POAC'17
Busan, KOREA

Proceedings of the 24th International Conference on
Port and Ocean Engineering under Arctic Conditions
June 11-16, 2017, Busan, Korea

Laser Scanning in Mechanical Ice Tests

Nataliya A. Marchenko[1], Alexander N. Sakharov[2]

[1] The University Centre in Svalbard, Longyearbyen, Norway
[2] Lomonosov Moscow State University, Moscow, Russia

ABSTRACT

Ice is interesting as natural phenomenon and in practical sense. Laser scanning is one of the numerous techniques to investigate ice properties, structure and dynamics.
Arctic Technology department of UNIS performs full-scale tests to investigate mechanical properties of sea ice. Laser scanning REIGL VZ-1000 was used to make 3D image of ice samples after testing and present the surface in details. Although this model of scanner was not specially designed for ice, the set of results was obtained. The scans were performed in spring 2016 on Svalbard (Van Mijen fjord) and in the Barents Sea during the cruise on RV Lance. Processing of 3-D images of ice surface of samples after full-scale indentation tests allows to see the fine structure, typical elements as splitting and tension crack, extrusion channel, etc. All these elements can be measured with high accuracy.
The main difficulties in scanning of ice are concern bad/strange scattering due to fractality of ice fracture surface. Scanning from several position gives the full 3D image, but it is complicated to obtain for small objects as the size of referencing point is large than scale of elements, which we would like to recognize on the point cloud (ice structure elements). The weather conditions during field work were quite warm (around 0^{o} C), that influenced the tests and the scanning surface.
The advantages and disadvantages of various soft wares for processing of laser scans are discussed.

KEY WORDS: laser scanning; ice; mechanical tests; failure; crack

INTRODUCTION

On the way of mastering harsh polar environment, the knowledge about sea ice properties is vital, because ice can influence on constructions and transportation. Various methods and techniques are used to measure ice force and resistance. Full-scale mechanical test in natural environment give unique information about real sea ice and all additional means to get more data are valuables.
The international team of sea ice researchers performs full scale ice mechanical test in the

fjords of Svalbard and in the Barents Sea during last 7 years and essential experience are gained, reliable equipment is created, important data are obtained (Karulin, Marchenko et al. 2014, Karulin, Marchenko et al. 2015, Konstantinova, Marchenko et al. 2016, Murdza, Marchenko et al. 2016).

In 2016, laser scanning was firstly tried and tested with intention to find the way of saving the images of ice samples and deformation they received during testing, to understand what features of ice could be visible in the scans and what type of failure mode is due to mechanical behavior of ice in the tests.

In the course of ice testing we examine various ice properties and characterizations and the most important of them – strength under various type and rate of loading. Both brittle and ductile failure had been investigated in tension- compression tests, beam bending tests and the most interesting – indentation test in which the fracture surface can be scanned and investigated.

There was a lot of skepticism at the beginning, as it is known that ice has bad reflectivity. Even the idea to scan ice sample looked strange. But the possibility to see the fracture surface, cracks and crystals on 3D point cloud was very attractive. Due to the vector representation of the surface one can get quantitative characteristics. So various ice samples were scanned and processing gave interesting and encouraging results.

LASER SCANNING. DEVICES, TECNIQUE AND CHALLENGES

The laser scanner used for the measurements was a Riegl VZ-1000 which is part of Riegls V-line 3D Terrestrial Laser Scanners. It uses a narrow infrared pulsed laser beam in conjunction with fast rotating multi-facet polygonal mirror to acquire fast and precise laser ranging. It uses frequencies in the range from 70 to 300 kHz and achieves its maximum range of 1400 m at 70 kHz. The Riegl VZ-1000 is capable of detecting and processing multiple echo from the same direction, which means complex structures, fences, wires and vegetation can be handles. The minimum measurement distance is 1.5 m. Accuracy (conformity with actual value) is reported to be 8 mm and precision (degree to which further measurements show same results) 5 mm. A high-resolution, full-frame, calibrated Nikon D700 was used to automatically acquire RGB images for making textures during post-processing (Riegl 2017).

Riegl VZ-100 was not specially designed for ice and short distance scan. Ice test samples are usually has size 60-80 cm. The best results Riegl VZ-100 gives on the long range scanning (450-700 m distance) with opaque objects with size of several tens meters. Among Riegl VZ-400i, VZ-400 would be better. But it is too expensive equipment to have several units with various characteristics. So we used what we have. Furthermore the other models have own challenges. Designed for ice Riegl VZ-6000 is the best for glaciers and snow fields, but works on long distance (longer than 5 m) (Riegl 2017).

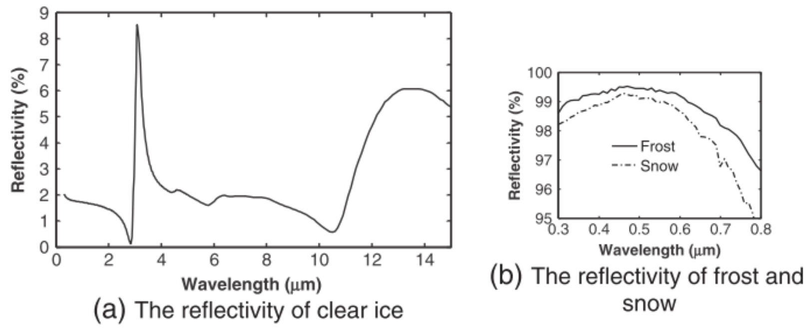


Figure 1. The reflectivity of clear ice, frost and snow (directional (10°) hemispherical reflectance (Baldridge, Hook et al. 2009)

All scanners have a problem with ice. X. L. Gong and S. Bansmer made special investigation to find out the best way to scan ice and proposed a 3-D ice shape measurement technique through laser light sheet scanning in laboratorial condition (Gong and Bansmer 2015). They referred to A.M. Baldridge's and co-authors (Baldridge, Hook et al. 2009) investigation of ice reflectivity (Figure1) and use a thin layer of frost instead of opaque paints was used to increase the surface reflectance of clear ice. Fine snow layer gave also good results.
In our experiments we found that fresh ice samples, just after testing naturally covered by thin layer of ice powder and have sufficient reflectivity. After some time, for example keeping in cold storage room, samples lose that layer and not directly suitable for scanning. They looks nondiagnostic on scan, due to changing of reflectivity (Figure 2) and need to be covered by some powder - snow or hoarfrost. But it is difficult to perform on vertical surfaces.

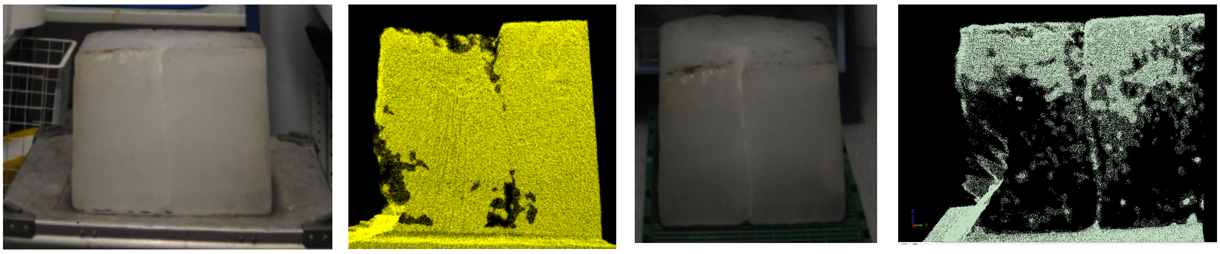
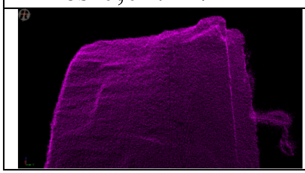
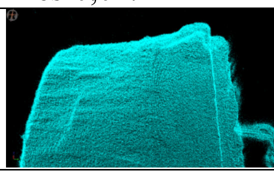
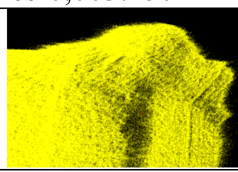


Figure 2. Ice sample after storage on photos and on scans

During field work (see next section) we used the closest range scanning program 450 m (300 kHz) and tested it for various resolutions. The high resolution gives the large file (Table 1) and the hope to see the fine structure of surface, might be, large crystals, grain. But it comes that resolution higher than 0,01 deg gives much noise and hides the important features - the surface looks very fluffy. Actually resolution 0,02 is completely enough, and actually the best. Resolution 0,04 is not visible on illustration, for example in Word files, even it looks nice in RiScan program. So it is not presented in Table 1

Table 1. Appearance and size of scans with various resolutions.

Res-0,02. 27 MB	Res-0,01. 111 MB	Res-0,003. 572 MB
		

SCANNING OF SAMPLES IN THE FIELD. SPRING 2016

Laser scanning complain was performed during field work in Van Mijen fjord (Western fjord of Spitsbergen), performed by Arctic Technology department of UNIS and guest researches at the beginning of March 2016; and in western part of the Barents Sea while cruising on RV Lance in May 2016. The samples after several tests were scanned. These particular testes and results are described in details in (Konstantinova, Marchenko et al. 2016, Murdza, Marchenko et al. 2016). So here we only describe the scanning itself.

Indentation Test 1 (07.03.2016)

After indentation test, described in (Konstantinova, Marchenko) the sample of ice with splitting cracks was scanned with various resolutions from different points (Figure 3). The dimensions (depth – 0,368 m and opening at the mouth – 0, 036 m) of crack were visible and performed on scan image. The crack inclined in the angle of near 30^0 in vertical direction and propagated to warmer and weaker bottom layers of sample.

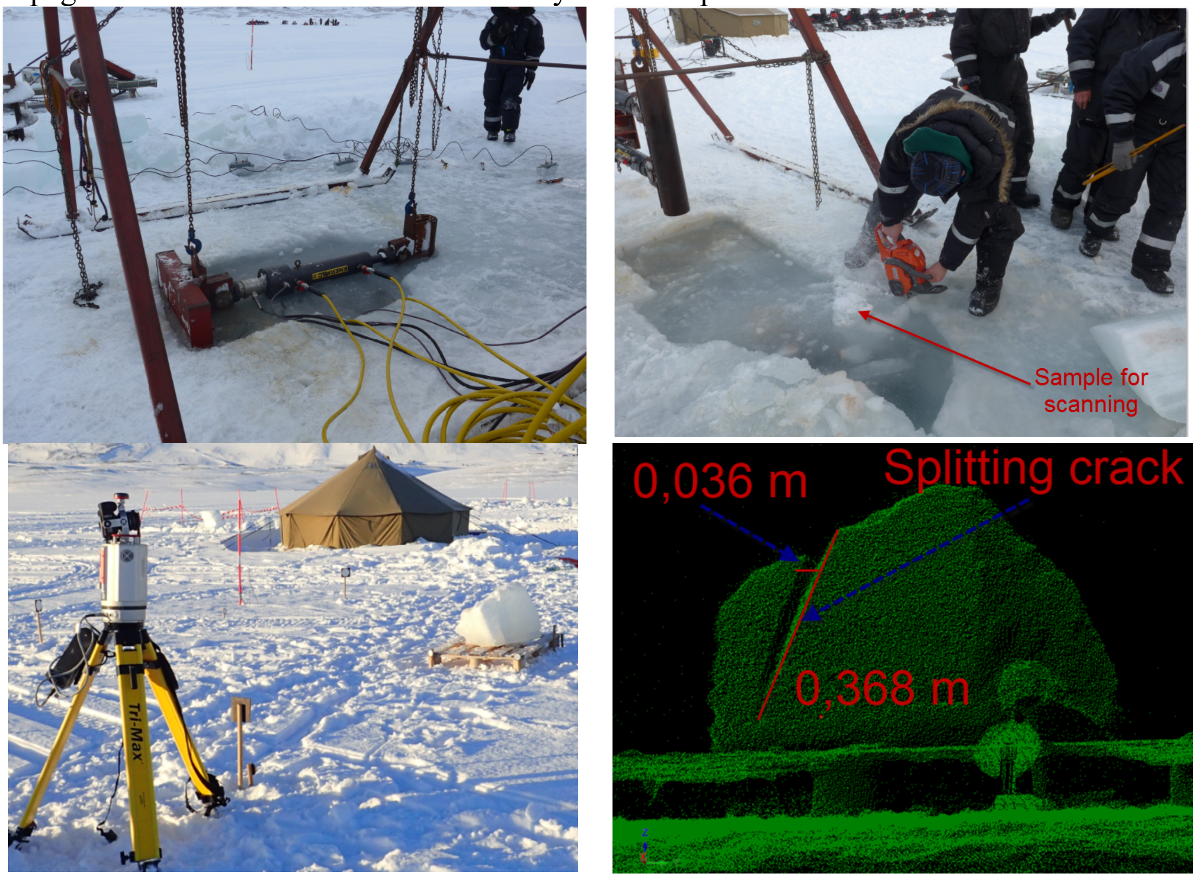


Figure 3. Test setup, place of sample, scanning process and result

Indentation Test 2 (08.03.2016)

The most impressive scan was performed after indentation test on 8 of March 2016.

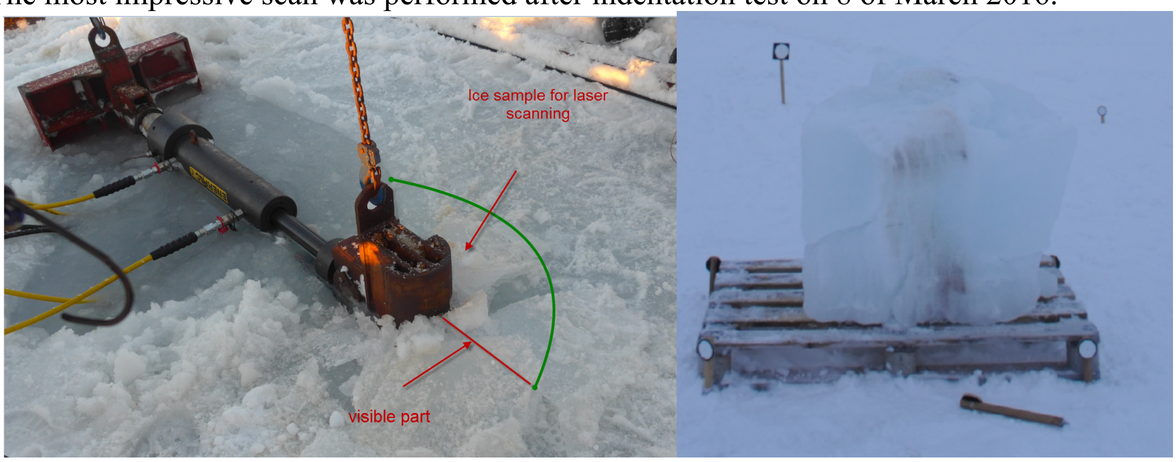


Figure 4. Indentation test setup with ice sample for scanning and photo of sample

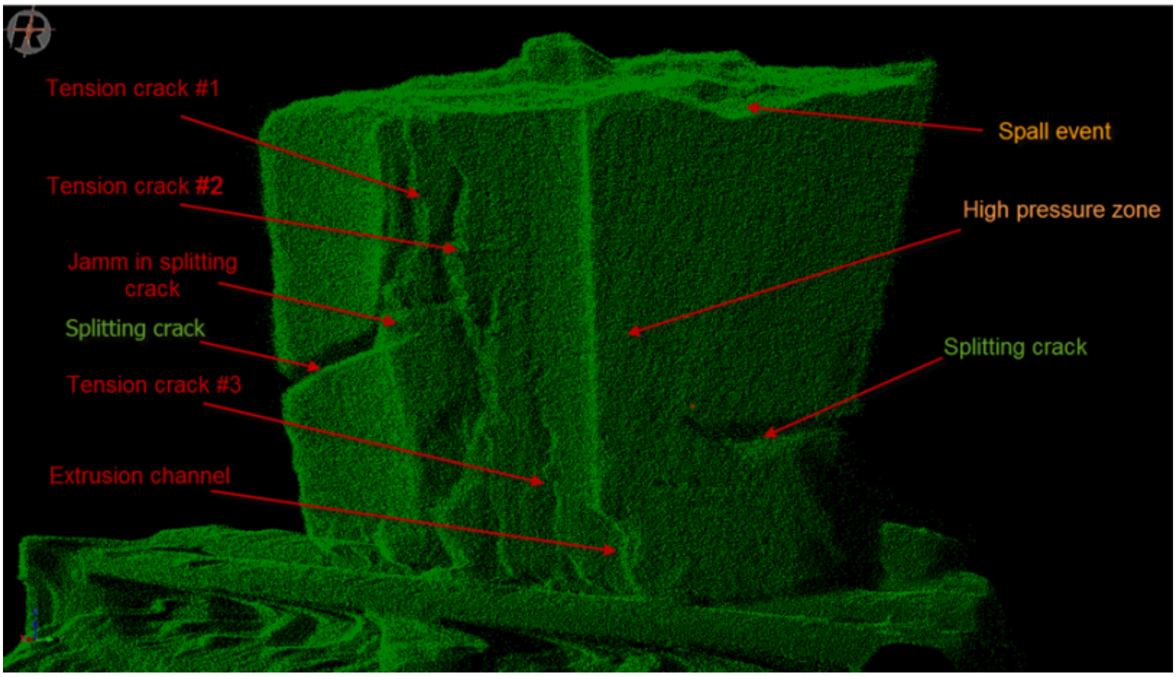


Figure 5. and 3D point cloud on Scan image with key features

Several splitting and tension cracks are visible. The result of indentation test in situ (Konstantinova, Marchenko et al. 2016) plot Force in load cylinder vs displacement (Figure 6) show the quasi periodical regime of ice failure during indentation. On the plot we can see the quasi period L_0 = 3-4 cm from one unloading event to another one. In complex sequences alternate the splitting and jam processes, spalling and other discontinuous events which are firing an unloading.

It's quite difficult to analyze the correlation between these elementary events and total force decreasing. We can only make a proposal that approximately half of these gash on load graph are in accordance of tension discontinuous, which formed at the back side of the semi cylinder of indentor (Figure 7).

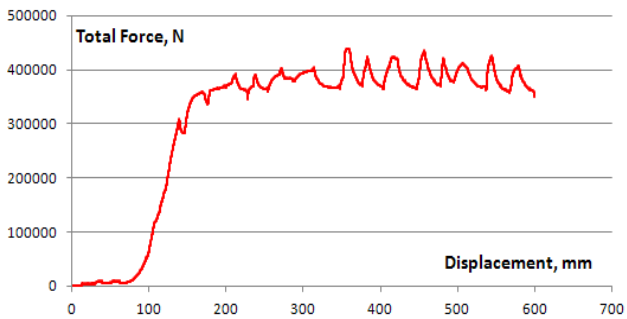


Figure 6.

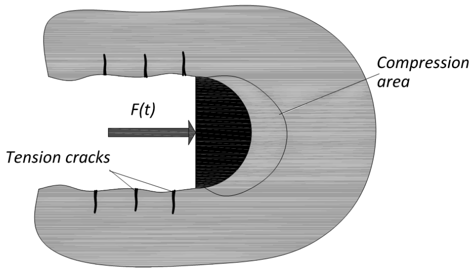


Figure 7.

L-shape Beam Test (10.03.2016)

Beam tests are used traditionally to deteminate flexural strength. In our modification test L-shape bending also torsion deformations and shear stress are included. Complex bending deformation of ice appears when the forces applied on the ice edge initiate torsion. It may happen when the ice edge is displaced upward and downward on different segments on the contact line with a structure. Complex bend is realized when surface waves propagating in different directions penetrate below the floating ice. Superposition of bend and plane stress state is realized when surface wave propagates in region covered by ice compressed in the direction not coinciding with the direction of wave propagation. Test with floating L-shape beam was firstly performed in Spring 2016 to formulate ice failure criterion in case when the principal stresses have different signs.

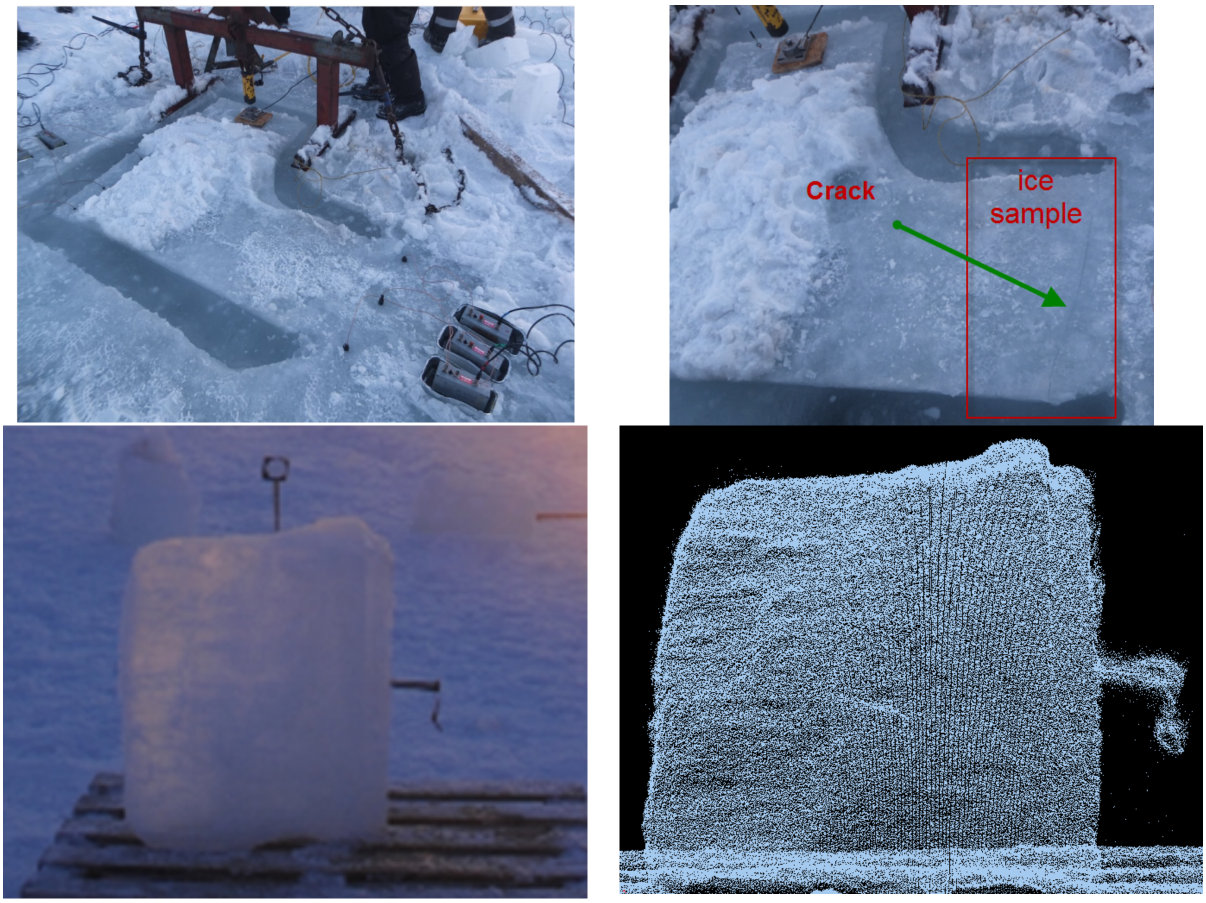
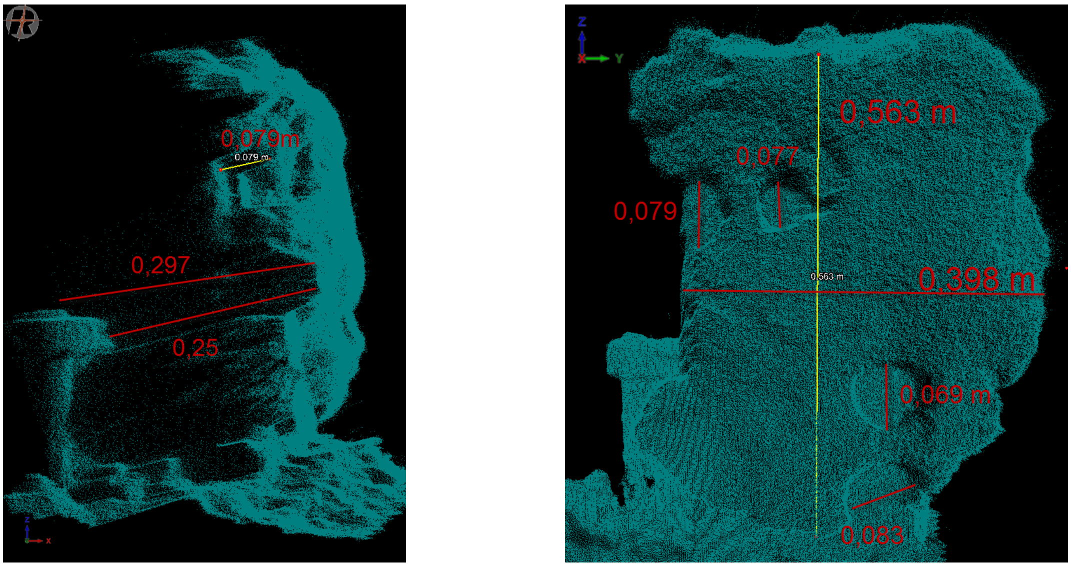


Figure 8. L-shape beam setup, sample place, photo and scan

Test with L-shape beam is describes in detail (Murdza, Marchenko et al. 2016). For laser scanning the sample cutting by crack had been taken. (Figure 8). So we actually scan and perform failure surface. It will be described in PROCESSING section

"Cheese ice" in the Ridge in the Barents Sea (03.05.2016)

During research cruise RV Lance in the Barents Sea, mechanical properties of ice in ridges and rubbles were investigated. The ice sample after indentation test had a loose structure with cylindrical holes, so we call it as "cheese ice" and captured by scanning (Figure 9). In the ice sample with size 0,563x0,398 m and approximately 0,3 m width, we discovered and imprinted 4 visible holes 0,069-0,079 m diameter and 0,007 m depth, that looked as thermokarst phenomena, because it difficult to imagine such holes created mechanically inside ridge.
We do not know exactly the genesis of such structure, but the object was recorded and can be further explored. So it is possible to investigate not only the fracture surface, that we get as the result of mechanical tests, but structures that are associated with thermodynamic processes within the ice and scan provides a good illustration of thermal phenomena in the hummocks (Figure 9).



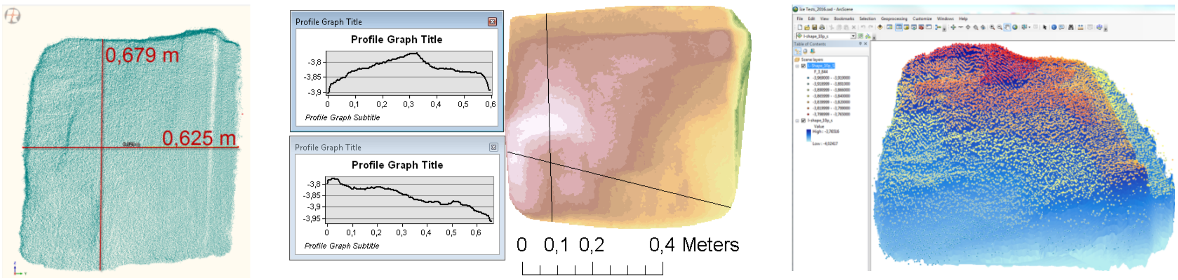
Side view Front view

Figure 9. "Cheese ice" sample after indentation test

PROCESSING

Let's consider various processing software and methods on the example of L-shape sample, that had size 0,62x0,68 m (Figure 10). We took scan with 0,02 deg resolution, that gave us after cleaning 215923 points in 3D point cloud of sample.
Processing of scanner data in RiScan program (Riegl 2016) (the very first step of working with scan data) allows to present 3D point cloud, clean from unnecessary points, apply various filters and export as ASCII code to TXT. file to process further in other more common program, for example ArcGIS (ESRI 2017)(Figure 10). RiScan program in special for Riegl scanner users, that has might be several thousand installations, rather expensive and unique. ArcGIS is very popular, widespread mapping software with millions of users and free

viewers. So export to ArcGIS will make scanner data affordable for the masses. One can make profiles across ice samples in ArcMap (2D part of ArcGIS) (Figure 10. Middle)



RiScan programm ArcMap ArcScene

Figure 10. L-shape sample images in various software

ArcMap allows to identify the geometric characteristics by the cross section. This is a way to describe the rough surfaces with a set of parallel lines and roughness of the ice can be studied with the help of profiles in ArcGIS. The other way is to analyze the surface by ArcGIS 3D Analyst tools, and as steepness representation, curvative map, hillshade (Figure 11).

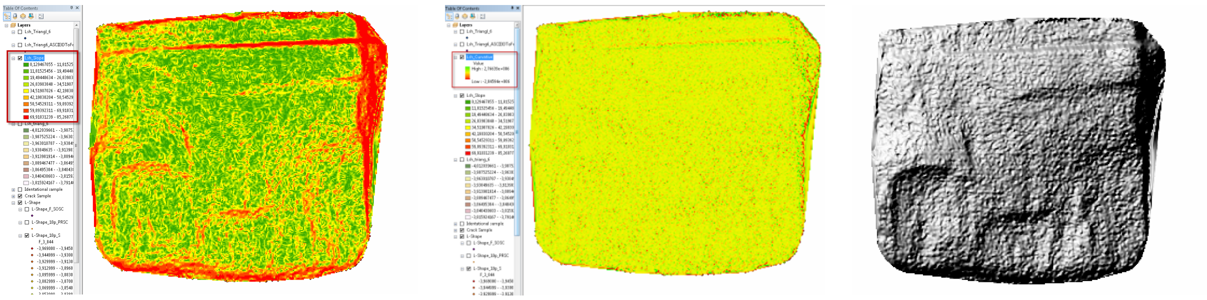

Map of surface sectors steepness Curvature map Hillshade

Figure 11. Processing with 3D Analyst tools in ArcMAP

ArcScene (3D part of ArcGIS package) perform three-dimensional image that can be rotated, viewed from different angles and color, symbolized in accordance with different data/sample specific (Figure 10. Right).

Very important features of ArcGIS software (ESRI 2017) is openness, existing of viewers and online options. Publishing of surface maps (2D) and scene (3D) makes scanning data available for researchers and audience (students), who does not have RiScan and ArcGIS software.

Various filters and processing in RiScan

As it mentioned due to noise scan surface looks furry/fuzzy and could not be triangulated by plane triangulation method with good results (Figure 12)

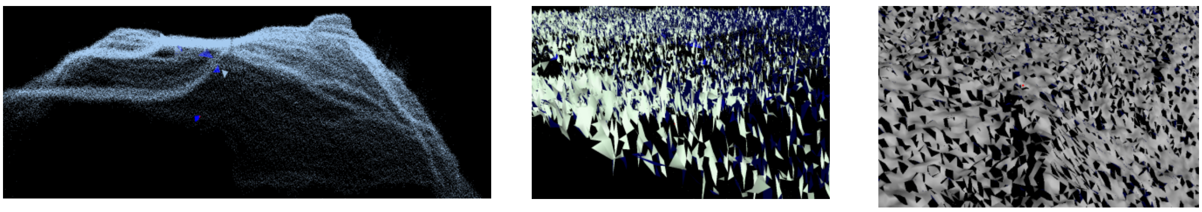
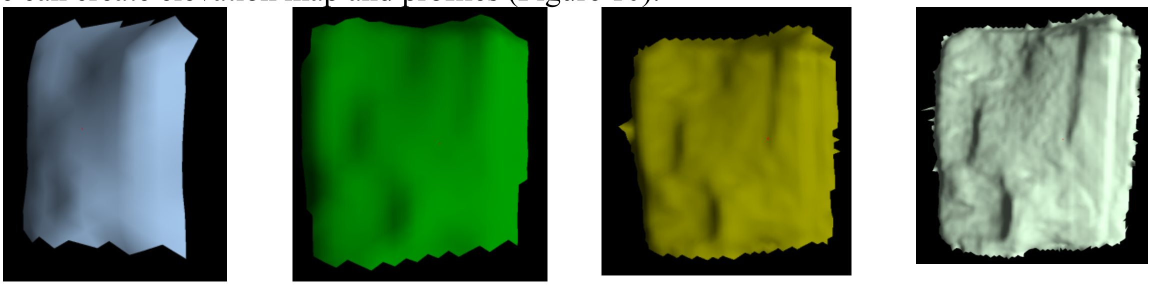


Figure 12. Plane triangulation method. Various type and zooming

But triangulation with icosahedron gives interesting results (Figure13). At level 9 you can see structures on ice fracture surface due to combine bending and torsion failure in L-shape beam bending test. Further we can export TXT file in other software, for example ArcGIS, where we can create elevation map and profiles (Figure 10).



Level 6, points 124, polys 207	Level 7, points 420, polys 763	Level 8, points 1524, polys 2895	Level 9, points 5788, polys 11256

Figure 13. Triangulation with icosahedron. Various levels

CONCLUSIONS

We would like to emphasize that there is no alternative for 3D laser scanning to reflect and store the image of ice, ice sample and visible results of mechanical (and other) tests. Since pictures can not allocate the structures, the work on the ice destruction are illustrated by the diagrams and plots/drawing, which are a generalization of what researchers have seen by their 3-dimensional vision. They could not fix on it in another way.

3D scan provides such an opportunity. It remembers the 3-dimensional image of the fracture surface and allows to decipher the structure of destruction not in the field (in harsh weather conditions and limited time), but in the course of a desk job, in office without losing of information.

It is not possible to perform the calculations associated with the analysis of the energy costs for the destruction taking into account the irregular nature of the surface by the methods which are used now widely. But the result of 3D scan and its processing provides such capability.

Moreover, the opportunity to receive a vector model of the fracture surface and to determine its properties, confronts engineers and programmers over the task of trying to build an algorithm for calculating the properties of the surface and to create the theory of destruction, which would be able to compute/evaluate the energy of destruction taking into account the structural features.

The results of 3D scanning give us the really new way to acquaint students with the structure and the show the nature of the destruction of ice. Students will be able to look into the cracks and cavities of ice that had melted long ago.

It is necessary to continue the work and create a bank of 3D models, which will be extremely useful in the future. Many mechanics agree that ice is a unique material from the standpoint of variety of forms and structures destruction. Therefore, such a bank model would also be in demand for the Materials Science. Even from a small number of scans can be concluded that the most interesting images of the structures were obtained in compression tests, as well as a crumpled ice on indentation tests. Moreover the little experience, which is now accumulated, gives us possibility to suggest that in situ mesoscale test is the most appropriate purpose for the laser scanning, allowing to perform not only a quantitative assessment, but also qualitative evaluation allowing you to allocate the structure. If vertical profiles of temperature and salinity of the ice would be added to a vector model of the scanned surface of the tested samples, it would have the necessary amount of raw data for measurement and analysis of test results.

On the way to creation of data bank and using in education of laser scanner point clouds, the combination RiScan and ArcGIS software is very important. ArcGIS viewers and online options make scanning data available for wide range of researchers and audience (students).

ACKNOWLEDGEMENTS

The authors would like to thank the SAMCoT project (funded by the Research Council of Norway), the SITRA project (funded by the Norwegian Centre for International Cooperation in Education) and the colleagues for supporting this study.

REFERENCES

Baldridge, A. M., S. J. Hook, C. I. Grove and G. Rivera (2009). "The ASTER spectral library version 2.0." Remote Sensing of Environment **113**(4): 711-715.

ESRI. (2017). "ArcGIS software." from http://www.esri.com/.

Gong, X. L. and S. Bansmer (2015). "Laser scanning applied for ice shape measurements." Cold Regions Science and Technology **115**: 64-76.

Karulin, E., A. Marchenko, M. Karulina, P. Chistyakov, A. Sakharov, A. V. Ervik and D. Sodhi (2014). Field Indentation Tests of Vertical Semi-Cylinder on First-Year Ice. 22nd IAHR International Symposium on Ice. Singapore**:** 8.

Karulin, E.B., Marchenko, A.V., Karulina, M.M., Sakharov, A.N., Chistyakov, P.V., Verbitskaya, M.Yu., Ignatieva, E.D., 2015. Compression testing of sea ice by penetrating the ice sheet with a semi-cylindrical indenter. Process numerical simulation. Transactions of the Krylov Shipbuilding Research Institute, 86 (370), 75-86. ISBN 0869-8422.

Konstantinova, M., A. Marchenko, M. Karulina, A. Sakharov, E. Karulin and P. Chistyakov (2016). In-situ Investigations of Ice Deformations and Loads in Indentation Tests. Proc. Of 23rd IARH International Symposium on Ice (IAHR-ICE 2016). AnnArbor, Michigan-US.

Murdza, A., A. Marchenko, A. Sakharov, P. Chistyakov, E. Karulin and M. Karulina (2016). Test with L-shaped Cantilever Beam for Complex Shear and Bending Strength. Proc. Of 23rd IARH International Symposium on Ice (IAHR-ICE 2016). AnnArbor, Michigan-US.

Riegl. (2016). "RiSCAN PRO. Operating and Processing Software for RIEGL 3D Laser

Scanners." from
http://www.riegl.com/uploads/tx_pxpriegldownloads/11_DataSheet_RiSCAN-PRO_2016-09-19.pdf.

Riegl. (2017). "Terrestrial Laser Scanning." from
http://www.riegl.com/nc/products/terrestrial-scanning/.