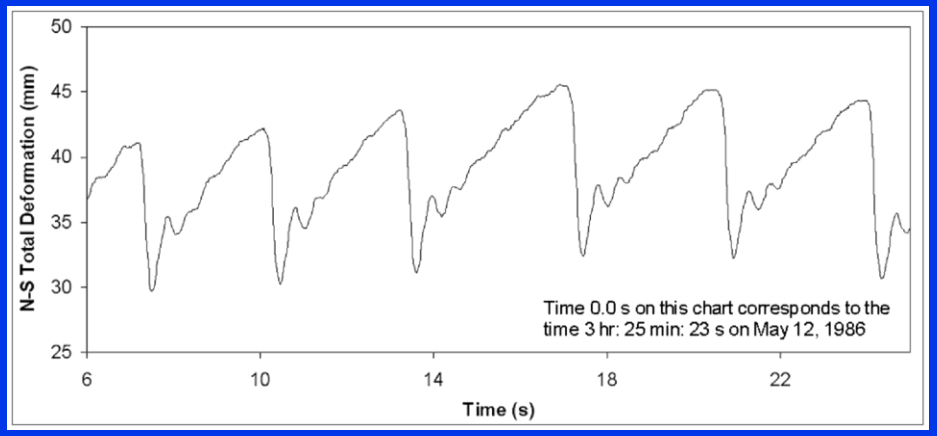
Lab tests of the Blade Runners concept for reducing ice-induced vibration of structures

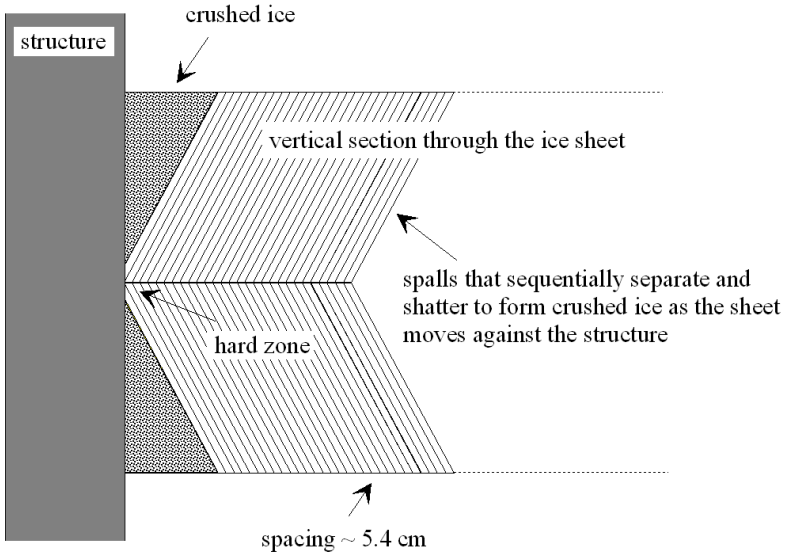
Gagnon, Bob

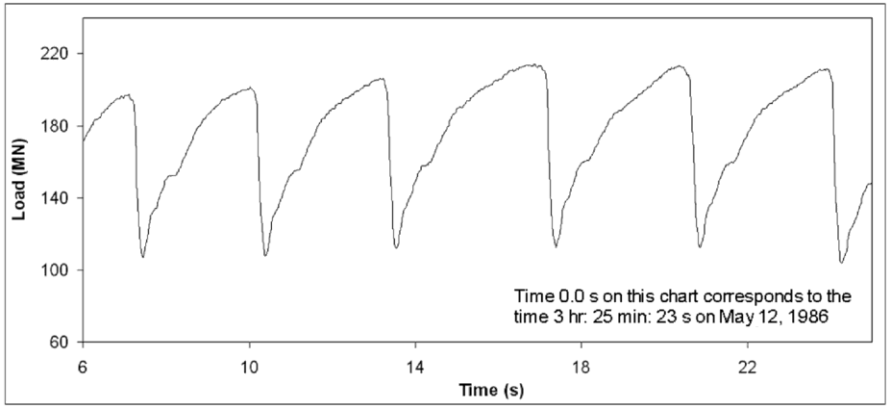
Lab Tests of the Blade Runners Concept for Reducing Ice-Induced Vibration of Structures

Robert Gagnon

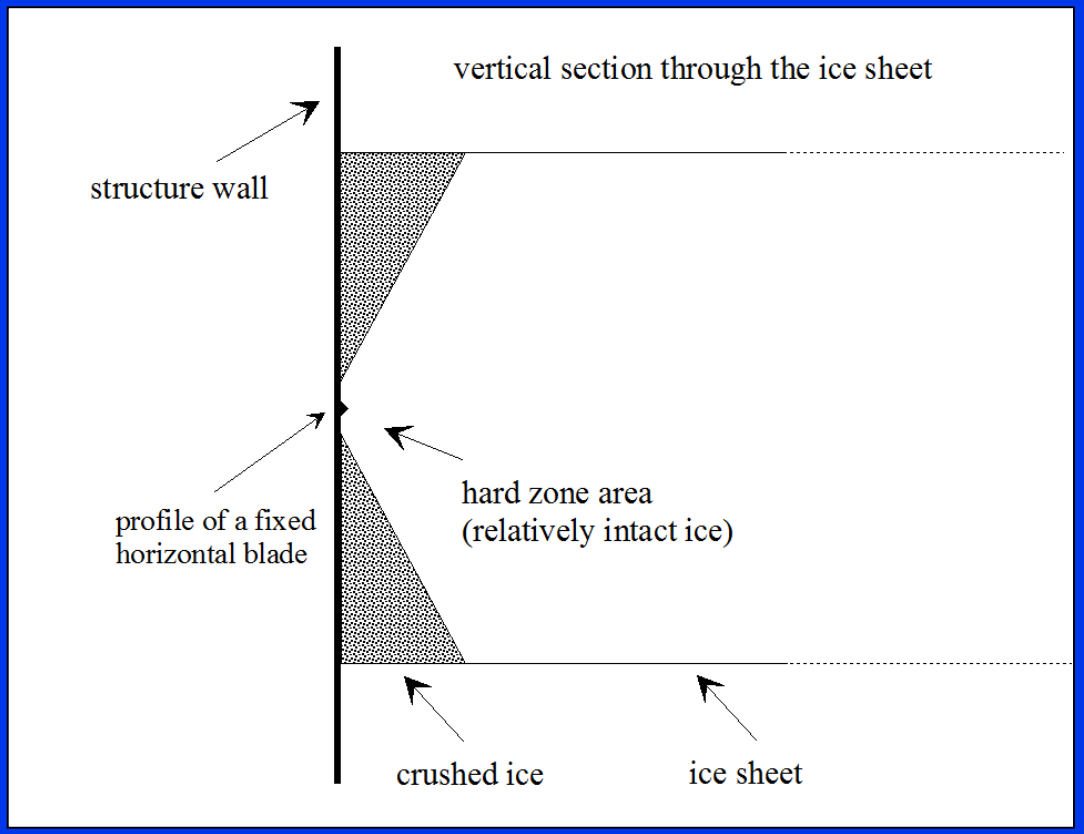


Background Information

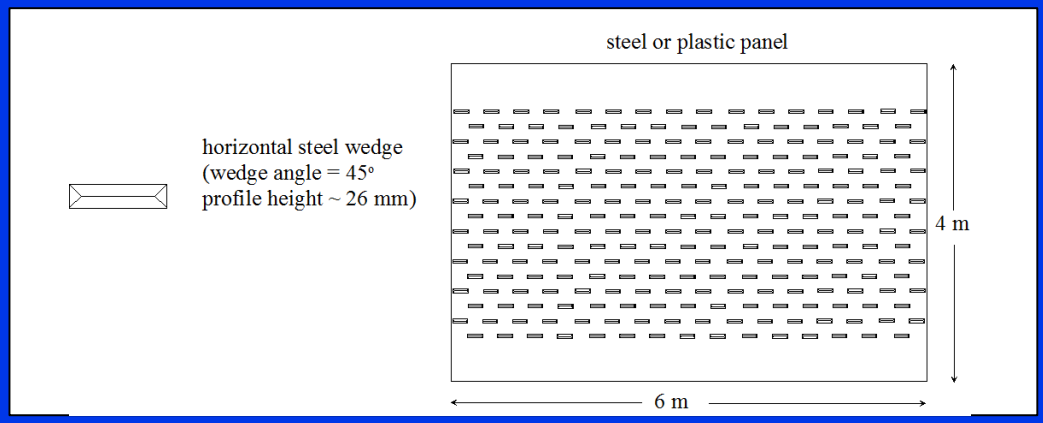


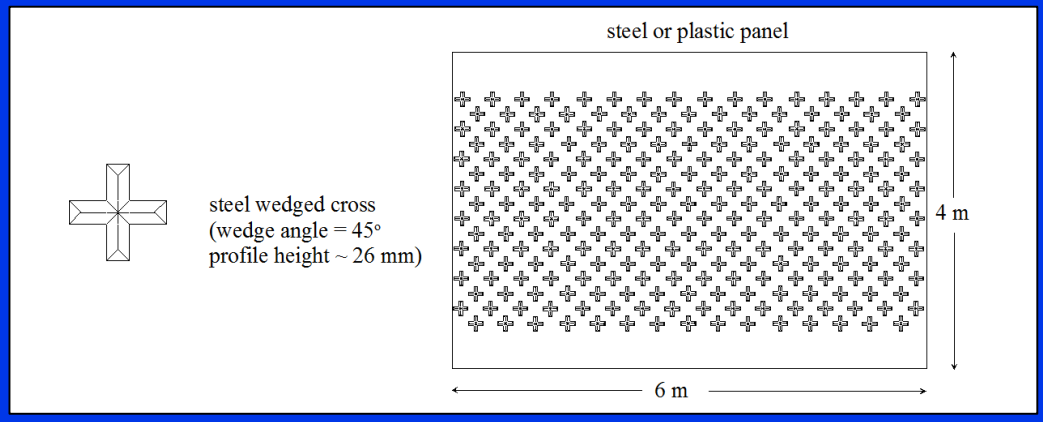


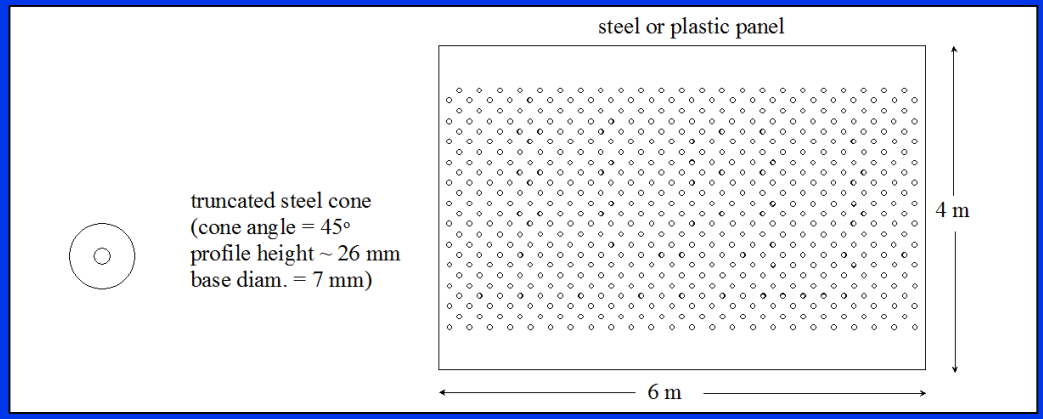
Blade Runners Concept



Multi-blade Panel Configurations







Test program objectives, i.e. obtain answers to the following questions:

1. What blade-array characteristics were the best at reducing high-amplitude sawtooth load patterns (HASLP)?

2. Does entrapment of crushed ice, and potential degradation of ability to reduce HASLP, occur for any of the blade-arrays?

3. Does the rough texture of the blade-arrays on the crushing platen surfaces lead to high, and undesirable, frictional forces?

Setup for Tests

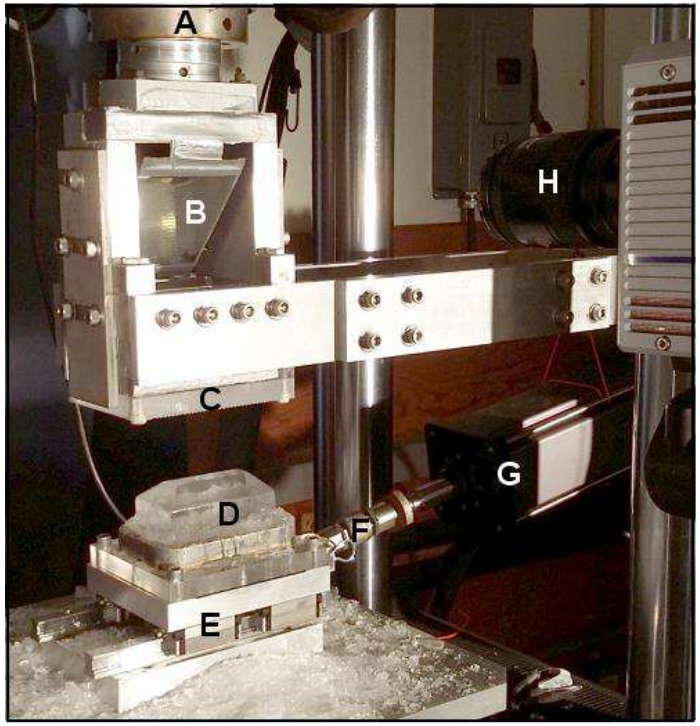
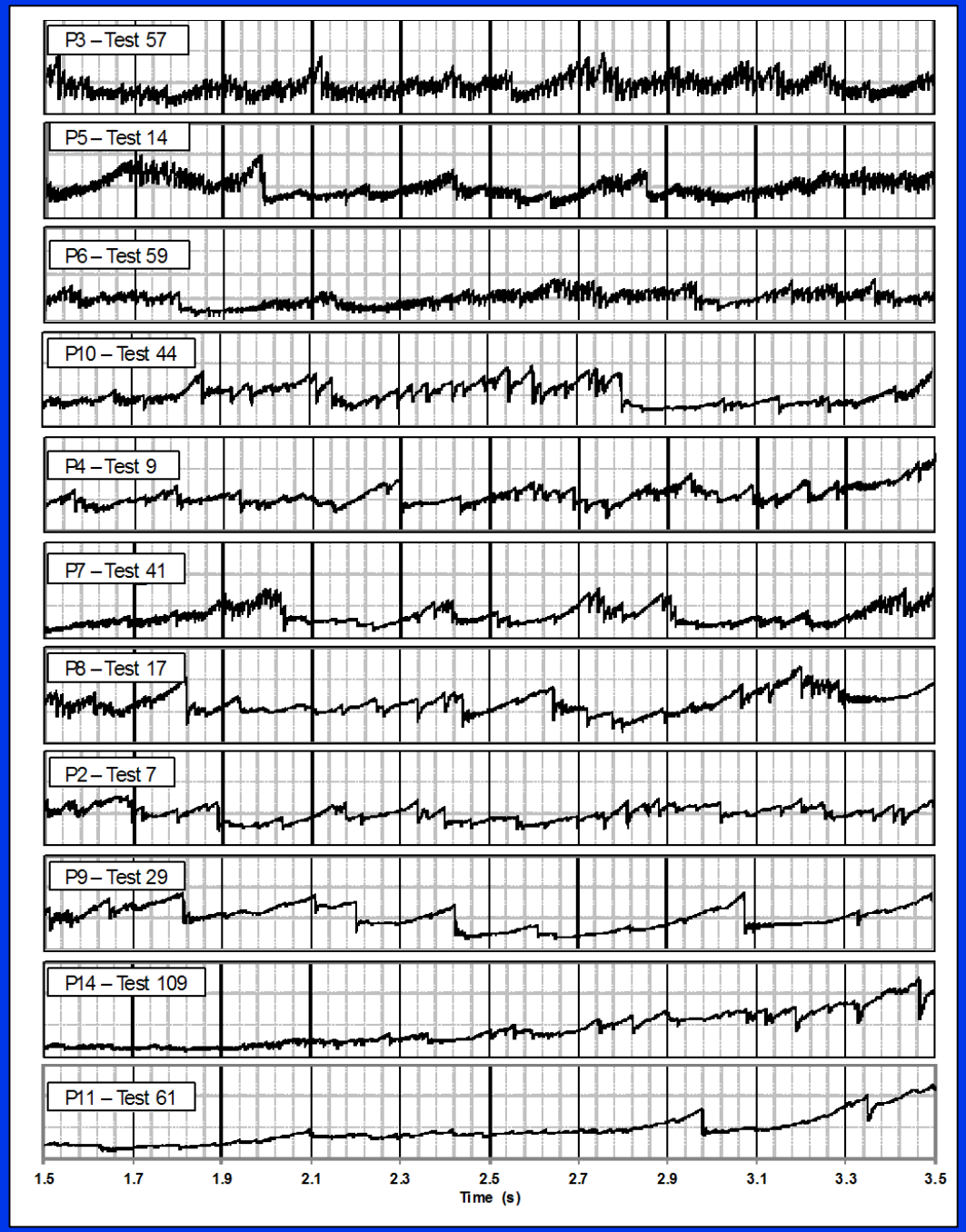


Figure 4. Photograph of the crushing-friction test setup. (A) Vertically-oriented test-frame load cell for measuring the normal load; (B) Mirror; (C) Acrylic crushing-platen; (D) Ice specimen in ice holder; (E) Rail-car assembly; (F) Load cell used to measure the horizontal friction force; (G) Linear actuator used to slide the rail-car and ice sample horizontally; (H) High-speed imaging camera.

Crushing Platens and Ice Samples in Holders

Post-Test Ice Sample Showing Ice Hard Zone, Surrounding Crushed Ice and Blade Pattern

Load Records for Various Crushing Platens

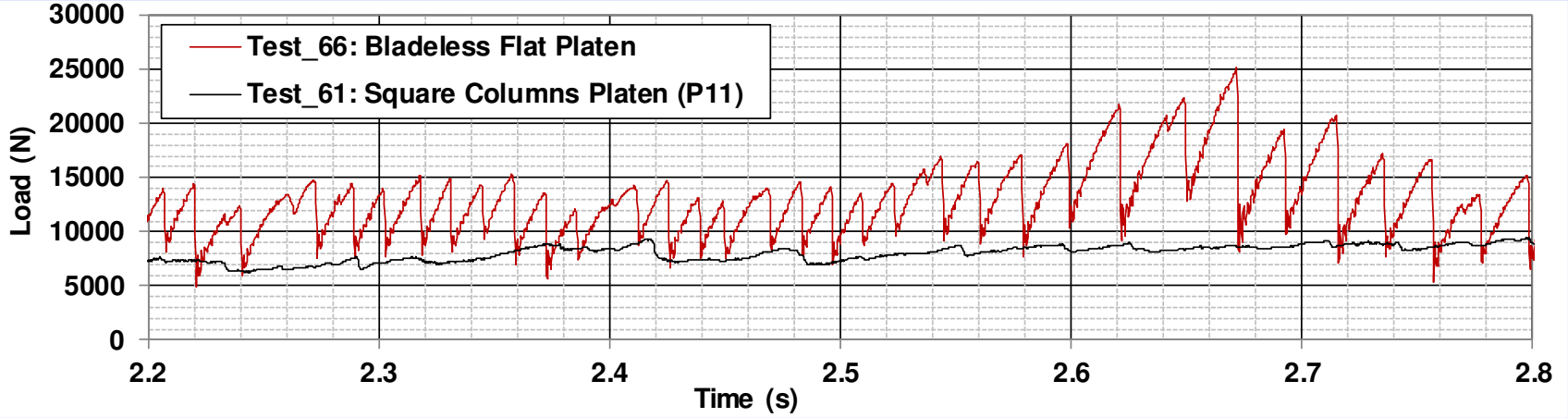


poor performers

good performers

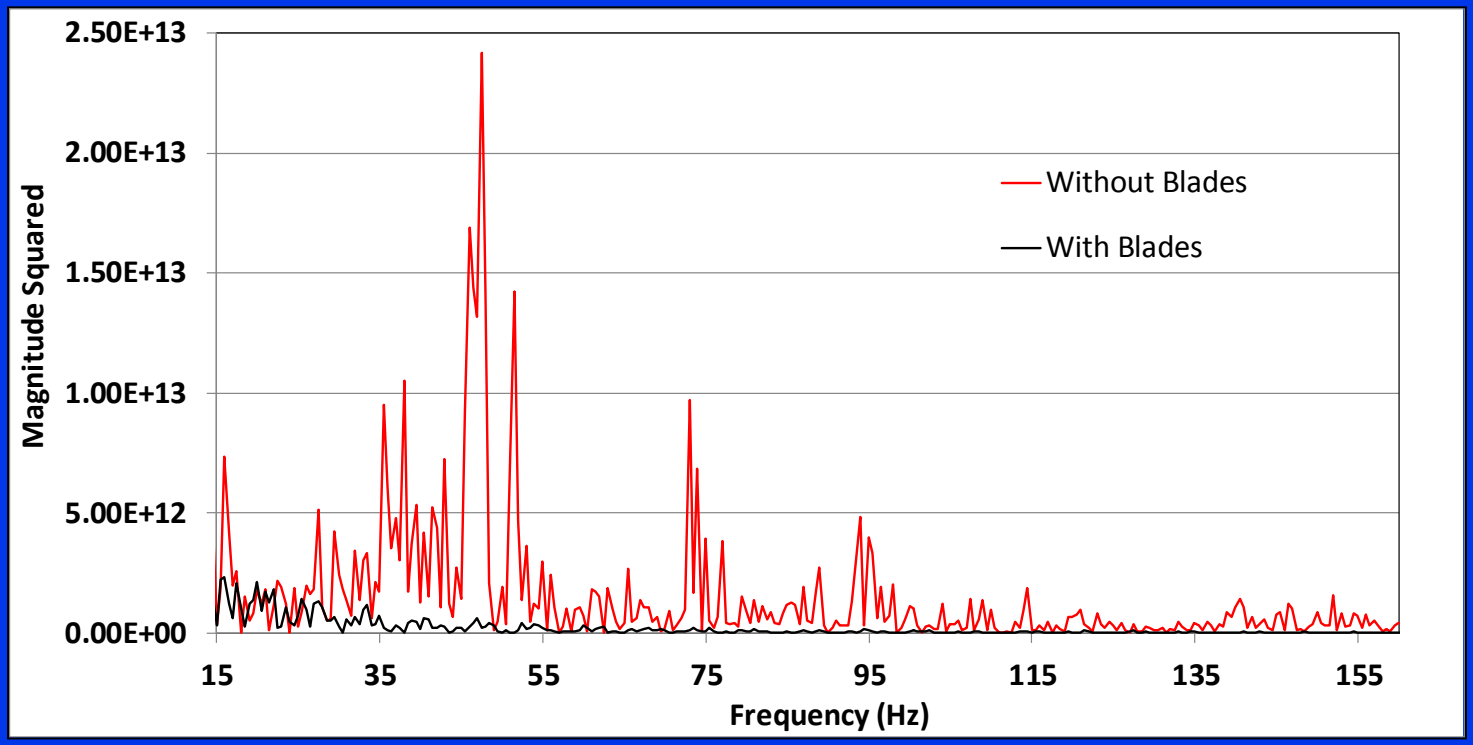
Load records from tests using eleven of the crushing platens. The efficacy of the blade shapes, array patterns and spacings to reduce high-amplitude sawtooth load patterns (HASLP) increases from the top record to the bottom record. Platen P11 (at the bottom), that had an array of square columns on its surface, was one of the best performing platens, that is, the record is relatively smooth. The y-axis scale on all the records is 0-30 kN. For these tests the vertical crushing rate was 10 mm/s and there was no frictional horizontal sliding. The best performing platens had the closest blade spacing.

Load Record Comparison for a High-Performance Blade-Runners Platen and a Flat Bladeless Platen



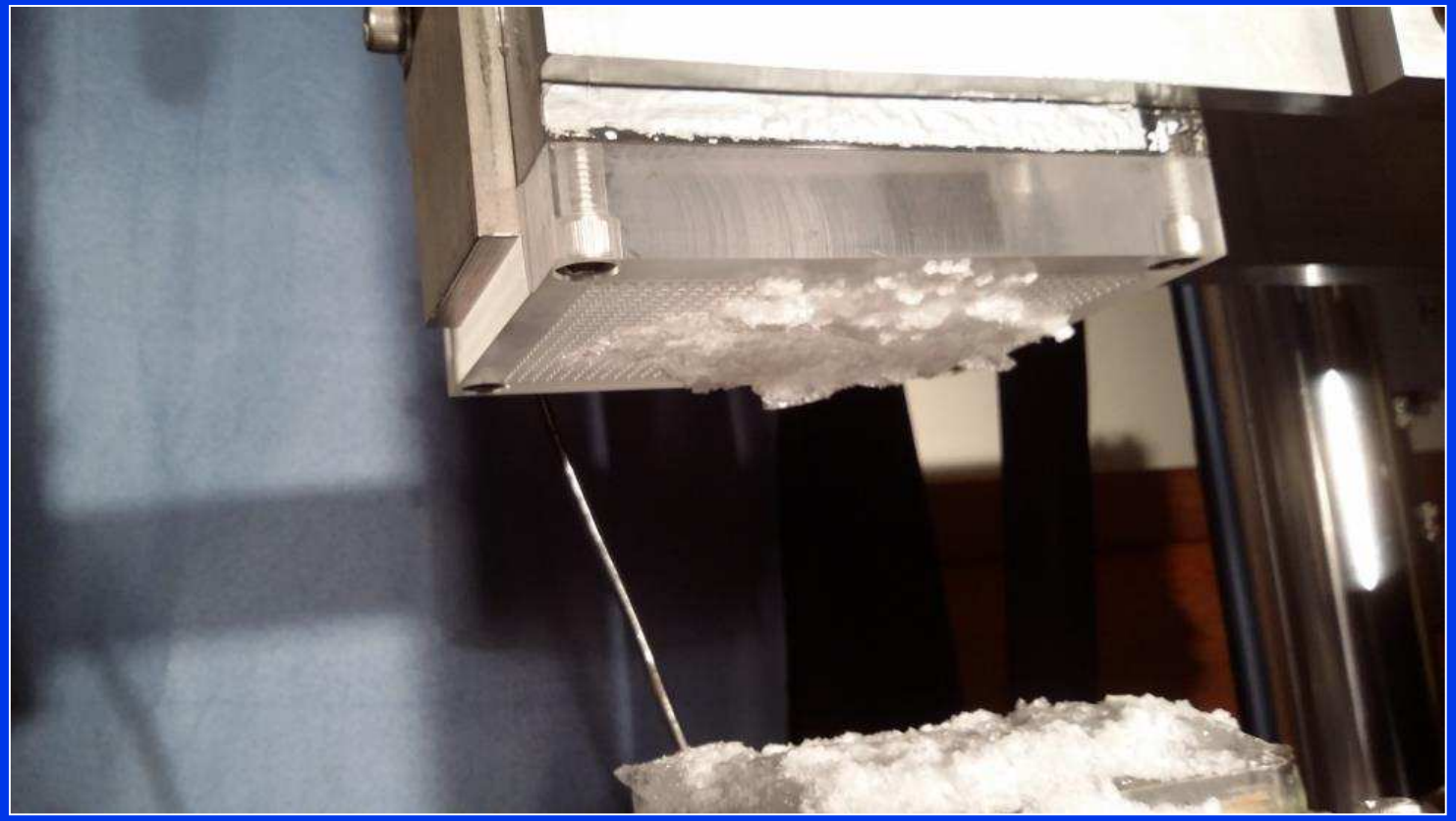
Expanded view of the load records from one of the best performing crushing platens (P11) and from a 'bladeless' flat acrylic platen. The prominent sawtooth load pattern is evident in the latter case.

Power Spectrum Comparison for a High-Performance Blade-Runners Platen and a Flat Bladeless Platen



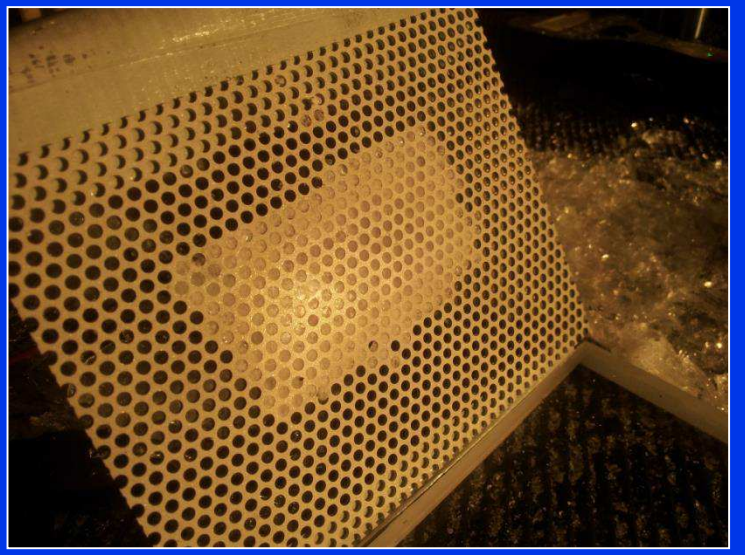
Magnitude-squared frequency domain plots obtained from Fourier transforms of the time domain load traces (1.5 s to 3.5 s) of the two tests in Figure 6, showing power amplitudes at respective frequencies. Note that the high-amplitude peaks associated with the 'no blade' case (flat platen) are substantially reduced in the case with the blades (square columns platen (P11)).

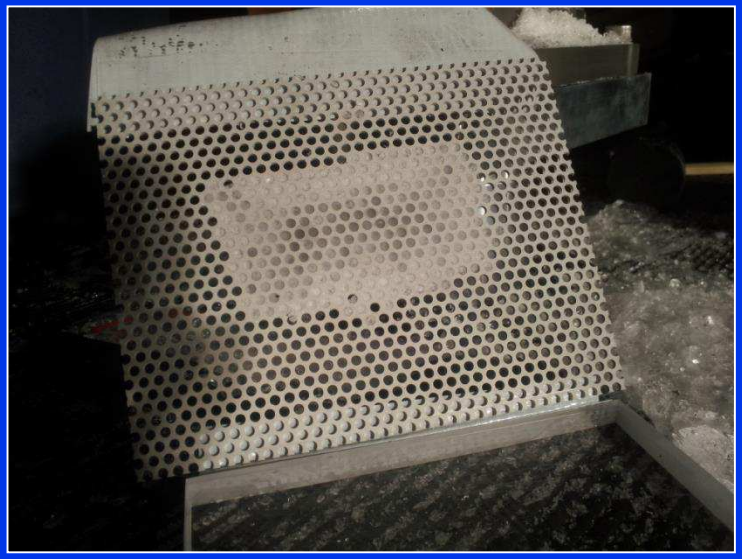
Post-Test Image of Crushed Ice on Crushing Platen



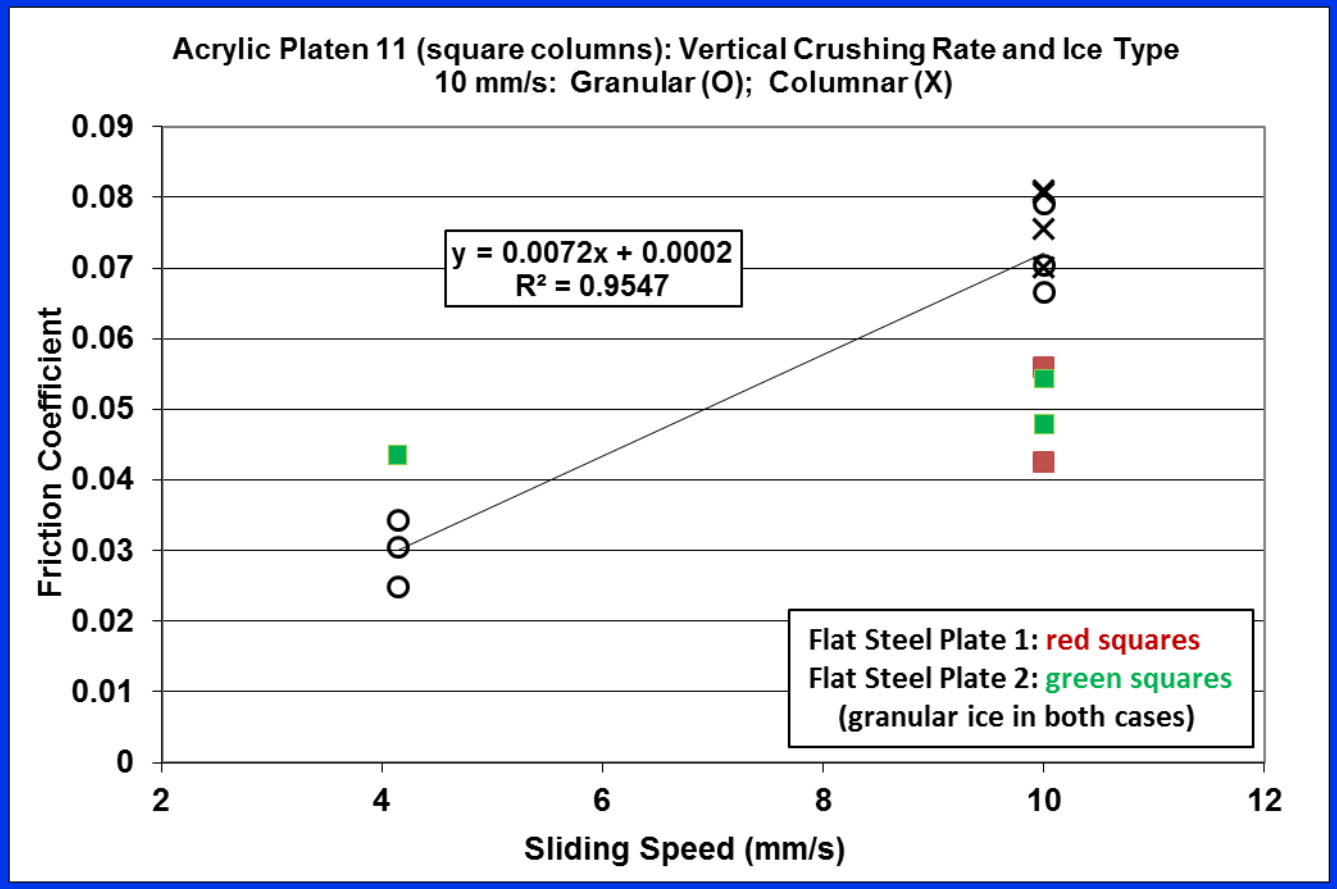
Post-Test Image of Crushed Ice on Crushing Platen
(as viewed through the platen)

Post-Test Images of Crushed Ice on a Crushing Platen with a Blade Pattern Consisting of a Flat Surface with Shallow-depth Holes (i.e. perforated sheet on flat acrylic)





Crushing-Friction Experiments



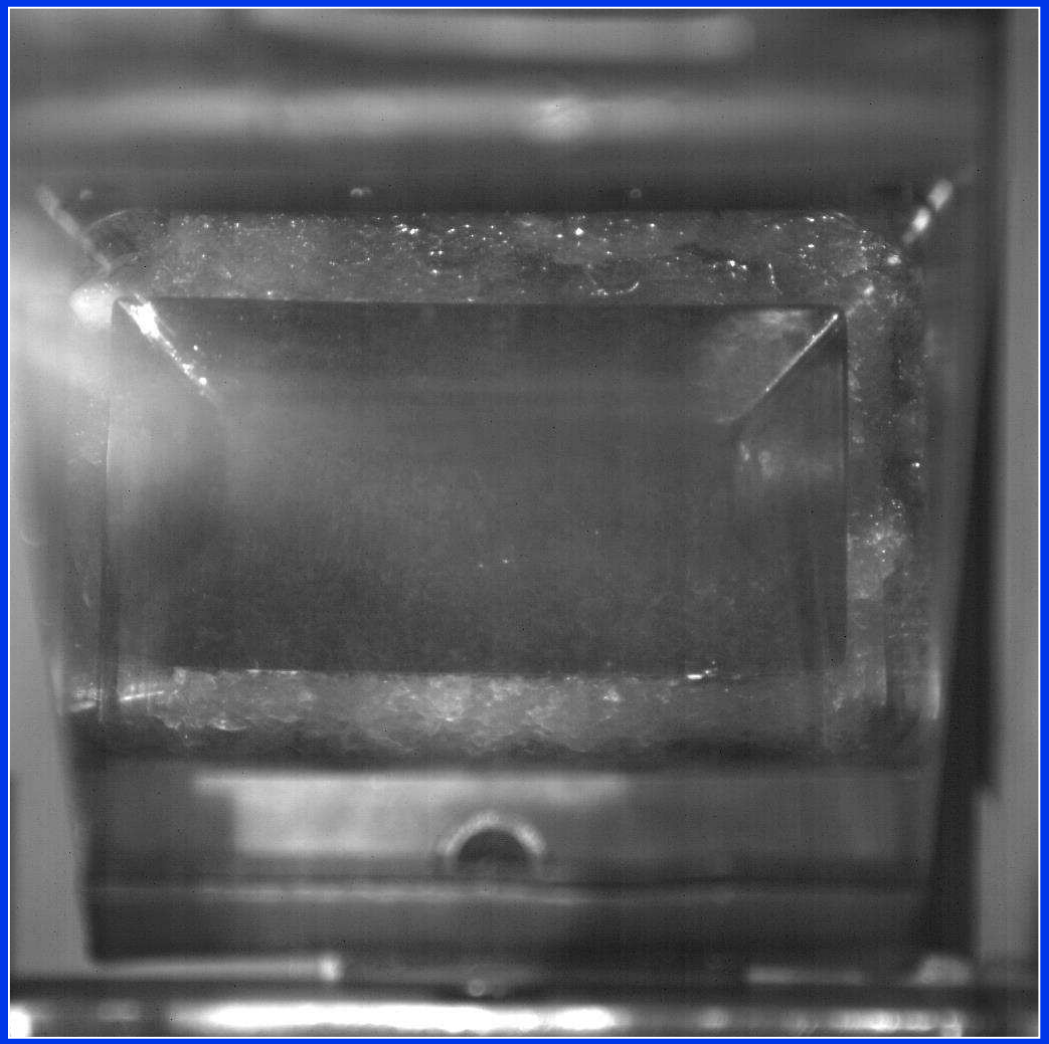
Most of the data above are from a paper submitted to Cold Regions Science and Technology (under review).

Two high-speed imaging records of ice crushing experiments:

- Test_66_PO (Flat acrylic platen, no sliding)
- Test_61_P11 (Square-columns acrylic platen, no sliding)

Test_66_PO (Flat acrylic platen, no sliding)

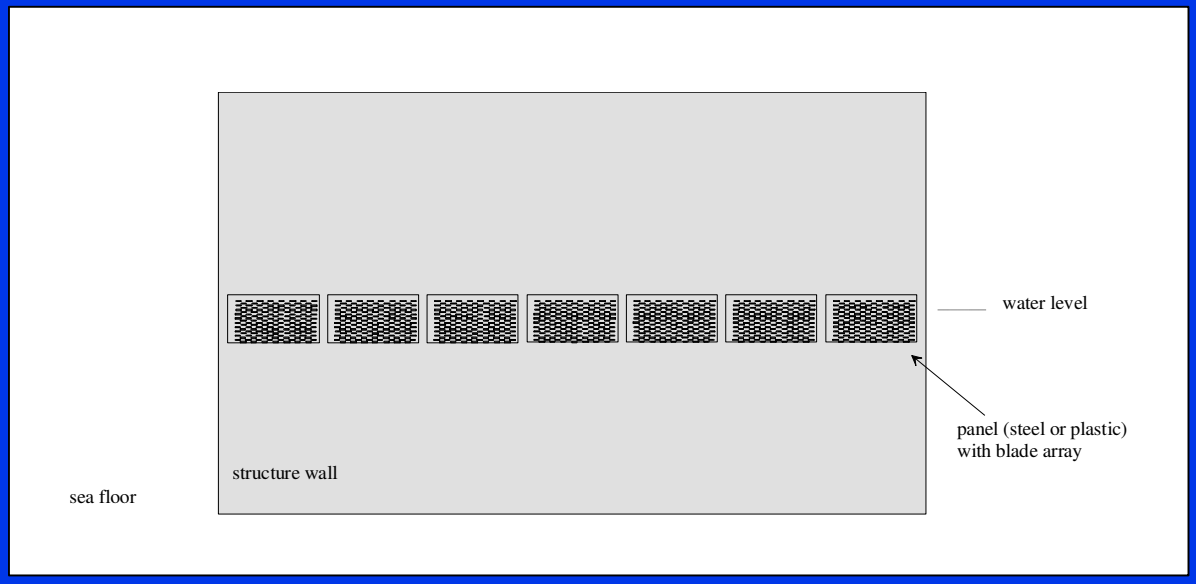
Capture rate: 500 images/s

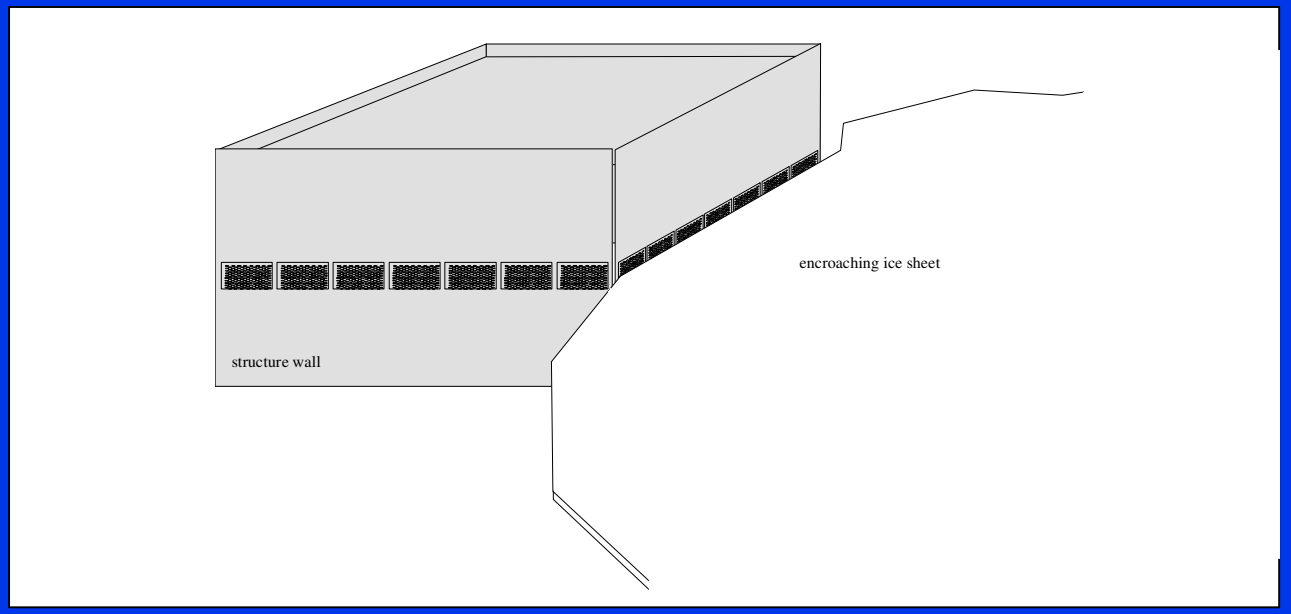


Test_61_P11 (Square-columns acrylic platen, no sliding)

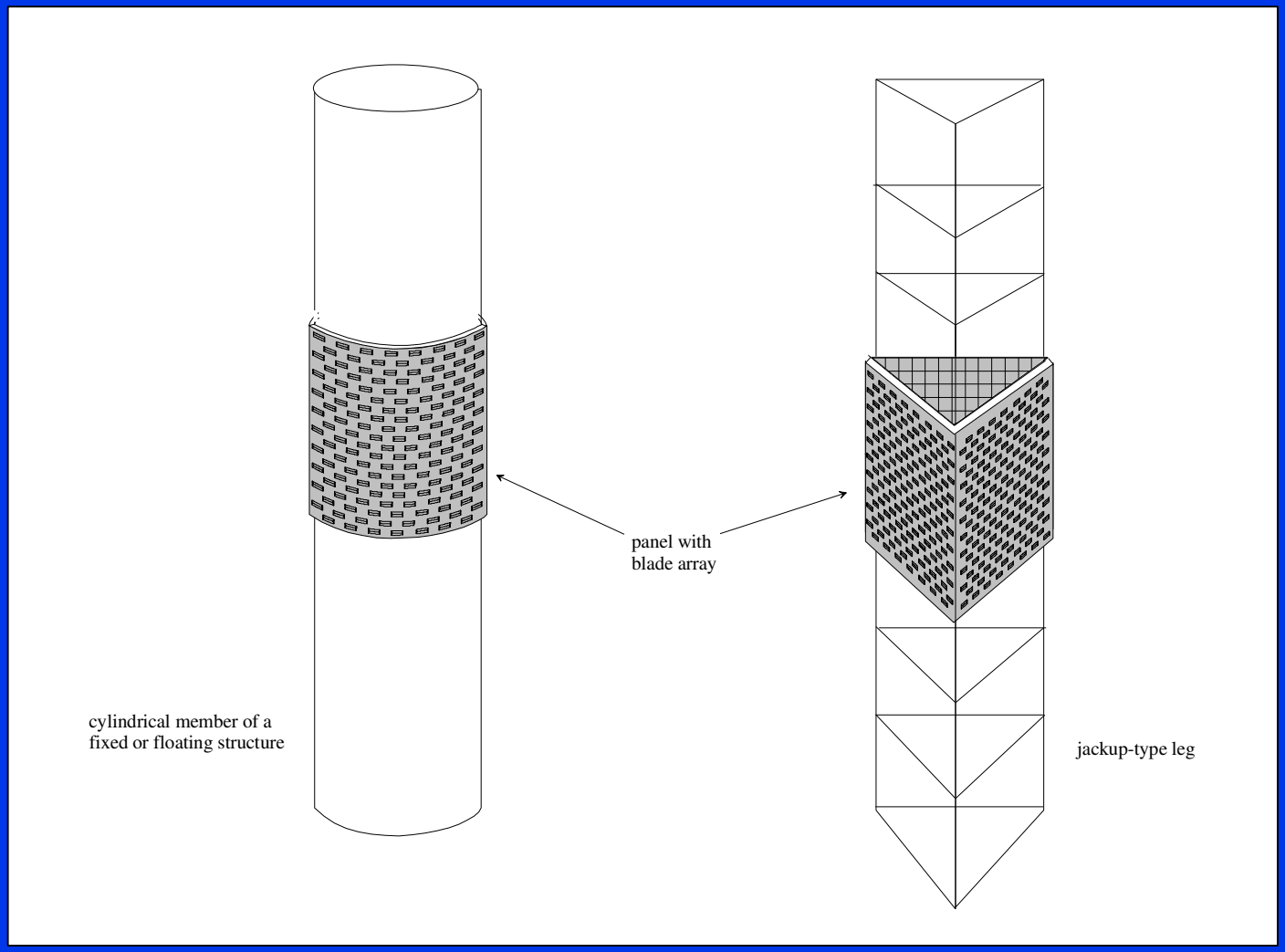
Capture rate: 500 images/s

Potential Applications

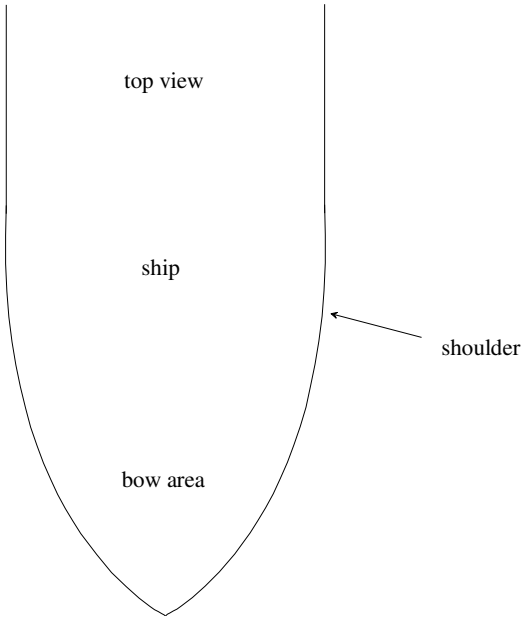


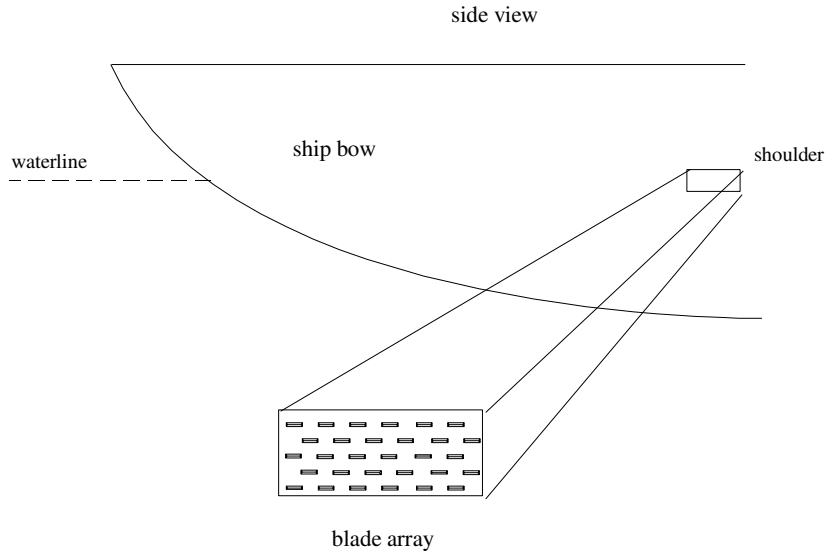


Potential Applications
(offshore oil/gas platforms and wind turbines)



Potential Applications
(ships)





Conclusions

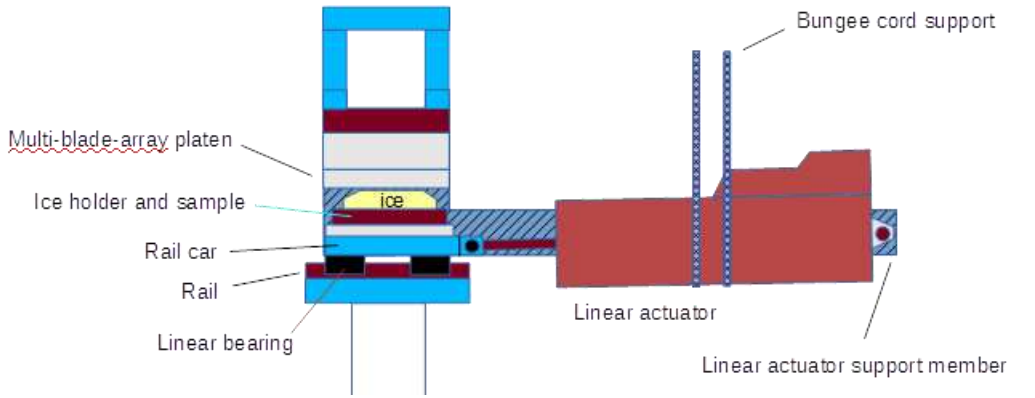
(*Answers to the three questions addressed in this test program*)

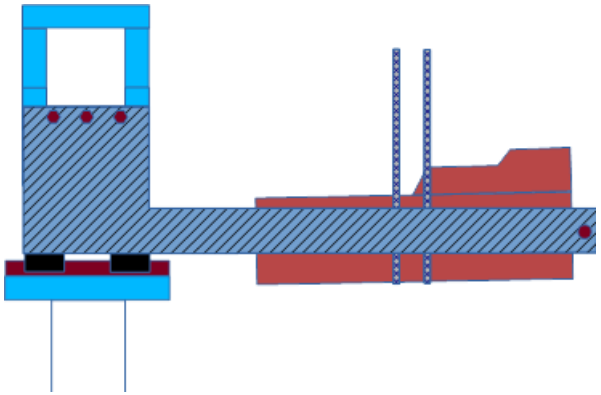
1. What blade-array characteristics were the best at reducing high-amplitude sawtooth load patterns (HASLP)?
Answer: Square pyramids and columns (2 mm base and 2 mm edge-to-edge spacing)

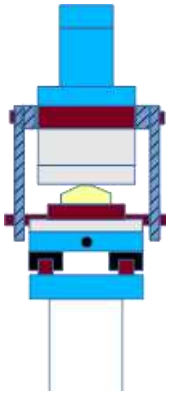
2. Does entrapment of crushed ice, and potential degradation of ability to reduce HASLP, occur for open blade-arrays?
Answer: NO

3. Does the rough texture of the blade-arrays on the crushing-platen surfaces lead to high, and undesirable, frictional forces?
Answer: NO

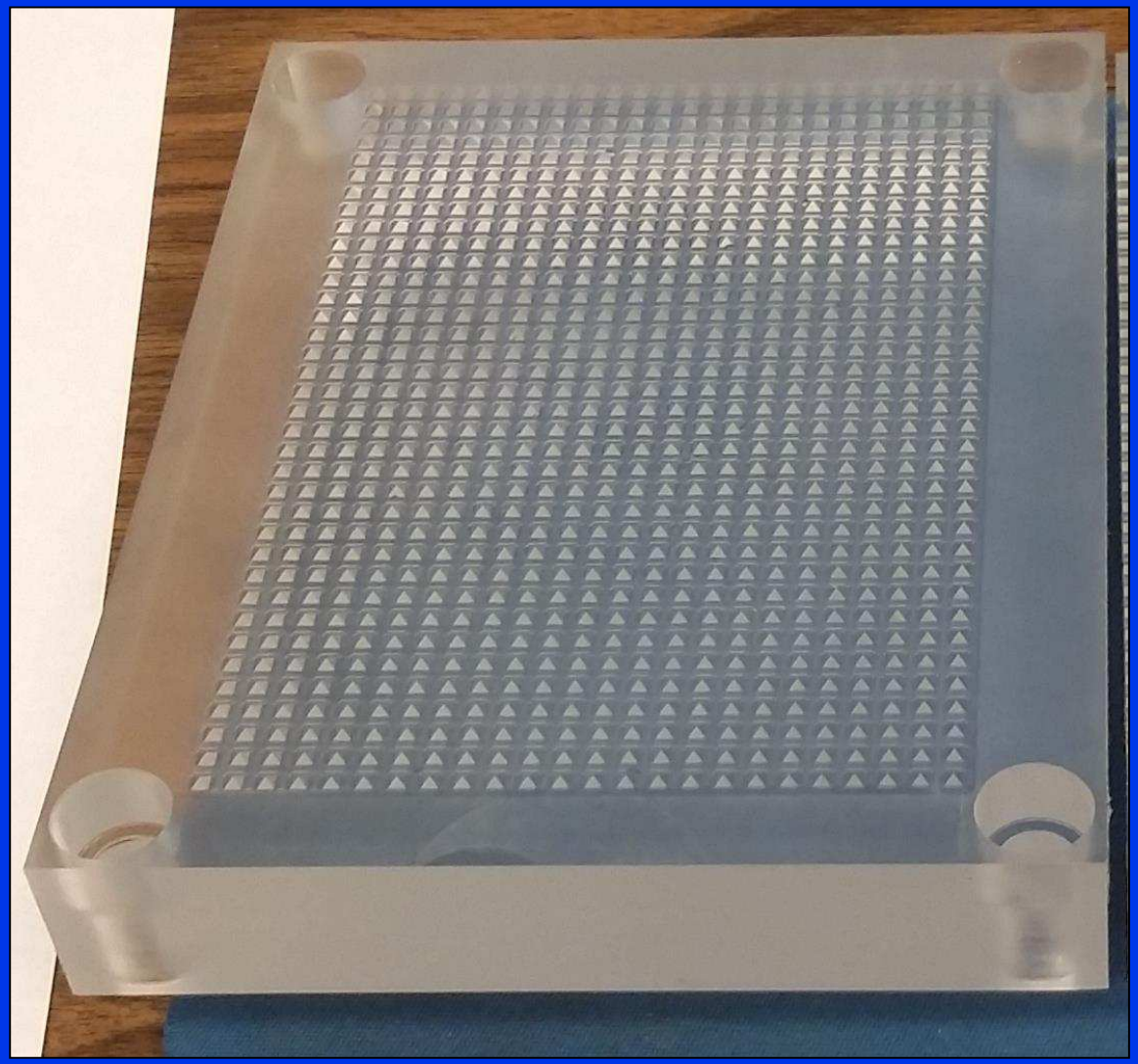
Apparatus Schematic





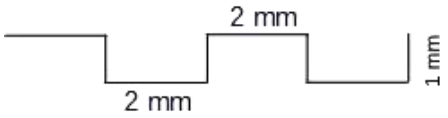


Blade Runners Crushing Platen # 14



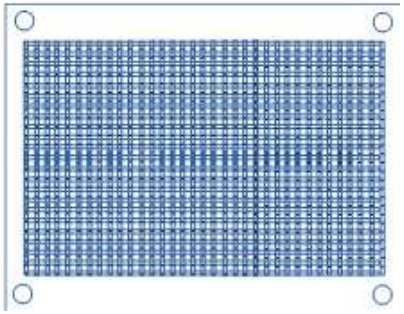
Platen # 11 Surface Profile

Profile



Flat top square towers (base: 2 mm x 2 mm)
Tower height 1 mm
Center-to-center vertical row spacing 4 mm
Center-to-center horizontal row spacing 4 mm

Platen: Acrylic



Ice Sample Growth and Preparation

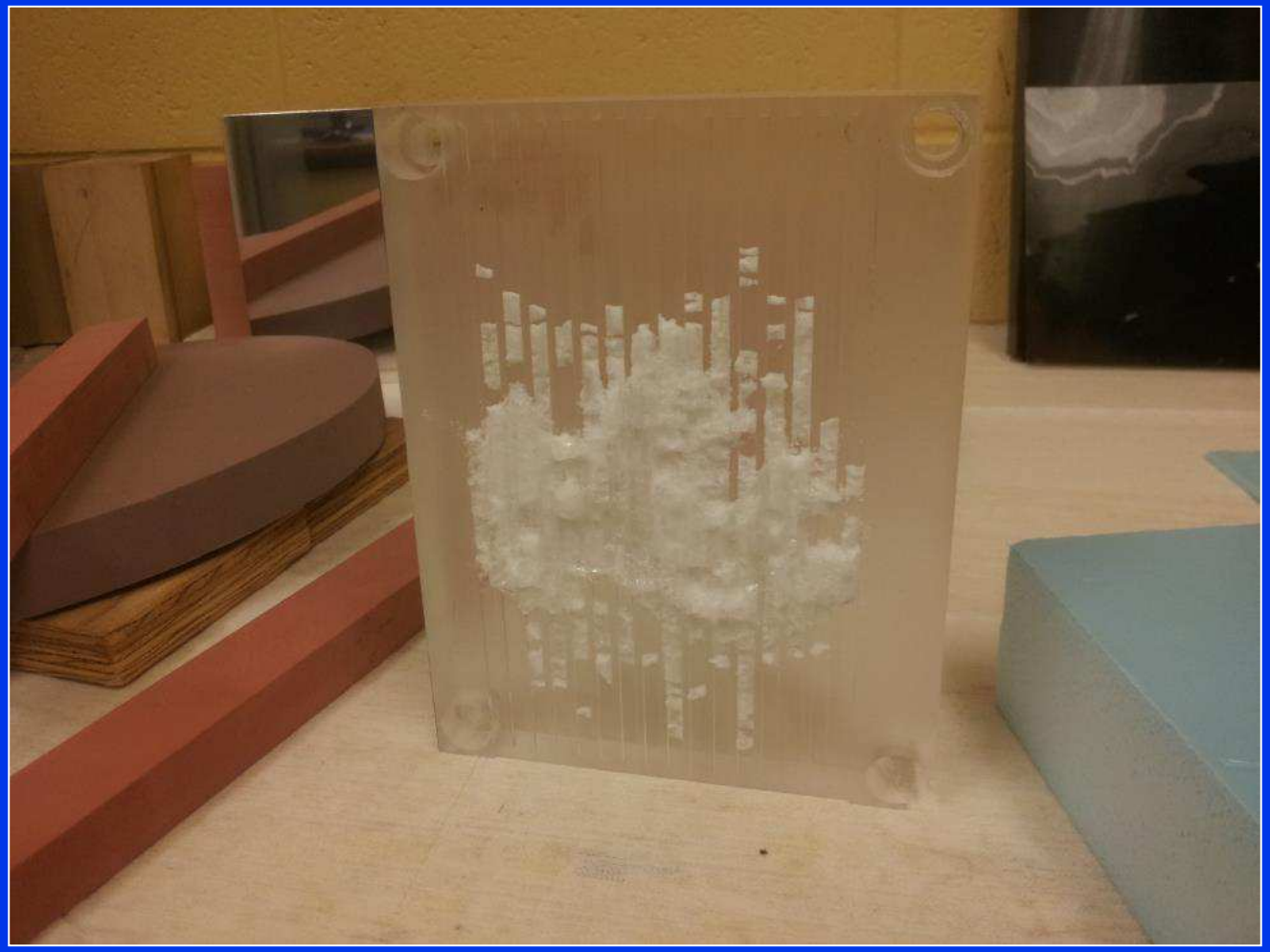
Holders for Ice Samples

Ice Sample Growth and Preparation

Post-Test Image of Platen and Ice Sample

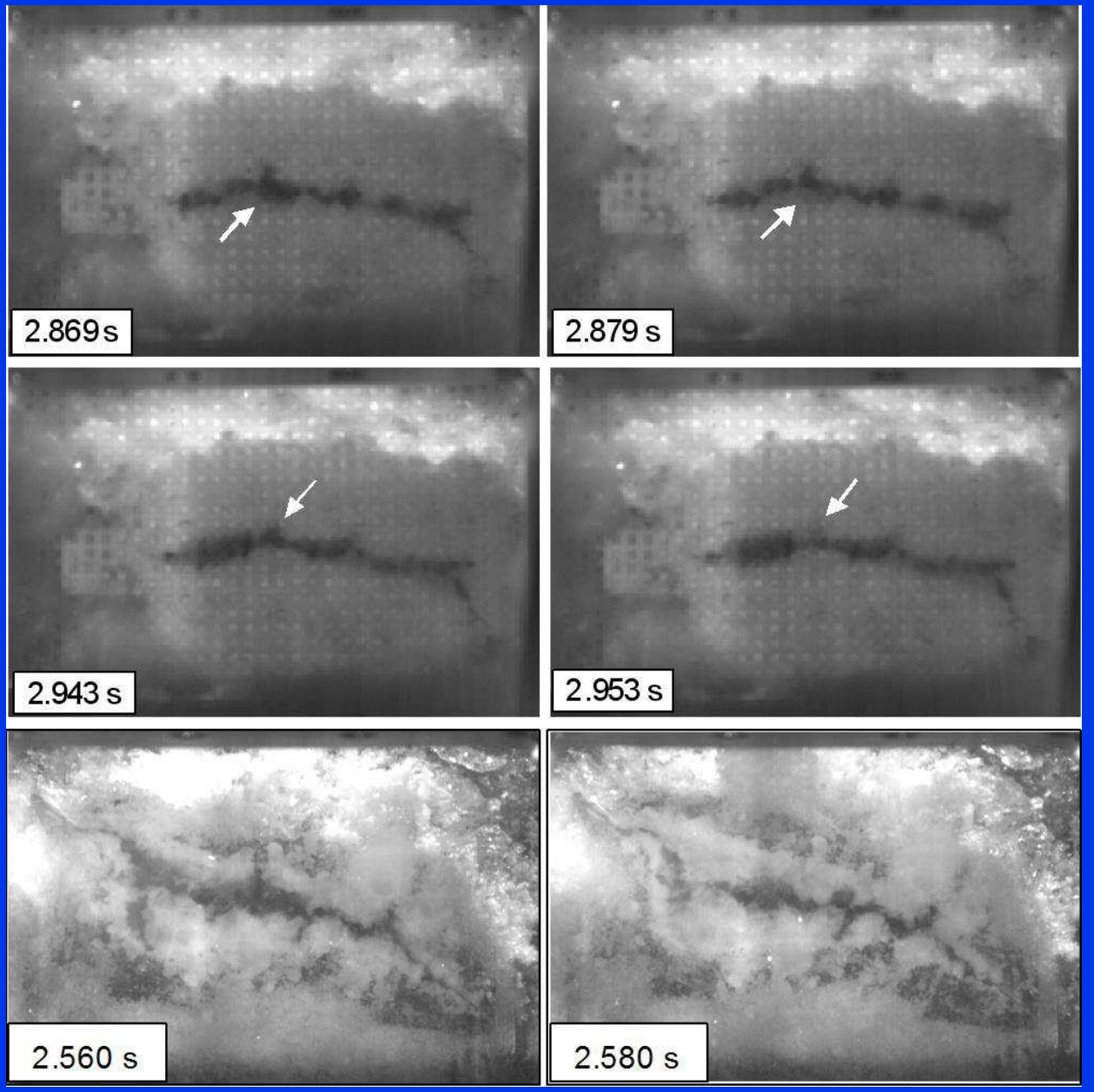
Post-Test Samples

Post-Test Image of Crushed Ice on a Crushing Platen that has Linear Blades



Flat Steel Platens Showing Central ‘cleaned’ Portions that Resulted from the Action of the Ice Hard Zones during the Crushing Tests

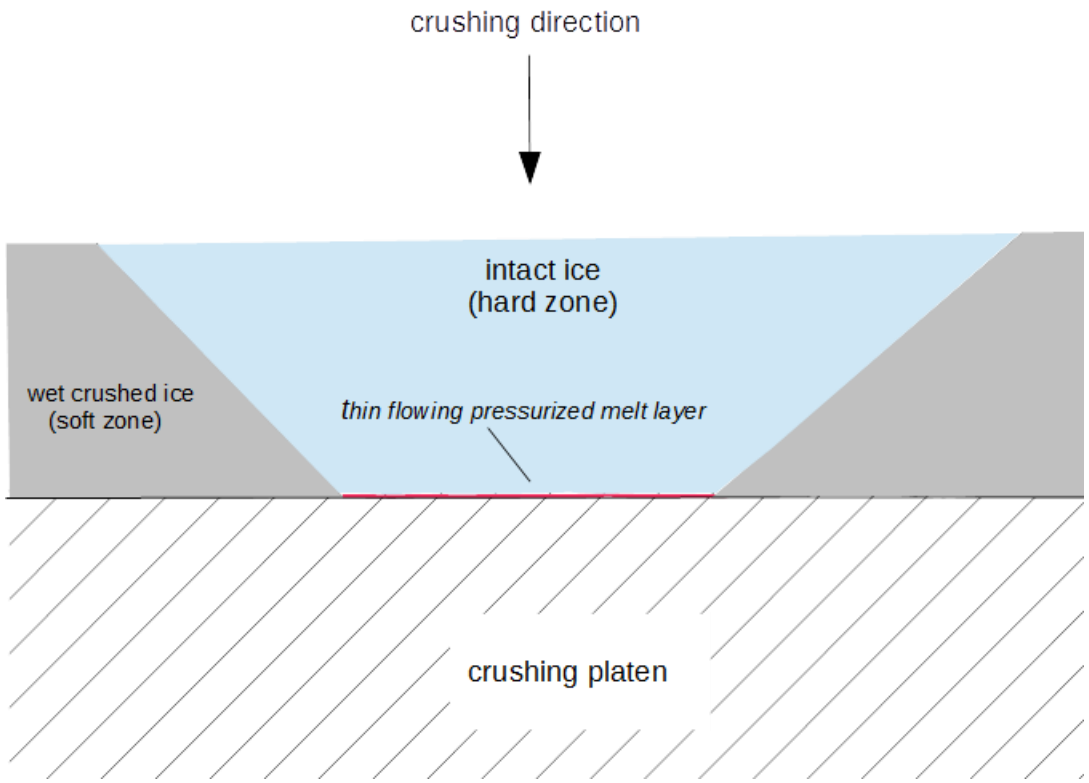
Two sets of two images from the high-speed image record of a test using platen P11. The view is through the transparent acrylic crushing platen. The grid of small square columns is apparent. Time stamps are included on the images. A horizontally-elongated dark hard zone that consists of relatively intact ice where the pressure is high is visible in each image. The hard zone is surrounded by crushed ice (the white material). The high-speed digital camera captured images at 500 images/s, however the figure shows two non-sequential pairs of images, at 2.869 s and 2.943 s, where each pair capture a single small spalling event (indicated by arrows). Note that many significantly smaller spalling events than those in the first two image pairs also occur. In contrast, the third pair of images is from a test using a flat bladeless crushing platen, where a large (typical) spall event was captured that spanned a significant portion of the whole hard zone (the central dark dendritic region angled towards the upper left). The images in any pair are not sequential. The width of each image is ~133 mm.



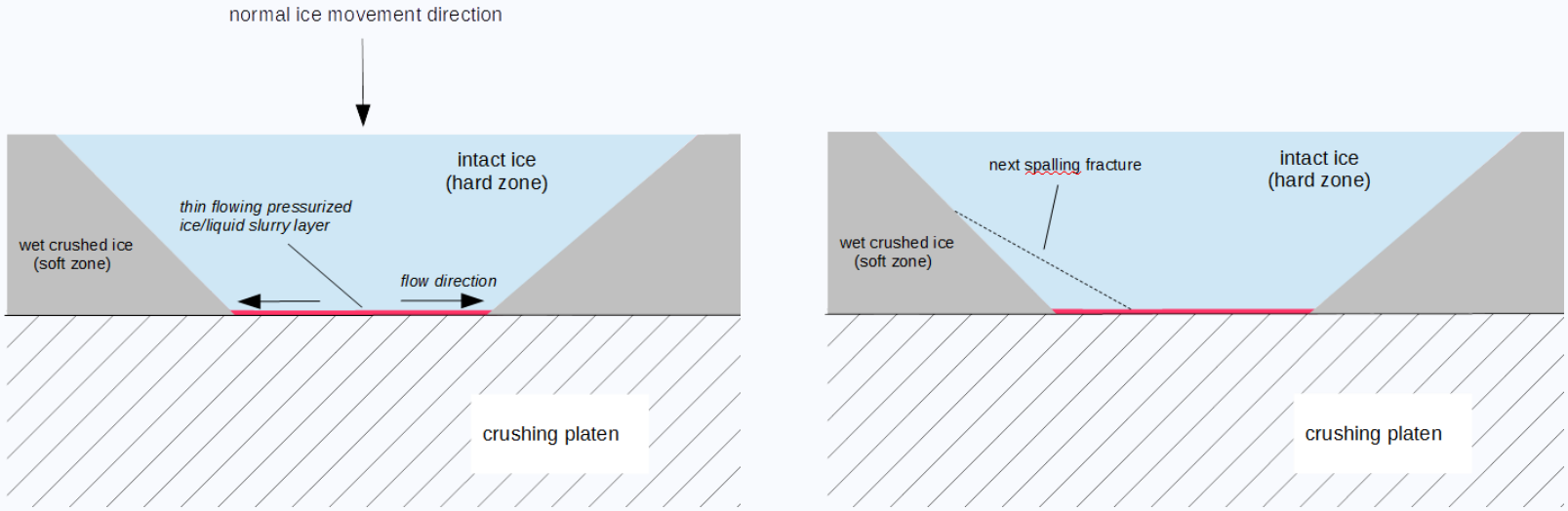
Conclusions

- The multi-blade array concept effectively reduced high-amplitude sawtooth load patterns (HASLP) by increasing the spalling rate and decreasing the spall size.
- Certain platens were the best performers due to the shape, spacing and arrangement of the blades on the platen surfaces.
- Entrapment of crushed ice did not occur for any of the platens that had open arrays of blades.
- The ice crushing-friction coefficients for all of the blade-array platens were extraordinarily low, that is, in the same vicinity as that of flat steel.
- The friction coefficient was a constant for any particular ratio of vertical crushing rate and sliding rate.
- Columnar and granular ice yielded similar results.
- Assuming that the technology scales appropriately, we can extrapolate to the field case of an ice sheet encroaching from a non-normal direction on a structure face with blades on it. From the above conclusions we can surmise that frictional forces on the faces of the structure would be no different than not having blades present. Furthermore the frictional forces would be independent of the ice sheet speed.

Ice Crushing on a Flat Surface



Conceptual Model for Ice Crushing



Ice Crushing on the Surface of Platen # 11