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Field measurements on the behavior of brash ice

Victoria Bonath[1], Vasiola Zhaka[1], Bjørnar Sand[2]
[1] Luleå University of Technology (Luleå, Sweden)
[2] Northern Research Institute Narvik (Narvik, Norway)

ABSTRACT

The behavior and properties of brash ice are important issues for the design of ice-going vessels. Heavy brash ice conditions may cause vessels to be dependent on ice-breaker assistance and time delays in the shipping schedule. Brash ice properties are not well studied and full-scale field data are missing in order to verify numerical models on brash ice and broken sea ice in general. The recent study describes new field equipment for testing brash ice and its functionality is tested on brash ice produced by the Swedish Ice-breaker Oden during ice management operations in the Barents Sea. The equipment consists of a big collector, connected to a crane, which is lowered below the brash ice cover. The brash ice mass above is pulled up by the crane and the force required for pulling is measured. A series of 18 field tests were performed and presented. Strengths and weaknesses of the method were evaluated. Ice blocks sizes were measured. The peak load during pull-up was often at least twice the weight of the lifted ice blocks when the blocks were interlocked. For free floating blocks, the peak load conformed to the weight of the blocks.

KEY WORDS Brash Ice; Field test; Ice properties.

Introduction

The focus on challenges related to winter navigation increases with the increased activities in ice infested waters. Along with climatic changes and the decrease of severe ice conditions, the interest in the design of ice-going merchant vessels and the year-round opening of arctic harbors increases. Less severe ice-conditions are usually related to longer time periods of ice free waters, but severe ice conditions can still occur during winter months. During heavy ice conditions, usually ice-breakers break up the ice cover in order to make it passable for merchant vessels. For narrow ship channels, the ice cover will be broken repeatedly during one winter season depending on the number of passages. Since the ice production in a repeatedly broken ice channel is significantly higher than the ice production on level ice (see e.g. Sandkvist, 1986) and concentrated ice accumulations at the channel edges impede the channel transit (e.g., Mellor, 1980), an ice channel transit is one of the main design loads for ice capable merchant vessels. The broken ice mass in a ship channel is known as brash ice, consisting of various sizes and shapes of ice blocks that float in a mix of open water and submerged snow. Defining brash ice properties and characteristics is necessary in order to verify simulations and analytical models for calculating ice loads on ships going through ice channels. Mellor (1980) calculated ship resistance in brash ice, using an analytical approach based on Mohr-Coulomb failure criterion. Sorsimo et al. (2014) compared analytical results for the brash ice resistance with numerical simulations using the discrete element methods resulting in a consistently lower brash ice resistance for the numerical approach. Li et al. (2018) evaluated simulations of ship transits in brash ice. Both Sorsimo et al. (2014) and Li et al. (2018) pointed out the lack of full-scale data on brash ice properties and brash ice behavior. Sandkvist (1986) described the changing geometry of a narrow brash ice channel during a winter season. Block size distribution of brash ice has been analysed by Touvinen (1979), anyhow the data were based on photographs of the brash ice surface. Ice tank tests with artificially produced brash ice have been performed. Kitazawa & Ettema (1985) studied brash ice resistance and found it to be linearly proportional to brash ice layer thickness. Further the channel width was a factor influencing brash ice resistance, as the brash ice mass is confined in narrow channels, compared to wider channels.

This study presents the results of a series of full-scale pull-up test performed in brash ice, using new equipment, which was constructed at the Luleå University of Technology. The aim with the pull-up test series was to examine brash ice behavior and to create a basis for simulation of the test.

Method

All measurements where performed at the Swedish research Icebreaker Oden during the Oden Arctic Technology Research Cruise (OATRC) 2015 in the North of Svalbard (N 82°, E 016°) from September 20 to September 29. Brash ice was produced by ice management operation and it has been broken by repeated passages of the ice breakers Oden and Frej. Location of measurements was randomly chosen during the ice management operation, when the ice-breaker was stopped. In total 18 measurements were performed during 14 occasions.

The pull-up tests are performed with help of a brash ice collector shown in Fig. 1. The brash ice collector can be operated by a crane. The ice collector is made by a synthetic net (60 x 60 mm mesh size), which is clamped to eight folding arms. The folding arms are connected to a hub at the inside and coupled by a steel wire at the outer end. The collector pole has a stiff connection to the hub at the lower end and an eye bolt at the top to connect the hook eye of a crane. For load measurements a load cell can be attached between the crane hook and shaft as shown in Fig. 2.

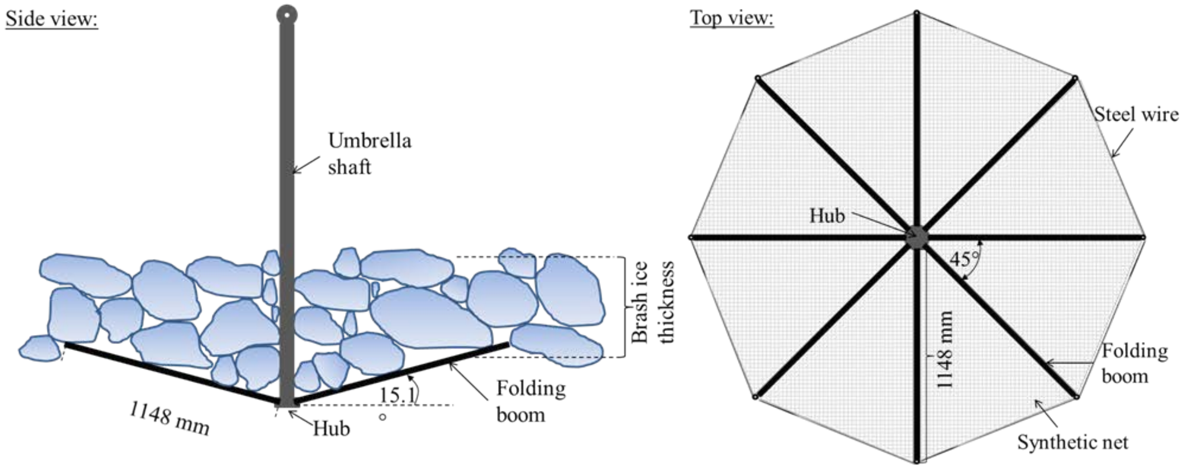

Figure 1. Side view and top view of the brash ice collector

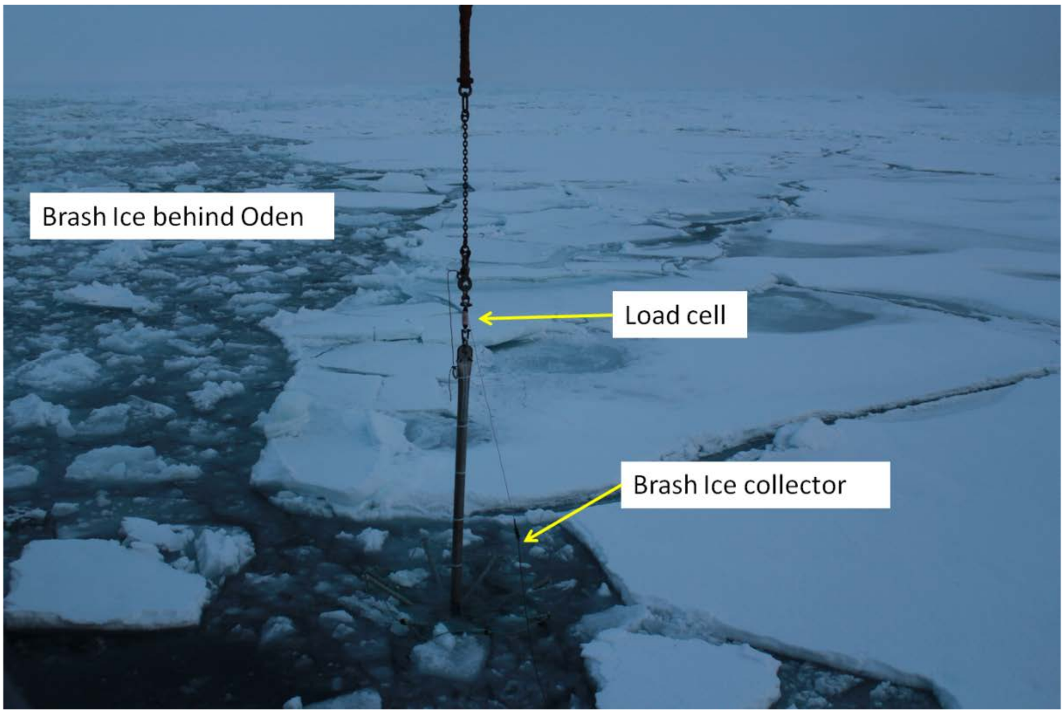

Figure 2. The brash ice collector is pushed through the brash ice cover. The load cell is attached between the crane hook and collector pole.

The collector is lowered down by the ship crane (Fig. 3a). Passing through the ice layer the folding booms close (Fig. 3b) and open again when they penetrated the ice layer. Collector is lifted up until the unfolded net has full contact with the bottom of the ice layer. The brash ice thickness can be estimated with help of markings at the collector shaft every 10 cm for the first meter then every 50 cm (Fig. 3c). After estimating the brash ice thickness, the collector is pulled up with constant speed and the load history is recorded. The weight of the lifted ice mass can be estimated from the load cell recordings, after drainage of all water entrapped in the brash ice mass (Fig. 3d). The brash ice is unloaded onboard of the vessel and ice block sizes are measured in 3 dimensions with a yard stick. Macroporosity values from the brash ice can be obtained by estimating the ice volume from the weight of the lifted ice mass and divide this by the total volume of brash ice mass above the collector, when it touches the bottom surface of the brash ice (Fig. 3c). This method is restricted to the cases, where no ice blocks fall down the collector during lifting, because otherwise the weight measured of the ice mass on the collector is not the real weight of the original ice volume above the collector. The lifting speed was kept constant. Its magnitude is determined from the time difference between the collector had under ice contact to that point where the collector reached the water surface. The ratio of the brash ice thickness and the time difference gives the lifting speed. The block size measurements give information on the block size distribution within brash ice.

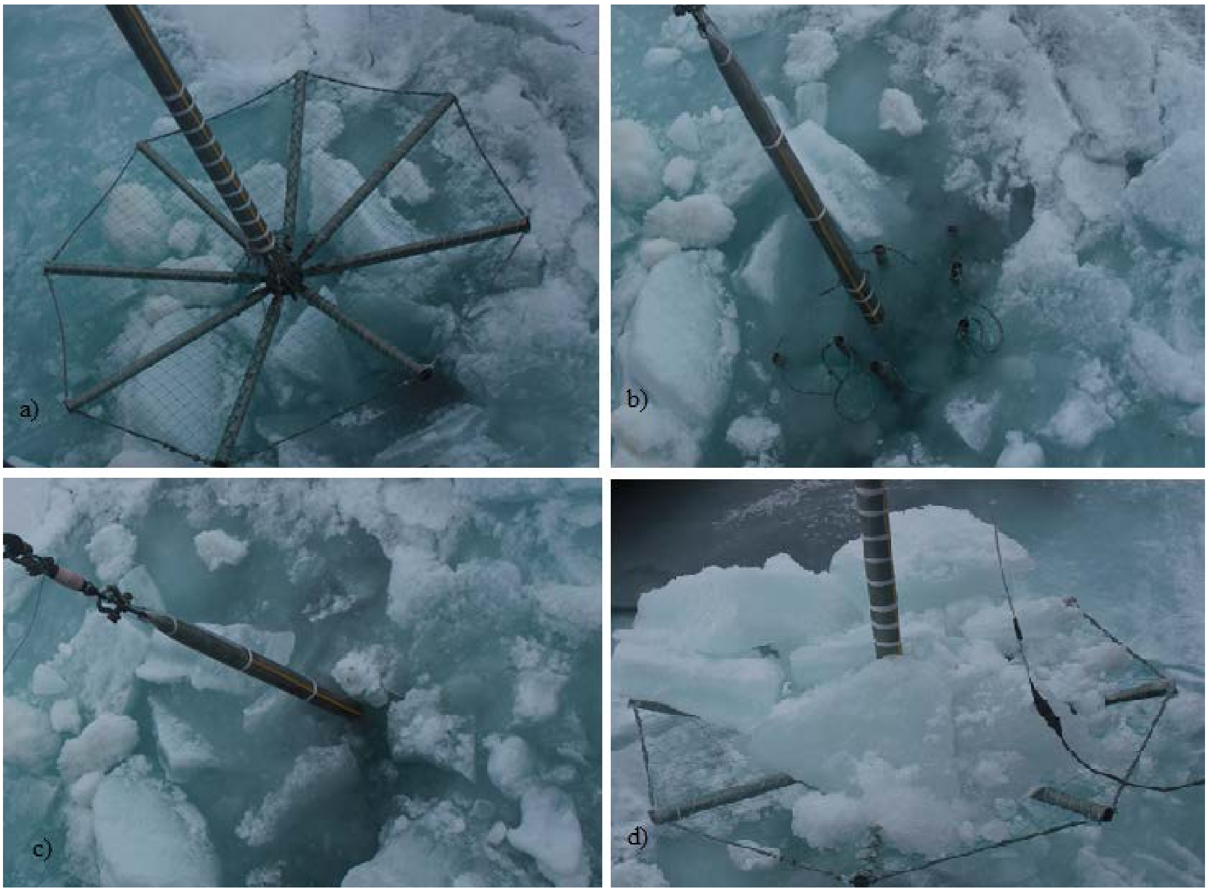

Figure 3. a) Ship crane is bringing down the collector, b) the collector is pushed through the ice brash layer, c) the stick reaches the bottom of the ice brash, d) collector is lifted up and water is drained before the ice samples reaches the board of the ship.

Results and Analysis

Only tests which were sorted as successful, e.g. no blocks above the collector area were falling off during lifting, are presented here. Anyhow if blocks were placed on the edge of the collector and sliding of during lifting, as it was the case in tests #3 and #9, the test was still successful, but the macroporosity was not calculated. Table 1 gives an overview on all successful tests performed during that test series. There were two main reasons for unsuccessful test results: The ship was in movement and the ice blocks were too big in size for the collector. If the ship was in movement, no straight pull-up could be performed and since the collector is not a stiff arrangement, it could tilt. The second restriction of the test procedure was when ice block sizes exceeded 1m, which was the case at many measuring locations. Big ice blocks were falling of the collector and again tilted it.

Table 1. Time, Air temperature, the estimated brash ice thickness and lifting speed and the calculated macro porosity are listed for chosen tests.

Test No.	Date/Time (yyyy-mm-dd/hh:mm)	Air temperature (°C)	Ice thickness (m)	Lifting speed (cm/s)	Macroporosity (-)
#3	2014-09-22/13:10	1.4	1.3	2.0	-
#9	2014-09-25/10:30	-6	1.1	3.7	-
#6_2	2014-09-23/15:30	-12	0.5	1.4	0.77
#11_2	2014-09-26/10:45	-11	0.5	1.9	0.77
#13	2014-09-29/15:15	0	0.5	1.0	0.57

Two main load scenarios were observed. The loading history of one load scenario is shown in Fig. 4. Frictional forces between the ice blocks determine the first part of the lifting of the ice blocks, which leads to compaction of the ice mass. When the brash ice is compacted and starts to be lifted above the water surface, a sudden load peak occurs. This load peak is caused by three components: Firstly, the impact of the weight of the blocks changes as the buoyancy forces approach zero. Secondly, frictional forces between the ice blocks are still prevailing. Thirdly, ice blocks placed on the collector edge are locking the upwards lift and create high forces. The load peak drops at the moment when the blocks at the collector edge released. This load scenario was only observed for brash ice thickness above 1m, within more confined ice masses. The ice blocks above the collector do sort of interlock with the surrounding ice blocks during compaction and a load peak will be reached just before the collector is lifted above the ice surface (Fig. 5). Test #3, which was performed under lower lifting speed (2 cm/s), has slightly higher, but more constant frictional forces, compared to test #9 (3.7 cm/s). In test #3 a small load peak occurs directly after the pull up of the brash ice starts. This peak could be either related to static friction or interparticle bonds that have to be broken. Sorsimo et al. (2014) showed in numerical simulations that a variation of the static friction coefficient of ice-ice contact gave only little impact on the compressive forces on a ship. Instead the interlocking between particles should be considered. Interlocking of particles or bonding at particles contact edges together with frictional forces between the particles are the determining factors for the shear resistance of soils. This approach could be applicable for brash ice as well.

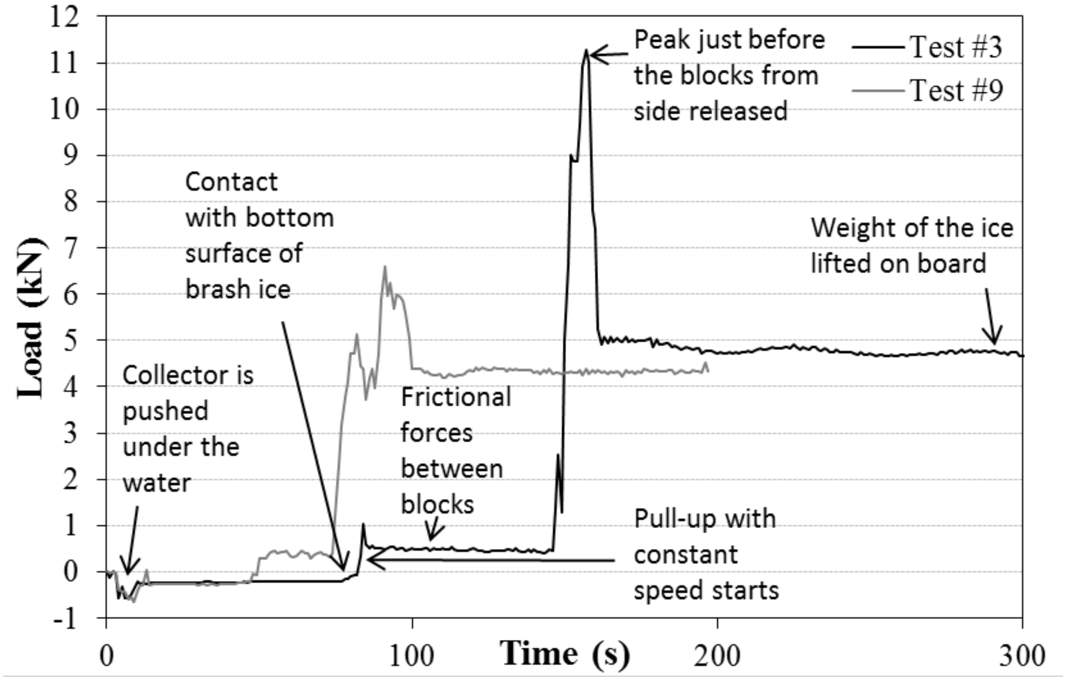

Figure 4. Load scenarios of tests #3 and #9 during pull-up of the brash ice.

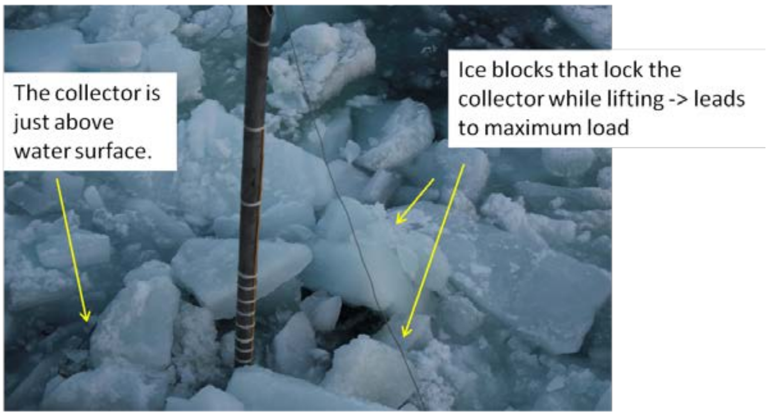

Figure 5. The collector is locked by ice blocks lying on the collector edge.

Another load scenario is shown in Fig. 6, where the high load peak, which was observed in the previous cases, is missing. The lifting starts with compaction of the ice mass. In tests #6_2 and #11_2 a clear load peak is recognizable at the point where the collector got in contact with the bottom of the brash ice mass, which is similar to that explained for test #3 subjected to interlocking or bonding of particle edges. After breakage of these forces, the lifting is accompanied by frictional forces, again until the collector edge reached the water surface. The following load peak is equivalent to the weight of the ice and the water entrapped. Even though the brash ice thickness is equal in all three tests, the peak load of test #13 is almost twice the peak load of tests #6_2 and test #11_2. As this load is equal to the weight of the collected ice, it is obvious that the brash ice in test #13 must have a higher packing density compared to the other tests, e.g. the macroporosity is lower (Table 1). A higher packing density could be achieved by a well-balanced composition of block sizes and shapes. A certain amount of small particle sizes are needed to fill the pore spaces in between the bigger ice blocks. Fig. 7 shows that test #13 had a big variation of block sizes. The smallest ice blocks or ice particles where probably not measured or already melted on board before measuring, so that they do not appear in table 2. The higher variation of ice blocks, from very small to big, could be due to the warmer temperatures during that testing day. The air temperature was above the melting point of the ice. This weakens the ice so that it was easily broken into smaller blocks/slush of the ship propellers during the ice management operations.

The frictional forces in test #13 are small compared to tests #6_2 and #11_2, which is probably also due to higher air temperatures (Kietzig et al., 2010).

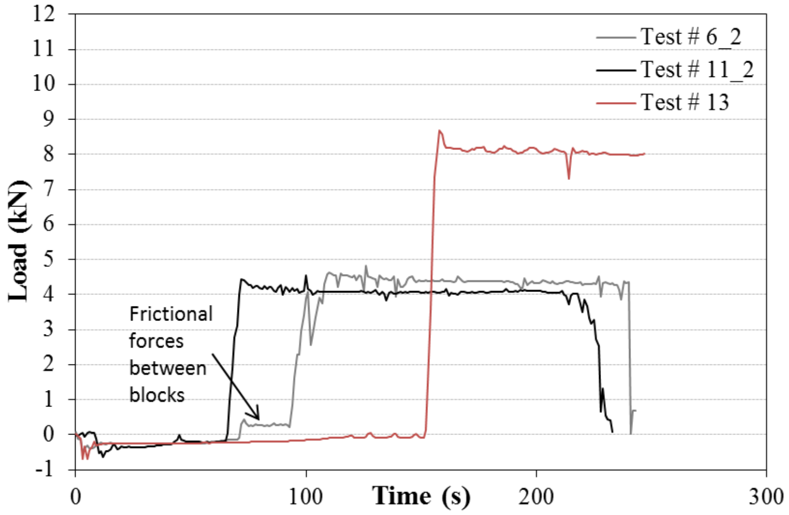

Figure 6. Load scenarios of tests #6_2, #11_2 and #13 during pull-up of the brash ice.

Average dimensions from the blocks on the collector are presented in table 2. The dimensions for the measured ice blocks are similar for all tests with very high standard deviations, whereof test #9 has the highest mean block size dimensions. It has to be considered that the measured block sizes only show the block size range that could be taken up by the collector. Block sizes above one meter or ice blocks smaller than the mesh size may have falling off during lifting. The histogram in figure 2 shows the tendency of lognormal block size distribution, which would be in accordance with Touvinen (1979).

Figure 7. Brash ice collected during test #13.

Table 2. Mean sizes and standard variations of ice block dimensions width 1 (biggest dimensions), width 2 and width 3 (smallest dimension)

Test No.	Width 1 (cm)		Width 2 (cm)		Width 3 (cm)	
	mean	stdev	mean	stdev	mean	stdev
#3	17	16	12	11	6	6
#9	27	26	15	12	9	7
#6_2	21	19	13	12	7	7
#11_2	19	26	12	9	6	5
#13	19	14	13	11	8	6

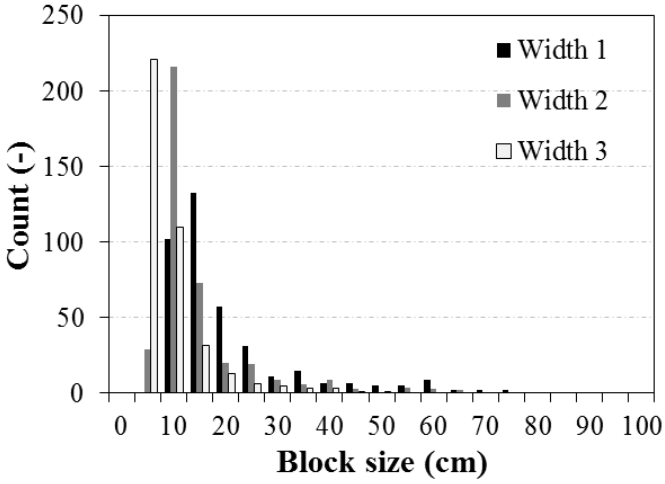

Figure 7. Histogram showing the measured block sizes width 1 (biggest dimension), width 2 (middle dimension) and width 3 (smallest dimension).

CONCLUSIONS

The brash ice collector is simple to operate from a crane. The test procedure gives results on the macroporosity of the brash ice and also on the forces required for pulling a determined volume of brash ice upwards. The tests should be performed under calm conditions. Since brash ice produced from ice management, which is broken over big areas, contains a number of large floes, the test equipment is less applicable for that kind of ice. A more homogenous block mass with smaller rounded blocks would be preferable, such as one can find in a very frequently broken ship channel. Regarding the simplicity of the test procedure, this should be a valuable input for modelling brash ice behavior. According to the recent results, brash ice properties depend amongst others on the brash ice layer thickness, the brash ice composition and confinement and the ice temperature.

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