2019:00157- Unrestricted

Report

MonArc Project Report 2019

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

Authors
Anatoly Sinitsyn
Pavel Kotov
Aleksandra Sibiriakova
Arne Aalberg

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

SINTEF Byggforsk
SINTEF Building and Infrastructure
Address:
Postboks 4760 Torgarden
NO-7465 Trondheim
NORWAY
Switchboard: +47 40005100

info@sintef.no

Enterprise /VAT No:
NO 919 303 808 MVA

Report

MonArc Project Report 2019

Monitoring of Arctic Infrastructure

KEYWORDS:
Infrastructure, permafrost, foundations, monitoring, climate change, Svalbard, Arctic.

VERSION
Version

DATE
2019-12-23

AUTHOR(S)
Anatoly Sinitsyn, SINTEF
Pavel Kotov, Lomonosov Moscow State University
Aleksandra Sibiriakova, Lomonosov Moscow State University
Arne Aalberg, The University Centre in Svalbard (UNIS)

CLIENT(S)
The Research Council of Norway

CLIENT'S REF.
Marianne Johansen

PROJECT NO.
102015781

NUMBER OF PAGES/APPENDICES:
41/3

ABSTRACT
This report presents the performed activities and deliverables within the Monitoring of Arctic Infrastructure project (MonArc) in 2019 and gives references to field data records collected in 2017–2019. Settlements of surveyed buildings in 2017–2019 are presented. The performed activities include scientific and logistical planning of fieldworks, fieldworks, data processing, and reporting. The survey program 2019 comprised measurements on two buildings in Longyearbyen, one building in Barentsburg, one building in Pyramiden, a stretch of the town road, and two 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 2019- data set was established for each building, and compared to the 2017–2018 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.

PREPARED BY
Anatoly Sinitsyn

SIGNATURE Sinitsyn Anatoly Digitally signed by Sinitsyn Anatoly DN: cn=Sinitsyn Anatoly Date: 2019.12.20 17:06:38 +01'00'

CHECKED BY
Arne Aalberg (UNIS)

SIGNATURE Arne Aalberg

APPROVED BY
Lisbeth-Ingrid Alnæs

SIGNATURE Lisbeth Alnæs

REPORT NO.
2019:01231

ISBN
978-82-14-06258-8

CLASSIFICATION
Unrestricted

CLASSIFICATION THIS PAGE
Unrestricted

SINTEF

Document history

VERSION	DATE	VERSION DESCRIPTION
01	2019-12-16	The report presents detailed description of activities and deliverables for 2019, references to data records produced in 2017–2019, and settlements of surveyed buildings in 2017–2019.

Project numbers:
RCN project number: 246757/E10.
SINTEF project number: 102015781.
RiS-Database number: 10967.

Table of contents

APPENDICES

[List appendices here]

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.

The report presents detailed description of activities and deliverables for 2019, references to data records produced in 2017–2019, and settlements of surveyed buildings in 2017–2019. The activities include scientific and logistical planning of fieldworks, performance of the fieldworks, data processing and reporting.

2 Background – project elements

Activities in 2019 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 the 2019- results and reporting.
v. Estimation of settlements of surveyed buildings in 2017–2019.

Responsibilities were divided as following:

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

3 General information about field sites and works

The 2019 field works took place in the settlements (small towns) of Longyearbyen, Barentsburg, Pyramiden and Svea in the period July 19.–August 05. 2019. 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[1]:

- The two-storey building for temporal residence "Låven".
- 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 2017–2019.

4 Planning and Preparation of Field Works

Schedule for 2019 fieldwork is presented in Appendix A, Table 13.

The main goals at the preparation stage in 2019 were:

- To collect all necessary instruments, list of equipment is presented in Appendix B, Table 14.
- Logistical planning and booking of transportation and accommodation:
    - Tickets and accommodation (Trondheim/Longyearbyen; Moscow/Longyearbyen).
    - 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.

[1] The two-storey building for temporal residence "Barack 2002" (first surveyed in 2018) was not surveyed in 2019 as it will be soon removed due to decommissioning of the Svea settlement; "Låven" and "Magnetittlageret" are to be removed as well, but measurements there were performed in 2019 as longer data sets are available for these buildings (2017 and 2018).

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

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 tripod (station), which equals to 0,30 mm.

6 Results

6.1 Overview of the data

Description of the buildings for monitoring and drawings with monitoring points are presented in [1]. In 2019 some routines were slightly changed and improved (compare to 2017–2018), some monitoring bolts were excluded/added in the survey. Updated information is presented in Ch. 6.1.

The data sets of the 2017–2019- surveys are presented in the attached Excel files. The connections between the data sets and the relevant buildings are presented in Table 1.

Table 1. Overview of the 2017–2019- data sets.

File name	Description of data
File "Longyearbyen_Raw data 2018–2019", sheets:	
LRP1-LRP2 2018	Leveling reference points near Power plant.
LRP1-LRP2 2019	
LRP1-UGH1 2018	Leveling of the road from Power plant to UNIS Guest House.
LRP1-UGH1 2019	
UGH1-UGH9 2018	UNIS Guest House – leveling outside the building.
UGH1-UGH9 2019	
UGH10-UGH18 2018	UNIS Guest House – leveling under the building.
UGH10-UGH18 2019	
UGH1-LH1 2018	Leveling of the road from UNIS Guest House to The Vault Hotel.
UGH1-LH1 2019	
Vault hotel 2018	Vault hotel – leveling outside the building.
Vault hotel 2019 left	
Vault hotel 2019 right	
File "Longyearbyen_Comparison_2018-2019"	Settlements of foundations in Longyearbyen 2018-2019, i.e. comparison of elevations of monitoring bolts.

File "Pyramiden_Raw data 2017-2019", sheets:	
PRP1-PRP2 2017	Leveling from reference point №1 to the reference point № 2.
PRP1-PRP2 2018	
PRP1-PRP3 2017	Leveling from reference point №1 to the reference point № 3.
PRP1-PRP3 2018	
PRP1-PRP4 2017	Leveling from reference point №1 to the reference point № 4.
PRP1-PRP4 2018	
PRP1-PRP4 2019	
PRP1-PB1 2017	Leveling from reference point № 1 to the multi-purpose garage.
PRP1-PB2 2018	
PRP1-PB2 2019	
PB1-PB19 2017	Leveling outside the multi-purpose garage.
PB2-PB13 2018 and PB14-PB18 2018	
PB2-PB13 2019 and PB14-PB18 2019	
PUB1-PUB19 2017	Leveling under the multi-purpose garage.
PUB1-PUB19 2018	
PUB1-PUB19 2019	
File "Pyramiden_Comparison_2017-2019"	Settlements of foundations in Pyramiden 2017-2019, i.e. comparison of elevations of monitoring bolts.
File "Barentsburg_Raw data_2018-2019", sheets:	
BRP1-BRP2 2018	Leveling from reference point №1 to №2.
BRP1-BRP2 2019	
BRP1-BRP3 2018	Leveling from reference point №1 to №3.
BRP1-BRP3 2019	
BRP1-BB1 2018	Leveling from reference point №1 to the building "Komplex GRZ".
BRP1-BB1 2019	
BB1-BB17 2018	Leveling outside the building "Komplex GRZ".
BB1-BB17 2019	
File "Barentsburg_Comparison_2018-2019"	Settlements of foundations in Barentsburg in 2018-2019, i.e. comparison of elevations of monitoring bolts.
File "Svea_Raw data_2017-2019", sheets:	
SRP1-S1 2017	Leveling from the reference point №1 to the "New green barrack" ("Låven").
SRP1-S1 2018	
SRP1-S1 2019	
S1-S12 2017	Leveling outside "New green barrack" ("Låven").
S1-S16 2018	
S1-S16 2019	
Garage 2017	Leveling the garage from two stations ("station points").
Garage 2018	
Garage 2019	
File "Svea_Comparison_2017-2019"	Settlements of foundations in Svea in 2018-2019, i.e. comparison of elevations of monitoring bolts.

6.2 General remarks on data quality

Assessment of data quality is presented in Table 2–Table 7. Elevations of the monitoring bolts and reference points obtained during the surveys are presented in Ch. 6.4 (Figure 8–Figure 12).

Best data quality was achieved in 2019, hence the 2019- data set shall be used for comparison of the future data with the data from 2017–2019. Several reference points were found to be stable, these are – BRP 2 in Barentsburg, and PRP1, PRP4, PRP5 in Pyramiden. That confirms the possibility to use them for survey. In Longyearbyen, reference points LRP1–LRP2 were assumed to be stable (and were proven not moving in relation to each other, which is logical as they located very close to each other and should not be considered as independent). The reference point in Svea (SRP1) is assumed to be stable, but was not connected to other points nearby to confirm it's stability.

Settlements of the buildings in 2017–2019 were obtained by comparison of the actual heights of the monitoring points between 2017 and 2018 (where 2018- data was available); 2018 and 2019. The standard error of measurements was also obtained, serving as an indicator of the accuracy level.

Table 2. Assessment of data quality of measurements in Longyearbyen in 2018–2019.

Line	2018						2019					
	Error of closure, m	Parameter	Value	Equation	Maximum allowable error, m	Class	Error of closure, m	Parameter	Value	Equation	Maximum allowable error, m	Class
LRP1-UGH 1	0,0019	n	44	$\pm0,3\sqrt{n}$	0,0020	1	-0,0007	n	26	$\pm0,3\sqrt{n}$	-0,0007	1
		L	1,97	$\pm3\sqrt{L}$	0,0042	1		L	2,00	$\pm3\sqrt{L}$	-0,0015	1
UGH 1- LH 1	0,0045	n	30	$\pm1,5\sqrt{n}$	0,0082	3	-0,0009	n	14	$\pm0,3\sqrt{n}$	-0,0013	1
		L	1,33	$\pm5\sqrt{L}$	0,0058	2		L	1,26	$\pm3\sqrt{L}$	-0,0036	1
Guest house (UGH1-UGH9)	-0,0017	n	20	$\pm0,5\sqrt{n}$	-0,0022	2	0,0015	n	20	$\pm0,5\sqrt{n}$	0,0022	2
		L	0,38	$\pm3\sqrt{L}$	-0,0018	1		L	0,38	$\pm3\sqrt{L}$	0,0018	1
Guest house (UGH10-UGH18)	-0,0023	n	22	$\pm0,5\sqrt{n}$	-0,0023	2	-0,0002	n	22	$\pm0,5\sqrt{n}$	-0,0014	1
		L	0,14	$\pm5\sqrt{L}$	-0,0037	2		L	0,14	$\pm5\sqrt{L}$	-0,0020	1
The Vault Hotel	-0,0006	n	24	$\pm0,3\sqrt{n}$	-0,0015	1	-0,0001	n	16	$\pm0,3\sqrt{n}$	-0,0012	1
		L	0,34	$\pm3\sqrt{L}$	-0,0018	1		L	0,29	$\pm3\sqrt{L}$	-0,0016	1
							0,0002	n	4	$\pm0,3\sqrt{n}$	0,0006	1
								L	0,10	$\pm3\sqrt{L}$	0,0010	1

Note:

n – number of stations;

L – distance, km.

Table 3. Assessment of data quality of measurements in Barentsburg in 2018–2019.

Line	2018						2019					
	Error of closure, m	Parameter	Value	Equation	Maximum allowable error, m	Class	Error of closure, m	Parameter	Value	Equation	Maximum allowable error, m	Class
BRP1-BRP2	0,0003	n	14	$\pm0,3\sqrt{n}$	0,0011	1	0,0010	n	14	$\pm0.3\sqrt{n}$	0,0011	1

		L	0,61	$\pm 3\sqrt{L}$	0,0023	1		L	0,61	$\pm 3\sqrt{L}$	0,0023	1
BRP1-BRP3	0,0044	n	24	$\pm 1{,}5\sqrt{n}$	0,0073	3	-0,0005	n	26	$\pm 0{,}3\sqrt{n}$	-0,0015	1
		L	1,16	$\pm 5\sqrt{L}$	0,0054	2		L	1,17	$\pm 3\sqrt{L}$	-0,0032	1
BRP1-BB1	0,0009	n	6	$\pm 0{,}5\sqrt{n}$	0,0012	2	-0,0007	n	6	$\pm 0.3\sqrt{n}$	-0,0007	1
		L	0,26	$\pm 3\sqrt{L}$	0,0015	1		L	0,26	$\pm 3\sqrt{L}$	-0,0015	1
Building	0,0010	n	32	$\pm 0{,}3\sqrt{n}$	0,0017	1	-0,0006	n	32	$\pm 0.3\sqrt{n}$	-0,0017	1
		L	0,34	$\pm 3\sqrt{L}$	0,0017	1		L	0,34	$\pm 3\sqrt{L}$	-0,0017	1

Note:

n – number of stations;

L – distance, km.

Table 4. Assessment of data quality of measurements in Pyramiden in 2017–2018.

Line	2017						2018					
	Error of closure, m	**Parameter**	**Value**	**Equation**	**Maximum allowable error, m**	**Class**	**Error of closure, m**	**Parameter**	**Value**	**Equation**	**Maximum 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	$\pm 3\sqrt{L}$	0,0027	1

Table 5.Assessment of data quality of measurements in Pyramiden in 2019.

Line	2019					
	Error of closure, m	**Parameter**	**Value**	**Equation**	**Maximum allowable error, m**	**Class**
PRP1-PRP4	-0,0005	n	26	$\pm 0{,}3\sqrt{n}$	-0,0015	1
		L	0,98	$\pm 3\sqrt{L}$	-0,0030	1
PRP1-PB1	-0,0009	n	12	$\pm 0{,}3\sqrt{n}$	-0,0010	1
		L	0,44	$\pm 3\sqrt{L}$	-0,0020	1
Garage	0,0001	n	20	$\pm 0{,}3\sqrt{n}$	0,0013	1
		L	0,29	$\pm 3\sqrt{L}$	0,0054	1
	0,0005	n	14	$\pm 0{,}3\sqrt{n}$	0,0011	1
		L	0,38	$\pm 3\sqrt{L}$	0,0019	1
Under the garage	0,0006	n	4	$\pm 0{,}5\sqrt{n}$	0,0010	2
		L	0,2	$\pm 5\sqrt{L}$	0,0027	1

Note:

n – number of stations;

L – distance, km.

Table 6. Assessment of data quality of measurements in Svea in 2017–2018.

Line	2017						2018					
	Error of closure, m	**Parameter**	**Value**	**Equation**	**Maximum allowable error, m**	**Class**	**Error of closure, m**	**Parameter**	**Value**	**Equation**	**Maximum allowable error, m**	**Class**
SRP1-S1	0,0076	n	8	$\pm 5\sqrt{n}$	0,01414	4	0,0009	n	8	$\pm 0.5\sqrt{n}$	0,0014	2
		L	0,32	$\pm 20\sqrt{L}$	0,01131	4		L	0,32	$\pm 3\sqrt{L}$	0,0017	1
Green barrack	-0,0012	n	22	$\pm 0{,}3\sqrt{n}$	-0,00141	1	0,0008	n	30	$\pm 0.3\sqrt{n}$	0,0016	1
		L	0,35	$\pm 3\sqrt{L}$	-0,00177	1		L	0,35	$\pm 3\sqrt{L}$	0,0018	1

Table 7. Assessment of data quality of measurements in Svea in 2019.

Line	2019					
	Error of closure, m	**Parameter**	**Value**	**Equation**	**Maximum allowable error, m**	**Class**
SRP1-S1	0,0005	n	10	$\pm 0{,}3\sqrt{n}$	0,0009	1
		L	0,31	$\pm 3\sqrt{L}$	0,0017	1
Green barrack	-0,0012	n	30	$\pm 0{,}3\sqrt{n}$	-0,0016	1
		L	0,35	$\pm 3\sqrt{L}$	-0,0018	1

Note:

n – number of stations;

L – distance, km.

6.3 Outline of monitoring program and notes on changes

Outline of monitoring program and notes on changes introduced in 2019 are presented below. Project results for the years of 2017 and 2018 are presented in [1, 3].

Longyearbyen

Monitoring continued as planned in Longyearbyen, addressing the UNIS Guest House and The Vault Hotel as in 2017–2018, and using the same fixed point (a bolt on the Power plant). Monitoring plans at the UNIS Guest House and The Vault Hotel are presented in Appendix C, Figure 24–Figure 26.

Barentsburg

The three-story building "Komplex GRZ" and the three reference points remained in the 2019- monitoring program in Barentsburg. Monitoring plan for the building "Komplex GRZ" is presented in Appendix C, Figure 27.

Pyramiden

The two reference points (PRP1, PRP4) and the multi-purpose garage remained in 2019- monitoring program in Pyramiden (**Error! Reference source not found.**). Monitoring plan for the multi-purpose garage is p resented in Appendix C, Figure 28.

In 2019, geodetic track around the multi-purpose garage remained to be divided (compare to survey 2017-) in two parts (the right and the left track), these parts were however different compare to measurements in 2018.

Svea

The measurements were performed from the same fixed reference point as was used in 2017–2018. Two buildings; "Låven" and the multi-purpose garage "Magnetittlageret", were surveyed. The building "Barack 2002" (which was included in the program in 2018) was not surveyed due to the notice that it will be removed in a short while[2] due to decommissioning of Svea. Monitoring plan for the multi-purpose garage is presented in Appendix C, Figure 29.

The "Låven" barack was surveyed in relation to the reference point used in Svea (SRP1), while the Multi-purpose garage "Magnetittlageret" was surveyed in relation to the points located on its foundation.

Multi-purpose garage "Magnetittlageret" is supported 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 – point SGP1 on the right-hand side, and point SGL1 on the left-hand side). Each side of the garage (Figure 1) was measured separately. Measurements were performed on the top of foundation opposite to the middle of each fifth channel (Figure 2), i.e. eight points were surveyed along each side of the garage.

[2] In 2018 the owner had intension to exclude barack 2002 from the decommissioning program. The "Låven" barack and the multi-purpose garage "Magnetittlageret" will be removed during the decommissioning as well, but they were monitored a bit longer (since 2017), hence measurements were repeated in 2019 as well.

Figure 1. Multi-purpose garage "Magnetittlageret".

Figure 2. Measurement at the "Magnetittlageret" garage.

6.4 Results

6.4.1 Longyearbyen

Only preliminary field survey was performed in Longyearbyen in 2017, the results of this survey could not serve as a solid base-line data set. Raw data and calculated elevations are presented in Excel file "Longyearbyen_Raw data_2018-2019". Elevations of monitoring bolts and standard errors of measurements for 2018–2019 are presented in Excel file "Longyearbyen_Comparison_2018–2019" and in Table 8. Absolute displacements are presented in Figure 3–Figure 4. Monitoring bolts of the UGH settled for 1,9–10,6 mm, and of the Vault Hotel – for 1,0–3,9 mm in 2018–2019.

Table 8. Results of survey in Longyearbyen in 2018–2019.

№ of reference point/ monitoring bolts	Height relative to the reference point, m	Standard error of measurements, m	Height relative to the reference point, m	Standard error of measurements, m	Absolute displacement S_{Hi}, 2018–2019, mm	Standard error m_{2s}, mm
	2018		2019			
LRP1	0		0		0	
LRP2	0,5820		0,5820		0,00001	
UGH1	8,1708	0,0008	8,1680	0,0001	-2,8544	0,8576
UGH2	8,6970	0,0003	8,6908	0,0001	-6,1809	0,3463
UGH3	9,0875	0,0003	9,0806	0,0001	-6,8856	0,3463
UGH4	9,2115	0,0003	9,2029	0,0001	-8,6314	0,3463
UGH5	10,0528	0,0003	10,0429	0,0001	-9,8157	0,3463
UGH6	10,4687	0,0003	10,4689	0,0001	0,2627	0,3463
UGH7	10,7642	0,0003	10,7545	0,0001	-9,7247	0,3463
UGH8	10,3771	0,0003	10,3679	0,0001	-9,2337	0,3463
UGH9	9,7183	0,0003	9,7077	0,0001	-10,5632	0,3463
UGH10	8,3615	0,0004	8,3540	0,0006	-7,4961	0,7116
UGH11	8,2305	0,0004	8,2261	0,0006	-4,3630	0,7116
UGH12	8,2706	0,0004	8,2669	0,0006	-3,7710	0,7116
UGH13	8,2408	0,0004	8,2369	0,0006	-3,8602	0,7116
UGH14	8,4316	0,0004	8,4287	0,0006	-2,8604	0,7116
UGH15	8,6457	0,0004	8,6438	0,0006	-1,9182	0,7116
UGH16	8,1875	0,0004	8,1853	0,0006	-2,1978	0,7116
UGH17	7,6723	0,0004	7,6714	0,0006	-0,9857	0,7116
UGH18	7,2708	0,0004	7,2711	0,0006	0,2828	0,7116
LH 1	20,1074	0,0005	20,1054	0,0003	-2,0138	0,6236
LH2	19,9277	0,0004	19,9256	0,0002	-2,1517	0,4115
LH3	19,9286	0,0004	19,9276	0,0002	-1,0180	0,4115
LH 4	19,9305	0,0004	19,9277	0,0002	-2,7402	0,4115

№ of reference point/ monitoring bolts	Height relative to the reference point, m	Standard error of measurements, m	Height relative to the reference point, m	Standard error of measurements, m	Absolute displacement S_{Hi}, 2018–2019, mm	Standard error m_{2s}, mm
	2018		2019			
LH 5	19,9312	0,0004	19,9309	0,0002	-0,2698	0,4115
LH 7	19,9282	0,0004	19,9243	0,0002	-3,9170	0,4115
LH 8	19,9180	0,0004	19,9150	0,0001	-2,9179	0,3678
LH 9	19,9268	0,0004	19,9247	0,0001	-2,0128	0,3678

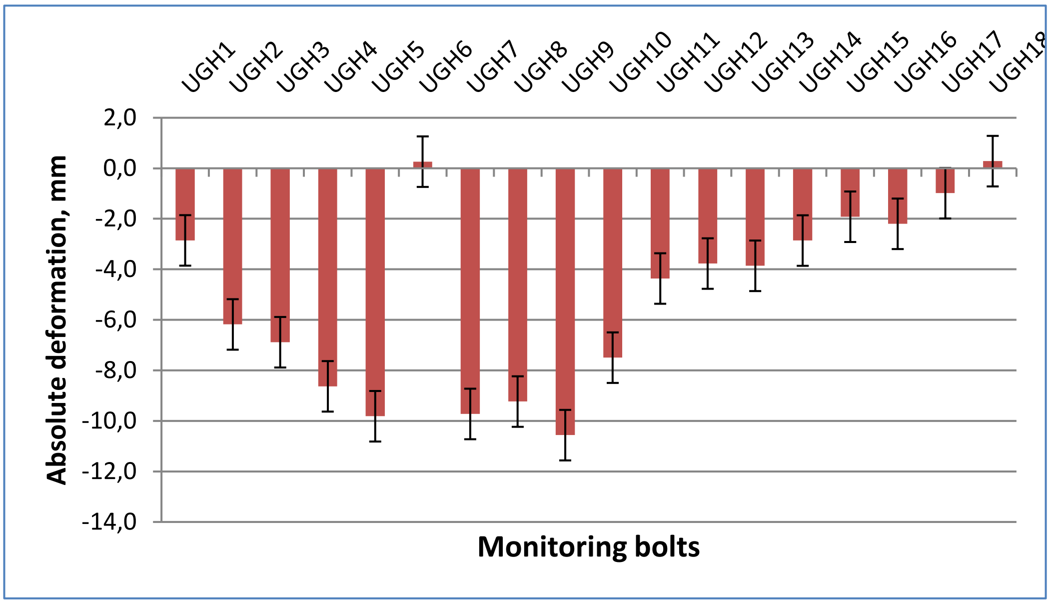

Figure 3. Absolute displacements (and errors of measurements) of monitoring bolts at the UGH building in 2018–2019.

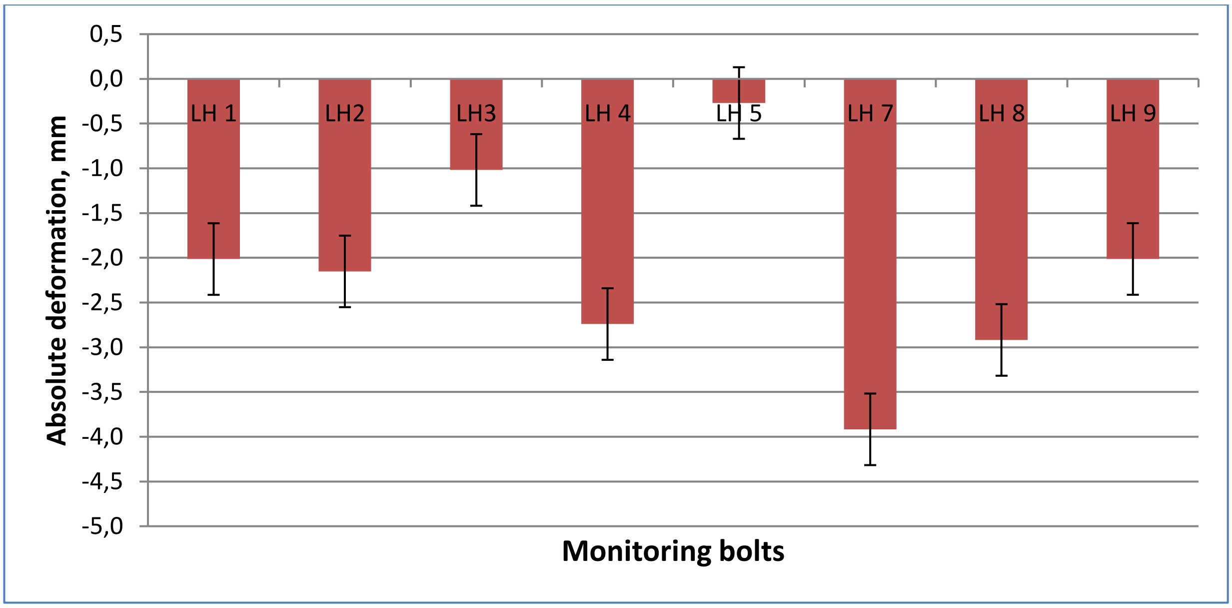

Figure 4. Absolute displacements (and errors of measurements) of monitoring bolts at The Vault Hotel in 2018–2019.

6.4.2 Barentsburg

Only preliminary field survey was performed in Barentsburg in 2017, the results of this survey could not serve as a solid base-line data set. Raw data and calculated elevations are presented in the Excel file "Barentsburg_Raw data_2018–2019". Elevations of monitoring bolts and standard errors of measurements for 2018–2019 are presented in the Excel file "Barentsburg_Comparison_2018–2019" and in Table 9. Absolute displacements are presented in Figure 5. Monitoring bolts of the building "Komplex GRZ" settled in the range 0,4–1,8 mm in 2018–2019.

Table 9. Results of survey in Barentsburg in 2018–2019.

№ of reference point/ monitoring bolts	Height relative to the reference point, m	Standard error of measurements, m	Height relative to the reference point, m	Standard error of measurements, m	Absolute displacement S_{Hi}, 2018–2019, mm	Standard error m_{2s}, mm
	2018		2019			
BRP1	0,0000		0,0000			
BRP2	3,1512	0,0003	3,1520	0,0002	0,8450	0,3333
BRP3	-1,9636	0,0014	-1,9598	0,0002	3,8074	1,4319
BB1	4,2151	0,0002	4,2146	0,0003	-0,5480	0,4133
BB2	4,2316	0,0001	4,2305	0,0001	-1,1231	0,2042
BB3	4,3840	0,0001	4,3823	0,0001	-1,7683	0,2042
BB4	4,3898	0,0001	4,3880	0,0001	-1,7299	0,2042
BB5	4,4525	0,0001	4,4513	0,0001	-1,1430	0,2042
BB6	4,2687	0,0001	4,2680	0,0001	-0,7231	0,2042
BB7	4,4281	0,0001	4,4273	0,0001	-0,8103	0,2042
BB8	4,5665	0,0001	4,5655	0,0001	-0,9986	0,2042
BB9	4,2586	0,0001	4,2582	0,0001	-0,3773	0,2042
BB10	4,4589	0,0001	4,4585	0,0001	-0,3924	0,2042
BB11	4,4469	0,0001	4,4465	0,0001	-0,3611	0,2042
BB12	4,4343	0,0001	4,4334	0,0001	-0,8765	0,2042
BB13	4,4275	0,0001	4,4264	0,0001	-1,1436	0,2042
BB14	4,4054	0,0001	4,4042	0,0001	-1,1715	0,2042
BB15	4,3265	0,0001	4,3252	0,0001	-1,2609	0,2042
BB16	4,3745	0,0001	4,3738	0,0001	-0,7398	0,2042
BB17	4,4823	0,0001	4,4811	0,0001	-1,1986	0,2042

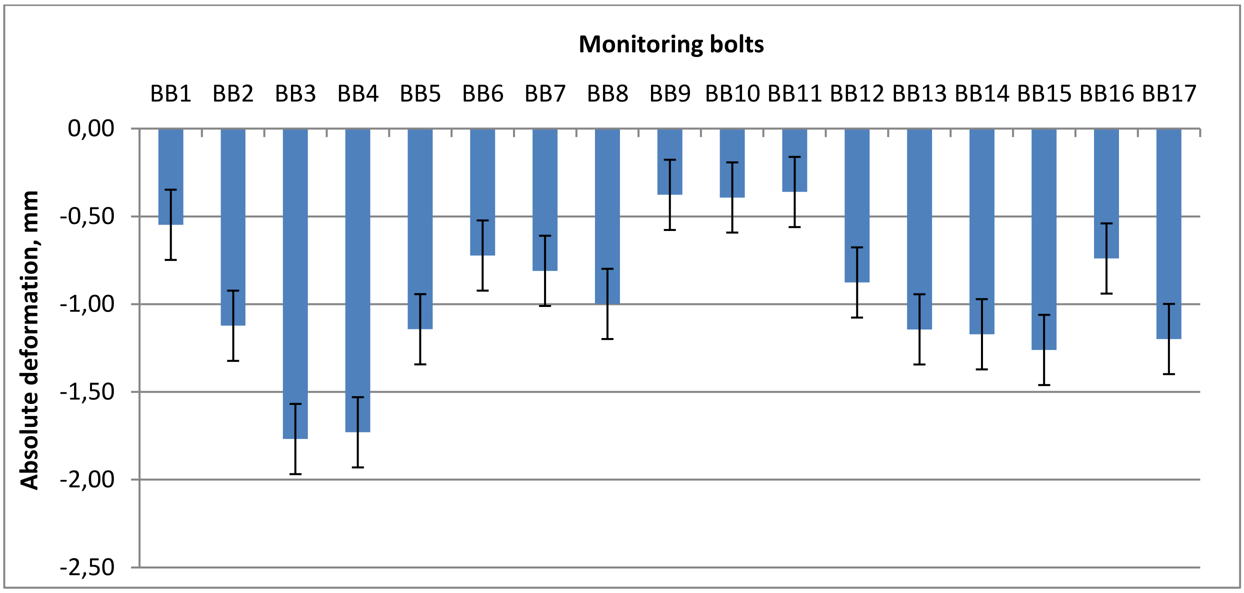

Figure 5. Absolute displacements (and errors of measurements) of monitoring bolts at the building "Komplex GRZ" in 2018–2019.

6.4.3 Pyramiden

The 2018- assessment according to (3) showed that only the reference points PRP1 and PRP4 were stable in 2017–2018, and reference points PRP1, PRP4, PRP5 – in 2019; reference points PRP2–PRP3 were not stable. Additional reference point PRP5 was established for future surveys and comparisons in 2018. PRP5 is the top of large borehole casing located next the meteorological station (PRP4).

Raw data and calculated elevations are presented in Excel file "Pyramiden_Raw data_2017–2019". Elevations of monitoring bolts and standard errors of measurements for 2017–2019 are presented in the Excel file "Pyramiden_Comparison_2018–2019" and in
Table 10. Absolute displacements are presented in Figure 6–Figure 8.

Absolute displacements of the monitoring points on the outer walls at the multi-purpose garage are in the range 1,5–5 mm/year, with some increase in 2018–2019 compare to 2017–2018. 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.

Absolute displacement and errors of measurements of the monitoring points under the multi-purpose garage are in the range 1-2,5 mm/year, with decrease in magnitude for 2018–2019 in comparison to 2017–2018. The latter is opposite to the situation at the outer walls. Settlements under the central part of the garage are smaller than at the outer walls. One may suggest that permafrost conditions are colder (and hence the settlements of piles are smaller) under the building compare to the outer walls due to drier conditions and better surface conditions (absence of snow in the wintertime).

Settlements on stretch of the road were 1,5–7 and 0,5–5,2 mm/year in 2017–2018 and 2018–2019 respectively, frost heave was identified in the middle part of the stretch (monitoring point PR6) near a drainage culvert.

Table 10. Results of survey in Pyramiden in 2017–2019.

№ of reference point/ monitoring bolts	Height relative to the reference point, m	Standard error of measurements, m	Height relative to the reference point, m	Standard error of measurements, m	Height relative to the reference point, m	Standard error of measurements, m	Absolute deformation S_{Hi}, mm	Standard error m_{2s}, mm	Absolute deformation S_{Hi}, mm	Standard error m_{2s}, mm
	2017		2018		2019		2017/2018		2018/2019	
PRP1	0		0		0					
PRP2	1,0321	0,0009	1,0409	0,0003			8,8422	0,9735		
PRP3	3,8736	0,0008	3,5249	0,0003			-348,7040	0,8544		
PRP4	10,7398	0,0008	10,7340	0,0002	10,7282	0,0001	-5,7843	0,8212	-5,8343	0,2299
PRP5			11,1757	0,0002	11,1736	0,0001			-2,1227	0,2299
PB1	6,4051	0,0007								
PB2	6,7583	0,0007	6,7560	0,0002	6,7526	0,0005	-2,3578	0,7072	-3,3236	0,4984
PB3	5,8951	0,0006	5,8919	0,0001	5,8883	0,0001	-3,2097	0,5616	-3,5285	0,1078
PB4	4,7069	0,0006	4,7049	0,0001	4,7008	0,0001	-1,9092	0,5616	-4,1714	0,1078
PB5	4,6912	0,0006	4,6897	0,0001	4,6856	0,0001	-1,5083	0,5616	-4,1367	0,1078
PB6	4,6979	0,0006	4,6961	0,0001	4,6920	0,0001	-1,7739	0,5616	-4,1366	0,1078
PB7	4,7112	0,0006	4,7085	0,0001	4,7043	0,0001	-2,6600	0,5616	-4,2809	0,1078
PB8	4,6524	0,0006	4,6487	0,0001	4,6444	0,0001	-3,7538	0,5616	-4,2967	0,1078
PB9	4,6169	0,0006	4,6115	0,0001	4,6065	0,0001	-5,3484	0,5616	-5,0439	0,1078
PB10	4,5891	0,0006	4,5835	0,0001	4,5783	0,0001	-5,6470	0,5616	-5,1685	0,1078
PB10*	4,5981	0,0006								
PB11	6,3246	0,0006	6,3000	0,0001	6,2950	0,0001	(-24,6306)* -4,6306***	0,5616	-5,0163	0,1151
PB12	6,3992	0,0006								
PB13	6,4324	0,0006	6,4089	0,0001	6,4059	0,00005	(-23,4138)* -3,4138***	0,5616	-3,0416	0,0938
PB14	6,5469	0,0006	6,5453	0,0002	6,5419	0,00005	-1,6478	0,5948	-3,3573	0,2173
PB15	4,5658	0,0006	4,5631	0,0002	4,5607	0,00005	-2,6948	0,5948	-2,4686	0,2173
PB16	4,5722	0,0006	4,5701	0,0002	4,5677	0,00005	-2,1566	0,5948	-2,3930	0,2173

№ of reference point/ monitoring bolts	Height relative to the reference point, m	Standard error of measurements, m	Height relative to the reference point, m	Standard error of measurements, m	Height relative to the reference point, m	Standard error of measurements, m	Absolute deformation S_{Hi}, mm	Standard error m_{2s}, mm	Absolute deformation S_{Hi}, mm	Standard error m_{2s}, mm
	2017		2018		2019		2017/2018		2018/2019	
PB17	4,6086	0,0006	4,6069	0,0002	4,6055	0,00005	-1,7027	0,5948	-1,4696	0,2173
PB18	4,5673	0,0006	4,5657	0,0002	4,5627	0,00005	-1,5529	0,5948	-3,0278	0,2173
PB19	5,7905	0,0006								
PB 1*			6,4053	0,0002						
PR 1	2,3793	0,0007								
PR 2	5,4939	0,0007								
PR 3	2,1835	0,0008	2,1195	0,0002	2,1173	0,0001	(-64,0135)** -4,0135***	0,8212	-2,2721	0,2299
PR 4	2,3703	0,0008	2,3073	0,0002	2,3066	0,0001	(-62,9735)** -2,9735***	0,8212	-0,7021	0,2299
PR 5	2,4572	0,0008	2,3899	0,0002	2,3847	0,0001	(-67,2768)** -7,2768***	0,8212	-5,2380	0,2299
PR 6	2,8132	0,0008	2,7596	0,0002	2,7605	0,0001	(-53,5739)** 6,4261***	0,8212	0,9071	0,2299
PR 7	2,9169	0,0008	2,8554	0,0002	2,8549	0,0001	(-61,4888)** -1,4888***	0,8212	-0,4598	0,2299
PR 8	3,8677	0,0008	3,8039	0,0002	3,8025	0,0001	(-63,7789)** -3,7789***	0,8212	-1,3726	0,2299
PUB 1	5,5052		5,5027	0,0003	5,5004	0,0003	-2,5307	0,3368	-2,2854	0,4573
PUB 2	5,4271		5,4255	0,0003	5,4227	0,0003	-1,6197	0,3368	-2,7417	0,4573
PUB 3	5,5689		5,5669	0,0003	5,5646	0,0003	-1,9816	0,3368	-2,3291	0,4573
PUB 4	5,5933		5,5910	0,0003	5,5889	0,0003	-2,2598	0,3368	-2,1644	0,4573
PUB 5	5,5035		5,5014	0,0003	5,4998	0,0003	-2,1378	0,3368	-1,5965	0,4573
PUB 6	5,5754		5,5735	0,0003	5,5720	0,0003	-1,8716	0,3368	-1,4581	0,4573
PUB 7	5,5918		5,5901	0,0003	5,5887	0,0003	-1,7084	0,3368	-1,3874	0,4573
PUB 8	5,5875		5,5857	0,0003	5,5843	0,0003	-1,7839	0,3368	-1,3966	0,4573
PUB 9	5,5783		5,5762	0,0003	5,5748	0,0003	-2,1666	0,3368	-1,3924	0,4573
PUB 10	5,6319		5,6302	0,0003	5,6284	0,0003	-1,7532	0,3368	-1,8082	0,4573
PUB 11	5,5206		5,5184	0,0003	5,5172	0,0003	-2,2131	0,3368	-1,1639	0,4573

№ of reference point/ monitoring bolts	Height relative to the reference point, m	Standard error of measurements, m	Height relative to the reference point, m	Standard error of measurements, m	Height relative to the reference point, m	Standard error of measurements, m	Absolute deformation S_{Hi}, mm	Standard error m_{2s}, mm	Absolute deformation S_{Hi}, mm	Standard error m_{2s}, mm
	2017		2018		2019		2017/2018		2018/2019	
PUB 12	5,5724		5,5705	0,0003	5,5695	0,0003	-1,9577	0,3368	-0,9444	0,4573
PUB 13	5,5691		5,5675	0,0003	5,5662	0,0003	-1,5973	0,3368	-1,2502	0,4573
PUB 14	5,5866		5,5841	0,0003	5,5833	0,0003	-2,4816	0,3368	-0,7953	0,4573
PUB 15	5,6049		5,6033	0,0003	5,6017	0,0003	-1,6661	0,3368	-1,5640	0,4573
PUB 16	5,5774		5,5748	0,0003	5,5739	0,0003	-2,5690	0,3368	-0,8882	0,4573
PUB 17	5,5467		5,5447	0,0003	5,5436	0,0003	-1,9984	0,3368	-1,1359	0,4573
PUB 18	5,4535		5,4515	0,0003	5,4499	0,0003	-1,9967	0,3368	-1,5903	0,4573
PUB 19	5,5481		5,5459	0,0003	5,5439	0,0003	-2,2168	0,3368	-1,9734	0,4573

* – these values were obtained with inverted bar staff, hence a difference of 20 mm (diameter of a monitoring bolt) was taken into account. This value of 20 mm was subtracted from these values to calculated absolute values of displacements for the points PB11, PB13.

** – these values include heights of the base plate (used in 2017), which is 60 mm; thickness of the base plate was taken into account to calculate the absolute values of displacements for points PR3–PR8.

*** – absolute values of displacements.

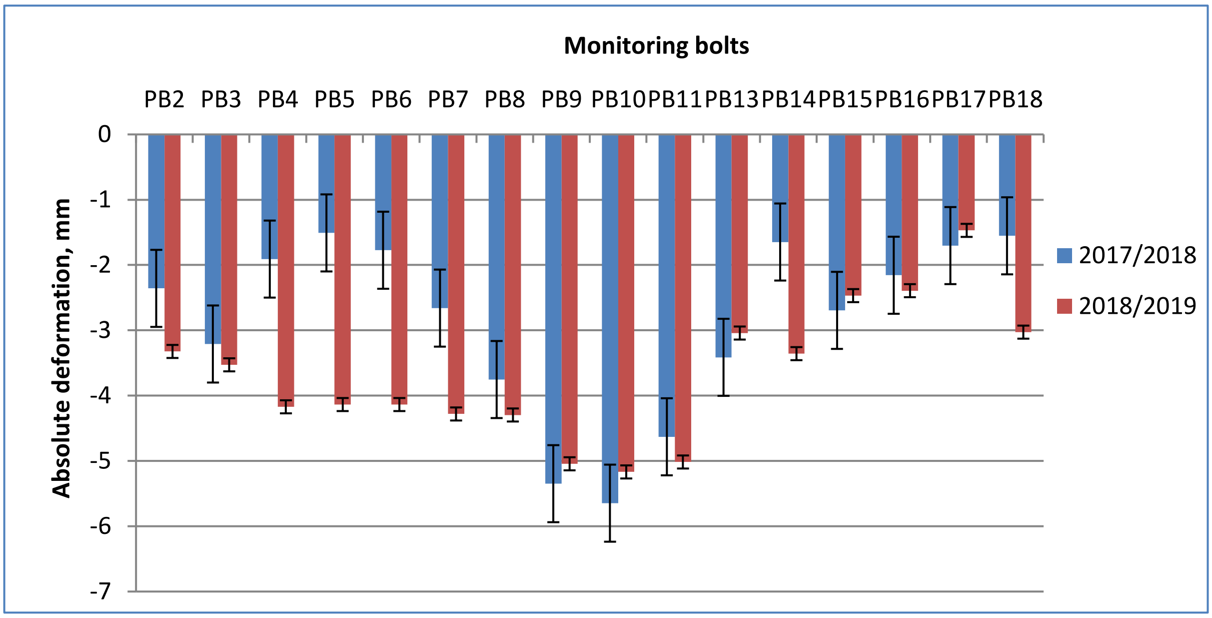

Figure 6. Absolute displacements of monitoring points (and errors of measurements) on the outer walls at the multi-purpose garage in Pyramiden in 2017-2018 and 2018–2019.

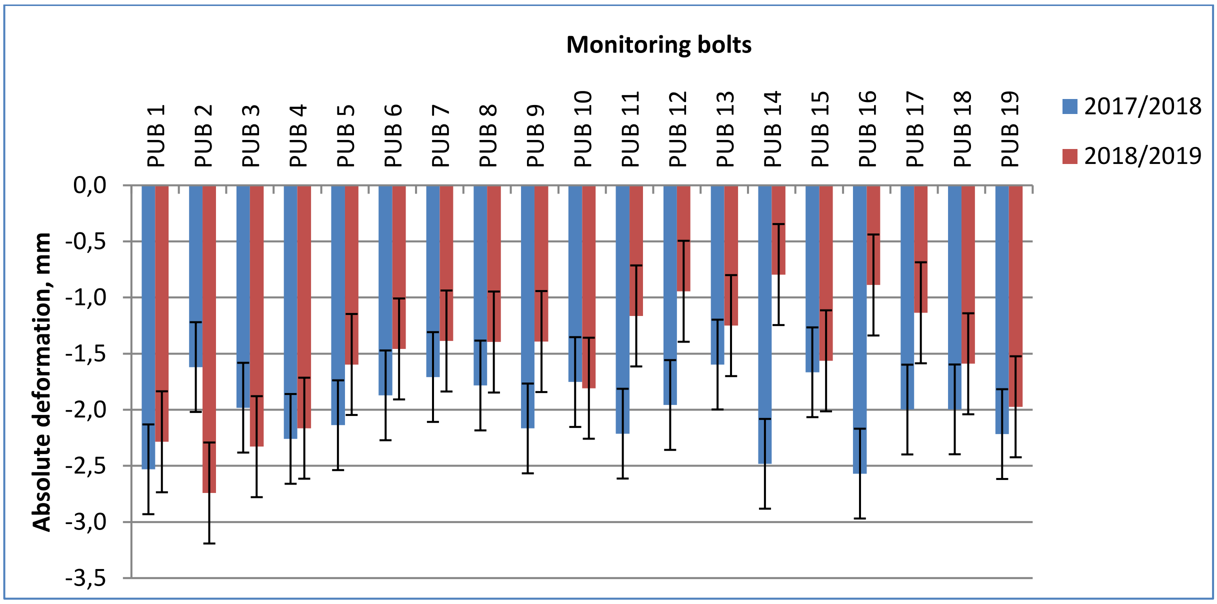

Figure 7. Absolute displacements of monitoring points (and errors of measurements) under the multi-purpose garage in Pyramiden in 2017–2018 and 2018–2019.

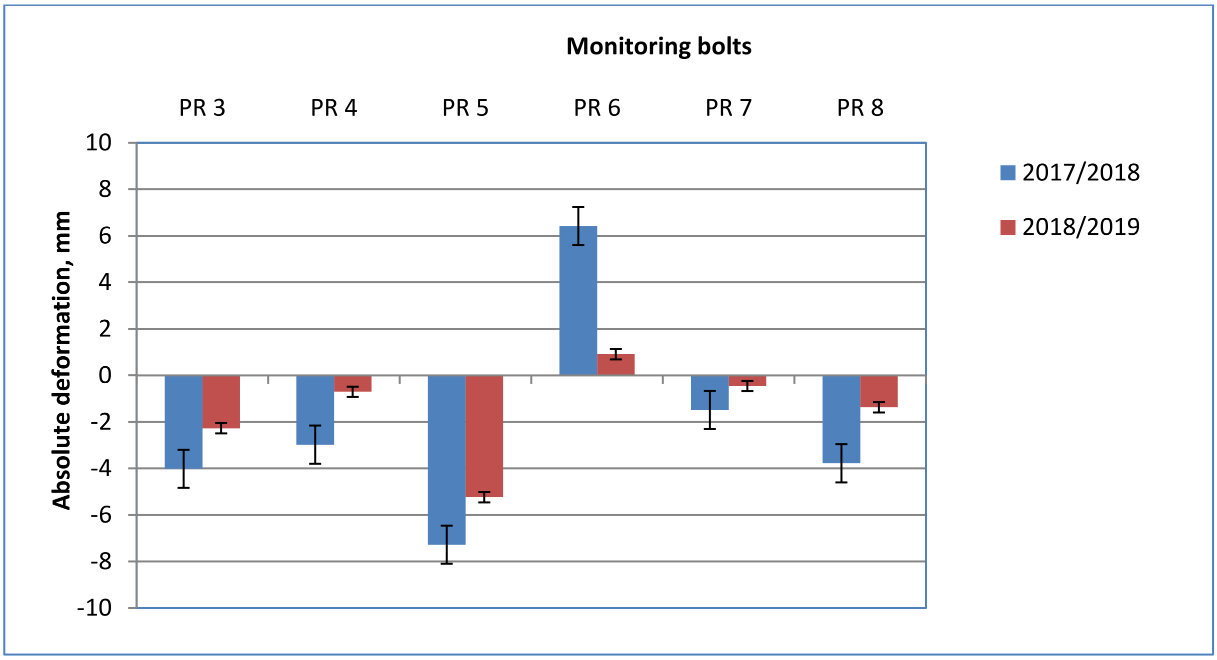

Figure 8. Absolute displacements of monitoring bolts on stretch of the road in Pyramiden.

6.4.4 Svea

Raw data and calculated elevations are presented in Excel file "Svea_Raw data_2017–2019". Elevations of monitoring bolts and standard errors of measurements are presented in the Excel file "Svea_Comparison_2017–2019" and in Table 11–Table 12. Absolute displacements at the barack "Låven" are presented in Figure 6–Figure 8.

Absolute displacements of the monitoring points at the barack "Låven" were in the range of 0,1–4,8 mm/year 2017–2019.

For the "Magnetittlageret" garage, elevations of measured points (for the right-hand side – SGP2–SGP9; for the left-hand side – SGL2–SGL9) were measured in relation to the first channel on each side (for the right-hand side – SGP1; for the left-hand side – SGL1) for 2017–2019 and are presented in Figure 10–Figure 11.

Absolute displacements on both sides of the garage (relative to the first points on each side) are presented in Figure 12–Figure 13. One can see significant differential (1–14 mm) vertical displacements on both sides of the garage in 2017–2018 and 2018–2019. Displacements were higher in 2017–2018. Largest displacements are noted on the right-hand side when one facing entrance of the garage (the entrance towards the airport).

Table 11. Results of survey at barack "Låven" in Svea.

Reference point/ monitoring bolts	Height relative to the reference point, m	Standard error of measurements, m	Height relative to the reference point, m	Standard error of measurements, m	Height relative to the reference point, m	Standard error of measurements, m	Absolute deformation, mm	Standard error, mm	Absolute deformation, mm	Standard error, mm
	2017		2018		2019		2017/2018		2018/2019	
SRP1	0		0		0					
S1	9,9866	0,0082	9,9832	0,0020	9,9808	0,0003	-3,4605	8,3868	-2,3815	1,9811
S2	9,9428	0,0003	9,9380	0,0003	9,9359	0,0003	-4,8128	0,4141	-2,1464	0,3857
S3	9,9508	0,0003	9,9470	0,0003	9,9444	0,0003	-3,7998	0,4141	-2,5643	0,3857
S4	9,9146	0,0003	9,9100	0,0003	9,9090	0,0003	-4,6177	0,4141	-0,9971	0,3857
S5	9,9516	0,0003	9,9479	0,0003	9,9469	0,0003	-3,6883	0,4141	-0,9858	0,3857
S6	10,0271	0,0003	10,0229	0,0003	10,0220	0,0003	-4,1657	0,4141	-0,9084	0,3857
S7	10,1960	0,0003	10,1922	0,0003	10,1909	0,0003	-3,7622	0,4141	-1,2939	0,3857
S8	10,1868	0,0003	10,1837	0,0003	10,1835	0,0003	-3,1084	0,4141	-0,2329	0,3857
S9	10,1507	0,0003	10,1488	0,0003	10,1463	0,0003	-1,9076	0,4141	-2,4820	0,3857
S10	10,0396	0,0003	10,0382	0,0003	10,0357	0,0003	-1,3527	0,4141	-2,5114	0,3857
S11	10,0445	0,0003	10,0440	0,0003	10,0412	0,0003	-0,5012	0,4141	-2,7586	0,3857
S12	10,2977	0,0003	10,2976	0,0003	10,2969	0,0003	-0,1182	0,4141	-0,6994	0,3857
S13			10,0402	0,0003	10,0383	0,0003			-1,8643	0,3857
S14			10,0364	0,0003	10,0328	0,0003			-3,5984	0,3857
S15			10,0442	0,0003	10,0394	0,0003			-4,8363	0,3857
S16			10,0306	0,0003	10,0266	0,0003			-4,0376	0,3857

Table 12. Results of survey at multi-purpose garage "Magnetittlageret" in Svea.

Monitoring points	Elevation of monitoring points, m			Elevation of monitoring points, m			Absolute deformation, mm	
	2017	2018	2019	2017	2018	2019	2017/2018	2018/2019
SGP 1	0	0	0					
SGP 2	-0,00085	0,004166	0,00553	-0,851	4,166	5,53	-5,017	-1,364
SGP 3	-0,01553	-0,008038	-0,004245	-15,534	-8,038	-4,245	-7,496	-3,793
SGP 4	-0,02026	-0,009563	-0,005562	-20,258	-9,563	-5,562	-10,695	-4,001
SGP 5	-0,01571	-0,003312	0,006385	-15,705	-3,312	6,385	-12,393	-9,697
SGP 6	-0,00319	0,010372	0,017747	-3,186	10,372	17,747	-13,558	-7,375
SGP 7	0,023384	0,035429	0,041395	23,384	35,429	41,395	-12,045	-5,966
SGP 8	0,052791	0,064226	0,069575	52,791	64,226	69,575	-11,435	-5,349
SGP 9	0,070978	0,081899	0,087573	70,978	81,899	87,573	-10,921	-5,674
SGL 1	0	0						
SGL 2	0,00921	0,005784	0,009928	9,21	5,784	9,928	3,426	-4,144
SGL 3	0,008571	0,012019	0,016859	8,571	12,019	16,859	-3,448	-4,84
SGL 4	-0,01188	-0,005845	-0,000669	-11,88	-5,845	-0,669	-6,035	-5,176
SGL 5	-0,03562	-0,028945	-0,026525	-35,622	-28,945	-26,525	-6,677	-2,42
SGL 6	-0,00521	-0,000337	0,006307	-5,214	-0,337	6,307	-4,877	-6,644
SGL 7	0,027135	0,034351	0,039001	27,135	34,351	39,001	-7,216	-4,65
SGL 8	0,061368	0,069959	0,075397	61,368	69,959	75,397	-8,591	-5,438
SGL 9	0,097243	0,10817	0,116412	97,243	108,17	116,412	-10,927	-8,242

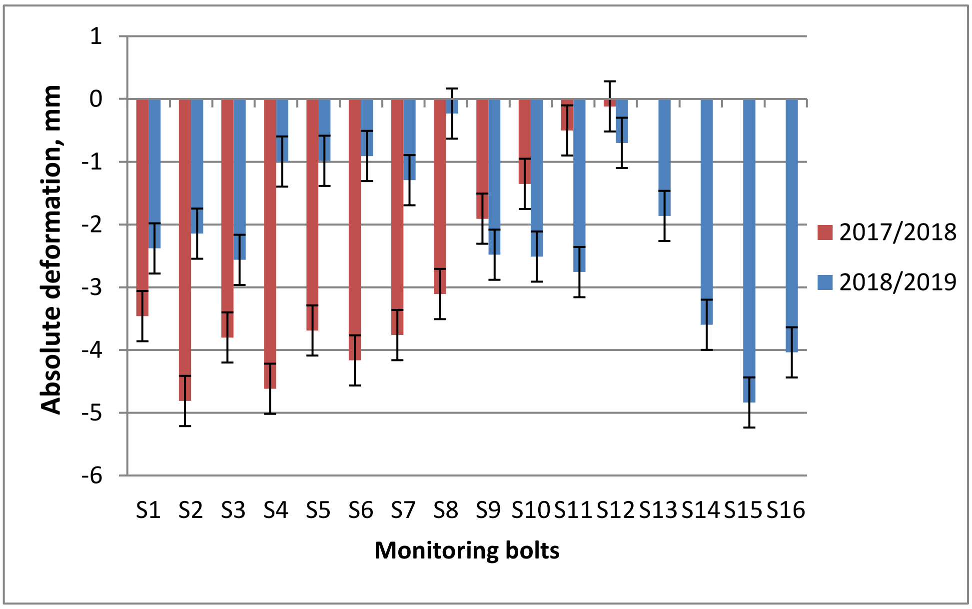

Figure 9. Absolute displacements (and errors of measurements) at the barack "Låven" in 2017–2018 and 2018–2019.

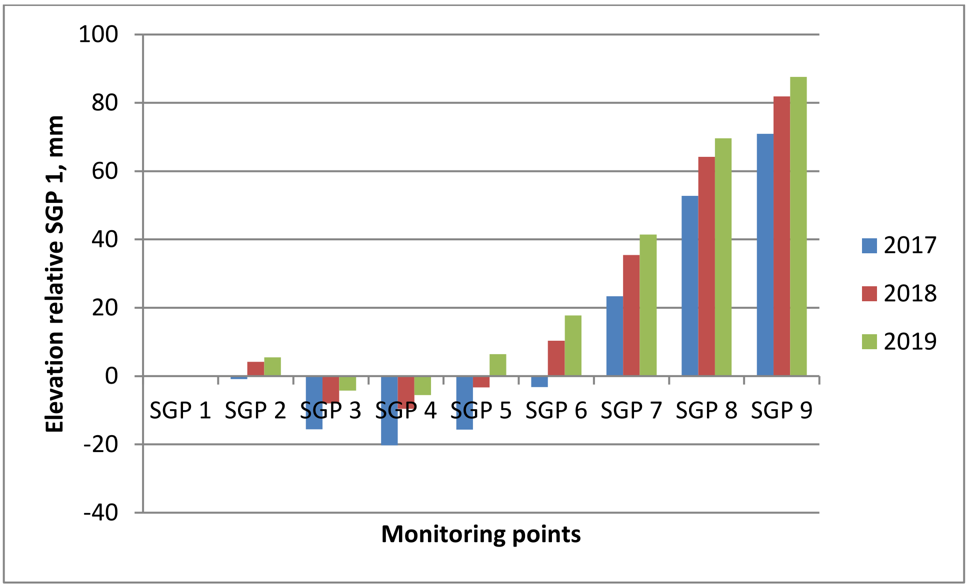

Figure 10. Elevations of points SGP2–SGP9 relatively to SGP1 on the right-hand side on the "Magnetittlageret" garage.

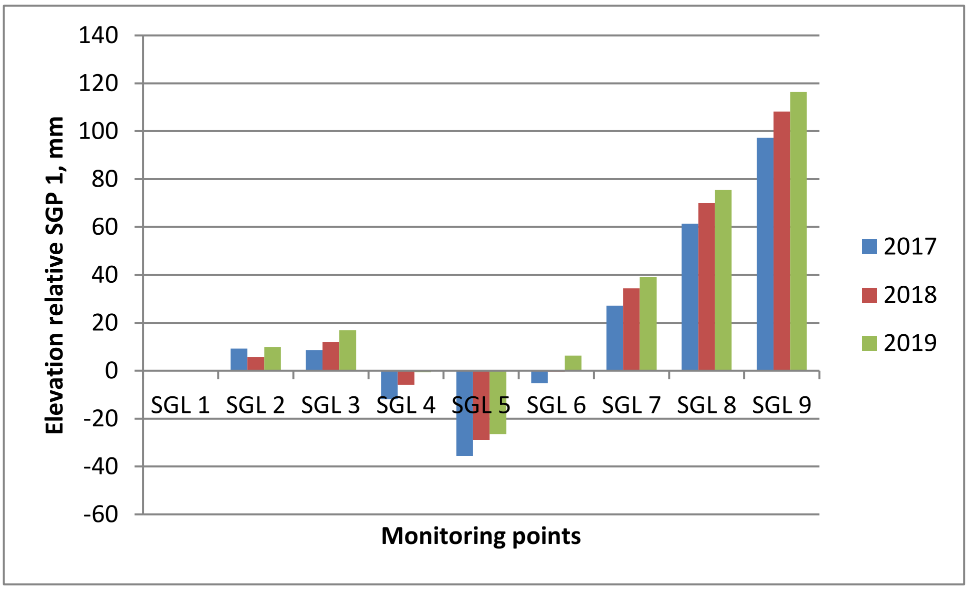

Figure 11. Elevations of points SGL2–SGL9 relatively to SGL1 on the left-hand side on the "Magnetittlageret" garage.

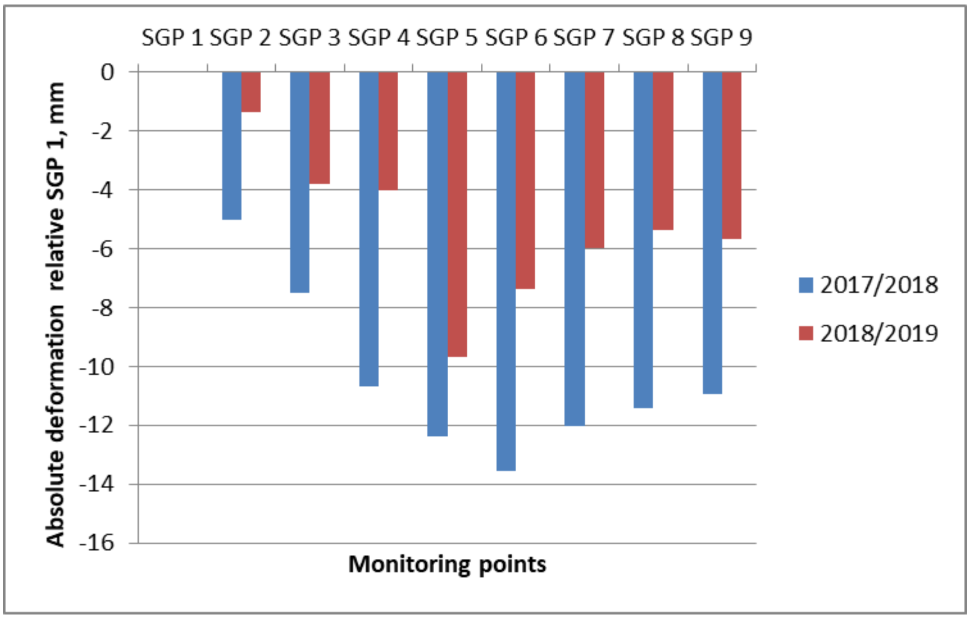

Figure 12. Absolute displacements (SGP 1–SGP 9) at right-hand side of multi-purpose garage "Magnetittlageret".

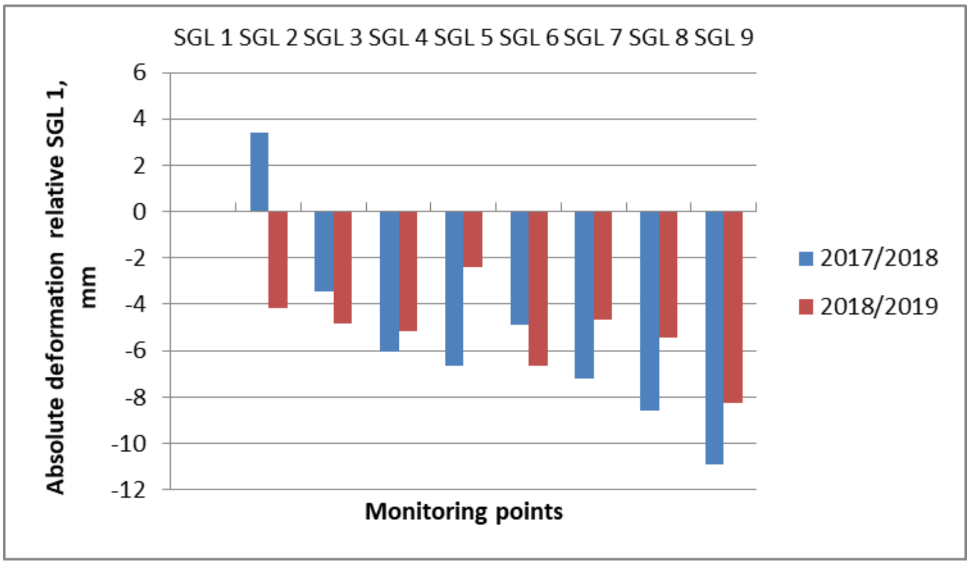

Figure 13. Absolute displacements (SGL1–SGL 9) at left-hand side of multi-purpose garage "Magnetittlageret".

7 Visual observations of the buildings

Photo and video material obtained by the project is stored in the project folder internally at SINTEF and will be available through the project web-site.

Longyearbyen

Issues with drainage were observed around the southern end of the UGH in 2017–2019 (near UGH 6), i.e. water accumulated in front of the southern end of UGH and was not sufficiently drained further. That created a small swamp in front of the building. Such conditions may be favourable for frost heave on pile foundations in this part of the building, one may also assume that rot of timber piles in this area may be somewhat intensified compare to dryer conditions.

Barentsburg

Cracks were observed in the northern part of the building, on the north (Figure 14) and east-facing walls (Figure 15). Drainage coming out from under the building was also observed at the north-facing wall (Figure 16–Figure 17). It seems that the drainage pattern might go somewhere under the building. However, no cracks were observed on outer walls in other parts of the building, hence presence of continuous drainage pattern under the building is questionable. Most probably this drainage also serves for water collected on the roof as the outer downpipes are absent; hence water must be conveyed by some downpipes located inside the building.

Observed cracks are thought to be caused by excessive settlements of foundation. Settlements of foundations were probably caused by thawing/warming of permafrost due to surface drainage mentioned above, or due to other reasons (as leakage of warm water). One can see that the cracks are located in the northern part of the building. Accumulation of cracks in one particular part of the building probably relates to maintenance issues rather then possible impacts of climate warming.

Figure 14. Cracks (highlighted with red circle) on the north-facing wall of the building "Komplex GRZ" in Barentsburg.

Figure 15. Cracks (highlighted with red circles) on the east-facing wall of the building "Komplex GRZ" in Barentsburg.

Figure 16. Drainage coming from under the building "Komplex GRZ" in Barentsburg and cracks (highlighted with red circles).

Figure 17. Drainage coming from under the building "Komplex GRZ" in Barentsburg (continuation, building is behind the photographer.

Pyramiden

Cracks were observed in western part on the multi-purpose garage, on its north- (Figure 18) and south-facing walls (Figure 19). The following reasons might be outlined among the ones caused the cracks:

- Issues with drainage – one can observe water running on the surface of the outer walls of this building during the rain events (video was filmed by the project). Absence of outer downpipes on the walls of this buildings points out that such pipes should be located inside of the building. Probably this drainage system (for instance, water intakes on the roof or downpipes inside the building) is partly malfunctioning as water has to run on the surface of the outer walls.
- Water leakages in the past (as warm water, sewage water) might be also among the reasons for settlements. Happening of water leakages (in ca. 2010) was mentioned by the maintenance staff, they told that water from the shower room was drained in the western part on the building for some time (perhaps weeks?).
- Possible presence of a talik zone under the western part of the building was pointed out by the owner of the building [4]. This idea may be supported by the fact that the thermosyphons were installed around several buildings in Pyramiden to improve permafrost conditions locally.

Figure 18. Cracks (highlighted with red circles) on the north-facing wall of the multi-purpose garage in Pyramiden.

Figure 19. Cracks (highlighted with red circles) on the south-facing wall of the multi-purpose garage in Pyramiden.

Svea

Only minor cracks were observed in several locations of shallow foundation of multi-purpose garage “Magnetittlageret” in Svea (Figure 20–Figure 23).

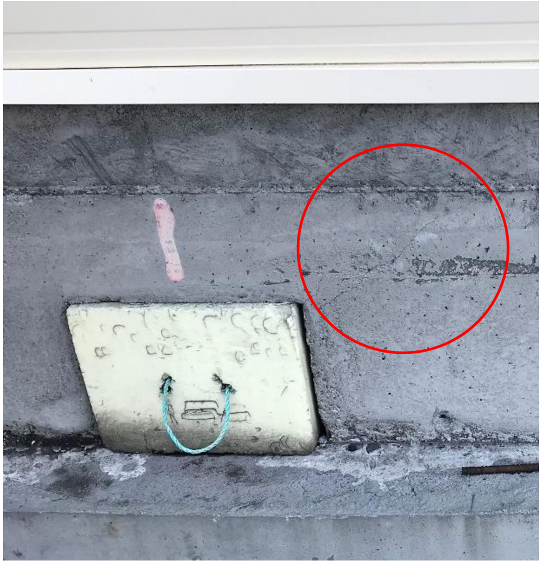

Figure 20. Cracks (highlighted with red circles) on foundation of the "Magnetittlageret" garage.

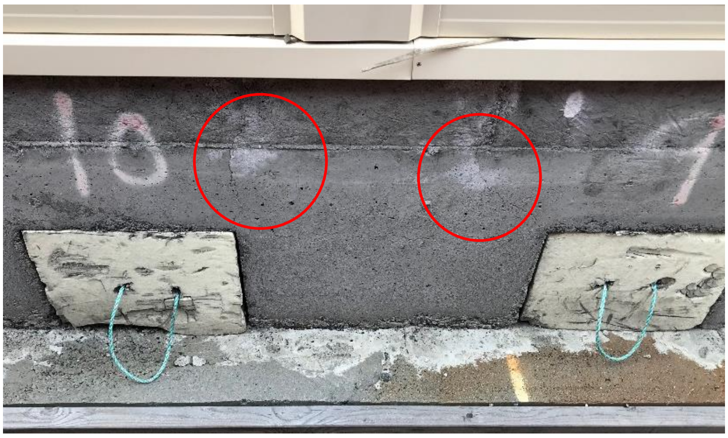

Figure 21. Cracks (highlighted with red circles) on foundation of the "Magnetittlageret" garage.

Figure 22. Cracks (highlighted with red circles) on foundation of the "Magnetittlageret" garage.

Figure 23. Cracks (highlighted with red circles) on foundation of the "Magnetittlageret" garage.

SINTEF

Appendixes

A Schedule for 2019 field work.

Schedule for 2019 fieldwork is presented in Table 13.

Table 13. Schedule for 2019 fieldwork.

	Date	Activity	Personnel	Designations	
Jul	Fri 19 (01:00)	AS, PK - arrival		PK	Pavel Kotov
	Sat 20	LYR, office	AS, PK	AS	Anatoly Sinitsyn
	Sun 21	LYR: Survey	AS, PK		
	Mon 22	LYR/BB (arrival, survey)	AS, PK	LYR	Longyearbyen
	Tue 23	BB: Survey	AS, PK	BB	Barentsburg
	Wed 24	BB/PYR (arrival, survey)	AS, PK	PYR	Pyramiden
	Thu	PYR: Survey	AS, PK		
	Fri 26	PYR/LYR	AS, PK		
	Sat 27	LYR: data processing in office	AS, PK		
	Sun 28	LYR: day off			
	Mon 29	Svea: survey	AS, PK		
	Tue 30	Svea: survey	AS, PK		
	Wed 31	Svea: survey	AS, PK		
Aug	Thu 1	LYR: day off			
	Fri	LYR: Workshop			

B List of instruments and equipment

A list of instruments which belongs to the project is given in Table 14.

Table 14. List of instruments and equipment applied in fieldwork in 2019.

	Equipment	Location
1.	Digital laser level Leica Sprinter 250M, long staff bar, short staff bar[3], tripod, Leica software, extra 2AA batteries, base plate (2 pcs, 3 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.	"SINTEF storage room".
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" notebook.	"SINTEF storage room".
6.	Steel peggs (12 pcs), hammer.	"SINTEF storage room".

[3] Was lost in Pyramiden in 2019. One should bring a new part, should measurements under the garage be repeated in the future.

C   Monitoring plans of the buildings

Monitoring plans of surveyed buildings are presented below.

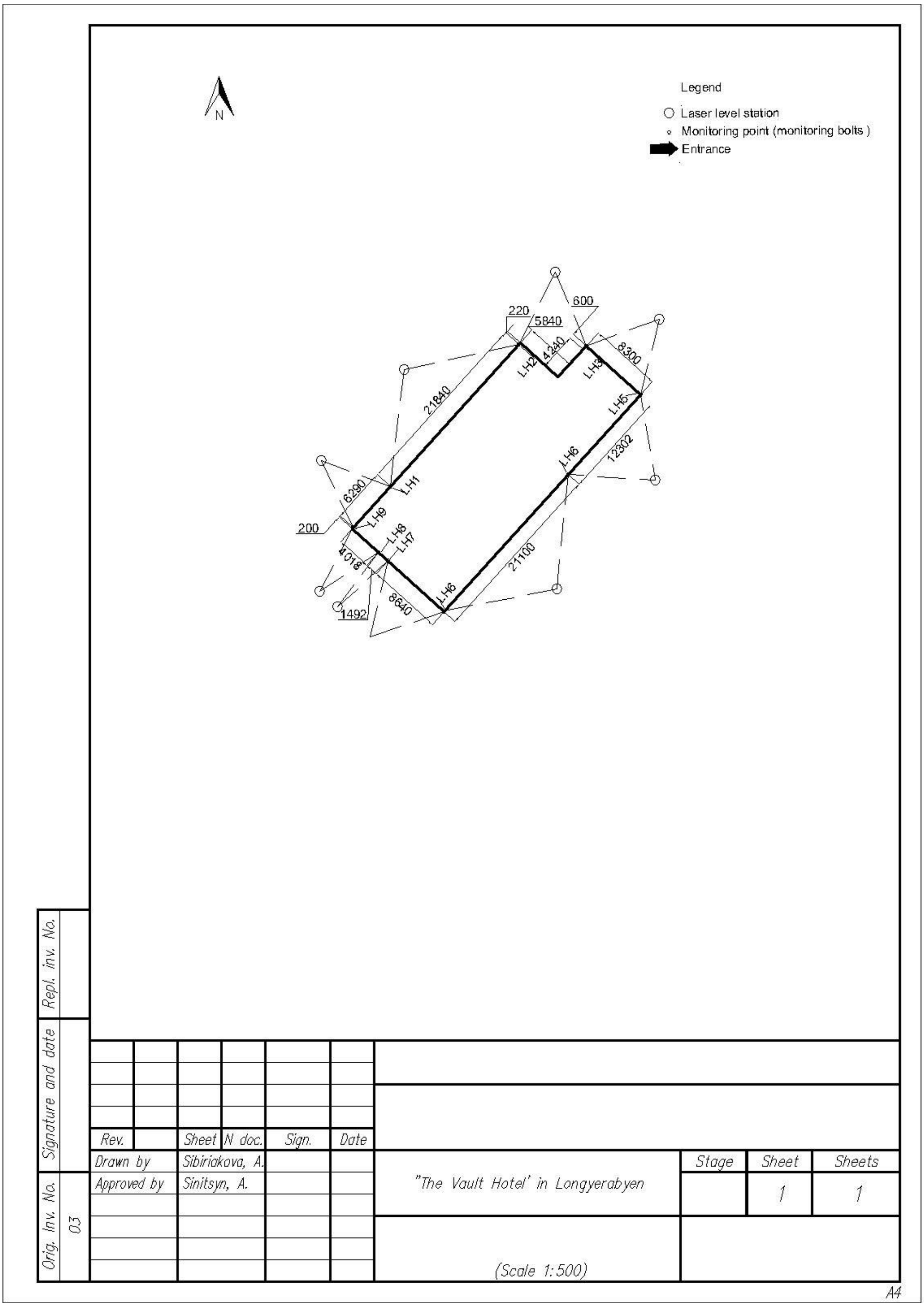

Figure 24. Monitoring plan of The Vault hotel.

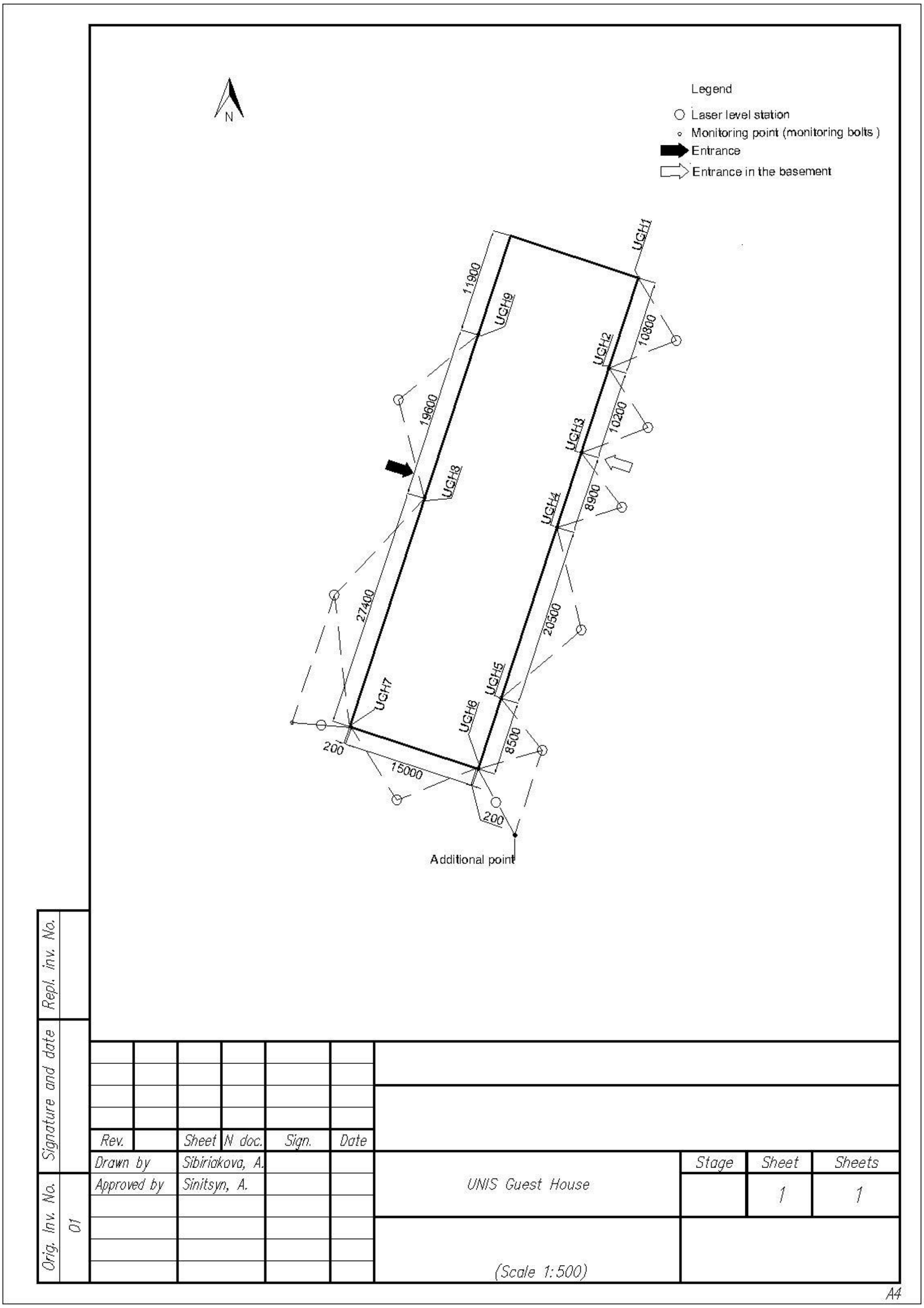

Figure 25. Monitoring plan of the UNIS Guest House (locations of monitoring points on the outer pile foundations).

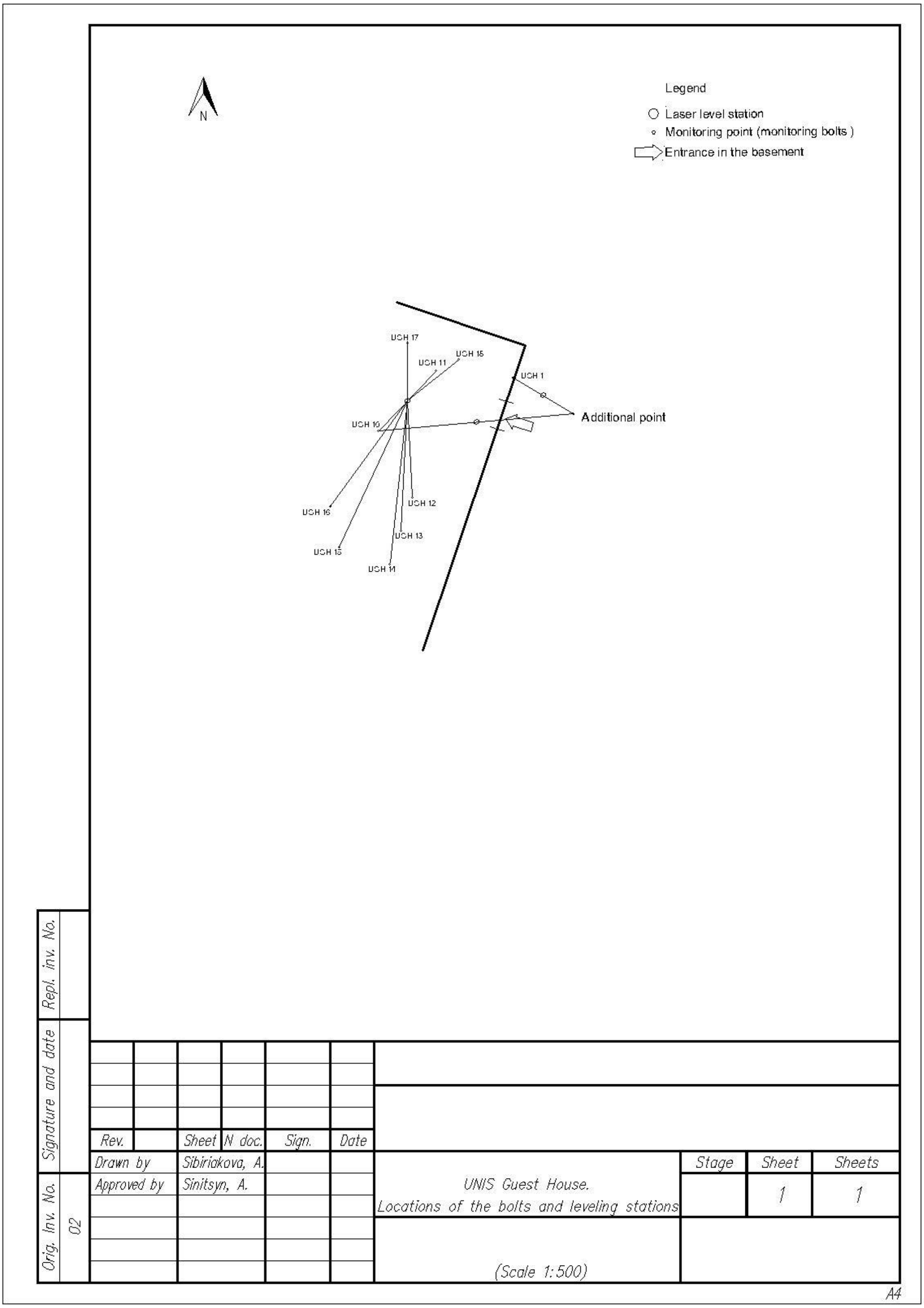

Figure 26. Monitoring plan of the UNIS Guest House – locations of monitoring points on the inner pile foundations under the building.

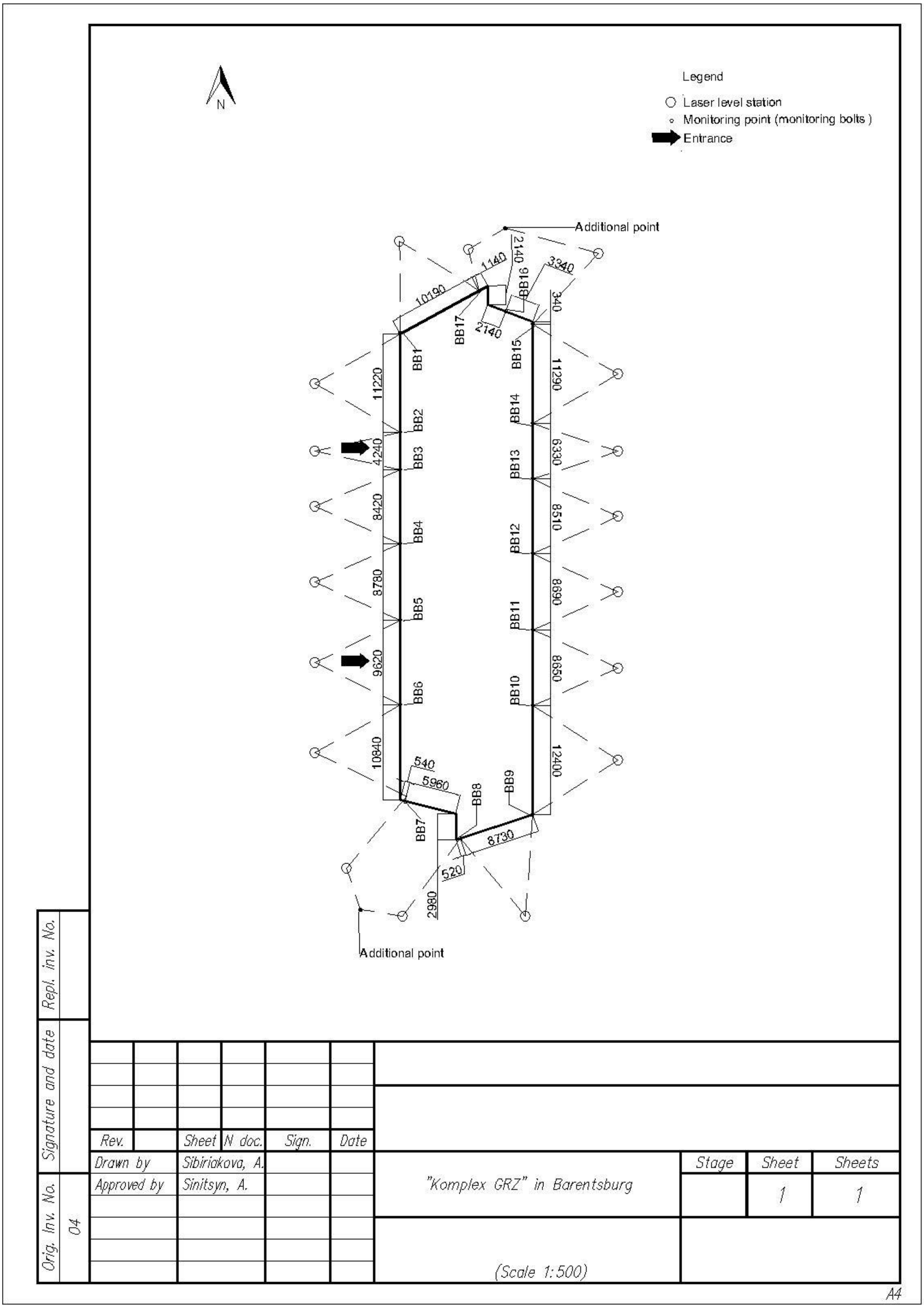

Figure 27. Monitoring plan of the building "Komplex GRZ".

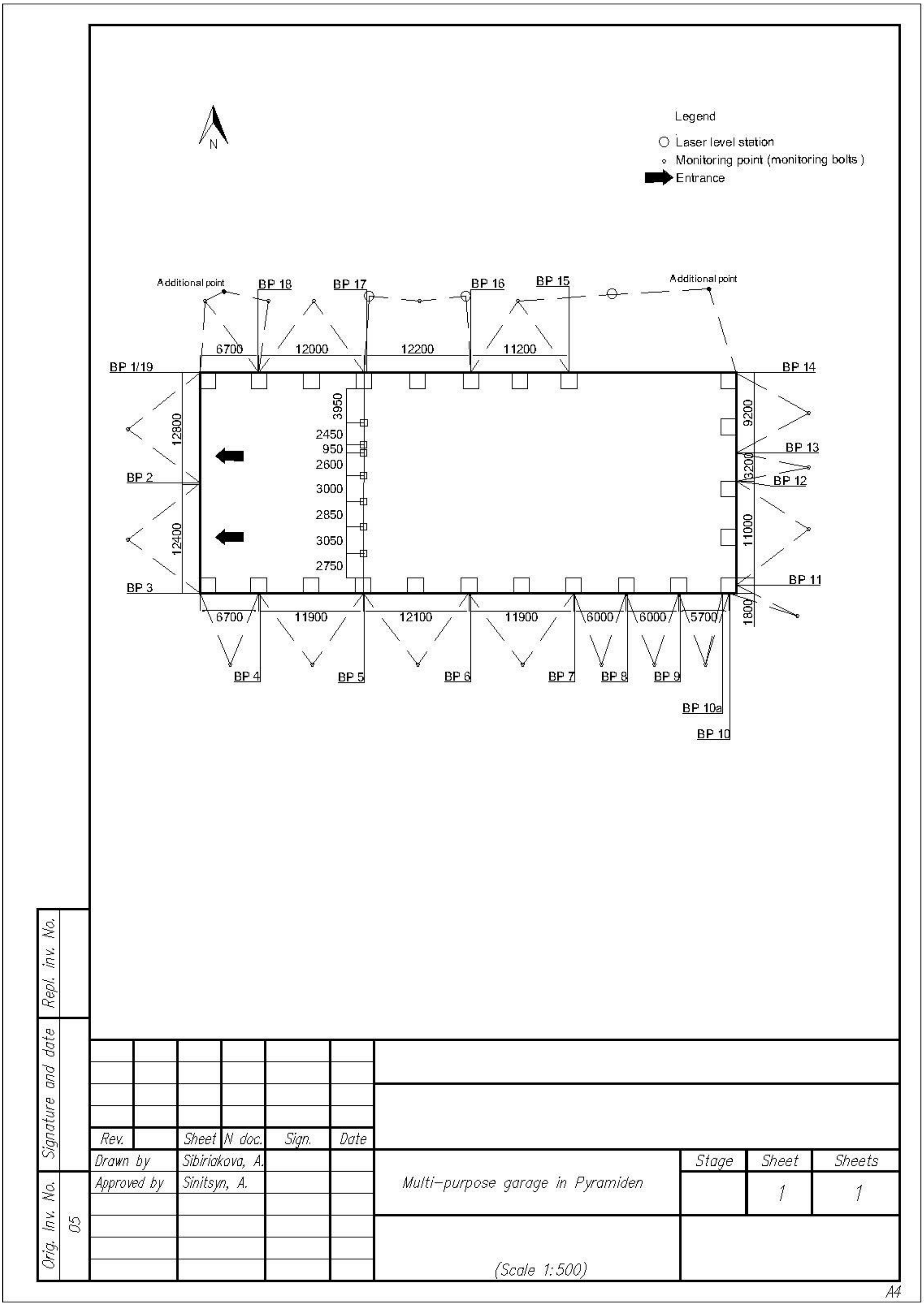

Figure 28. Monitoring plan of the multi-purpose garage in Pyramiden.

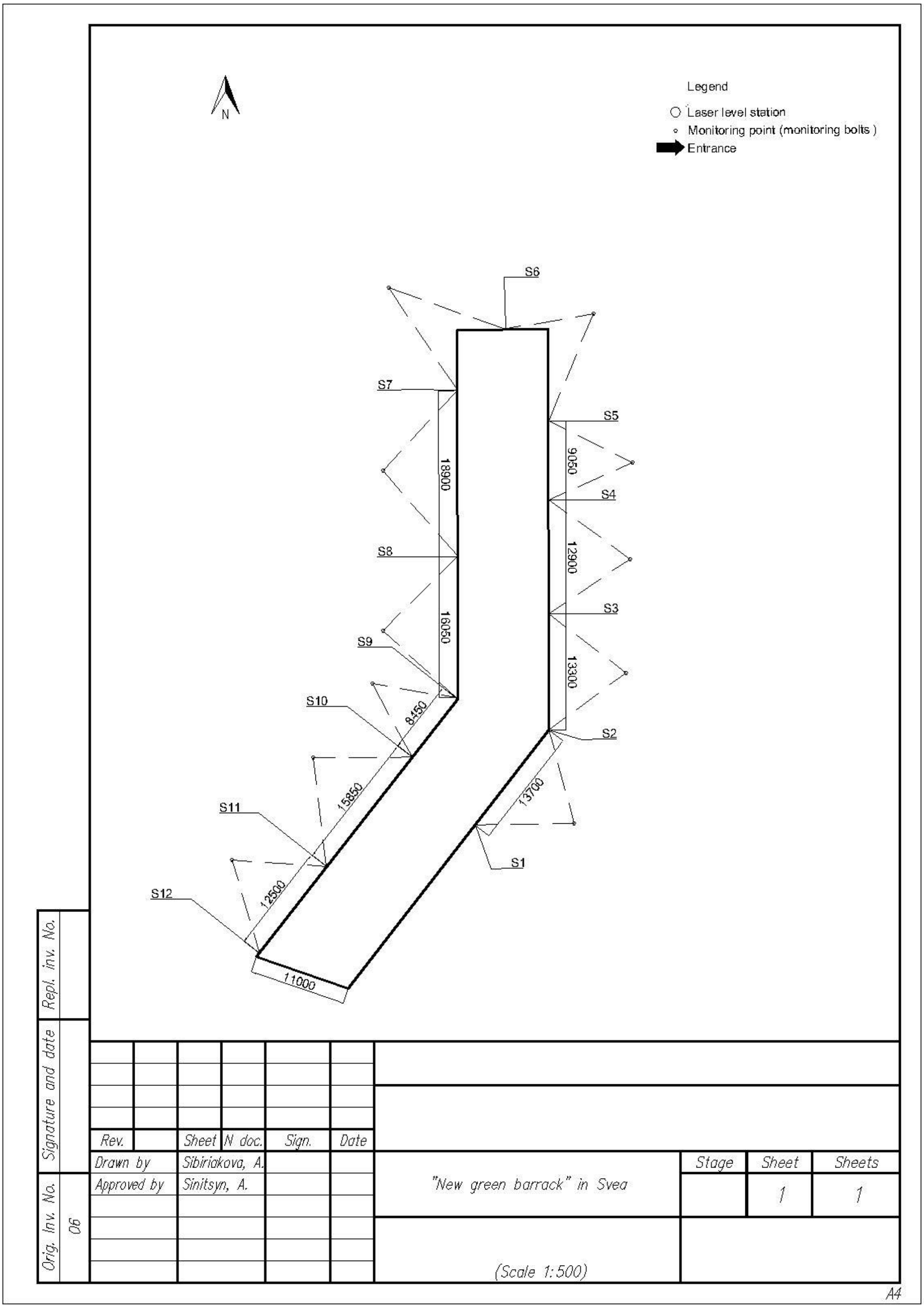

Figure 29. Monitoring plan of the "Låven" barack in Svea.

SINTEF

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.
3. Sinitsyn, A., P. Kotov, and A. Aalberg. MonArc Project Report 2018. 2019. p. 35.
4. Sinitsyn, A., Personal communication Mr. Tsikolenko, S.V. (Technical Director of Trust Arcticugol), august 2019. 2019.

Technology for a better society

www.sintef.no