AT-211

Ice Mechanics, Loads on Structures and Instrumentation

FIELD WORK

Tidal motion effect on ice and constructions at Kapp Amsterdam, Svea

Group 2

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Contents

List of figures

ABSTRACT

Our fieldwork took place from 17th to 19th March around the Kapp Amsterdam Quay in Svea. Visual observations were performed that showed significant deformations of construction elements supporting the coal quay in Kapp Amsterdam. Ice pressure measurements were also made at the quay. The pressure cells together with temperature sensors were mounted both on the inside and outside of one of the open cofferdams. The temperature of the air, snow, ice and water column was monitored using a thermistor string. A tidal effect on ice was observed. This means a pressure increase in the water, causing it to migrate through the ice inside the cofferdam.

INTRODUCTION

The climate warming associated with Arctic leads to the tendency of improving the conditions for human activities in Northern regions. Therefore, more opportunities for exploration of oil and gas sources and creating the new shipping routs have appeared recently, which makes investigation of sea ice physical and mechanical properties essential. Harsh Arctic climate conditions require good understanding of sea ice behavior, such as ice strength and deformation of construction materials, for designing safe offshore structures.

Quay description

Kapp Amsterdam Quay is located in Sveabukta in the inner part of the Van Mijen fjord on Spitsbergen. The entrance is closed by the island of Akseløya, and the quay is therefore naturally protected from wave actions and drifting sea ice (fig.1). The quay is the main location for unloading of coal from the Svea mine into cargo vessels with dead weights up to 70 000 t. The quay fundament is a grid of vertical steel piles with a diameter of 800 mm, connected to the seabed and steel joggle skirts (cofferdams) connected to some of the piles. Each cofferdam has two walls perpendicular to the shore and one frontal wall against the sea side of the quay. The two lateral walls are extended and fixed on the shore outside the quay. The total length of the quay is 195m, and its width is 15m. Each section has dimensions 20m in length and 15m width. (Fig.2).

During winter time ice on the sea surface is formed inside and outside the quay. The ice inside the quay is confined because of interaction with the joggle skirt and the vertical piles supporting the quay.

Figure 1. Kapp Amsterdam geographical location (from http://toposvalbard.npolar.no/)

Figure 2. Kapp Amsterdam overview

OBSERVATIONS

Quay deformation observations

Significant deformations of the sheet piling were observed in alongshore direction. The sheet piling is gouged out from the inside and leans up to approximately 85 cm outward from the filled part of the foundation (from the line connecting the vertical piles supporting the quay in the middle part of the skirt) (fig.3). The largest deformations observed, are marked as red lines in figure 4. Distance measurements in this figure are given in meters.

The steel rods with bolts were used to stop the deformation of the skirt. Some of the rods were broken off. Therefore the construction was reinforced and the steel plates were welded in addition to stop the deformation. Small displacements in parts of the skirt in the horizontal direction were visible. The origin for the skirt deformation is unknown and can relate either to soil or ice actions or both.

Figure 3. Deformation of sheet piling

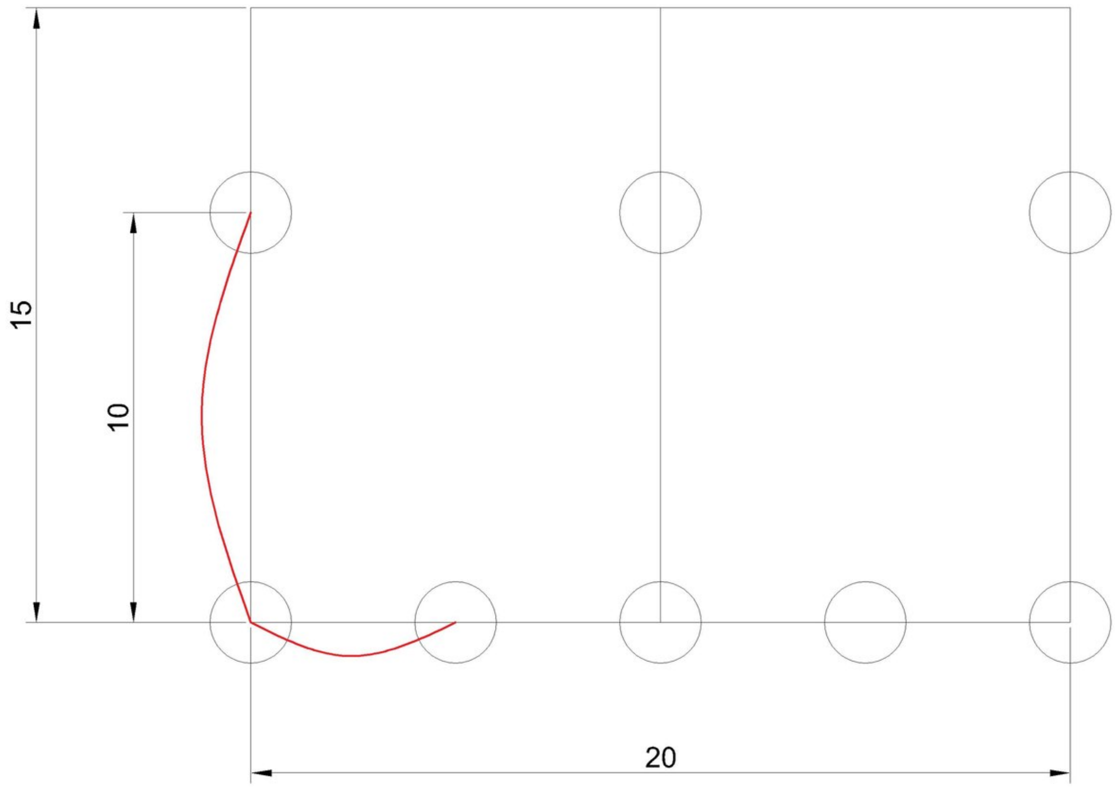

Figure 4. The drawing of the quay with the most significant deformations marked red

Ice processes observations

In wintertime, the ice below the quay is frozen to the cofferdam and hangs on the walls (fig.5). The ice between the quay and the shore is grounded. At low tide the ice inside hangs along the skirt with the lowest point of the ice in the middle. At high tide the increasing water pressure below the ice causes water to penetrate through the ice onto its surface (fig.7). The water drains through the ice downward when the water level decreases again.

It was also observed that the brine could penetrate through the ice. Upward brine migration through the ice during high tide induced by the vertical pressure gradient, was accompanied by the formation of lateral stresses in the ice. The presence of those stresses is explained by the brine freezing when it migrates from the ice bottom toward the ice surface in the temperature field with strong negative gradient. The effect repeats on each tidal cycle and therefore can create significant deformations of the joggle skirts over repeated tidal cycles.

Figure 5. Ice bustles on the piles

TIDAL EFFECT MEASUREMENTS

Experimental set up

To understand the influence of tidal actions on the quay structure, four pressure sensors were installed on the walls of the cofferdam: The first sensor was installed on the outer side facing the fjord, the second – on the inner side of the same wall, and the two others – on two levels of side wall from the inner side, third was above the fourth. Additional four pressure sensors were frozen in the ice inside the cofferdam – two parallel to shoreline (first was on depth of 0.6 m, second – on 1.1 m below ice surface) and two perpendicular to it (third – 0.6m deep, fourth – 1.1m deep). Temperature near pressure cells were measured with built in sensors. In additions thermistor string measuring temperature profile was attached to construction. Tide was measured with SeaBird-39. Camera taking time-lapse pictures was attached to the cofferdam.

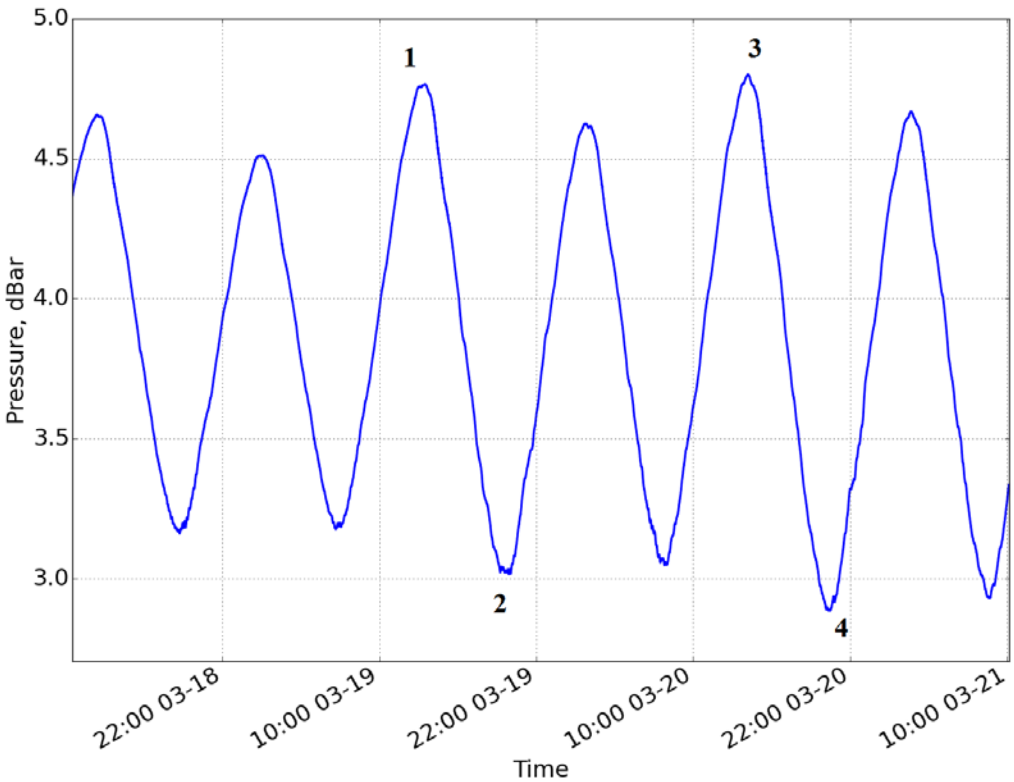

Figure 6. Tide

(1)

(2)

(3)

(4)

Figure 7. High tide (1), (3); Low tide (2), (4).

Results and discussion

Tidal motion of water surface is shown on figure 6. Amplitude of tide was approximately 1.5 m. Maximal and minimal tides at points 1, 2, 3, 4 were observed with camera (figure 7). Maximum and minimum pressure from SeaBird-39 coincides with pictures taken.

Figure 8 presents temperature data from thermistor string and tidal pressure. Temperature 1 shows the air temperature below the quay, 1.5 m from the ice. Sensor 2-4 detects temperatures near the snow surface, and temperatures inside snow. Oscillations with period of 1 day can be observed on records from the first four sensors. Other temperature sensors show temperature inside ice on different levels. Data from sensor 5-10 shows the period of temperature oscillations to be about 12 hours, which corresponds to the tide time (period of tide is about 12.4 hours). Thus we can expect influence of tide on temperature of ice and therefore on ice expansion which can lead to pressures on walls.

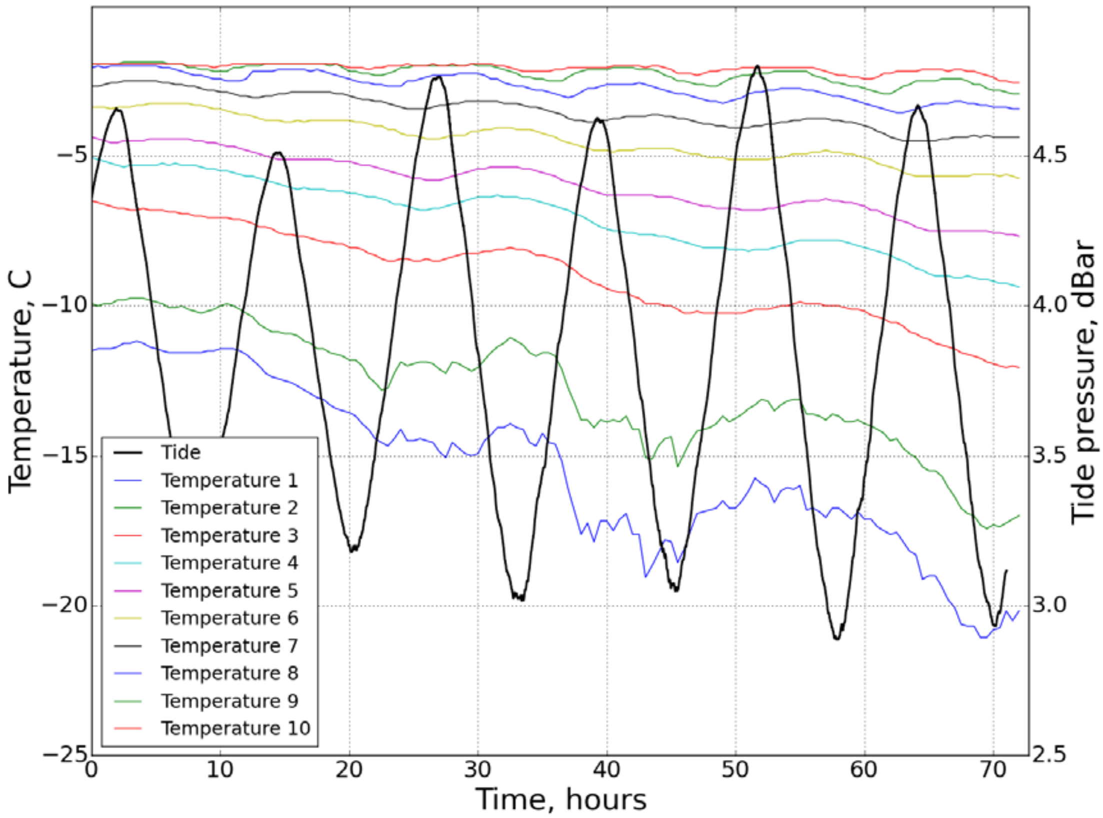

Figure 8. Temperature from thermistor string

Figures 9 and 10 shows the temperature with time from sensors built in pressure cells. Figure 9 represents data for pressure sensors fixed on walls. These sensors were installed in advance, thus ice froze around. Therefore we can observe influence of tide on temperature of ice. For sensors installed in the ice (figure 10) amplitude of temperature oscillations is much smaller. This can be due to presence of slush as well as ice around pressure sensors, since they were installed just before measurements started.

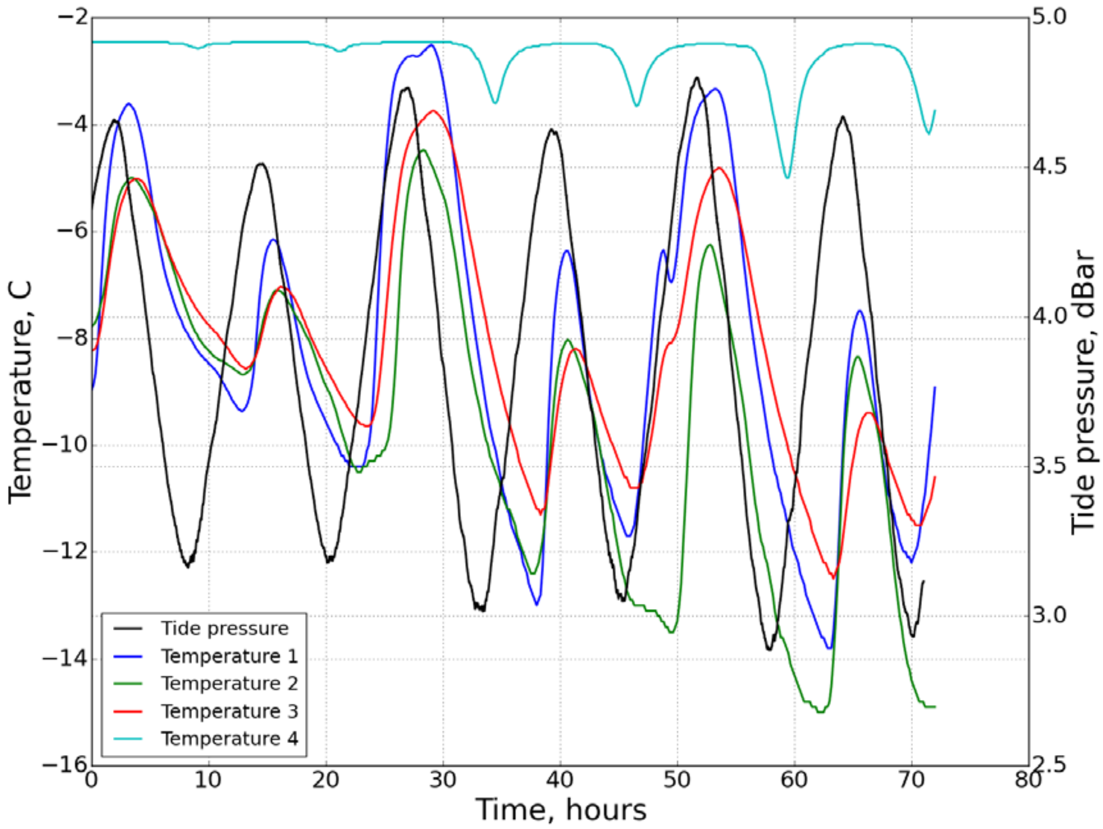

Figure 9. Temperature from pressure sensors installed on walls

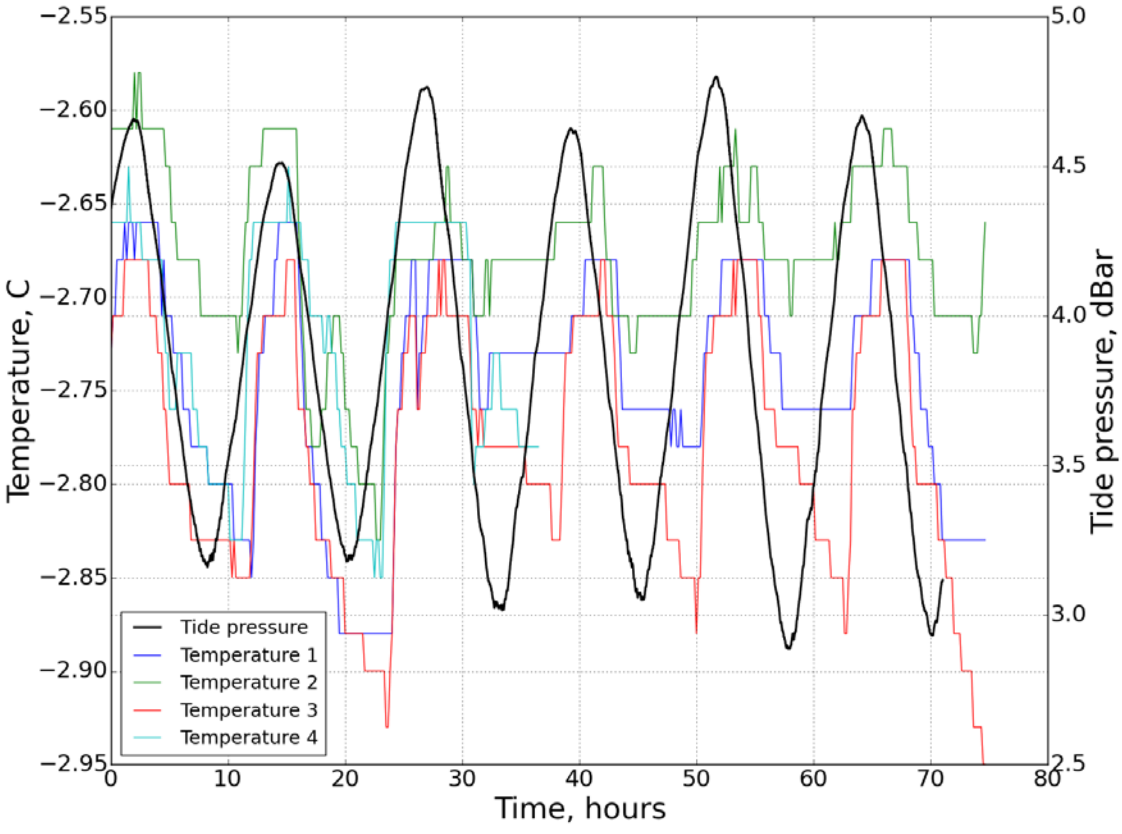

Figure 10. Temperature from pressure sells installed in the ice

Data from pressure cells installed in the ice inside cofferdams are shown on figure 11. Pressure oscillations have the same period as tides. Maximum of pressure is a bit shifted from maximum of tide. This can be explained due to tidal pressure, where water starts to penetrate through the ice and part of it freezes inside of ice causing ice expansion. Since it takes time for water to freeze, maximum of pressure can be observed a bit later than maximum of pressure from underneath. As a result, it can be observed that pressure reaches its maximum earlier for bigger depth.

Pressure measured on walls of the cofferdam is presented on figure 12. General trend here is similar to those for sensors installed in the ice, but we observe greater pressure on sensors that measured pressure on outer side of the wall compared to the results shown on figure 11. This means that ice from the fjord can have strong influence on constructions of the quay – as it was after 12 hours of our observation, when pressure reach value about 10 times greater than usual.

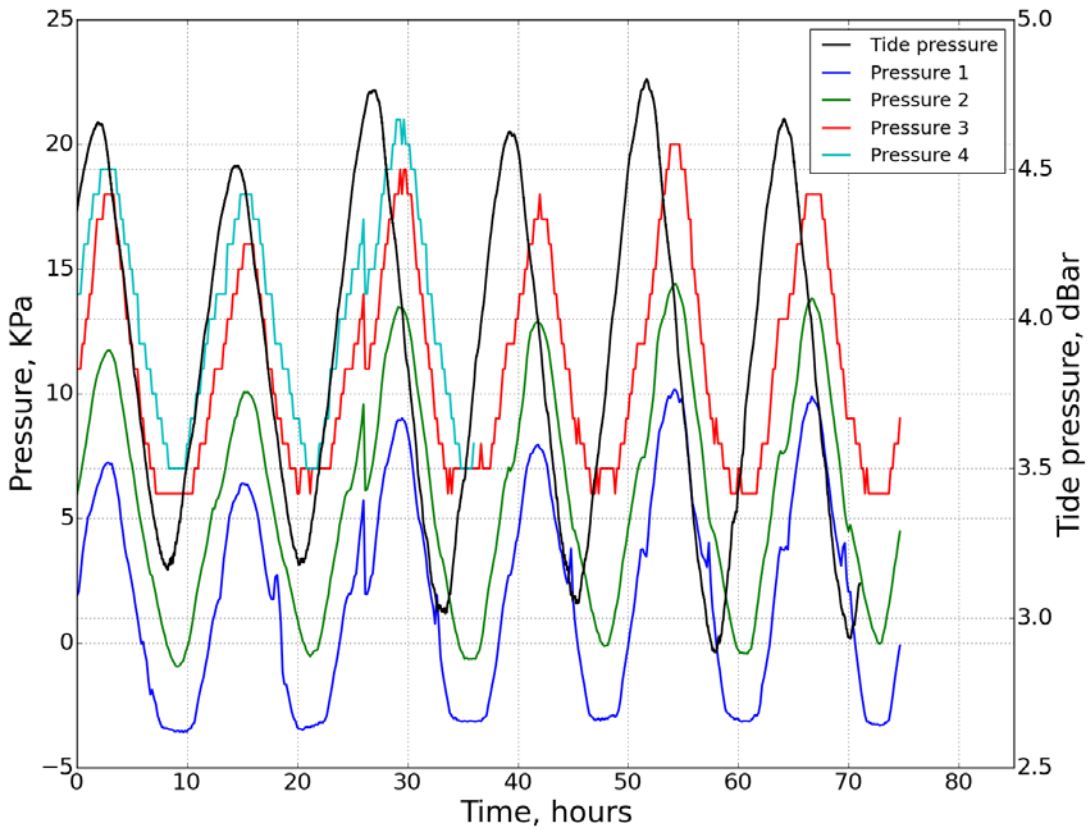

Figure 11. Pressure data from sensors installed in the ice

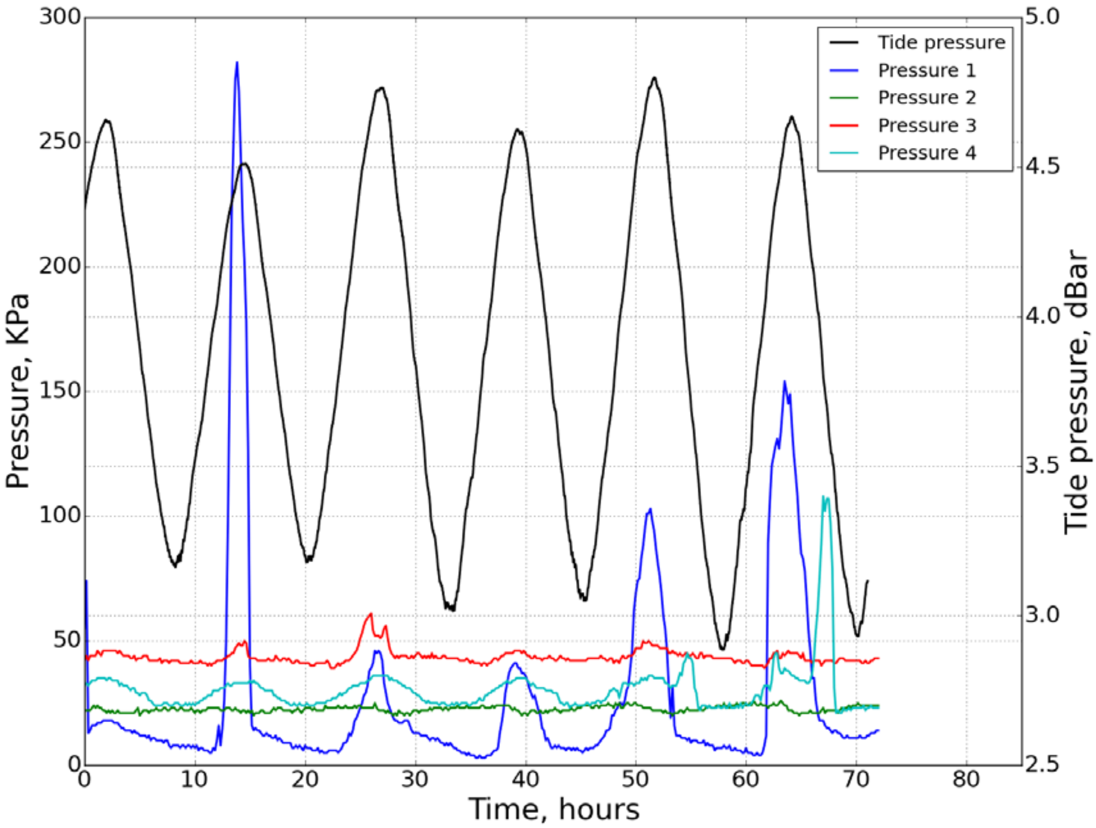

Figure 12. Pressure data from sensors installed on walls

DISCUSSION

During our fieldwork in Svea we observed ice bustles accumulating on the piles of Kapp Amsterdam. The deformations of the quay is caused by pressure from the ice exerted on piles and cofferdams, as well as tidal effects on ice.

During our investigation of the quay construction, no outgrowths of ice were observed on the wall, only on the piles. According to the articles (Wrangborg, D. et al. 2015, Marchenko, A. et al. 2011), the increase in pressure affecting the quay, have been taking place for several years.

During low tide, the bustles remained stable even when the surface level changed. The amplitude of tidal motion was estimated to approximately 1.5m.

Water and slush were observed on the ice surface inside Kapp Amsterdam, because of water migrating through the ice, due to higher pressure from below during the tidal motion. During low surface temperatures, brine moving in pores and cracks freezes. This leads to ice expansion, and subsequently the pressure acceleration in the ice. This is presented in the plots of pressure sensors data. The maximum pressure in the ice is shifted from the maximum of tidal pressure, by the freezing time of penetrated water.

The pressure sensors installed on the quay walls, shows that the sea ice (from the fjord) has a big influence on the quay construction. In our observations, pressure reached values of 10 times greater than usual.

The plots of the surface temperatures have a period of approximately 12 hours, while the temperature plot from the sensors installed deeper down is about 24 hours. From this, we can establish that tide has an influence on the observed oscillations.

CONCLUSION

After finishing our experiment we discovered that ice pressure on the cofferdam walls and ice temperature varied synchronously with semidiurnal tide.

Pressure below the ice varies due to tidal cycles. Increased pressure results in the upward migration of brine through the ice. This brine fills air pockets, cracks inside the ice as well as the gaps between the ice pieces. Low atmosphere temperatures during winter time initiate the brine freezing process, which leads to increase of the pressure inside the ice, and thus ice loads on the cofferdam walls. After numerous tidal cycles the pressure on the structures increase, which leads to quay deformation. Pressure increase due to tide was around 10 kPa inside the quay. Loads from the side of the fjord were up to 280 kPa.

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