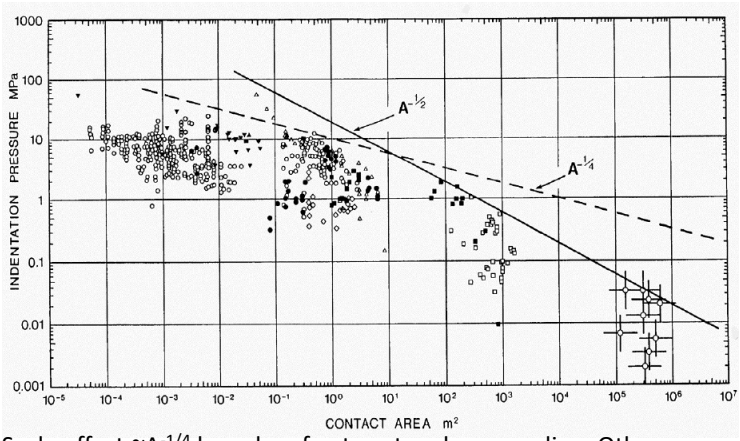


$$p = 2.5 \frac{mk}{\sqrt[3]{v/v_0}} \cdot R_{cr}$$

m shape factor 0.65 ... 1.0
k contact factor 0.4 ... 0.7
v_0 = 1 m/s

MODELS FOR ICE PRESSURE

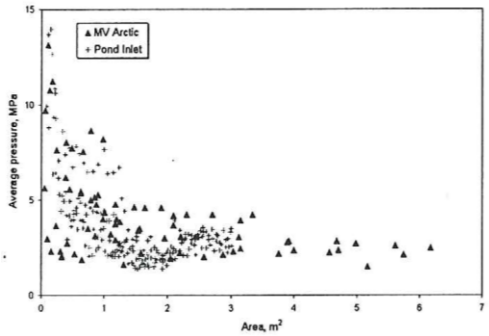
PRESSURE AREA RELATIONSHIP



Both nominal and gauge areas

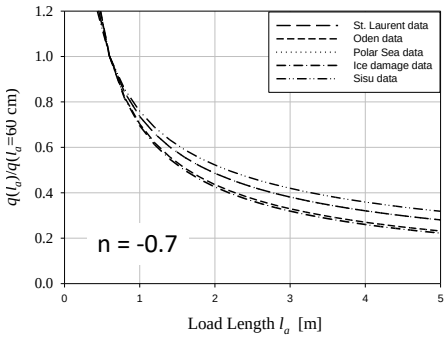
Scale effect ~$A^{-1/4}$ based on fracture toughness scaling. Other suggestions exist based on fracture mechanics – see works of Dempsey & Palmer

MODELS FOR ICE PRESSURE



Nominal areas

Frederking 1998

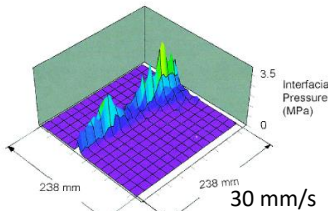


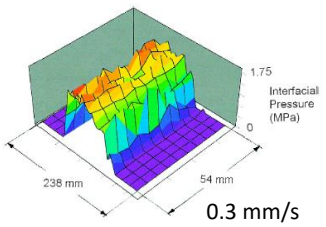
Gauge areas

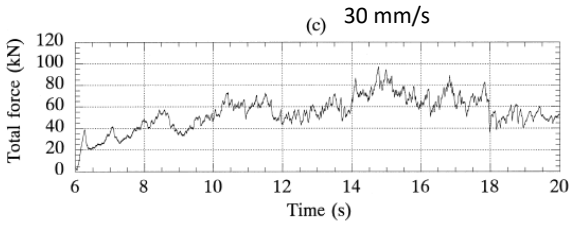
Riska 2007

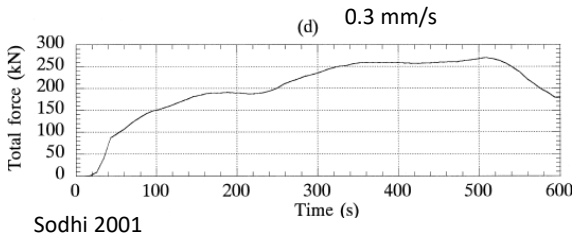
MODELS FOR ICE PRESSURE

Effect of indentation speed – change in failure







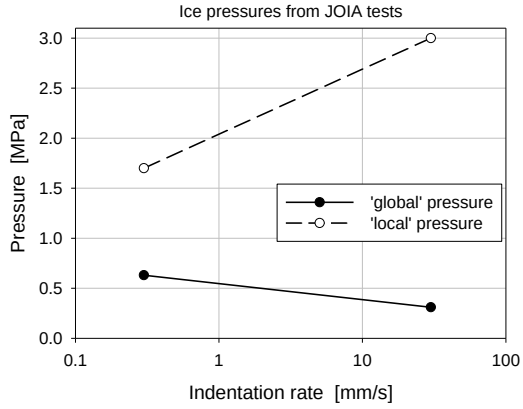


Sodhi 2001

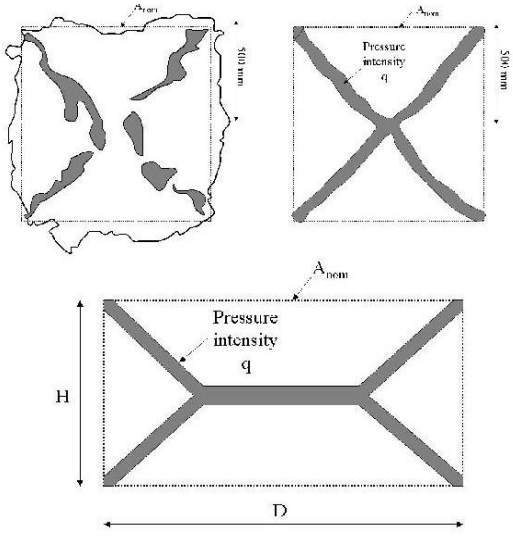
MODELS FOR ICE PRESSURE

Effect with indentation speed

- Is there an area where the rate effect disappears?
- Does the indentation rate influence 'pressure – area'?



MODELS FOR ICE PRESSURE



Assume that pressure on the line width w is constant, then the average pressure F_{TOT}/A_{nom} is

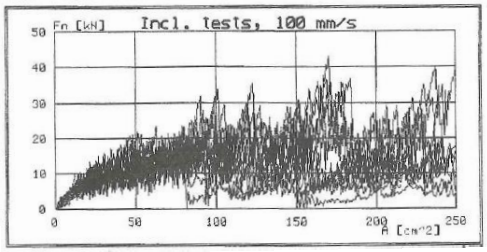
$$p_{av} = q \cdot \left(\frac{2\sqrt{2-1}}{D} + \frac{1}{H} \right)$$

And finally given with the aspect ratio C=D/H and nominal area A_{nom}

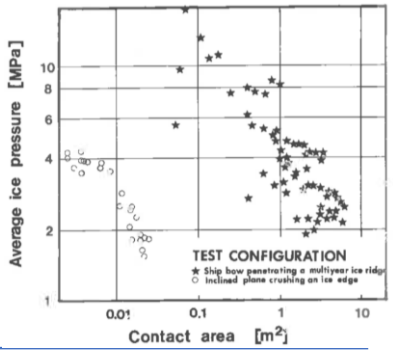
$$p_{av} = q \cdot \left(\frac{2\sqrt{2-1}}{\sqrt{C}} + \sqrt{C} \right) \cdot \frac{1}{\sqrt{A_{nom}}}$$

MODELS FOR ICE PRESSURE

Maximum pressures vs. pressures during indentation



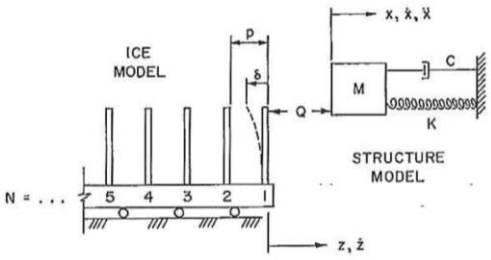
The process pressure – area relationship; fitting to the first 80 cm^2 contact gives pressure exponents of -0.28 to -0.43 (Riska et al. 1990)



Ship ramming results, n = -0.43 (Riska 1987)

MODELS FOR DEFORMATIONS AT THE CONTACT

Modelling the different deformation components for a simulation model

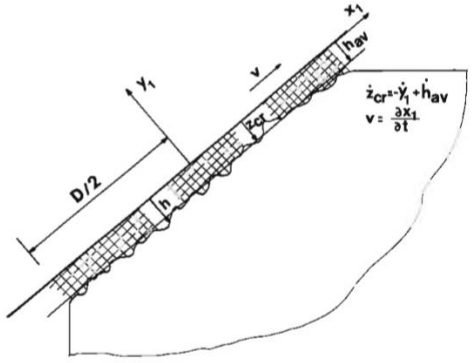


(Matlock et al. 1969)

First model for deformations at the contact (to my knowledge) – Finite failure depth concept which includes elastic deformation and failure

MODELS FOR DEFORMATIONS AT THE CONTACT

Modelling the different deformation components for a simulation model

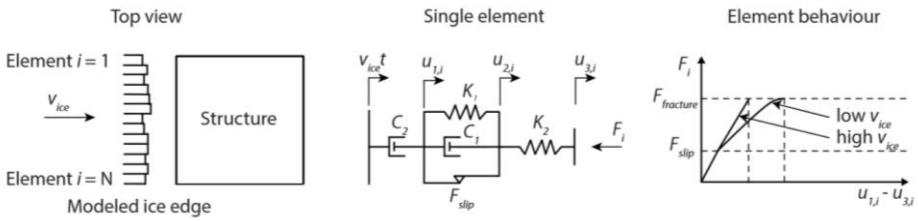


(Riska 1987)

Including the crushed ice layer in contact, two components in contact deformation

MODELS FOR DEFORMATIONS AT THE CONTACT

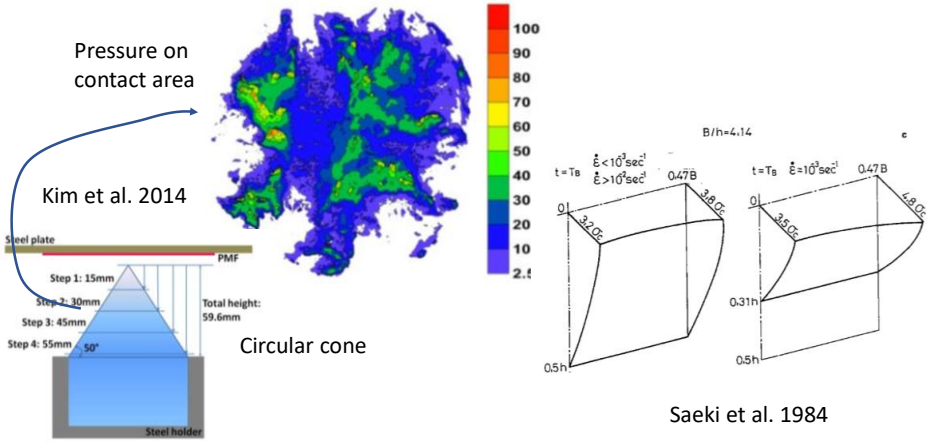
Model of ice deformations for IIV, includes ice elastic deformation and damping term as well as a zonal approach with a finite failure depth – question is that several of these are not based on ice mechanics...



(Hendrikse 2016)

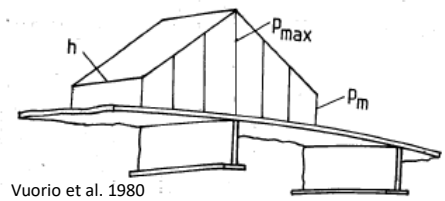
QUESTIONS STILL DEBATED
Apart from the above ones

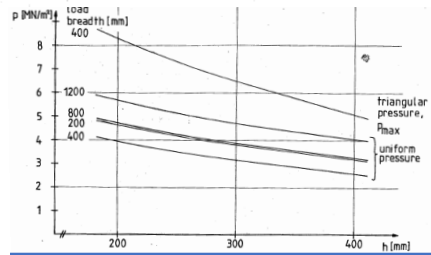
- Shape of the pressure distribution;

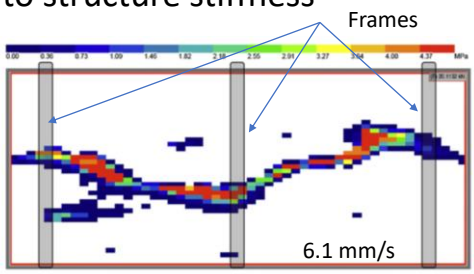


QUESTIONS STILL DEBATED
Apart from the above ones

Pressure distribution due to structure stiffness





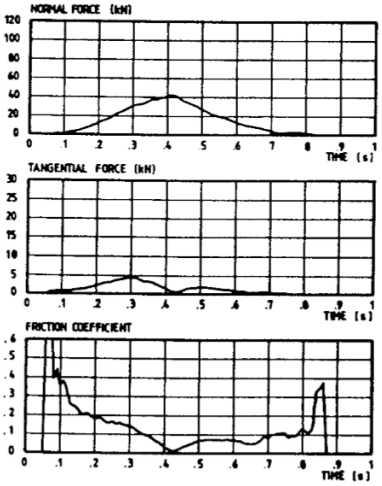


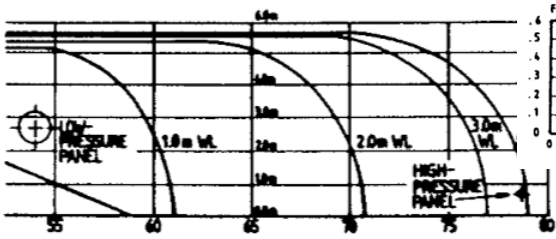
Tactile sensors see no pressure large scale distribution but important is how the plate responds; actual vs. effective pressure!

QUESTIONS STILL DEBATED

Apart from the above ones

- Effect of friction;

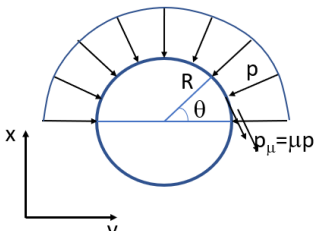




Enkvist & Mustamäki 1986

QUESTIONS STILL DEBATED

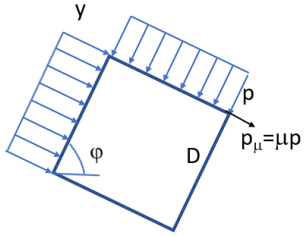
Effect of shape on pressure, case of vertical piles.



Without friction

$$F_x = -ph_i \cdot 2R$$

$$\Rightarrow p_{eq} = p, D_{eq} = D$$

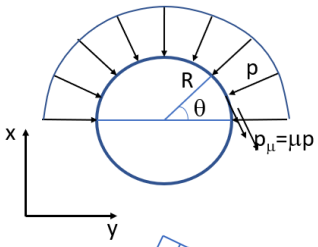


$$F_x = -ph_i \cdot D(cos\varphi + sin\varphi)$$

$$\Rightarrow p_{eq} = p, D_{eq} = D(cos\varphi + sin\varphi)$$

QUESTIONS STILL DEBATED

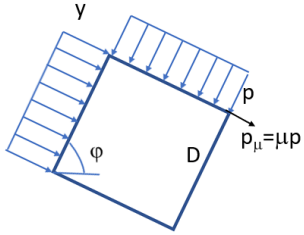
Effect of shape on pressure, case of vertical piles.



With friction

$$F_x = -ph_i \cdot 2R \cdot (1+\mu)$$

$$\Rightarrow p_{eq} = p(1+\mu),\ D_{eq} = 2R$$



$$F_x = -ph_i \cdot D(cos\varphi + sin\varphi) \cdot (1+\mu)$$

$$\Rightarrow p_{eq} = p(1+\mu),$$
$$D_{eq} = D(cos\varphi + sin\varphi)$$

CONCLUSION

- Two con census views; pressure-area relationship and a multitude of deformation components at contact;
- Fracture of ice not included in simulation;
- Crushed ice does not play a role in modelling;
- Effect of ductile-to-brittle transition on pressure still open;
- Effect of indentation speed on ice pressure unclear;
- Does cross sectional shape influence ice pressure?
- Existence of friction in normal contact.


Thank you for your attention!