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Report

MonArc Project Report 2018

Monitoring of Arctic Infrastructure
(MonArc – project duration 2017-2019)

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SINTEF Building and Infrastructure
Rock and Soil Mechanics
2018-12-03

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Monitoring of Arctic Infrastructure

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ABSTRACT
This report presents the performed activities and deliverables within the Monitoring of Arctic Infrastructure project (MonArc) and gives references to field data records collected in 2018. The performed activities include scientific and logistical planning of fieldworks, fieldworks, data processing, and reporting. The monitoring program 2018 comprised measurements on two buildings in Longyearbyen, one building in Barentsburg, one building in Pyramiden (and a stretch of the town road), and three buildings in Svea. The field activities included geodetic surveys by leveling the previously established monitoring points on buildings (2017) with a laser level device. A 2018- data set was established for each building, and compared to the 2017 sets ([1]). The data sets give the year to year development of settlements, and will serve as reference for future long-time assessment of vertical movements (settlements) of the infrastructure in a 10-years perspective.

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01	2018-12-03	The report presents detailed description of activities and deliverables, and references to data records produced in 2018.

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SINTEF

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APPENDICES

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1 Introduction

The Monitoring of Arctic Infrastructure (MonArc) project, with funding from The Research Council of Norway, creates and facilitate research cooperation between Norwegian and Russian researchers in Svalbard through a joint effort in monitoring of selected infrastructure, focusing on vertical settlements of foundations and the development in time due to climate change and impact of local human activities (as particularities of maintenance, functionality of drainage systems, etc.).

The project partners are SINTEF Byggforsk, Trondheim; Moscow State University – Geology faculty, Geocryology department (MSU); The University Centre in Svalbard, Department of Artic Technology (UNIS); Trust Arcticugol, Moscow; Longyearbyen Lokalstyre; and Store Norske Spitsbergen Grubekompani Aktieselskap, Longyearbyen (SNSG).

The project tasks consist in monitoring of elevations of installed monitoring points on elements of selected buildings (mostly foundation piles) in the towns of Longyearbyen, Barentsburg, Svea and Pyramiden.

This report presents detailed description of activities and deliverables concerning data records produced in 2018. The activities include scientific and logistical planning of fieldworks, performance of the fieldworks, data processing and reporting.

2 Background – project elements

Activities in 2018 included:

i. Fieldwork planning and preparation. This comprised communication with authorities, planning of fieldwork execution, and logistical planning (transportation and accommodation).
ii. Execution of fieldworks (field measurements).
iii. Processing of data after the field campaigns.
iv. Interpretation of results and reporting.

Responsibilities were divided as following:

- Overall responsibility for the project, and for fieldwork and safety: Anatoly Sinitsyn.
- Field work preparation: Anatoly Sinitsyn, Arne Aalberg, Pavel Kotov.
- Field measurements: Pavel Kotov, Anatoly Sinitsyn, Arne Aalberg.
- Data processing: Pavel Kotov, Anatoly Sinitsyn.
- Reporting: Pavel Kotov, Anatoly Sinitsyn, Arne Aalberg.

3 General information about field sites and works

The 2018 field works took place in the settlements (small towns) Longyearbyen, Barentsburg, Pyramiden and Svea in the period July–August 2018. The following buildings were surveyed:

Longyearbyen:

- The UNIS Guest House (UGH), road 229.05.
- The building "Elvesletta Byggetrinn 1", located at the crossing of roads 500 and 503. This building constitutes The Vault Hotel.

Barentsburg:

- The three-storey residential building "Komplex GRZ", located at the heliport.

Pyramiden:

- The multi-purpose garage.

Svea:

- The two-storey building for temporal residence "Låven".
- The two-storey building for temporal residence "Brakke (Barakk) 2002".
- The multi-purpose garage/storage, “Magnetittlageret”.

The following works were performed:

i. Leveling between the reference points installed on the foundation parts (mostly piles) to assess stability, by assessing their relative movements since last round of leveling.
ii. Visual observations of buildings (photography documentation of the buildings and the monitoring points).
iii. Leveling of the monitoring points on the buildings and defining level of these points in relation to the reference points.
iv. Assessment of settlements in 2017–2018.

4 Planning and Preparation of Field Works

The overall scheme of field works is presented in Appendix A (Table 13–Table 15).

The main goals at the preparation stage in 2018 were:

- To collect all necessary instruments, list of equipment is presented in Appendix B, Table 16.
- Logistical planning and booking of transportation and accommodation:
    - Tickets and accommodation for partners from MSU (Moscow-Longyearbyen-Moscow).
    - Local accommodation was organized in the following premises: UNIS Guest House (Longyearbyen), Hostel "Pomor" (Barentsburg), Hotel "Tulpan" was used for housing in (Pyramiden), barracks is Svea (provided by Store Norske).
    - Transportation to/from Barentsburg and Pyramiden was done using the catamaran "Aurora Explorer", transportation by Lufttransport AS to/from Svea was organized by Store Norske.

5 Methods

The main operation during geodetical monitoring of structures is collection of elevation data fixed on the buildings. This data is used for assessment, analysis and forecast of settlements of the structures. Methodology for data processing is presented in [1]. Changes of elevations of the monitoring points in relation to each other or in relation to the reference points are the decisive parameters. The absolute displacement of the monitoring points is used for determining settlements of the structures. Absolute displacement is defined according to the standard [2], i.e., the movement of the monitored point relative to a anchored and stable vertical “fixed-point”. Absolute displacement S_{Hi} was calculated according to (1), standard error m_{2s} was calculated according to (2):

$$S_{Hi} = H_i - H_0 \quad (1)$$

H_0 – elevation of the monitoring point (bolt) in the initial (zero) cycle of monitoring;
H_i – elevation of the monitoring point (bolt) in an *i*-cycle of monitoring.

$$m_{2s} = m_2H_i + m_2H_0 \quad (2)$$

m_2H_0 and m_2H_i – mean square error of defining the elevation of monitoring point in zero and *i*-cycle of monitoring.

It was assumed that elevations of the reference points (stable vertical fixed-points) are constant in all cycles of the monitoring. The former assumption requires verification; hence several reference points were used in some locations. Ideally solid rock and rock anchored fixed-points are used in similar investigations for instance on the mainland, but this is not present near the monitored sites in Svalbard.

The elevations of the reference points are considered to be constant if the change of the excess between the reference points K will be according to (3):

$$K < 2m_{CT} \cdot 2\sqrt{n}, \quad (3)$$

n – quantity of stations by one measuring way.
m_{CT} – mean square error of determining the excess of stative (station), which equals to 0,30 mm.

6 Field surveys

Description of buildings for monitoring and drawings with monitoring points are presented in [1]. In 2018 some routines were slightly changed and improved, some monitoring bolts were excluded/added in the survey. Updated information on buildings is presented below.

The data-sets of the 2018- surveys are presented in the attached Excel files. The connections between the data sets and the relevant buildings are presented in **Error! Reference source not found.**.

Table 1. Overview of the 2018- data set.

File name	Description of data
File "Longyearbyen"	
Sheet "UGH1-UGH9 2018"	UNIS Guest House – leveling outside the building.
Sheet "UGH10-UGH18 2018"	UNIS Guest House – leveling under the building.
Sheet "Vault hotel 2018"	Vault hotel – leveling outside the building.
Sheet "UGH1-LH1 2018"	Leveling of the road from UNIS Guest House to The Vault Hotel.
Sheet "LRP1-UGH1 2018"	Leveling of the road from Power plant to UNIS Guest House.
Sheet "LRP1-LRP2 2018"	Leveling reference points near Power plant.
File "Pyramiden"	
Sheet " PB1-PB13-2018" and Sheet " PB14-PB18-2018"	Leveling outside the multi-purpose garage.
Sheet " PRP1-PB2 2018"	Leveling from reference point № 1 to the multi-purpose garage.
Sheet " PUB1-PUB19 2018"	Leveling under the multi-purpose garage.
Sheet " PRP1-PRP2 2018"	Leveling from reference point №1 to the reference point № 2.
Sheet " PRP1-PRP3 2018"	Leveling from reference point №1 to the reference point № 3.
Sheet " PRP1-PRP4 2018"	Leveling from reference point №1 to the reference point № 4.
File "Barentsburg"	
Sheet " BB1-BB17 2018"	Leveling outside the building ("Komplex GRZ").
Sheet " BRP1-BB1 2018"	Leveling from reference point №1 to building ("Komplex GRZ").
Sheet " BRP1-BRP2 2018"	Leveling from reference point №1 to №2.
Sheet " BRP2-BRP3 2018"	Leveling from reference point №2 to №3.
File "Svea"	
Sheet " SRP1-S1 2018"	Leveling from the reference point №1 to the "New green barrack" ("Låven").

Sheet " S1-S16 2018"	Leveling outside "New green barrack" ("Låven").
Sheet " SRP1-SB1 2018"	Leveling from the reference point №1 to the barack "2002".
Sheet " SB1-SB5 2018" and Sheet " SB6-SB9 2018"	Leveling outside the barack "2002".
Sheet " Garage 2018"	Leveling the garage from two stations ("station points").

6.1 Outline of monitoring program and notes on changes

Outline of monitoring program and notes on changes introduced in 2018 are outlined below.

Longyearbyen

Monitoring continued as planned in Longyearbyen, addressing the UNIS Guest House and The Vault Hotel as in 2017, and using the same fixed point (a bolt on the Power plant). The monitoring objects are depicted in (Figure 1).

Figure 1. Points for survey in Longyearbyen.

Additional reference point "R" (close to the Vault Hotel, described in the 2017 report) was excluded as it does not exist any longer.

Monitoring bolt LH 6 at The Vault Hotel was excluded from the measurements as it was not possible to get access with the measuring due to new elements of the drainage system. A modified monitoring plan at The Vault Hotel is presented in Figure 2.

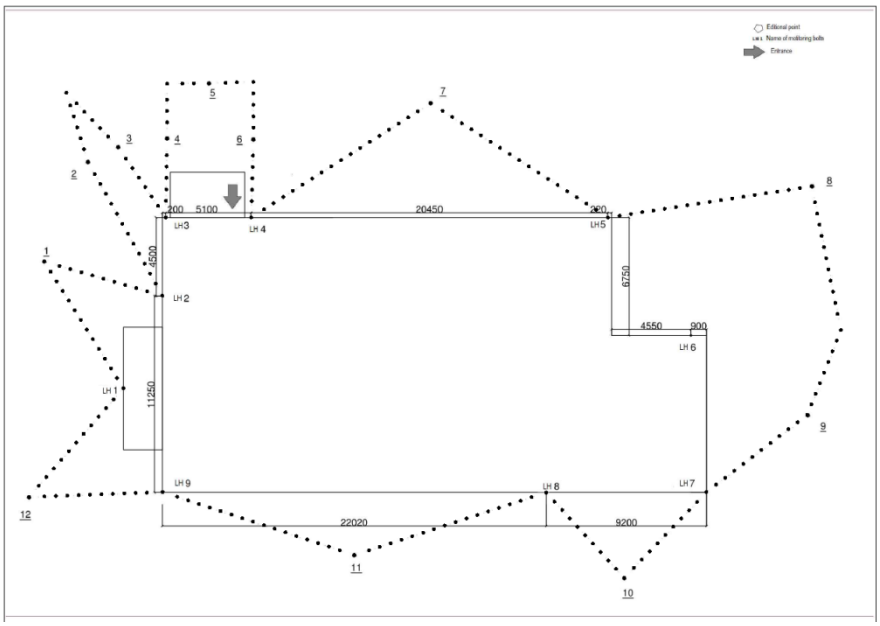

Figure 2. Sketch of monitoring positions at The Vault Hotel (showing locations of bolts and leveling stations).

Barentsburg

The three-story building "Komplex GRZ" and the three reference points (2017) remained in the monitoring program in Barentsburg (Figure 3).

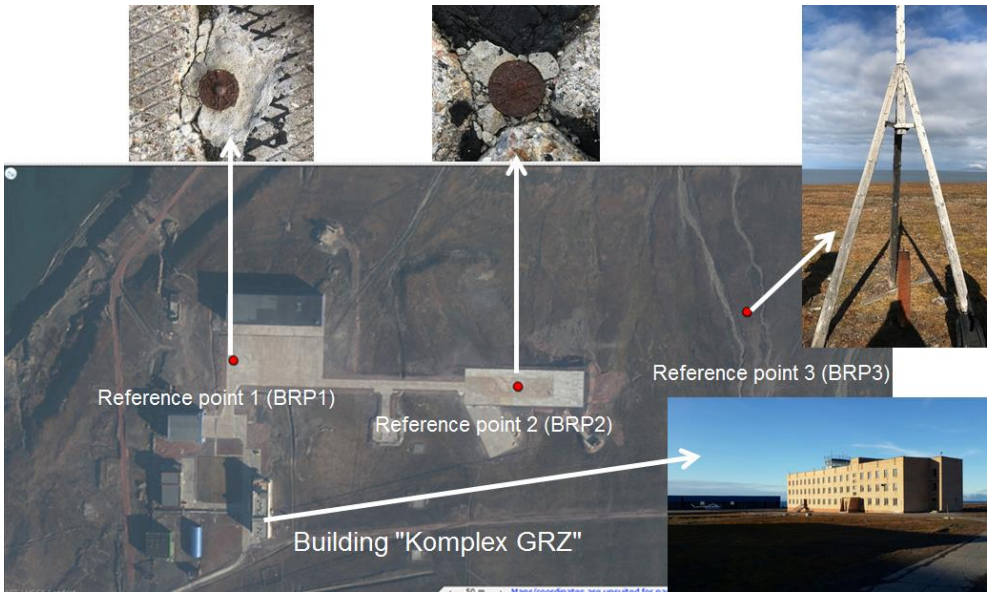

Figure 3. The three-storied building "Komplex GRZ" and location of the reference points.

Pyramiden

The four reference points from 2017 remained in Pyramiden. An additional "Reference point N5" was established close to the Reference point 4. Seven monitoring points remained on the road (from the garage to the Reference points 3 and 4), monitoring points PR1 and PR2 (on the road) were excluded from

monitoring work as the bolts at these locations was damaged/ lost (probably due to snow cleaning during winter). The multi-purpose garage (Figure 4) was monitored again.

Figure 4. Locations of the monitoring objects in Pyramiden: the multi-purpose garage, reference points, and monitoring points on the road (PR1–PR9).

Geodetic track around the multi-purpose garage was divided in two parts (the right and the left track). The following monitoring bolts were excluded from the monitoring due to lack of access: PB1, PB10*, PB12. A new bolt "PB1*" was installed above the location of the previous PB1, which had disappeared (see Figure 5).

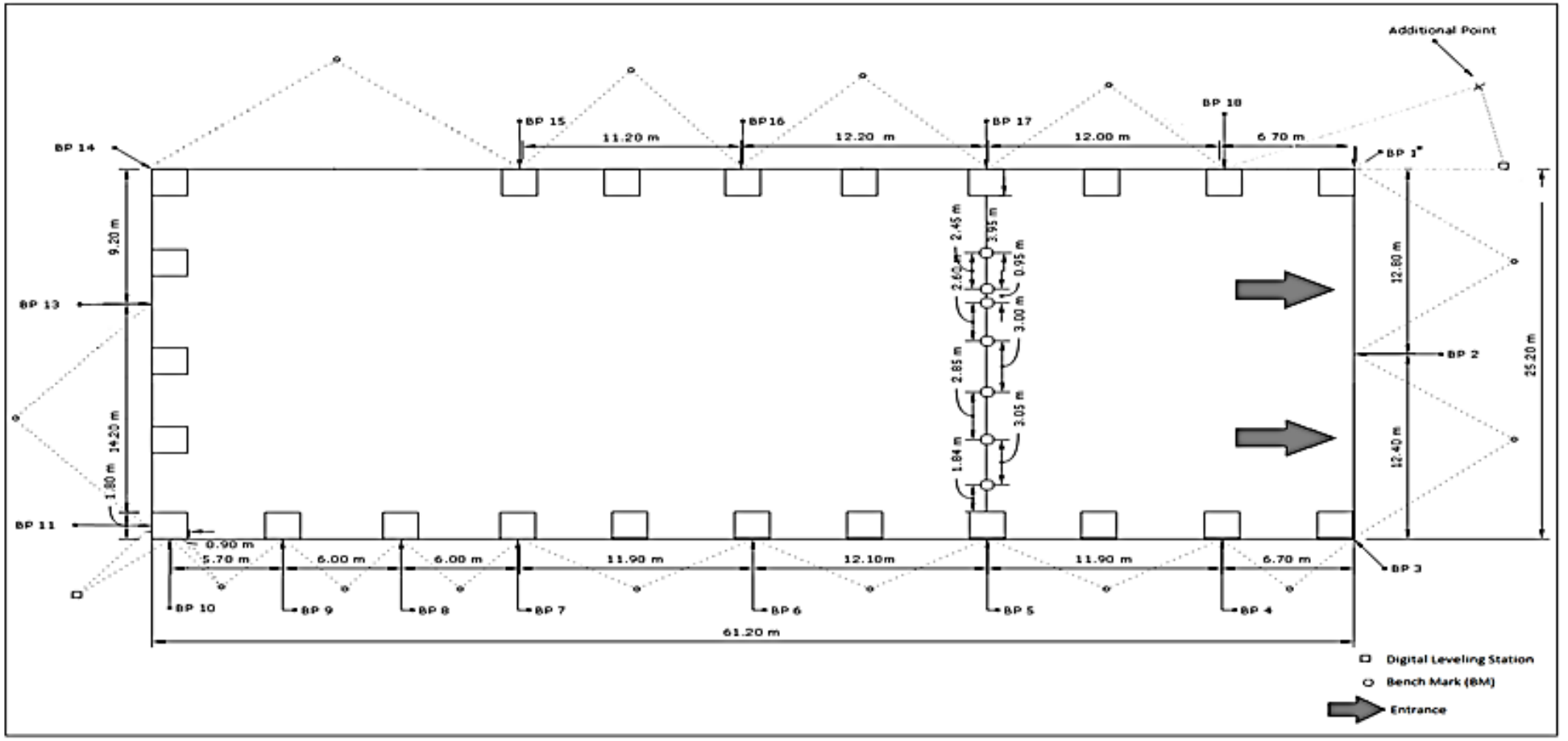

Figure 5. Sketch of monitored points and tracks at the multi-purpose garage (locations of bolts and leveling stations).

Svea

The measurements were performed from the same fixed reference point as was used in 2017. Two buildings "Låven" and the multi-purpose garage “Magnetittlageret” were surveyed. A new building was included in the 2018-program, namely the barack "2002" (Figure 6).

Figure 6. Locations of the monitored buildings in Svea.

Two additional monitoring bolts (S13–S16) were added and surveyed at the barack "Låven" (Figure 7).

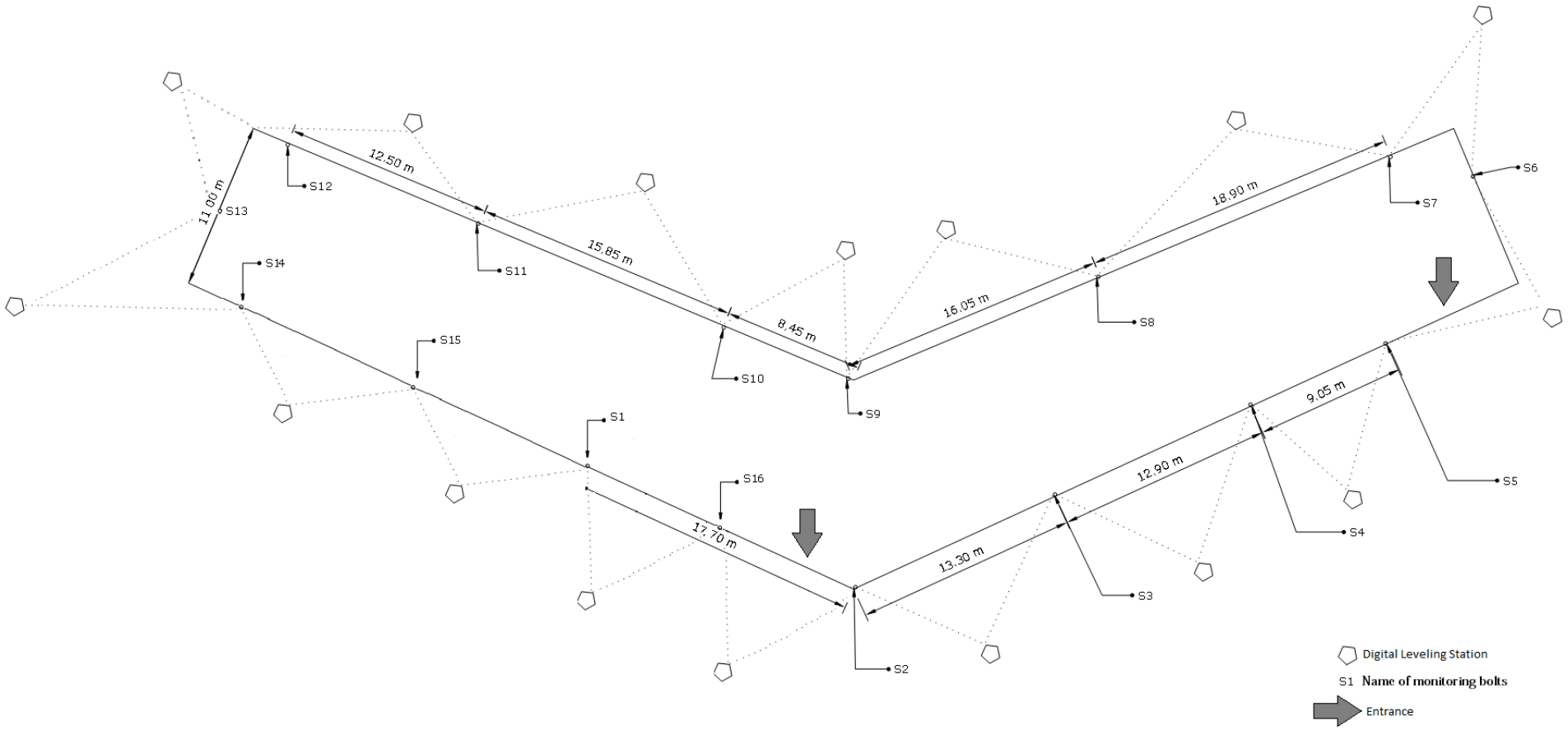

Figure 7. Locations of bolts and leveling stations at the barack "Låven".

Barack "2002" was surveyed for the first time, with the setup as shown in Figure 8. The height measurements were performed in relation to the reference point mentioned above.

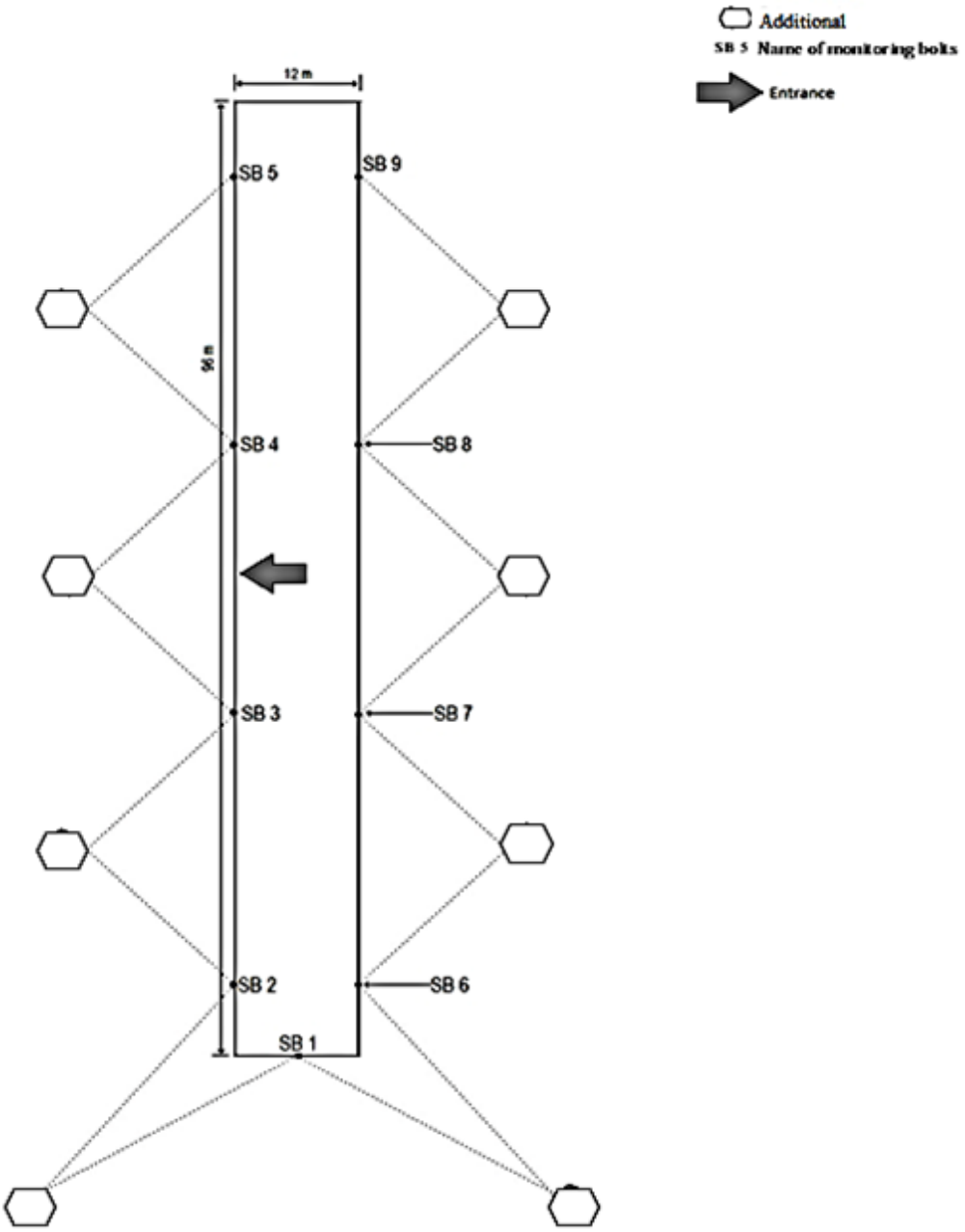

Figure 8. Locations of bolts and leveling stations at the barack "2002".

6.2 Results of 2018- survey

Elevations of the monitoring bolts and reference points obtained during the 2018- survey are presented in this section (Table 2–Table 5). All measurements were performed for first or second accuracy class of survey (Table 6–Table 9).

Longyearbyen

Raw data and calculated elevations are presented in Excel file «Longyearbyen». Elevations of monitoring bolts and standard errors of measurements are presented in Table 2.

Table 2. Results of survey in Longyearbyen in 2018.

№ of reference point/ monitoring bolt	Elevation relative to the reference point, m	Standard error of measurements, m
LRP1	0	0
LRP2	0,5820	
UGH1	8,1708	0,0008
UGH2	8,6970	0,0003
UGH3	9,0875	0,0003
UGH4	9,2115	0,0003
UGH5	10,0528	0,0003
UGH6	10,4687	0,0003
UGH7	10,7642	0,0003
UGH8	10,3771	0,0003
UGH9	9,7183	0,0003
UGH10	8,3615	0,0004
UGH11	8,2305	0,0004
UGH12	8,2706	0,0004
UGH13	8,2408	0,0004
UGH14	8,4316	0,0004
UGH15	8,6457	0,0004
UGH16	8,1875	0,0004
UGH17	7,6723	0,0004
UGH18	7,2708	0,0004
LH 1	20,1076	0,0005
LH2	19,9279	0,0004
LH3	19,9303	0,0004
LH 4	19,9309	0,0004
LH 5	19,9316	0,0004
LH 7	19,9289	0,0004
LH 8	19,9187	0,0004
LH 9	19,9277	0,0004

Barentsburg

Raw data and calculated elevations are presented in the Excel file «Barentsburg». Elevations of monitoring bolts and standard errors of measurements are presented in Table 3.

Table 3. Results of survey in Barentsburg in 2018.

№ reference point/ monitoring bolts	Height relative to the reference point, m	Standard error of measurements, m
BRP1	0	0
BRP2	3,1512	0,0003
BRP3	3,5249	0,0022
BB1	4,2151	0,0002
BB2	4,2316	0,0001
BB3	4,3840	0,0001
BB4	4,3897	0,0001
BB5	4,4523	0,0001
BB6	4,2686	0,0001
BB7	4,4279	0,0001
BB8	4,5663	0,0001
BB9	4,2583	0,0001
BB10	4,4586	0,0001
BB11	4,4465	0,0001
BB12	4,4339	0,0001
BB13	4,4271	0,0001
BB14	4,4050	0,0001
BB15	4,3260	0,0001
BB16	4,3741	0,0001
BB17	4,4819	0,0001

Pyramiden

Raw data and calculated elevations are presented in Excel file «Pyramiden». Elevations of monitoring bolts and standard errors of measurements are presented in Table 4.

Table 4. Results of survey in Pyramiden in 2018.

№ reference point/ monitoring bolts	Height relative to the reference point, m	Standard error of measurements, m
PRP1	0	0
PRP2	1,0409	0,0003
PRP3	3,5249	0,0003
PRP4	10,7340	0,0002
PRP5	11,1757	0,0002
PB1		
PB2	6,7584	0,0002

№ reference point/ monitoring bolts	Height relative to the reference point, m	Standard error of measurements, m
PB3	5,8943	0,0001
PB4	4,7074	0,0001
PB5	4,6922	0,0001
PB6	4,6986	0,0001
PB7	4,7110	0,0001
PB8	4,6511	0,0001
PB9	4,6140	0,0001
PB10	4,5859	0,0001
PB11	6,3024	0,0001
PB13	6,4114	0,0001
PB14	6,5453	0,0002
PB16	4,5631	0,0002
PB15	4,5701	0,0002
PB17	4,6084	0,0002
PB18	4,5657	0,0002
PB 1*	6,4053	0,0002
PR 3	2,1194	0,0002
PR 4	2,3072	0,0002
PR 5	2,3897	0,0002
PR 6	2,7594	0,0002
PR 7	2,8552	0,0002
PR 8	3,8036	0,0002
PUB 1	5,5053	0,0003
PUB 2	5,4281	0,0003
PUB 3	5,5695	0,0003
PUB 4	5,5936	0,0003
PUB 5	5,5040	0,0003
PUB 6	5,5761	0,0003
PUB 7	5,5927	0,0003
PUB 8	5,5883	0,0003
PUB 9	5,5788	0,0003
PUB 10	5,6328	0,0003
PUB 11	5,5210	0,0003
PUB 12	5,5731	0,0003
PUB 13	5,5701	0,0003
PUB 14	5,5867	0,0003
PUB 15	5,6059	0,0003
PUB 16	5,5775	0,0003
PUB 17	5,5473	0,0003
PUB 18	5,4541	0,0003
PUB 19	5,5485	0,0003

Svea

Raw data and calculated elevations are presented in Excel file «Svea». Elevations of monitoring bolts and standard errors of measurements are presented in Table 5.

Table 5. Results of survey in Svea in 2018.

№ reference point/ monitoring bolts	Height relative to the reference point, m	Standard error of measurements, m
SRP1	0	0
S1	9,8897	0,0009
S2	9,8446	0,0003
S3	9,8535	0,0003
S4	9,8165	0,0003
S5	9,8545	0,0003
S6	9,9295	0,0003
S7	10,0987	0,0003
S8	10,0902	0,0003
S9	10,0553	0,0003
S10	9,9448	0,0003
S11	9,9505	0,0003
S12	10,2042	0,0003
S13	9,9467	0,0003
S14	9,9430	0,0003
S15	9,9508	0,0003
S16	9,9371	0,0003
SB1	-5,4886	0,0006
SB2	-5,4414	0,0002
SB3	-5,5343	0,0002
SB4	-5,5257	0,0002
SB5	-5,5629	0,0002
SB6	-6,4766	0,0003
SB7	-6,9901	0,0003
SB8	-6,4733	0,0003
SB9	-6,6027	0,0003

7 Settlements of the buildings in the years 2017 and 2018

7.1 Assessment of data quality

Assessment of data quality is presented in Table 6–Table 9. Analysis of the error of closure (deviation between start and stop of a closed levelling track) and the maximum allowable error showed that the measurement quality in the 2018 measurement series was better than in 2017, for all monitored objects. In several cases the measurements were with an outcome fulfilling the requirements of accuracy class 1, i.e. the highest (best) accuracy class (see Table 6–Table 9**Error! Reference source not found.**).

Table 6. Assessment of data quality of measurement in Longyearbyen.

Line	2017						2018					
	Error of closure, m	Parameter	Value	Equation	Maximal allowable error, m	Class	Error of closure, m	Parameter	Value	Equation	Maximal allowable error, m	Class
LRP1-UGH 1	-0,0084	n	44	$\pm 5\sqrt{n}$	-0,00995	3	0,0019	n	44	$\pm 0.3\sqrt{n}$	0,0020	1
		L	0,98	$\pm 10\sqrt{L}$	-0,00991	3		L	0,98	$\pm 3\sqrt{L}$	0,0030	1
UGH 1- LH 1	0,0122	n	26	$\pm 5\sqrt{n}$	0,02550	4	0,0045	n	30	$\pm 1{,}5\sqrt{n}$	0,0082	3
		L	0,56	$\pm 20\sqrt{L}$	0,01499	4		L	0,67	$\pm 10\sqrt{L}$	0,0082	3
Guest house (UGH1-UGH9)	-0,0004	n	20	$\pm 0.3\sqrt{n}$	-0,00134	1	-0,0017	n	20	$\pm 0.5\sqrt{n}$	-0,0022	2
		L	0,38	$\pm 3\sqrt{L}$	-0,00184	1		L	0,38	$\pm 3\sqrt{L}$	-0,0018	1
Guest house (UGH10-UGH18)	0,0088	n	22	$\pm 5\sqrt{n}$	0,02345	4	-0,0023	n	22	$\pm 0.5\sqrt{n}$	-0,0023	2
		L	0,13	$\pm 10\sqrt{L}$	0,01089	3		L	0,14	$\pm 5\sqrt{L}$	-0,0037	2
The Vault Hotel	0,0006	n	24	$\pm 0.3\sqrt{n}$	0,00147	1	-0,0006	n	24	$\pm 0.3\sqrt{n}$	-0,0015	1
		L	0,47	$\pm 3\sqrt{L}$	0,00206	1		L	0,34	$\pm 3\sqrt{L}$	-0,0023	1

Note:
n – number of stations;
L – distance, km.

Table 7. Assessment of data quality of measurement in Barentsburg.

Line	2017						2018					
	Error of closure, m	Parameter	Value	Equation	Maximal allowable error, m	Class	Error of closure, m	Parameter	Value	Equation	Maximal allowable error, m	Class
BRP1-BRP2	-0,0251	n	13	$\pm 5\sqrt{n}$	-0,0180		0,0003	n	14	$\pm 0.3\sqrt{n}$	0,0011	1
		L	0,59	$\pm 20\sqrt{L}$	-0,0153			L	0,61	$\pm 3\sqrt{L}$	0,0023	1
BRP2-BRP3	-0,0109	n	11	$\pm 5\sqrt{n}$	-0,0166	4	0,0041	n	10	$\pm 1{,}5\sqrt{n}$	0,0047	3
		L	0,53	$\pm 20\sqrt{L}$	-0,0146	4		L	0,55	$\pm 10\sqrt{L}$	0,0074	3
BRP1-BB1							0,0009	n	6	$\pm 0.5\sqrt{n}$	0,0012	2
								L	0,26	$\pm 3\sqrt{L}$	0,0015	1
Building							0,0015	n	34	$\pm 0.3\sqrt{n}$	0,0017	1
								L	0,34	$\pm 3\sqrt{L}$	0,0017	1

Note:
n – number of stations;
L – distance, km.

Table 8. Assessment of data quality of measurement in Pyramiden.

Line	2017						2018					
	Error of closure, m	Parameter	Value	Equation	Maximal allowable error, m	Class	Error of closure, m	Parameter	Value	Equation	Maximal allowable error, m	Class
PRP1-PRP2	-0,0011	n	12	$\pm 0.5\sqrt{n}$	0,00173	2	0,0015	n	14	$\pm 0.5\sqrt{n}$	0,0019	2
		L	0,52	$\pm 5\sqrt{L}$	0,00360	2		L	0,55	$\pm 5\sqrt{L}$	0,0037	2
PRP1-PRP3	-0,0110	n	18	$\pm 1.5\sqrt{n}$	0,00636	3	0,0011	n	18	$\pm 0.3\sqrt{n}$	0,0013	1
		L	0,72	$\pm 10\sqrt{L}$	0,00849	3		L	0,72	$\pm 3\sqrt{L}$	0,0025	1
PRP1-PRP4	0,0020	n	24	$\pm 0.5\sqrt{n}$	0,00245	2	0,0006	n	26	$\pm 0.3\sqrt{n}$	0,0015	1
		L	0,98	$\pm 5\sqrt{L}$	0,00496	2		L	0,98	$\pm 3\sqrt{L}$	0,0030	1
PRP1-PB1	0,0042	n	12	$\pm 1.5\sqrt{n}$	0,00520	3	-0,0017	n	12	$\pm 0.5\sqrt{n}$	0,0017	2
		L	0,44	$\pm 10\sqrt{L}$	0,00663	3		L	0,44	$\pm 5\sqrt{L}$	0,0033	2
Garage	0,0017	n	50	$\pm 0.5\sqrt{n}$	0,00212	2	0,0010	n	20	$\pm 0.3\sqrt{n}$	0,0013	1
		L	1,14	$\pm 5\sqrt{L}$	0,00321	2		L	0,29	$\pm 3\sqrt{L}$	0,0016	1
							0,0006	n	14	$\pm 0.3\sqrt{n}$	0,0011	1
								L	0,28	$\pm 3\sqrt{L}$	0,0016	1
Under the garage							-0,0007	n	4	$\pm 0.5\sqrt{n}$	0,0010	2
								L	0,30	$\pm 5\sqrt{L}$	0,0027	2

Note:
n – number of stations;
L – distance, km.

Table 9. Assessment of data quality of measurement in Svea.

Line	2017						2018					
	Error of closure, m	Parameter	Value	Equation	Maximal allowable error, m	Class	Error of closure, m	Parameter	Value	Equation	Maximal allowable error, m	Class
SRP1-S1	0,0056	n	8	$\pm 5\sqrt{n}$	0,01414	4	0,0003	n	8	$\pm 0.3\sqrt{n}$	0,0008	1
		L	0,32	$\pm 10\sqrt{L}$	0,00566	3		L	0,32	$\pm 3\sqrt{L}$	0,0017	1
Green barrack	-0,0012	n	22	$\pm 0.3\sqrt{n}$	-0,00141	1	0,0015	n	34	$\pm 0.3\sqrt{n}$	0,0017	1
		L	0,35	$\pm 3\sqrt{L}$	-0,00177	1		L	0,35	$\pm 3\sqrt{L}$	0,0017	1
SRP1-SB1							0,0001	n	6	$\pm 0.3\sqrt{n}$	0,0007	1
								L	0,32	$\pm 3\sqrt{L}$	0,0017	1
Barack "2002" (left side)							0,0004	n	8	$\pm 0.3\sqrt{n}$	0,0008	1
								L	0,14	$\pm 3\sqrt{L}$	0,0011	1
Barack "2002" (right side)							-0,0002	n	8	$\pm 0.3\sqrt{n}$	-0,0008	1
								L	0,14	$\pm 3\sqrt{L}$	-0,0011	1

Note:
n – number of stations;
L – distance, km.

7.2 Results

Settlements of the buildings in 2017–2018 were obtained by comparison of the actual heights of the monitoring points between 2017 and 2018. The standard error of measurements was also obtained, serving as an indicator of the accuracy level.

Longyearbyen

Data for buildings in Longyearbyen is presented in Table 10.

Table 10. Comparison of elevations of monitoring points in Longyearbyen for 2017–2018.

№ reference point/ monitoring bolts	Elevation relative to the reference point, m	Standard error of measurements, m	Elevation relative to the reference point, m	Standard error of measurements, m	Absolute displacement (S_{Hi}), mm	Standard error (m_{2S}), mm
	2017		2018			
LRP1	0	0	0	0		
UGH1	8,1648	0,0122	8,1708	0,0008	6,0	12,2
UGH2	8,6984	0,0003	8,6970	0,0003	-1,4	0,4
UGH3	9,0885	0,0003	9,0875	0,0003	-0,9	0,4
UGH4	9,2107	0,0003	9,2115	0,0003	0,9	0,4
UGH5	10,0526	0,0003	10,0528	0,0003	0,1	0,4
UGH6	10,4661	0,0003	10,4687	0,0003	2,5	0,4
UGH7	10,7649	0,0003	10,7642	0,0003	-0,6	0,4
UGH8	10,3773	0,0003	10,3771	0,0003	-0,2	0,4
UGH9	9,7186	0,0003	9,7183	0,0003	-0,3	0,4
UGH10	8,3598	0,0009	8,3615	0,0004	1,7	0,9
UGH11	8,2273	0,0009	8,2305	0,0004	3,2	0,9
UGH12	8,2668	0,0009	8,2706	0,0004	3,8	0,9
UGH13	8,2357	0,0009	8,2408	0,0004	5,1	0,9
UGH14	8,4259	0,0009	8,4316	0,0004	5,7	0,9
UGH15	8,6460	0,0009	8,6457	0,0004	-0,3	0,9
UGH16	8,1894	0,0009	8,1875	0,0004	-1,9	0,9
UGH17	7,6774	0,0009	7,6723	0,0004	-5,1	0,9
UGH18	7,2779	0,0009	7,2708	0,0004	-7,1	0,9
LH 1	20,1006	0,0077	20,1076	0,0005	7,0	7,7
LH2	19,9302	0,0003	19,9279	0,0004	-2,3	0,5
LH3	19,9297	0,0003	19,9303	0,0004	0,6	0,5
LH 4	19,9294	0,0003	19,9309	0,0004	1,5	0,5
LH 5	19,9286	0,0003	19,9316	0,0004	3,0	0,5
LH 7	19,9276	0,0003	19,9289	0,0004	1,4	0,5
LH 8	19,91812078	0,0003	19,9187	0,0004	0,6	0,5
LH 9	19,92898802	0,0003	19,9277	0,0004	-1,3	0,5

The reference points in Longyearbyen did not change their position over the 2017–2018 (fixed points were stable). Stationary points were not installed on the road from the reference point (LRP1 1) to UNIS Guest House (UGH 1) due to practical issues, hence accuracy of measurements was different in 2017 and 2018. In 2017, the standard error m_{2s} on the road was 1.22 cm, and difference of measurements in both directions was 0.6 cm. survey was conducted according the 3rd class of accuracy. In 2018, survey was conducted according to the 1st class of accuracy. Hence, it is not possible to define the change of elevation of the monitoring point UGH 1. In present assessment, position of UGH 1 is assumed to be stable between 2017 and 2018, and equal to the value obtained in 2018. This can be the reason that the elevation of some of monitoring points increased, which practically means that the pile foundations are lifted up (see Figure 9).

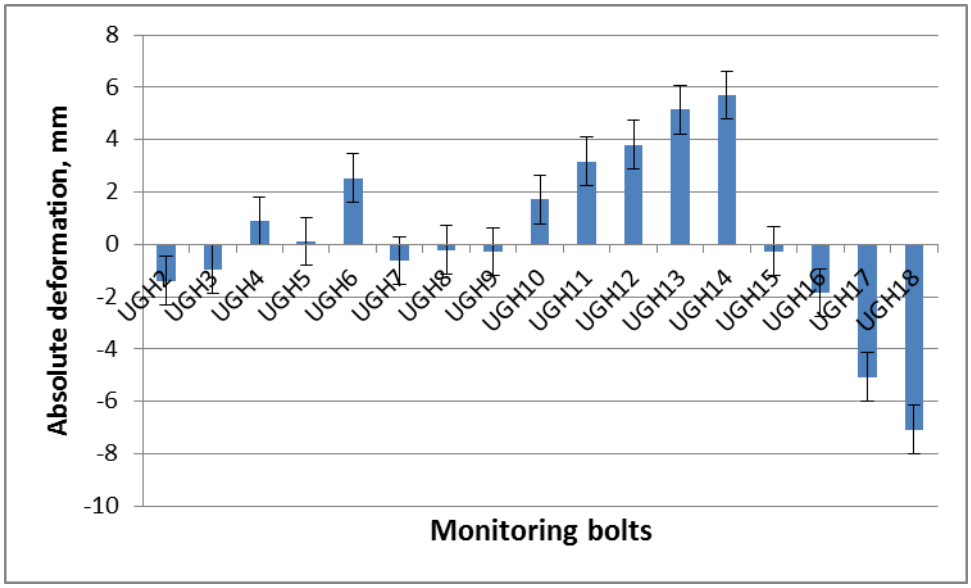

Figure 9. Absolute displacement of monitoring bolts at UNIS Guest House in 2017–2018.

Similar results were obtained for monitoring point LH 1 at The Vault Hotel, where difference of measurements (in back and forth directions) is higher than the standard error. Elevation of LH 1 is assumed to be stable in 2017–2018. Displacements of several monitoring points at The Vault Hotel have positive values (Figure 10), which signalize that the pile foundations are lifted up.

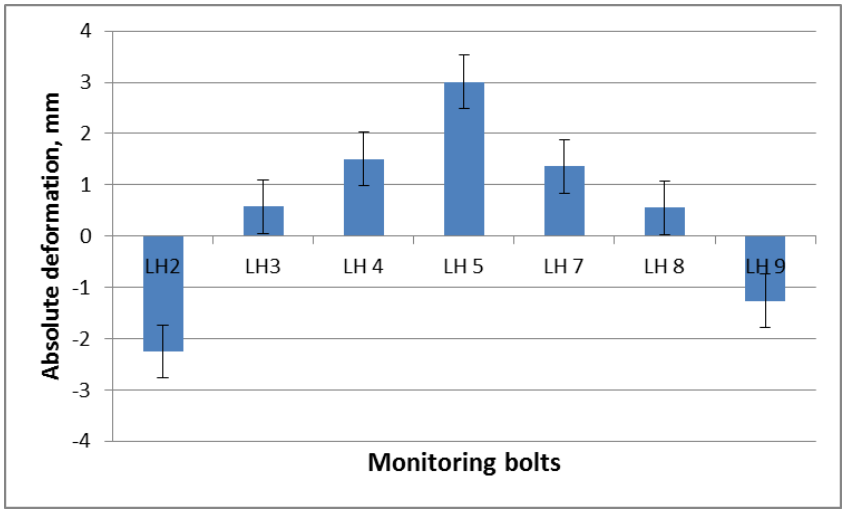

Figure 10. Absolute displacements of monitoring bolts (and errors of measurements) at The Vault Hotel in 2017–2018.

Presented displacements of monitoring points at UNIS Guest House and The Vault Hotel should be considered as estimates only, a confirmation and possible more accurate data are expected to be obtained in the 2019- field season.

Barentsburg

Only preliminary field survey was performed in Barentsburg in 2017, the results of this survey cannot serve as a solid base-line data set. The data set of 2018 will serve as such, hence comparative analysis will be performed firstly considering the 2019- field season.

Pyramiden

Data for the structures in Pyramiden is presented in Table 11.

Table 11. Comparison of elevations of the multi-purpose garage and part of the road in Pyramiden for 2017–2018.

№ reference point/ monitoring bolts	Elevation relative to the reference point, m	Standard error of measurements, m	Elevation relative to the reference point, m	Standard error of measurements, m	Absolute displacement (S_{Hi}), mm	Standard error (m_{2S}), mm
	2017		2018			
PRP1	0	0	0	0		
PB1	6,4051	0,0007				
PB2	6,7602	0,0007	6,7584	0,0002	-1,8	0,7
PB3	5,8970	0,0006	5,8943	0,0001	-2,6	0,6
PB4	4,7087	0,0006	4,7074	0,0001	-1,3	0,6
PB5	4,6931	0,0006	4,6922	0,0001	-0,9	0,6
PB6	4,6998	0,0006	4,6986	0,0001	-1,2	0,6
PB7	4,7131	0,0006	4,7110	0,0001	-2,1	0,6
PB8	4,6543	0,0006	4,6511	0,0001	-3,2	0,6

№ reference point/ monitoring bolts	Elevation relative to the reference point, m	Standard error of measurements, m	Elevation relative to the reference point, m	Standard error of measurements, m	Absolute displacement (S_{Hi}), mm	Standard error (m_{2S}), mm
	2017		2018			
PB9	4,6188	0,0006	4,6140	0,0001	-4,8	0,6
PB10	4,5910	0,0006	4,5859	0,0001	-5,1	0,6
PB11	6,3265	0,0006	6,3024	0,0001	-24,1*	0,6
PB13	6,4342	0,0006	6,4114	0,0001	-22,8*	0,6
PB14	6,5488	0,0006	6,5453	0,0002	-3,5	0,6
PB15	4,5677	0,0006	4,5631	0,0002	-4,6	0,6
PB16	4,5741	0,0006	4,5701	0,0002	-4,0	0,6
PB17	4,6105	0,0006	4,6084	0,0002	-2,1	0,6
PB18	4,5692	0,0006	4,5657	0,0002	-3,4	0,6
PR 3	2,1835	0,0008	2,1194	0,0002	-64,1**	0,8
PR 4	2,3703	0,0008	2,3072	0,0002	-63,1**	0,8
PR 5	2,4572	0,0008	2,3897	0,0002	-67,4**	0,8
PR 6	2,8132	0,0008	2,7594	0,0002	-53,8**	0,8
PR 7	2,9169	0,0008	2,8552	0,0002	-61,7**	0,8
PR 8	3,8677	0,0008	3,8036	0,0002	-64,0**	0,8
PUB 1	5,5052		5,5052	0,0003	-0,1	0,3
PUB 2	5,4271		5,4279	0,0003	0,8	0,3
PUB 3	5,5689		5,5693	0,0003	0,5	0,3
PUB 4	5,5933		5,5935	0,0003	0,2	0,3
PUB 5	5,5035		5,5038	0,0003	0,3	0,3
PUB 6	5,5754		5,5760	0,0003	0,6	0,3
PUB 7	5,5918		5,5925	0,0003	0,7	0,3
PUB 8	5,5875		5,5881	0,0003	0,7	0,3
PUB 9	5,5783		5,5786	0,0003	0,3	0,3
PUB 10	5,6319		5,6326	0,0003	0,7	0,3
PUB 11	5,5206		5,5208	0,0003	0,2	0,3
PUB 12	5,5724		5,5729	0,0003	0,5	0,3
PUB 13	5,5691		5,5700	0,0003	0,9	0,3
PUB 14	5,5866		5,5865	0,0003	0,0	0,3
PUB 15	5,6049		5,6057	0,0003	0,8	0,3
PUB 16	5,5774		5,5773	0,0003	-0,1	0,3
PUB 17	5,5467		5,5471	0,0003	0,5	0,3
PUB 18	5,4535		5,4539	0,0003	0,5	0,3
PUB 19	5,5481		5,5483	0,0003	0,2	0,3

* – these values were obtained with inverted bar staff, hence a difference of 20 mm was introduced. This value of 20 was taken into account to calculated absolute values of displacements for the points PB11, PB13 presented in Figure 11.

** – these values include heights of the base plate, which is 60 mm; thickness of the base plate was taken into account to calculate the absolute values of displacements for points PR3–PR8 presented in Figure 11.

Assessment according to (3) showed that only the reference points PRP1 and PRP4 were stable; and PRP2 and PRP4 were not. Hence additional reference point PRP5 was established for future surveys and comparisons. Absolute displacement of the monitoring points on the outer walls at the multi-purpose garage is presented in Figure 11. The Direction of the bar staff was changed on inverted (i.e. the bar staff was turned on the upside down) on the points PB11, PB13. Hence the difference of measurements (which equals to the diameter on monitoring bolt) was taken into account on Figure 11. One can see that the highest displacement is at the monitoring points PB9–PB11, where the drainage of water (collected on the roof) goes into the ground. Another area with large settlements is at the points PB16–PB19, this may be caused by a heavy tank installed inside on the building close to these points.

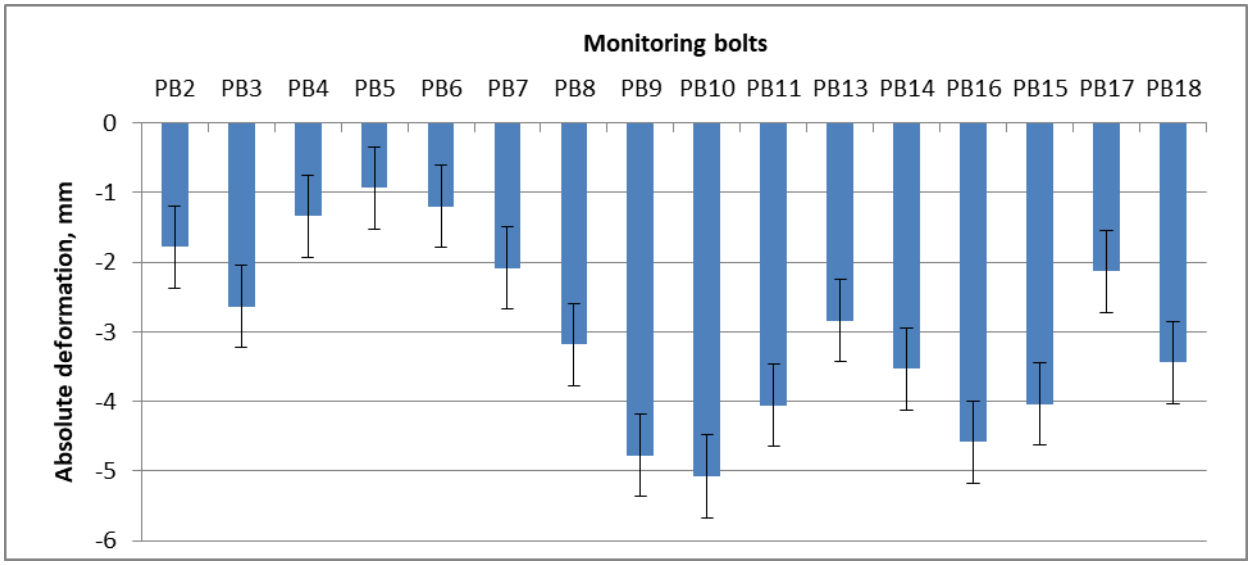

Figure 11. Absolute displacements of monitoring points (and errors of measurements) on the outer walls at the multi-purpose garage in Pyramiden.

Absolute displacement and errors of measurements of the monitoring points under the multi-purpose garage are presented in Figure 12. Standard errors were not assessed in 2017, hence the presented 2017–2018 comparison can serve as an estimate only. However, it seems as the settlements under the central part of the garage are smaller than at the outer walls.

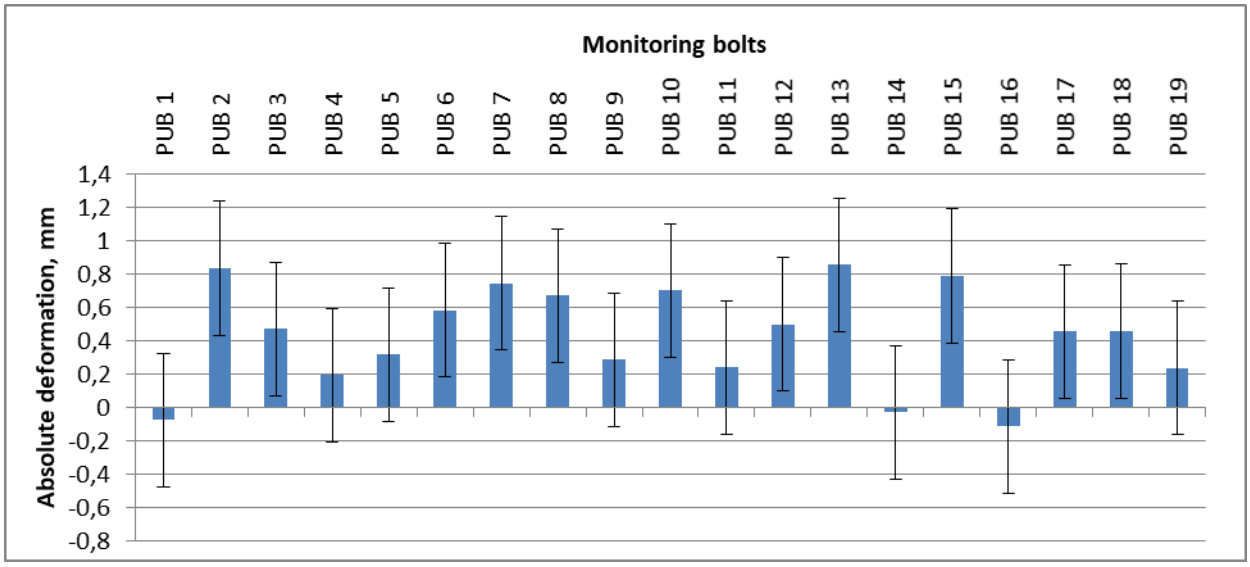

Figure 12. Absolute displacements and errors of measurements of the monitoring points under the multi-purpose garage in Pyramiden.

Absolute displacement and errors of measurements on the road from multi-purpose garage to the reference points is presented in Figure 13. During the 2017 survey, the bar staff was placed on a base plate, in 2018 the bar staff was placed directly on the monitoring bolts. Occurred difference in measurements was included in calculations. Largest displacement (settlement) found on the road is 8 mm. Also, heave of the road was detected near the point PR 6, which can be caused by water flow in a drainage culvert nearby this point.

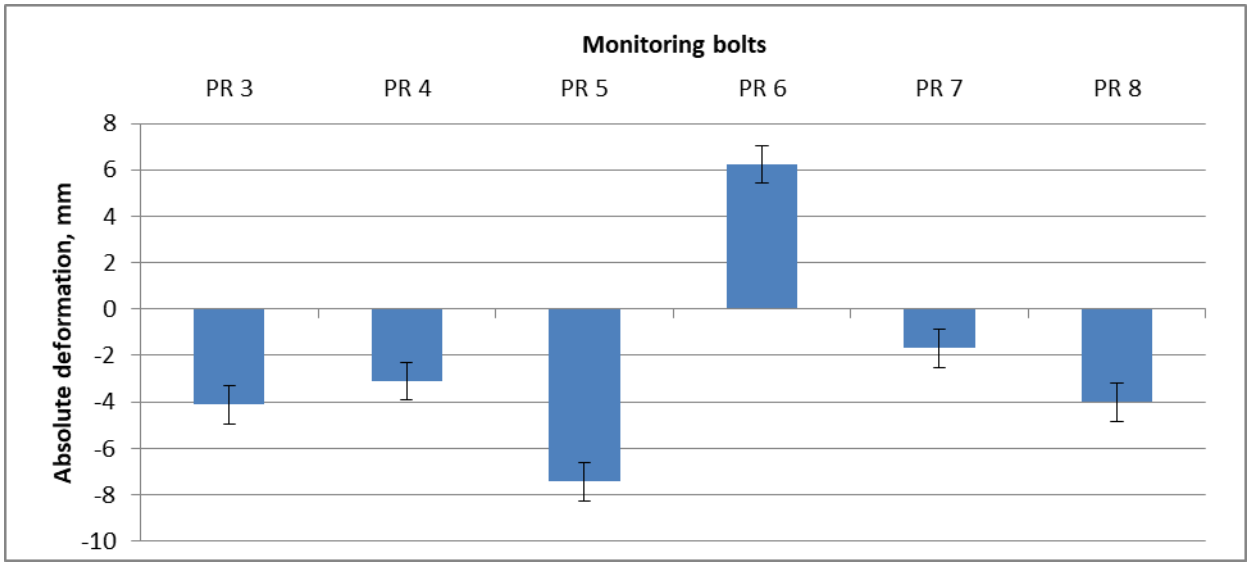

Figure 13. Absolute displacement (and errors of measurements) of monitoring bolts on the road from multi-purpose garage towards the reference points.

Svea

Data for the barack "Låven" in Svea is presented in Table 12.

Table 12. Comparison of elevations of monitoring points at the barack "Låven" for 2017–2018.

№ reference point/ monitoring bolts	Elevation relative to the reference point, m	Standard error of measurements, m	Elevation relative to the reference point, m	Standard error of measurements, m	Absolute displacement (S_{Hi}), mm	Standard error (m_{2S}), mm
	2017		2018			
SRP1	0	0	0	0		
S1	9,8926	0,0073	9,8897	0,0009	-2,9	7,3
S2	9,8488	0,0003	9,8446	0,0003	-4,3	0,4
S3	9,8568	0,0003	9,8535	0,0003	-3,3	0,4
S4	9,8206	0,0003	9,8165	0,0003	-4,1	0,4
S5	9,8576	0,0003	9,8545	0,0003	-3,1	0,4
S6	9,9331	0,0003	9,9295	0,0003	-3,6	0,4
S7	10,1020	0,0003	10,0987	0,0003	-3,2	0,4
S8	10,0928	0,0003	10,0902	0,0003	-2,6	0,4
S9	10,0567	0,0003	10,0553	0,0003	-1,4	0,4
S10	9,9456	0,0003	9,9448	0,0003	-0,8	0,4
S11	9,9505	0,0003	9,9505	0,0003	0,0	0,4
S12	10,2037	0,0003	10,2042	0,0003	0,4	0,4

The standard error is higher than the difference of measurements (in back and forth directions) for the first monitoring point (S1). Displacements for the barack "Låven" are presented in Figure 14. One can see that most of the monitoring points have settled (except S1), and the settlements do not exceed 4 mm.

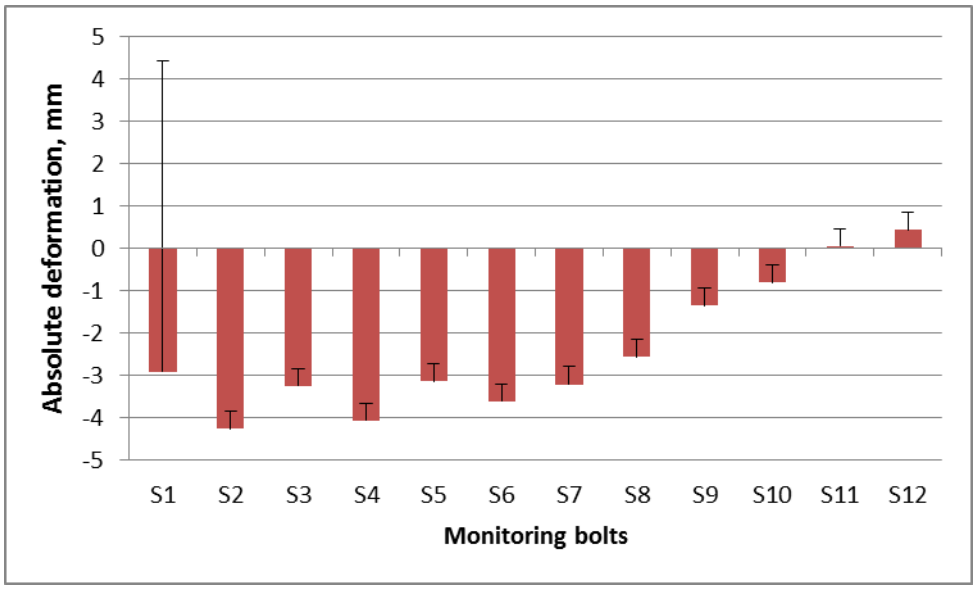

Figure 14. Absolute displacements (and errors of measurements) at the barack "Låven".

Multi-purpose garage “Magnetittlageret” is located on a shallow concrete foundation (thick plate), which has several parallel ventilation channels going across the building length axis (see Figures 18–19 in [1]). We measured the settlement of the foundation relative to the foundation surface of the first channel (i.e., top of the channel). Each side of the garage (Figure 15) was measured separately. Elevations of monitoring points relative to the first points on each side of the garage for 2017–2018 are presented in Figure 16–Figure 17.

Figure 15. Multi-purpose garage “Magnetittlageret”.

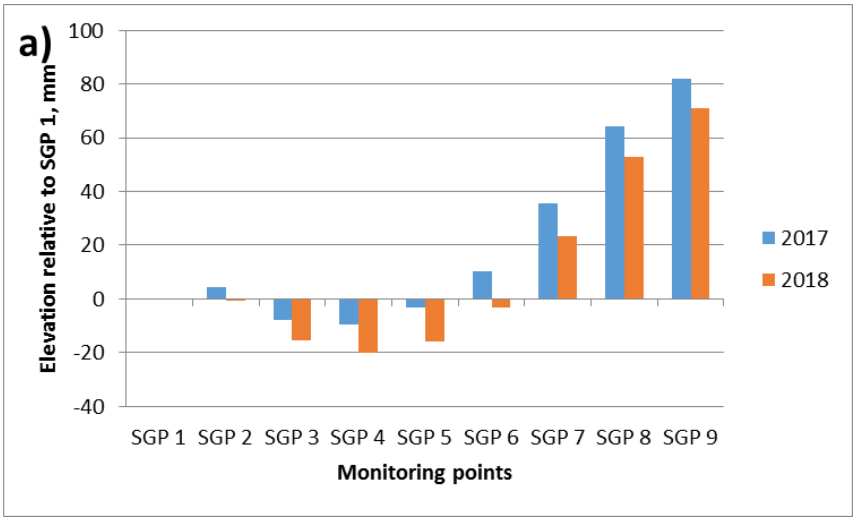

Figure 16. Displacements (SGP 1–SGP 9) at right-hand side of multi-purpose garage “Magnetittlageret”.

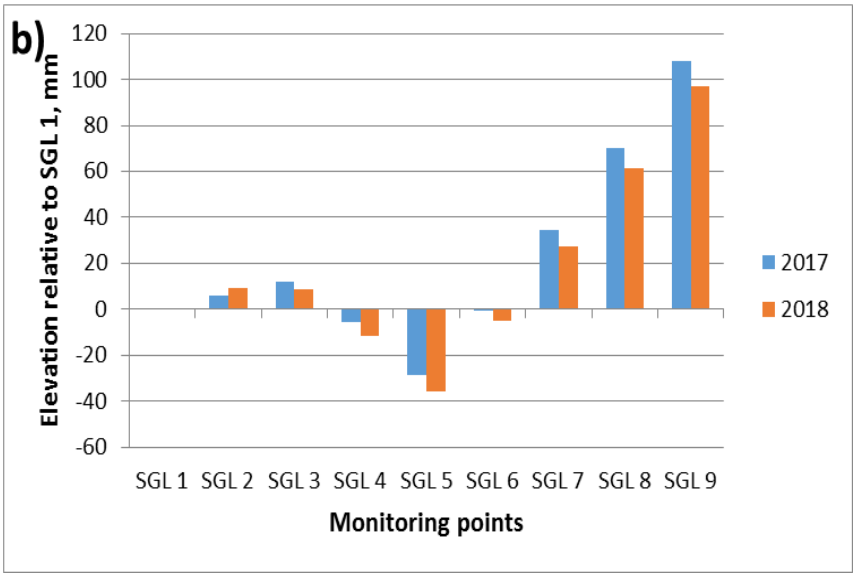

Figure 17. Displacements (SGL1–SGL 9) at left-hand side of multi-purpose garage "Magnetittlageret".

One can see significant differential vertical displacements on both sides of the garage. Largest displacements are noted on the right-hand side when one facing the entrance (towards the airport) of the garage side and vary from 5 to 13 mm, displacements for the left-hand side vary from 3 to 11 mm.

Absolute displacements on both sides of the garage are presented in Figure 18.

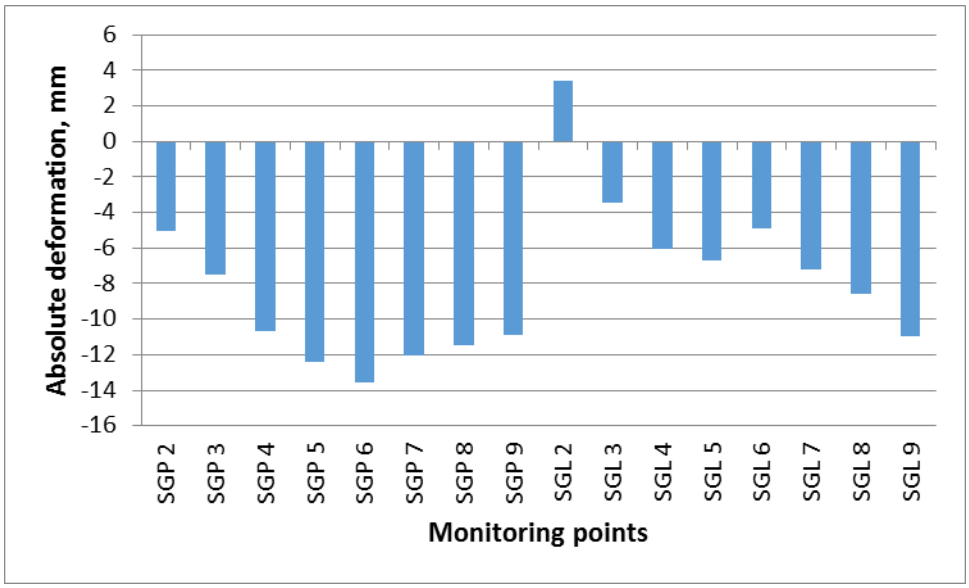

Figure 18. Absolute displacements of the monitoring points at the multi-purpose garage "Magnetittlageret".

Appendixes

A Daily reports for 2018.

Daily reports are presented in Table 14. designations for the schedule are listed in in Table 15.

Table 13. Daily reports.

Date	Activity
	Works in Longyearbyen
25.07.2018	Office: collecting equipment, HSE
26.07.2018	Leveling from PS to UGH
27.07.2018	Leveling at UGH.
28.07.2018	Leveling at UGH.
	Works in Barentsburg
30.07.2018	Leveling from the reference points towards the building
31.07.2018	Leveling at the building
	Works in Pyramiden
02.08.2018	Leveling from reference points and road
03.08.2018	Leveling at the building and below the building.
	Works in Longyearbyen
06.08.2018	Office - data checking, reporting
	Works in Svea
07.08.2018	leveling at the "New green barrack".
08.08.2018	Leveling from the reference point to new building, leveling at new building.
09.08.2018	Leveling at a multi-purpose garage in Svea.
	Works in Longyearbyen
10.08.2018	Office - data checking, reporting
	Works in Longyearbyen
13.08.2018	Leveling from UGH to “Elvesetta Byggertinn 1”.
14.08.2018	Leveling at the building of “Elvesetta Byggertinn 1”.
15.08.2018	Office - data checking, reporting
16.08.2018	Office - data checking, reporting
17.08.2018	Final meeting: discussion on obtained results and reporting.

Table 14. Schedule for fieldworks in 2018.

Date	Activity	Personnel
Tue 24	AS, PK - arrival	
Wed 25	Office: collecting equipment, HSE	
Thu 26	LYR: Survey	AS, PK
Fri 27	LYR: Survey	AS, PK
Sat 28	LYR: Survey	AS, PK
Sun 29	Day off	
Mon 30	BB: Survey	AS, PK
Tue 31	BB: Survey	AS, PK
Wed 1	move from BB to PIR	AS, PK
Thu 2	PIR: Survey	AS, PK
Fri 3	PIR: Survey	AS, PK
Sat 4	Day off	AS, PK
Sun 5	Day off	AS, PK
Mon 6	LYR: Office - data checking, reporting	AA, AS, PK
Tue 7	Svea: Survey	AS, PK
Wed 8	Svea: Survey	AS, PK
Thu 9	Svea: Survey	AS, PK
Fri 10	LYR: Office - data checking, reporting	AS, PK
Sat 11	Day off	
Sun 12	Day off	
Mon 13	LYR: Survey	AS, PK
Tue 14	LYR: Survey	AS, PK
Wed 15	Reporting	AS, PK
Thu 16	Reporting	PK, AA
Fri 17	Optional day, AS - departure	PK, AA
Sat 18	Day off	
Sun 19	PK - departure	

Table 15. Designations for fieldwork in 2018.

Designations	Notes
HSE	Health, Safety, Environment training at UNIS.
PK	Pavel Kotov
AS	Anatoly Sinitsyn
AA	Arne Aalbeg
LYR	Longyearbyen
BB	Barentsburg
PIR	Pyramiden
Svea	Svea

B List of instruments and equipment

A list of instruments which belongs to the project is given in Table 16.

Table 16. List of instruments and equipment applied in fieldwork in 2018.

	Equipment	Location
1.	Digital laser level Leica Sprinter 250M, long staff bar, short staff bar, tripod, Leica software, extra 2AA batteries, base plate (2 kg).	Digital laser level purchased by the project, stored in the storage room next to SINTEF office on the third floor at UNIS ("SINTEF storage room").
2.	50-m measuring tape.	UNIS AT department.
3.	VHF radio (2 pcs), charger for VHF radio, satellite phone, emergency beacon, rifle and flair gun (2 kits), ax, Jaärvenduk (sleeping bag for emergency situations).	UNIS Logistics department.
4.	Tool box.	"SINTEF storage room" on the third floor at UNIS.
5.	"Write in the train" note book.	SINTEF storage room
	List of additional instruments for 2019 fieldwork	
1.	New long bolts (ca 300 mm) for UGH, for barack "Låven", and for barack "2002".	
2.	Installation of new bolts at The Vault Hotel, buildings on Barentsburg and Pyramiden.	
3.	New measuring tape.	
4.	Additional (second) base plate.	

References

1. Sinitsyn, A., P. Kotov, K. Beutner, and A. Aalberg, *MonArc Project Report 2017*. 2018. p. 44.
2. STO SRO-S 60542960 00043-2015, *Ob'yekty ispol'zovaniya atomnoy energii. Geodezicheskiy monitoring zdaniy i sooruzheniy v period stroitel'stva i ekspluatatsii*, (*Geodetic monitoring of buildings and structures during construction and operation*). 2015.

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