POAC'13
Espoo, Finland

Proceedings of the 22nd International Conference on
Port and Ocean Engineering under Arctic Conditions
June 9-13, 2013
Espoo, Finland

THERMODYNAMIC CONSOLIDATION OF ICE RUBBLE IN WATER AT VARYING FREEZING POINT. EXPERIMENT

Aleksey Shestov [1, 2, 3], Aleksey Marchenko [1, 3]

[1] The University Centre in Svalbard, Longyearbyen, Norway
[2] Norwegian University of Science and Technology, Trondheim, Norway
[3] Sustainable Arctic Marine and Coastal Technology (SAMCoT), Centre for Research-based Innovations (CRI), Norwegian University of Science and Technology, Trondheim, Norway

ABSTRACT

A possible mechanism of thermodynamic consolidation of ice rubble in water at varying freezing point has been investigated in the laboratory. A number of experiments have been performed with cylindrical ice samples to estimate the extent of consolidation. All water was kept at freezing point during the experiment. Saline ice samples were periodically moved between water reservoirs of different salinities (0 and 35ppt), modeling systematic changes in the freezing point of the surrounding water. The mass, salinity and shape of the samples were observed. The results of the investigations are described and analyzed in the paper. The experiments showed that consolidation can occur, and showed a gradual increase in the total mass of the samples. The average relative mass increase of the samples, per period of the freezing point variations, is 3.4%. Brine drainage was observed while the samples were in fresh water, and conversely salt water accumulated in brine pockets while the samples were in salt water. The observed variability in the salinity of the sample was between 6 and 2 ppt.

INRODUCTION

Ice ridges are important features of the sea ice cover in the Arctic Basin and the adjacent shelf seas. Ice ridges are formed from the pressing-out of broken ice blocks below and on the surface of the level ice. Numerous reports estimate that ridged ice occupies between 10 and 40% of the ice-covered areas in different regions of the Arctic Basin. The mean vertical lengths of ice ridges reach 10-15 m, with maximum values of approximately 30 m. The vertical size of the ice ridges is considerably larger than the thickness of the level ice formed by the thermal freezing of seawater. Therefore, the influence of ice ridges on the ice loads on offshore constructions cannot be ignored. The initial strength of ice ridges is not very high because they are composed of unfrozen ice blocks. The formation of freeze-bonds between the blocks and further consolidation of the ridge keels are the most important processes that increase the ridge strength with time.

The influence of ridge keels on the seabed in shallow water regions (ice gouging) can cause damage to underwater pipelines and communications lines. This effect is of great importance for the Sakhalin shelf, Kara Sea, Barents Sea and Northern Caspian Sea shelf. The depth of ice gouging is a design parameter used to determine the burial depth for underwater pipelines. This work was initiated specifically because the authors were involved in the investigations of the ice gouging process in Baydaratskaya Bay in the Kara Sea. Since the 1990s, numerous gouges on the seabed have been registered in the Baydaratskaya Bay at depths of up to 20 m. The length and depth of some gouges observed at depths greater than 15 m exceeded 2 km and 1.5 m, respectively (see, e.g., Marchenko and others, 2007).

Numerical estimates have revealed that the thickness of consolidated layers formed due to atmospheric cooling in the upper parts of ridge keels cannot exceed the thickness of level ice formed under the same weather conditions by more than two-fold (see, e.g., Leppäranta and

Hakala, 1992; Høyland, 2002). Numerical simulations performed for realistic configurations of ridge keels and based on typical weather conditions in the Arctic show that the local effects caused by a high concentration of ice blocks inside the ridge keels can explain the extension of the consolidated parts of the ridge keel of up to 5-6 m (Marchenko, 2008; Shestov and Marchenko, 2009). The observed long, deep gouges cannot be formed by the impact of unconsolidated ridge keels into the seabed. Such gouges could be produced by ice ridge keels if they are consolidated.

Field studies of second-year and multiyear ridges demonstrated that their keels can be completely consolidated (see, e.g., Shestov and others, 2012). The investigation of the physical mechanisms that could provide thermodynamic consolidation of ridge keel below the bottom of the consolidated layer, which is formed due to atmospheric cooling, is the primary goal of the present study.

The experiment, described in this paper, is devoted to show the ability of thermodynamic consolidation of ice rubble in surrounding water being at its freezing point that is higher than the temperature of the ice in the rubble. The physics of the process in this case requires the increasing in the temperature of the ice already presented in the rubble and freezing of the surrounding water of low salinity. The increasing in the temperature of the salt ice means melting of the ice on the edges of brine pockets. Released coldness from such melting is spent on the freezing of new ice from low salinity water. As a consequence of this, macroporosity of the ice rubble is reducing, while microporosity of the salt ice in the rubble is increasing. In details thermodynamic of the process was discussed in Shestov and others (2010). To meet such scenario in the nature the appearance of water with low salinity around the ridge keel and permeability of the ridge keel to sea water are required.

The appearance of low salinity water can be realized by the penetration of melt water into the surface layers of seawater from the ice surface and ridge keels. In coastal zones, the fresh water penetrates into the sea from rivers and from spring water run-off. All of these factors, including summer ice melting, ice drift and sea currents, influence the spatial and temporal distribution of water salinity in the upper water layer in the Arctic. In the Arctic seas, the water salinity varies from a mean value of approximately 35 ppt to zero near the mouths of rivers (Dobrovol'skii and Zalogin, 1982). The freezing points of such water change from -1.9 to 0°C.

The penetration of water masses into the interior of the ridge keels can be caused by any currents that have a non-zero water velocity relative to the ice. These currents can be regular sea currents, tidal currents in shallow waters or convective currents below the ice. Measurements of water velocities inside the ridge keels to determine their permeability were performed and discussed in the papers by Gorbatsky and Marchenko (2007) and Marchenko and Høyland (2008).

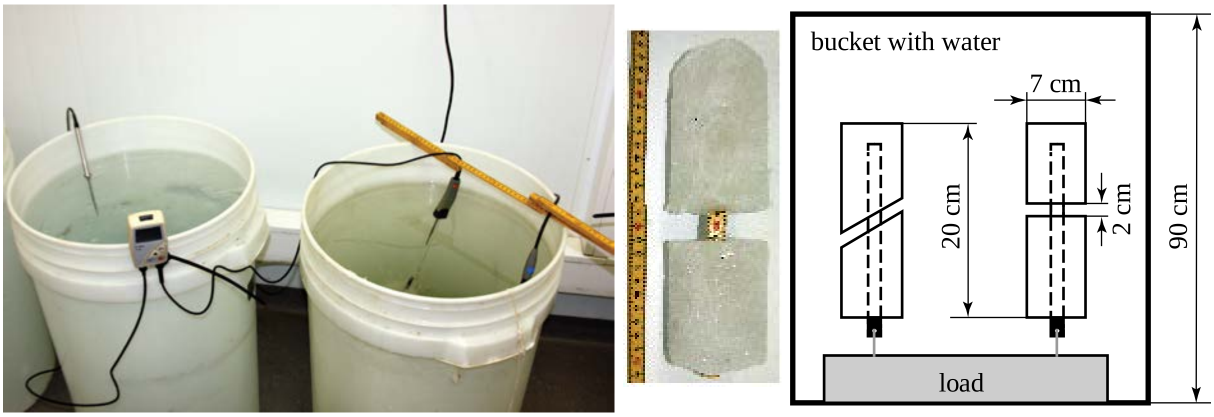
Further in the paper two laboratory experiments are described: the main one, modelling the consolidation of the ice rubble submerged into the sea water at varying freezing point, where salt ice samples were periodically moved from water at freezing point $-2°C$ to water at freezing point $0°C$, and accompanying one, showing the ability of the ice to drain the brine out while it is placed into fresh water and vice versa to accumulate the brine inside the brine pockets while it is placed into salt water. The primary results of this work are formulated, discussed and summarized in the conclusion section.

SET-UP

The described above possible physical mechanism, providing thermodynamic consolidation of the ridge keel further down below the consolidated layer formed by atmospheric cooling, was modelled in the experiment. In the regions with active tidal regime such scenario can be converted into periodical scheme. For example in the bay with active tide and presence of the river mouths or during the spring run-off we may expect the situation that in the coastal zone salinity of the water in the bay will be dependent on the phase of the tide. Then investigated process will be realizing periodically in many stages. Based on this and expected higher effect of the process under periodical scenario, the experiment was performed with periodical changes.

The experiment was performed during November 2011 in the cold lab of The University Centre in Svalbard. Two types of water were involved during the experiment: *fresh water* from Lake Isdamen with salinity of $0.2\ ppt$ and *sea water* from Advent Fiord with salinity of $35\ ppt$. During the experiment both waters were kept in different buckets (Figure 1a) under their freezing points $0\,^{\circ}C$ and $-1.9\,^{\circ}C$ correspondingly. To keep both waters under freezing points air temperature in the lab was kept about -3°C. Salt ice samples were periodically moved between these waters during the experiment.

Salt ice samples were cored up with core barrel from the ice grown up under the laboratory conditions from the *salt water*. Altogether six cylindrical samples of $20\ cm$ height and $7\,cm$ diameter were examined. The main observing parameter was the mass of the sample, while in addition to this in each sample an opening of $2\,cm$ width was made to model the macroporosity of the ice rubble. The opening was intended to model the caves inside the ice rubble and illustrate visually the process of ice rubble consolidation. The openings were made differently in different samples: horizontally and inclined by 45°. It was made to check the hypothesis that orientation of the opening influences to the degree of its shrinking. The suggestion was that brine drained out from the ice may more easily to flow down of the inclined opening. Under conditions of the present experiment the difference in these two cases was not found. The example of prepared sample and the sketch of set-up are illustrated in Figures 1b and 1c correspondingly.



a) b) c)

Figure 1. *Fresh water* and *sea water* under freezing point (a), prepared sample for the experiment (b) and the sketch of samples positions (c) during the experiment.

All six samples were tested in couples: S1 with S2, S3 with S4 and S5 with S6. Each couple of the samples was tested in the separate couple of buckets with two different waters. The experiment was organized in the way that all samples had their first stage in the *salt water* and further when the experiment was in the progress samples were tested in antiphase. For example while S1 was placed to the *salt water*, its partner S2 was placed to the *fresh water*. The initial temperature of all samples was $-1.9\,°C$. The initial salinity of samples was varied from couple to couple between 9 and $14\,ppt$, as listed in Table 3, while within the same couple it had similar values. The salinity was measured using ice piece taken from the sample's opening.

During the experiment samples were cyclically replaced from one type of water to another, beginning from salt water, as shown in Figure 2. The period of each cycle, $T_{c,\,i}$, was planned to be 6 hours, and half of the period, which is equal to the duration of one stage $t_{s,\,j}$, 3 hours respectively. Indexes i and j note the sequent numbers of cycles and stages respectively. In reality schedule was fulfilled with small deviations during the day time, but during the night there was one longer stage than usual. Since samples were tested in antiphase, as described above, this night stage was the fresh water stage for one sample from the couple and the salt water stage for another sample. Later it will be shown that longer night stage does not affect the results.

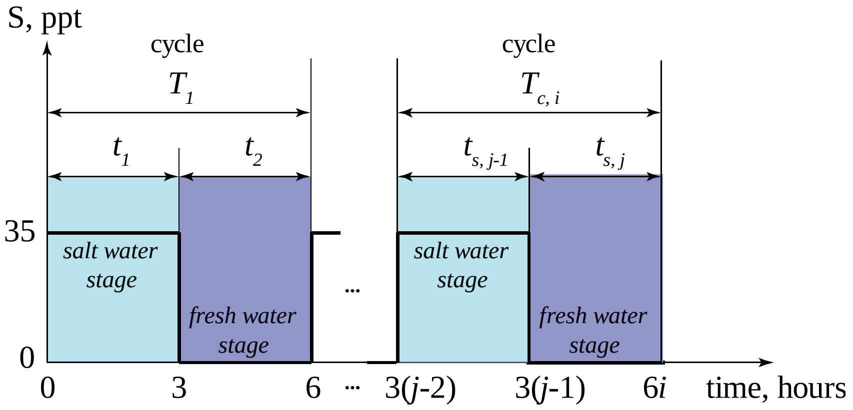


Figure 2. The idealized schedule of experiment, showing the way samples were supposed to be moved from the water of 35ppt salinity to the water of 0ppt salinity.

At each time moment $t_j = \sum_j t_{s,\,j}$, associated with the end of stage of number j, sample was lifted up from the water, its mass, m_j, was measured and sample was photographed. Each time moment, $t_i = \sum_i T_{c,\,i}$, associated with the end of the cycle of number i, corresponds to each second time moment t_j, i.e. $t_i = t_j$ and $m_i = m_j$ if $j = 2\,i$. In addition temperature courses of *salt water* and *fresh water* and salinity course of *salt water* were registered during experiments. Temperature was measured with interval of $5\,min$ and salinity with interval of $30\,min$. The measuring points of salinity and temperature were allocated about 10 cm above the top of the sample when it was in submerged position.

In the progress of the experiment the importance of salt drainage out of the sample and salt accumulation inside the brine pockets on different stages of the experiment was noted. To examine this, a separate analogous experiment focusing on the change in salinity of the sample in time was conducted. Vertically and horizontally submerged samples were used. In both cases several samples were involved in the experiment in parallel. This allowed taking the measurements of salinity at the different moments of time by removing samples from the water one by one while others continued to follow the schedule of the experiment. The schedule of experiment is given in Table 1 for vertically submerged samples and in Table 2 for horizontally submerged ones.

Table 1 Schedule of salt drainage experiment performed with vertically submerged samples. Time in hours, which each sample spent consequently in each stage and after that sample's salinity was measured.

sample name[1] stage	S-2.5	SF-0.5	SF-1.0	SF-2.0	SF-3.0	SFS-0.5	SFS- 1.5	SFS-4.0
Salt water	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Fresh water		0.5	1.0	2.0	3.0	3.0	3.0	3.0
Salt water						0.5	1.5	4.0

Table 2 Schedule of salt drainage experiment performed with horizontally submerged samples. Time in hours, which each sample spent consequently in each stage and after that sample's salinity was measured.

sample name[1] stage	S-2.5	SF-1.0	SF-3.0	SFS-1.0	SFS- 1.5
Salt water	2.5	2.5	2.5	2.5	2.5
Fresh water		1.0	3.0	3.0	3.0
Salt water				1.0	2.5

RESULTS

Figure 3 shows temperature courses of *salt water* and *fresh waters* between which samples were moving during different experiments. Figures 4a and 4b shows the mass change of samples S1 and S2 depending on time and on sequence number of stage correspondingly. The amplitude of mass change is about the same over stages in different waters even if durations of stages are different. The plot in Figure 4b has a regular form, what shows that it is not very important to keep the durations of stages equalled and that longer night stage does not affect the result. Important is to make the single stage is long enough to get the thermodynamic equilibrium between sample and surrounding water. Approximate estimation made in Comsol Multiphysics 4.2 software showed that characteristic time for sample of typical size we used is 45 min while shortest stage duration used in experiments was 3 hours.

Figures 5a and 5b show the mass change in time of samples S3 and S4 and samples S5 and S6 correspondingly. Sample S4 (Figure 5a) was destructed in the middle of the experiment when being moved between tanks. All others samples are fitted with the linear dependency of entire mass growing. To estimate the rate of ice sample mass growth the relative mass change was considered. Figure 6a shows the relative mass change per stage, $(m_j - m_{j-1})/m_{j-1}$, versus the sequence number of the stage j. The relative mass increase per one *fresh water* stage is about 0.2 during few first stages and then getting lower to the level of 0.15. Figure 6b shows the relative mass change per cycle, $(m_i - m_{i-1})/m_{i-1}$, versus the sequence number of the cycle i. Average value of two lowest clouds in Figure 6b, where most of the points are placed, gives 3.4% of relative mass increase per cycle.

---

[1] First letters in the name of the sample mean the stages, sample has passed completely and the last letter together with number shows the time sample spent in the current stage, which was last for it.

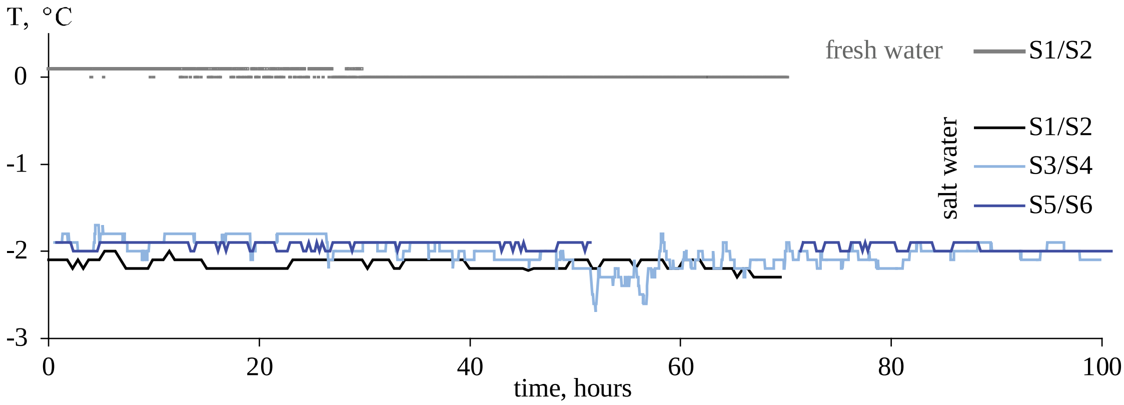
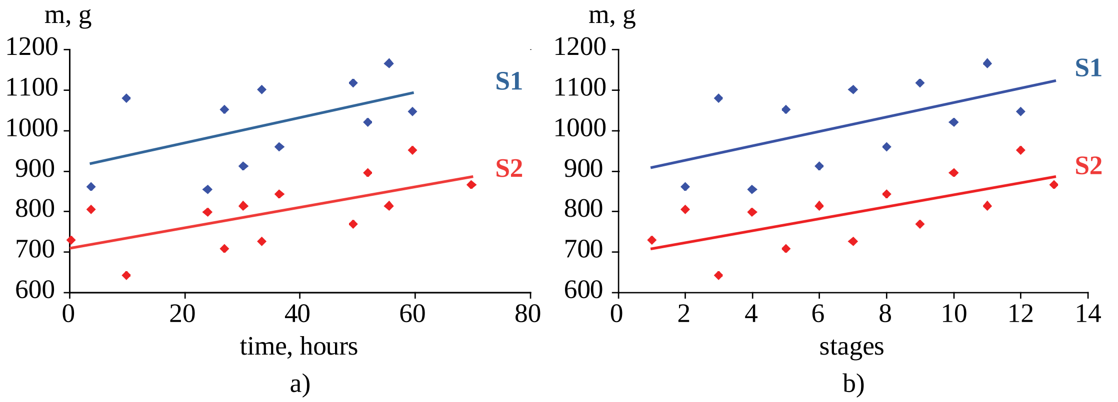
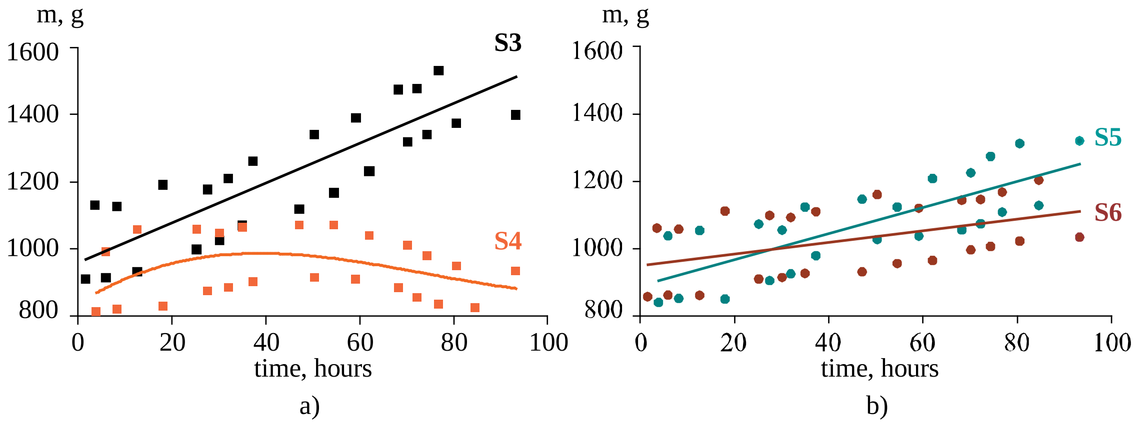


Figure 3. Temperature course of fresh and salt water during different experiments.



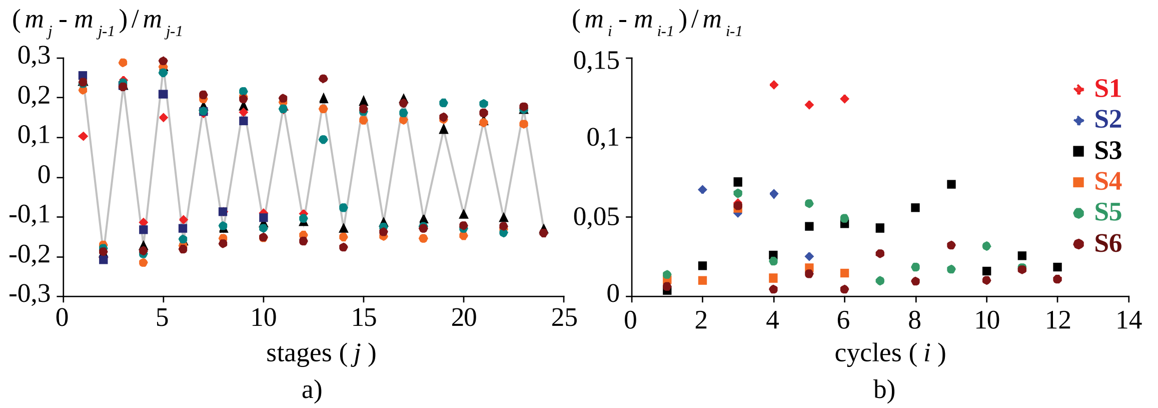
a) b)

Figure 4. Mass change of samples S1 and S2 versus time (a) and versus stage number (b).



a) b)

Figure 5. Mass change of samples S3 and S4 (a) and S5 and S6 (b) versus time.



a) b)

Figure 6. Samples relative mass change versus the sequence number of stage (a) and cycle (b).

Table 3 shows the salinity of samples at the beginning and the end and the salinity of *fresh water* at the end of the experiment. At the beginning of experiment, ice pieces, taken from the opening produced in the sample, were used for salinity measurements. At the end, each sample was cut into three parts. Middle part was chosen in the place of original opening. Upper and bottom parts were named according to the sample floating orientation during the experiment.

Table 3 Salinity of the samples and of *fresh water* at the start and at the end of the experiment.

	salinity, ppt	S1	S2	S3	S4	S5	S6
start	2cm of middle part (opening)	9.84	9.99	11.93	11.87	12.62	13.41
end	upper part	1.43	0.83	2.03	0.49	0.50	2.36
	middle part	3.88	0.87	3.69	0.50	0.67	4.10
	bottom part	7.79	0.44	4.43	0.43	0.63	7.70
start	*fresh water* in the bucket	0.2		0.2		0.2	
end		0.6		1.3		1.7	

Increase in the mass of samples accompanied by the increase in samples size. Table 4 shows diameter dimensions of samples S3, S4, S5 and S6 at the start and at the end of experiment. Figure 7 illustrates the size increase of the sample S1 comparing its view before and after the experiment. All other samples looked similarly. Consistency of the sample was different at its different levels. In the bottom part sample was very porous and such week that it was possible to crush it with moderate force applied by hand. This happened to sample S4 at the middle of the experiment (Figure 5a). See Figure 7b to allocate this week part at the bottom of the sample. Middle part, consolidated layer, at the level of original opening, was as strong and solid as upper part of the sample.

Table 4 Diameter dimensions at the end of experiment over different sample cross-sections.

	diameter, cm	S3	S4	S5	S6
start	all	7.2			
end	upper	9.6	9.1	9.1	8.9
	middle	10.0	8.6	10.1	8.6
	bottom	11.7	10.1	10.7	10.6

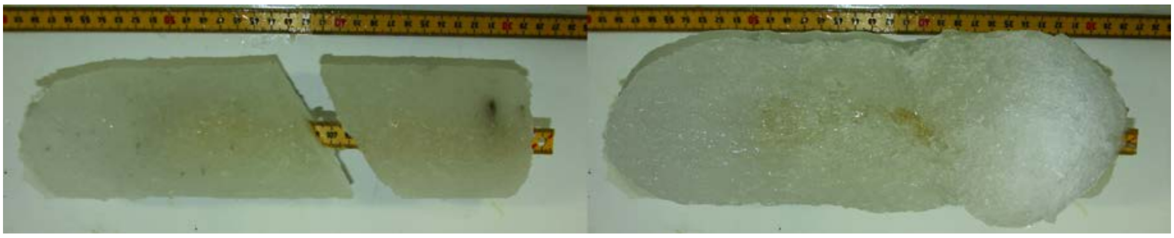


Figure 7. Salt ice sample S1 before (a) and after experiment (b) (samples' bottom to the right)

The salinity profiles of each sample, participated in the experiment tracking the change in the salinity of sample due to the brine drainage, are presented in Figure 8. The schedule of the experiment showing the state history of the sample before it was taken for salinity measurement is given in Table 1 and Table 2. The salinity profile of each sample along its length was performed with step of 2cm.

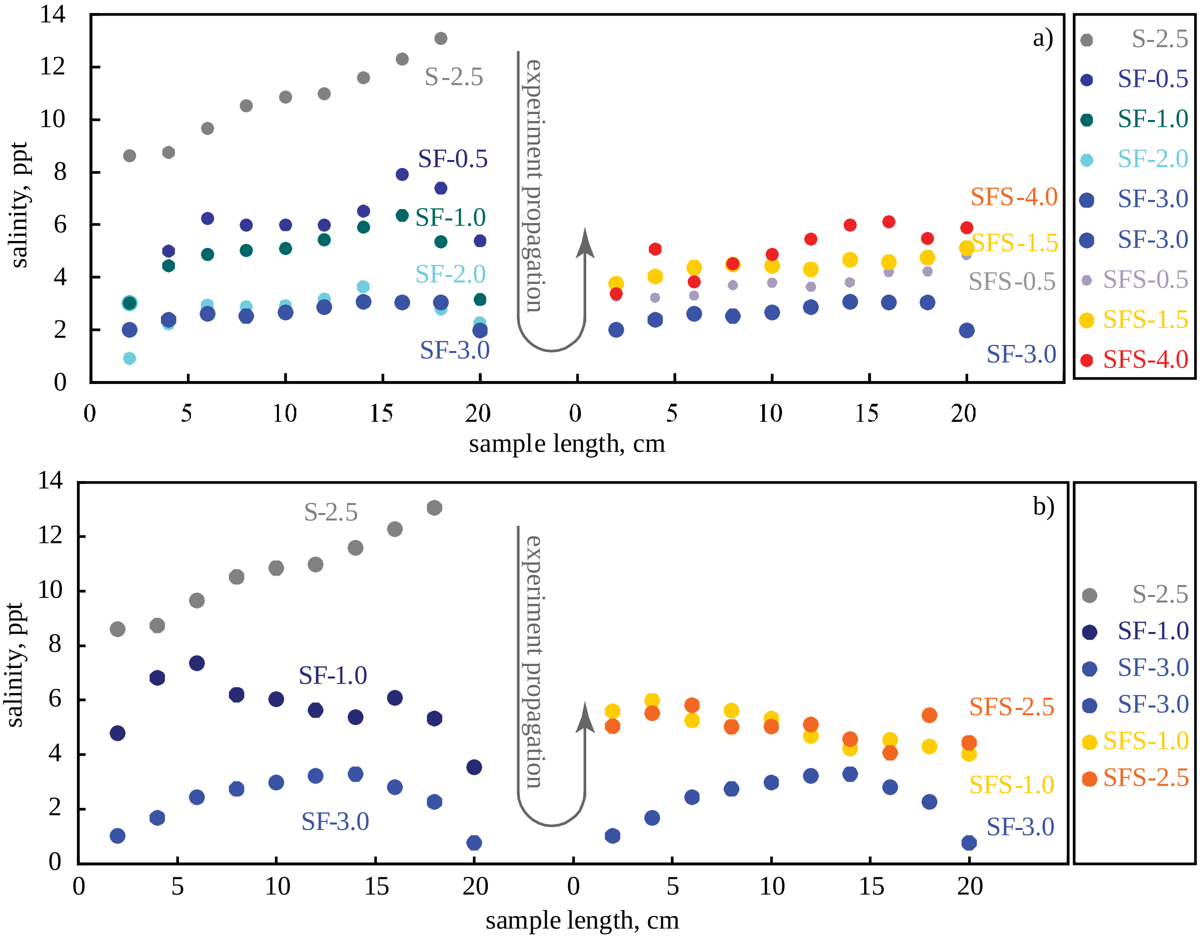


Figure 8. Salinity development of vertically (a) and horizontally (b) submerged samples under conditions of the main experiment.

DISCUSSIONS

The required conditions of the experiment may be considered as fulfilled. The temperature of *fresh water* stayed most of the time at value of $0\,^{\circ}C$ and reduced to $-0.1\,^{\circ}C$ by the end of experiment (Figure 3). The temperature of *salt water* stayed at value of $-2\,^{\circ}C$ with not considerable fluctuations from it and by the end of the experiment average level of the temperature of *salt water* was reduced by value of $0.1-0.2\,^{\circ}C$ (Figure 3). In both cases reduction in the temperature was a consequence of increase in salinity.

Fresh water salinity was noticeably increased by the end of experiment from its typical initial value of $0.2\,ppt$ to values up to $1.7\,ppt$ as registered in Table 3. The salinity of *salt water* during the experiment is developed from its initial value of about $35\,ppt$ with expected slightly increasing trend. The observed increase in salinity over the whole experiment was $2-3\,ppt$ and it is related to the formation of ice all the time during the experiment on the surface of water. The increase in salinity of *fresh water* can be caused both by salt transferring on the surface of the sample and inside its brine pockets, while sample is moving from one bucket to another.

All samples were gradually increasing their mass with characteristic "saw shape" (Figures 4 and 5) and growing in size as registered in Table 4. In *fresh water* ice samples are gaining in mass while their temperature is increasing. In *salt water* it is vice versa - ice samples are melting, while their temperature is decreasing.

To describe thermodynamic process in details we note temperatures of salt ice sample, *salt water* and *fresh water*, as following: T_{si}, T_{sw} and T_{fw} correspondingly. When ice sample is placed to the *fresh water* ($T_{si} < T_{sw}$), heat flux establishes towards the sample centre from the ice-water interface. This explains the ice formation on the outer boundary of the sample. Heat brought inside the sample warms it up what in its turn requires the brine solution to desalinate and adjust its freezing point to a new equilibrium temperature. This means that ice on the edges of brine pockets starts to melt to dissolve the solution. If sample would be isolated from the contact with *fresh water*, most of the sample would melt to reach the required equilibrium. This does not happen. Brine does melt some ice on its edge until brine channels are open enough for diffusion to take over in desalination process (Eide and Martin, 1975).

In *salt water* ($T_{si} > T_{sw}$) heat flux establishes from the sample centre to its boundaries. Heat, brought out from the sample, melts ice on its edges and cools the sample down. In relation to the brine solution there are two opposite possible mechanisms again: to freeze some ice on the brine pockets edges and to fulfil brine pockets with more saline *salt water* by diffusion process. We believe both processes take place. Diffusion processes of such type in the brine pockets bring us to the different specific heat capacity of the salt ice sample. This explains why periodical changes, ice sample is subjected to, increase the mass of the sample gradually and not vary it between the same values. And this clearly explains the appearance of the salt in the *fresh water*.

The results of salinity measurements of ice samples before and after the experiment are shown in Table 3. One sample in each couple has finished experiment in the *fresh water* and another in the *salt water*. At the end of the experiment all samples taken from the *fresh water* had salinity below $1\,ppt$, while salinity of the samples taken from the *salt water* was increasing from its top to its bottom from 2 to $7\,ppt$ with slight variability in values from sample to sample. Considerable difference in salinity of samples taken from different waters at the end of experiment, together with the results of experiment tracking the change in salinity of samples during the first stages of main experiment, proves very well the suggested above mechanism of brine salinity regulation by diffusion. In the accompanying experiment samples showed the ability to adjust their salinity by diffusion processes (Figure 8). Depending on the stage of the experiment salinity of the samples was varied between 2 and $6\,ppt$ with no principal difference in relation to the orientation of submerging.

The increase in salinity from the top to the bottom of samples taken from *salt water* at the end of experiment (Table 3) coincides with the consistency of sample. Ice sample is more solid and strong at the top and very porous and soft at the bottom (Figure 7). Such consistency of the sample might be due to the gravity salt drainage process in the sample. As a consequence of all of this the more porous the layer of ice, the more brine it may include while being in *salt water*.

Figure 6a shows the relative mass increase of sample of 0.15-0.20 per single stage in the *fresh water*, while temperature of the sample changes from -2˚C to 0˚C. This is the main part of the effect we may expect. Due to, discussed above, difference in the heat capacity of ice samples, we do observe an extra increase of 3.4% in the sample mass per each cycle in case of periodical process. This is estimated from the results of experiment given in Figure 6b. As seen in Figures 5a and 5b, under conditions of the experiment relative change in mass of the samples was up to 0.5 over the whole experiment.

In prior to this work an analogous pilot experiment with fresh ice samples was performed. The results of that are not included in the paper, but it should be mentioned that fresh ice samples involved in the same periodical movements were melting and losing in mass. This is due to the absence of brine pockets in the fresh ice and, as a consequence, the impossibility to establish the processes providing difference in the specific heat capacity during different stages.

CONCLUSIONS

Possible mechanism of thermodynamic consolidation of ice ridges keels in the water at the varying freezing point has been considered. Experimental studies have been performed to estimate the abilities and power of the effect. Cylindrical salt ice samples were periodically moving between waters of 35ppt and 0.2ppt salinity staying under their freezing point temperatures -2˚C and 0˚C correspondingly. The period of each cycle was about 6 hours. The experiment was intended to model the real situation when periodical tidal changes bring waters of different salinity under freezing point inside the ridge keel and cause its extra consolidation.

Mass of the samples was gradually increasing during the experiment under periodical changes, samples were subjected to. Under given formulation of the problem for the ridge keel it would mean the consolidation. During the single stage in the *fresh water*, when the temperature of sample was increasing from -2 to 0˚C, samples showed relative mass increase per stage between values of 0.15 and 0.20.

During the periodical scenario, samples demonstrated an extra relative mass increase of 3.4% in average per each period. In case of some samples this turned into 0.5 relative mass increases over the whole experiment (Figure 5). The increase in mass during period is possible due to the different heat capacity of sample at the different stages of one period. Sample freezes more ice on its edges during the *fresh water* stage than later melts during the *salt water* stage. Difference in the heat capacity is due to observed diffusion processes in the brine pockets of the sample. Such processes replace the brine solution with surrounding water and by this adjust the salinity of brine in the sample to thermodynamically required level.

The presence of diffusion processes in brine pockets was demonstrated in the accompanying experiment, where samples showed the ability to change their salinity during the different stages of experiment. Samples were draining brine out during the *fresh water* stage, that the salinity of sample was decreasing down to 2ppt approximately, and samples were accumulating more salt from surrounding water during the *salt water* stage, that their salinity were increasing back up to 6 ppt (Figure 8).

The process, modelled experimentally, may be considered as a process of the spring-summer ridge transformation, which explains the keel consolidation at the levels deeper below than the level of consolidated layer formed by usual atmospheric cooling during the winter season.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support from the Research Council of Norway through the Centre for Research-based Innovation SAMCoT and the support from all SAMCoT partners.

REFERENCES

Dobrovol'skii, A.D., and Zalogin, B.S., 1982. Seas of USSR. Moscow, Moscow State University, 192 pp. (in Russian)

Eide, L.I., and Martin, S., 1975. The formation of brine drainage features in young sea ice. *Journal of Glaciology,* Vol. 14, No. 70, 137-154.

Gorbatsky, V.V., and A.V. Marchenko, 2007. On the influence of turbulence in ice adjacent layer on water-ice drag forces and heat fluxes in the Barents Sea. Recent development of Offshore Engineering in Cold Regions. Yue (ed), POAC-07, Dalian, China, June 27-30, 2007, Dalian University Press, Dalian, pp. 648-659.

Høyland, K.V., 2002. Simulations of the consolidation process in first-year ice ridges. *Cold. Reg. Sci. Technol.*, 34, 143-158.

Lepparanta, M., Hakala, R., 1992. The structure and strength of first-year ridges in the Baltic Sea. *Cold Reg. Sci. Techn.*, 20, 295-311.

Marchenko, A.V., Ogorodov S.A., Shestov A.S., and Tsvetsinsky A.S., 2007. Ice gouging in the Baydaratskaya Bay: Field studies and numerical simulations. Recent development of Offshore Engineering in Cold Regions. Yue (ed), POAC-07, Dalian, China, June 27-30, 2007, Dalian University Press, Dalian, pp. 747-759.

Marchenko, A., 2008. Thermodynamic consolidation and melting of sea ice ridges. *Cold Reg. Sci. Techn.*, 52, 278-301.

Marchenko, A., and K., Hoyland, 2008. Properties of sea currents around ridged ice in the Barents Sea. Proc. of 19th IAHR Intern. Symp. on Ice "Using New Technology to Understand Water-Ice Interaction", Vancouver, BC, Canada, July 6-11, 2008, 1251-1262.

Shestov A.S., Marchenko A.V., 2009. Thermodynamic evolution of ice ridges under weather conditions in the Baydaratskaya Bay. POAC09-79, Luleå, Sweden, June 9-12.

Shestov A.S., Marchenko A.V. and Ogorodov S.A. 2010. Thermodynamic consolidation of ice ridges keels in the water with varying salinity. Proc. of 21st IAHR International Symposium on Ice, Lahti, Finland, June 14-18, 2010.

Shestov A.S., Høyland, K.V. and Ekeberg O.C., 2012. Morphology and physical properties of old sea ice in the Fram Strait 2006-2011. Proc. of 21st IAHR International Symposium on Ice, Dalian, China, June 11-15, 2012.