2019:00156- Unrestricted

Report

MonArc Project Report 2017

Monitoring of Arctic Infrastructure

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SINTEF Building and Infrastructure
Rock and Soil Mechanics
2017-12-31

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

VERSION	DATE
2017-01	2017-12-31

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CLIENT(S)	CLIENT'S REF.
The Research Council of Norway	Marianne Johansen

PROJECT NO.	NUMBER OF PAGES/APPENDICES:
102015781	46/3

ABSTRACT

The report presents detailed description of activities and deliverables within the MonArc project (Monitoring Arctic Infrastructures), and gives references to data records produced in 2017. The performed activities include scientific and logistical planning of fieldwork, fieldwork, data processing, and reporting. The monitoring program comprises measurements on two buildings in Longyearbyen, one building in Barentsburg, one building in Pyramiden, and two buildings in Svea. The field activities include identification of stable reference points in each settlement, installation of monitoring bolts in piles/foundations of selected buildings, and a systematically geodetic survey by leveling the monitoring points with a laser level device and establishing a present ("as-today") data set for each building.

The collected height-data for the monitoring points will serve as reference for future assessment of vertical settlements of infrastructure in the settlements. Similar leveling surveys will be repeated in 2018 and 2019. It is the intention to repeat the measurements in the future in order to document long-term performance of infrastructure, for instance in a 10-years perspective.

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REPORT NO.	ISBN	CLASSIFICATION	CLASSIFICATION THIS PAGE
2019:00156	978-82-14-06854-2	Unrestricted	Unrestricted

Document history

VERSION	DATE	VERSION DESCRIPTION
2017-01	2017-12-31	The report presents detailed description of activities and deliverables, and references to data records produced in the field-activity period in summer 2017.

102015781

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APPENDICES

[List appendices here]

1 Introduction

The Monitoring of Arctic infrastructure (MonArc) project, with funding from The Research Council of Norway, creates and facilitates research cooperation between Norwegian and Russian researchers in Svalbard on the basis of joint effort in the monitoring of infrastructure response to climate change influence.

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, Barentsburg;
- Longyearbyen Lokalstyre;
- Store Norske Spitsbergen Grubekompani Aktieselskap, Longyearbyen (SNSG).

The project tasks consist of monitoring vertical heights of chosen reference points on elements of selected buildings. Additional data, as design drawings of the buildings, reports on previous investigations of the buildings, data on soil conditions and soil temperatures is collected when available.

The report presents detailed description of activities and deliverables, and gives references to data records produced in the year 2017. The activities included scientific and logistical planning of fieldworks, performance of the fieldworks, data processing and reporting.

2 Background

The detailed project activities in 2017 included:

i. Fieldwork planning and preparation. This comprised communication with authorities, planning of fieldwork execution, purchase and collection of various field instruments, purchasing and testing of software, and logistical planning as booking of transportation and accommodation, and supplying food etc. for the fieldwork periods.
ii. Execution of fieldwork with field installations and measurements.
iii. Processing of data after the field campaigns.
iv. Interpretation of results and reporting.

Responsibilities were divided as follows:

- Overall responsibility for the project, and for fieldwork and safety: Anatoly Sinitsyn.
- Fieldwork preparation: Anatoly Sinitsyn, Arne Aalberg, Pavel Kotov, Katharina Beutner.
- Field installations: Anatoly Sinitsyn, Pavel Kotov, Katharina Beutner, Arne Aalberg, Sandmo & Svenkerud AS.
- Field measurements: Pavel Kotov, Katharina Beutner, Arne Aalberg.
- Data processing: Pavel Kotov, Katharina Beutner.
- Reporting: Anatoly Sinitsyn, Pavel Kotov, Katharina Beutner, Arne Aalberg.

3 General information about sites and fieldwork

The fieldwork took place in four small towns of Longyearbyen, Barentsburg, Pyramiden and Svea in August 2017. The locations are marked in the map in Figure 1.

Figure 1. Map of Svalbard archipelago [10].

The choice of buildings/structures for the survey was done after the discussions with project partners and building owners. It was the intention to pick structures that could be representative for a larger number of buildings. Thus, both classical "old-solution" foundations with timber piles, and newer solutions with long steel pile foundations were chosen. The following structures were therefore chosen:

Longyearbyen:

- The UNIS Guest House (UGH), 229.05.

- The "Elvesletta Byggetrinn 1" new hotel building located at the crossing of roads 500 and 503.

Barentsburg:

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

Pyramiden:

- The multi-purpose garage.

Svea:

- The two-storey residential building for temporary residence, “Låven”.
- The multi-purpose garage, “Magnetittlageret”.

The following works were performed:

i. Visual search for the land reference points within the vicinity of the buildings. The requirement for such points are that they do not experience vertical movements in a long-term time span (decades).
ii. Visual observations of buildings and defining locations where the monitoring bolts will be installed.
iii. Installation of the monitoring bolts.
iv. Leveling of the monitoring bolts in relation to the land reference points.
v. Drawing of sketches, which present: a) scheme of a building; b) locations of points for monitoring; c) way points for leveling.
vi. Photography documentation of the buildings and the monitoring points.

4 Planning and preparation of fieldworks

The overall plan of field works is presented in Table 8–Table 9, Attachment 0.

The main goals at the planning stage were:

- To set up a list of structures for monitoring and to obtain permissions from the owners of the structures to perform the monitoring.
- To purchase and collect all necessary instruments, software, and tools. A list of equipment is presented in Table 10, Attachment 0.
- 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 in 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.
- Purchase of food for fieldwork, eating was also orginazed at the canteens at Barentsburg, Pyramiden and Svea.

5 Background data

5.1 Surveys of infrastructure

It is likely that some of the building (surveyed by the project) were previously surveyed. However, no reliable data that would be directly applicable for the present project was found.

Some previous surveys that were found are:

- Survey of selected buildings in Longyearbyen (Nybyen, Haugen, Lia and Gruvedalen). Performed in 2009 by means of a laser level, ruler and photographs. Results of the survey are presented in [12].
- Survey of conditions of timber pile foundations of 27 buildings on the roads 220, 221, 222, 226, 230, 232, 234, 236, 238, and 309. Survey was performed in autumn 2016. Conditions of piles and angular brace elements at many buildings were inspected. Some damages from rotting processes and fungi was found, significant number of piles was classified as significantly damaged. The results of survey are presented in [13].
- Survey of coastal structures (quays) in Svalbard is presented in [9].

5.1.1 Data on geotechnical conditions

Data on geotechnical conditions will be required should the re-analysis of bearing capacity and stability of surveyed infrastructure be performed in the future.

Results of geotechnical investigations were found only for Longyearbyen. Overview of geotechnical investigations performed until 2007 in Longyearbyen and at some adjacent locations is presented in [16]. The geomorphological conditions in Longyearbyen are presented in [6].

5.1.2 Data on structural design of infrastructure

Data on the structural systems, as detailed drawings, information on materials, loads etc. for the monitored buildings will be required for a re-analysis of the building stability and durability. The project will request and collect such data from the owners.

5.1.3 Existing codes, guidelines and recommendations

Norwegian requirements procedures for levelling are presented in .
Russian practice for measurements of deformations in structures is presented in [5], instructions for leveling are presented in [4]. General recommendations on acceptable differential settlement of foundations are defined for instance in [15]. The US recommendations is presented in [2].

6 Methods

6.1 Considerations on methodology

The technical goal of this project is to carefully monitor the development in vertical settlements in the foundations of the buildings. Vertical movements of foundations are considered as suitable indicator of foundation settlements. Only the buildings on more or less flat terrain are considered, hence measurements of horizontal displacements were not considered.

Considerations on methodology based on Russian practice
Following procedures, for instance, from [5] one can select an appropriate method for measurements of vertical (and horizontal) movements and shifts of foundations depending on a number of factors.

The precision class of measurements is defined based on two criteria: i) the acceptable design values of movements, and ii) the type of soil. One can assume that for the buildings surveyed in the project, the acceptable design values of vertical (and horizontal) movements are less or equal to 50 mm, or are in the range of 50 to 100 mm during the lifetime of the building (assumed to be 35 years). One may assume that mentioned above values may be practically observed within the period of one to two decades. Concerning criteria ii), sand, clay and silt can be practically encountered within the settlements in Svalbard. The reference [5] does not consider the state of the ground. Ground state in Svalbard is permafrost.

Assumptions made for the criteria i) and ii) lead to the precision class I (the highest class) or class II (see Table 1 and 2 in [5]). Geometrical leveling shall be chosen as the basic method for measurements of vertical movements (see Section 6 in [5]); the technique of "closed run" shall be applied. The "closed run" technique consists in levelling from a given point in the forth and back directions, i.e. measurements begin and end on a given point.

Additional considerations based on [5] point out that the classes II or III should be sufficiently accurate to trace "typical" settlements of foundations in permafrost conditions. "Typical" values of settlements are assumed to be of the order of 1–1,5 mm per year.

The method of differential leveling was chosen. This method is widely used due to number of advantages, i.e. high accuracy and rapid measurements, simple and inexpensive equipment, the ability to perform measurements in difficult conditions. Differential leveling is the most precise method for determining elevation, providing accuracy of the third or higher orders. This method is included in the standards for monitoring the infrastructure objects ([2, 5]).

Considerations on methodology based on the Norwegian practice
Reference [19] provides considerations for levelling over long distances, for instance along the roads.

Considerations on methodology based on the North American practice
Four classes of leveling are set according to the US and Canadian standards ([1, 3]). First-order and second-order leveling are used to establish the main areal level networks and to provide basic vertical control for the extension of the level networks of the same, or lower, accuracy (for support of mapping projects). Third-order leveling is used to provide elevations for an immediate control of cadastral, topographic, and construction surveys of permanent structures. Fourth-order is used in connection with the location and construction of highways, railroads, and other engineering works. Thus, third- or fourth-order levelling should be performed according to the goals of the current project.

6.2 General description of methodology

Fieldwork
The leveling team consists of at least two individuals: the instrument man and the rodman. Involvement of additional personnel (a second rodman and a writer, who makes drawings and writing notes when necessary) is useful for speeding up the data collection. The procedure of differential leveling according to the geodetic leveling manual [11] is described below.

The instrument man operates the level and makes all necessary adjustments of instrument (as correct installation of the tripod, leveling of the instrument, etc.). The instrument man ensures that i) no stations are omitted; ii) turning points (TPs) are properly selected; iii) and the bench marks (BMs) are properly established. The instrument man controls that the errors are within the specified limits. Storage and transportation of leveling instruments shall be performed according to the instructions, no signs of physical damage shall be present on the instrument.

Particularities of the rodman's work

The rodman is responsible for holding the leveling rod (barcode staff). The rodman is responsible for positioning and holding the rod, the skills of rodman affect the speed and accuracy of the leveling operation.

The sequence of rodman's operations during the survey is the following:

1. Clean the base (or shoe) of the rod before setting down the rod at any point, to clean the surface of the point (monitoring bolt, ground plate) in order to ensure a good contact between the rod and the point.
2. Place the rod firmly on the point, stand towards the instrument and (slightly behind the rod), hold the rod with both hands.
3. Hold the rod as vertical as possible. Place the rod level on the rod, and position the rod vertically as the bubble (on the rod level) is centred.
4. Set up the ground plate (containing the turning pin on its top) firmly in contact with the ground for setting up the turning point (TP). Do not place the ground plate on soft ground surface (as, for instance, covered with moss) as it can be deform under weight of the rod. The latter will result in incorrect readings between the foresight (FS) and backsight (BS).
5. Extend the rod to its maximum length when it is needed (the instrument man will request to do so if needed).

Particular notes about the leveling rod: the leveling rod is a precise instrument that has to be treated and handled with care. One should not handle it in the way that the painted faces become scratched, dented, or damaged. Use of a damaged rod may lead to corrupted readings.

Routines for differential leveling

The basic procedures used for determining the elevations by differential leveling are the following ([7], see Figure 2):

1. Setup the instrument.
2. Take the BackSight (BS) reading on a rod held on a point of known elevation (KE).
3. Add the BS reading to the known elevation to determine the height of instrument (HI); HI=KE+BS.
4. Take the ForeSight (FS) reading on a rod held at the point of unknown elevation (UKE).
5. Finally, subtract the FS reading from the HI reading to establish the elevation of the new point.

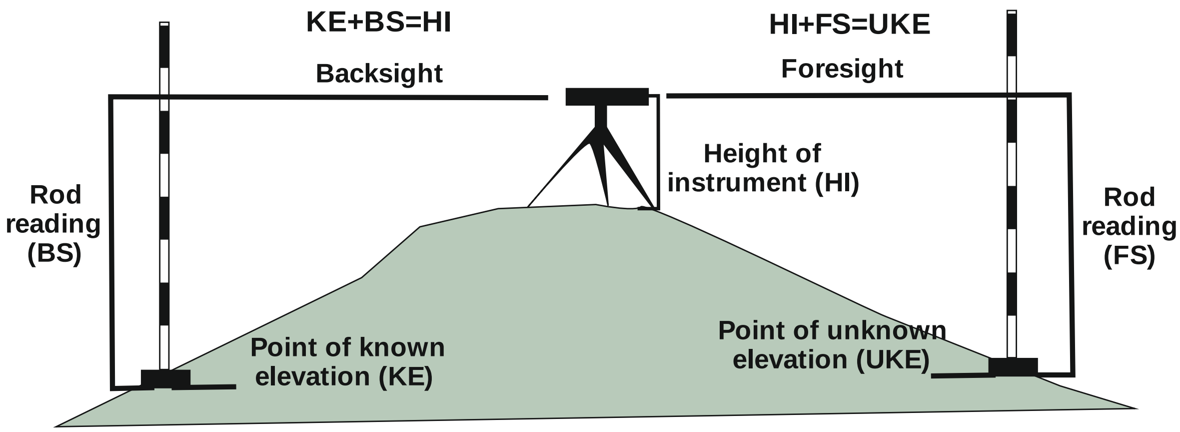

Figure 2. Setup of deferential leveling.

When the FS is completed, keep the rod on that point and move the instrument to the next location. Set up the instrument approximately midway between the old and new locations of the rod.
The new reading from the back rod becomes a BS, which is used to establish a new HI. The points other than the bench marks (BMs) or the temporary bench marks (TBMs) on which the rods are held for the BSs and FSs are called turning points (TPs). Other FSs made for points, which are not along the main route are known as the side points. This procedure can be used as many times as necessary to transfer a point of known elevation to another distant point of unknown elevation.

The double rodding is a form of differential leveling in which the accuracy of the leveling procedure is being controlled continuously. Double rodding is typically performed with the use of two rodmen. It is, however, possible to carry out the procedure using only one rodman. In double rodding, the HI is determined at each setup point by the backsight readings taken on two different levels. In this case, the result will be two HIs that differ slightly from each other (if no errors are present). Elevations computed this way will also differ slightly. In each case, the average value is taken as the elevation.

Data processing
Adjustments of intermediate bench mark elevations
Level lines that begin and end on the points with fixed elevations (for instance when the leveling is accomplished between two previously established BMs or over a loop that closes back on the starting point), such as BMs, are often called level circuits. In such cases, the elevation determined for the final BM normally is not equal to its previously established value. The difference between these two elevations for the same BM is known as the error of closure. The latter is illustrated in Figure 3.

One can see on Figure 3 the that the actual elevation of BM 1 is 136,000 m, and for BM 2 – 138,560. The elevation of BM 2 found through the differential leveling is 138,575 m. The error of closure of the level circuit is 136.575-138.56=0.015 m.

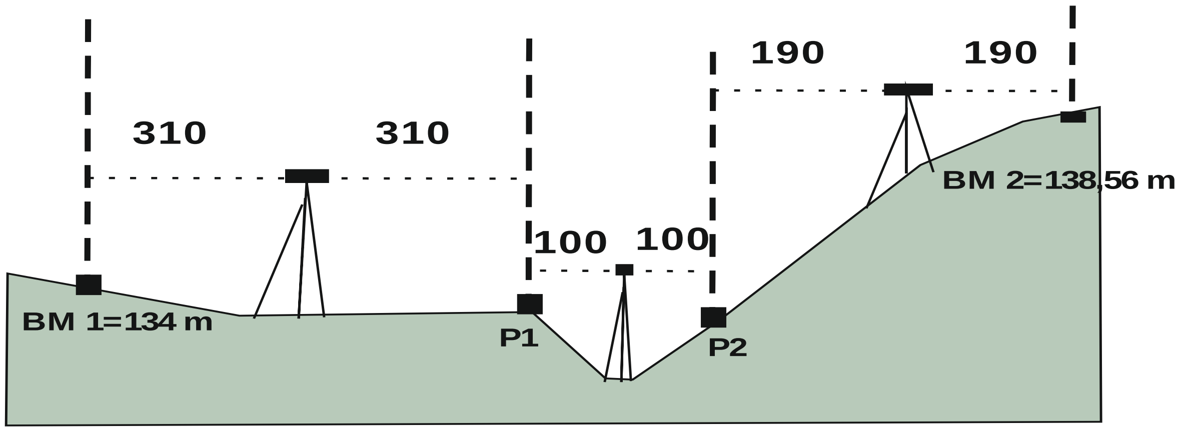

Figure 3. Differential level circuit.

Based on the results presented in Figure 3 one can assume that the errors occur progressively along the line for survey. Hence, adjustments for these errors shall be distributed proportionally along the line.

One can see that the total distance between BM1 and BM2 is 1200 m and the elevation on the closing BM2 is found to be 0.015 m greater than its known elevation (Figure 3). Therefore, it is needed to adjust the elevations determined for the intermediate P1 and P2. The correction shall be calculated as follows (Eq. 1):

$$C = E\frac{d}{D} \qquad \text{Eq. 1}$$

where: C – correction; E – Error of closure; d – distance between the starting BM and the intermediate BM; D – distance between the starting and closing BMs.

Example of calculations
P1 is 620 m from the starting BM1, see Figure 3. The distance between the starting and closing BMs (19) is 1200 m. The error of closure is 0.015 m.

$$\mathrm{C} = 0.015 * \frac{620}{1200} = 0.00775\ m$$

The adjusted elevation of P1 is 134-0.003 = 133.923 m.
The adjustments for P2 and BM 2 are made in a similar manner.

Precision in leveling
The precision of a level run is usually described in terms of maximum error of the closure. Maximum allowable error is defined by a standard being used. Comparison of Russian ([4, 5]), US ([3]) and Canadian ([1]) standards is presented in Table 1. The standards specify certain requirements and, in particular, the maximum allowable errors. It was decided to follow ([4, 5]) because it has the lesser maximum allowable error.

Table 1. Comparison of different standards in relation to classes of leveling.

GOST 24846-2012, Soils. Methods of measuring the strains of structure and building bases ([5]) Instruction for leveling of classes I, II, III and IV ([4])				
Parameters	**Classes**			
	I	II	III	IV
Maximum distance to the rod, m	25	40	50	100
The maximum difference of distances between BS and FS, m	0,2	0,4	1,0	3,0
Total difference of distances between BS and FS, m	1,0	2,0	5,0	10,0
Maximum permissible error, mm	$\pm 0.3\sqrt{n}$	$\pm 0.5\sqrt{n}$	$\pm 1.5\sqrt{n}$	$\pm 5\sqrt{n}$
Maximum permissible error, mm	$3\sqrt{L}$	$5\sqrt{L}$	$10\sqrt{L}$	$20\sqrt{L}$
Norm for kart I målestokkene 1:250, 1:500, 1:1000 og 1:2000 og kommunale oppmålings-arbeider [19].				
Error limits: deviation Δh (m) by levelling back and forth oven a distance L (km)	$\Delta h = 0.015\sqrt{L}$			
Standards and Specifications for Geodetic Control Networks ([3]), Specifications and recommendations for control surveys and survey markers ([1])				
Length of section, km	1-2	1-2	-	-
Maximum distance to the rod, m	50	110	-	-
Maximum allowable error, mm.	$4\sqrt{L}$	$8.4\sqrt{L}$	$12\sqrt{L}$	-

Note:
n – Number of stations;
L – Distance, km;

6.3 Comments on Implemented Methodology

Survey was performed by deferential leveling of class III according to [5]. The level lines begin and end up on the points with fixed elevations in that type of survey. Elevation of the reference point (defined in each settlememt) was set up as zero. List of reference points is presented in Appendix 0.

The leveling was performed in the forth and reverse directions. Leveling was carried out at two horizons of the instrument. Digital level Leica Sprinter 250 M and barcode staff Leica GSS 111 rod were used. Technical data ([8]) on the instrument is presented in Table 2. Raw data from the instrument was collected and processed in form of a table. Example of calculations is presented in Table 3.

Table 2. Technical data on used instruments.

Characteristics	Description
Height accuracies:	Standard deviation height measurement per 1 km double run (ISO 17123-2):
• Electronic measurement	1.0/0.7* mm
• Optical measurement	2.5 mm
Distance Accuracy	Standard deviation distance measurement 10 mm for D ≤ 10 m and for D > 10 m
Full Range	2–100 m
Measuring modes	Single and Tracking.

* With Sprinter aluminum barcode staff, 0.7 mm can be achieved with Sprinter fiberglass barcode staff (3 m, 1 section).

Table 3. Example of calculations, measurements at the UNIS Guest House.

Measurements (raw data)

Line	Station №	Points	№ of monitoring point (monitoring bolt)	Readings: Distance to the rod (barcode staff), m: Forth	Distance to the rod (barcode staff), m: Back	Difference, m	Average difference, m	Readings (m) on: Front rod	Readings (m) on: Back rod	Height difference on measured points, m	Average height height difference on measured points, m	Adjusted height difference on measured points, m
Forth	1	1-2	UGH2	7,34	8,49	1,15	1,14	1,7360	1,2082	0,5278	0,5277	0,5277
				7,33	8,47	1,14		1,7369	1,2093	0,5276		
	2	2-3	UGH3	8,39	7,75	0,64	0,64	1,8382	1,4483	0,3899	0,3901	0,3902
				8,40	7,76	0,64		1,8382	1,4478	0,3904		
	3	3-4	UGH4	8,00	7,73	0,27	0,26	1,6723	1,5502	0,1221	0,1223	0,1223
				7,99	7,73	0,26		1,6733	1,5509	0,1224		
	4	4-5	UGH5	12,55	12,16	0,39	0,37	2,0577	1,2169	0,8408	0,8412	0,8412
				12,50	12,16	0,35		2,0595	1,2179	0,8416		
	5	5-6		12,22	12,58	0,36	0,37	1,6280	0,7770	0,8509	0,8515	0,8515
				12,19	12,58	0,39		1,6301	0,7781	0,8521		
	6	6-7	UGH6	3,37	3,29	0,08	0,06	0,9803	1,4202	-0,4399	-0,4389	-0,4389
				3,34	3,29	0,05		0,9827	1,4206	-0,4379		
	7	7-8	UGH7	9,42	8,88	0,54	0,54	1,3114	1,0129	0,2986	0,2987	0,2987
				9,44	8,89	0,55		1,3105	1,0117	0,2988		
	8	8-9		5,52	3,57	1,95	1,95	0,9216	1,0399	-0,1183	-0,1186	-0,1186
				5,52	3,57	1,94		0,9234	1,0422	-0,1188		
	9	9-10	UGH8	17,44	19,02	1,58	1,60	1,4757	1,7436	-0,2679	-0,2679	-0,2679
				17,43	19,05	1,62		1,4768	1,7447	-0,2679		
	10	10-11	UGH9	11,10	9,74	1,36	1,38	1,2276	1,8864	-0,6587	-0,6588	-0,6587
				11,12	9,72	1,40		1,2285	1,8873	-0,6588		
Back	11	11-10	UGH8	9,74	11,10	1,36	1,38	1,8864	1,2276	0,6587	0,6588	0,6588
				9,72	11,12	1,40		1,8873	1,2285	0,6588		
	12	10-9		18,77	17,67	1,10	1,18	1,8034	1,5331	0,2704	0,2694	0,2694
				18,87	17,62	1,26		1,8026	1,5342	0,2684		
	13	9-8	UGH7	3,79	5,34	1,55	1,54	1,0799	0,9606	0,1193	0,1194	0,1194
				3,80	5,34	1,54		1,0813	0,9618	0,1195		
	14	8-7	UGH6	8,86	9,42	0,56	0,53	0,9760	1,2754	-0,2994	-0,2988	-0,2988
				8,87	9,37	0,50		0,9772	1,2754	-0,2982		
	15	7-6		3,46	3,13	0,33	0,32	1,3603	0,9230	0,4374	0,4379	0,4379
				3,47	3,15	0,32		1,3611	0,9227	0,4384		
	16	6-5	UGH5	12,46	12,31	0,14	0,15	0,7805	1,6328	-0,8524	-0,8522	-0,8522
				12,47	12,32	0,15		0,7817	1,6338	-0,8520		
	17	5-4	UGH4	12,45	12,53	0,08	0,10	1,2043	2,0472	-0,8430	-0,8427	-0,8427
				12,40	12,51	0,11		1,2047	2,0472	-0,8425		
	18	4-3	UGH3	8,09	8,21	0,13	0,13	1,5090	1,6313	-0,1223	-0,1221	-0,1220
				8,08	8,22	0,14		1,5105	1,6323	-0,1218		
	19	3-2	UGH2	7,98	8,41	0,43	0,42	1,3634	1,7531	-0,3897	-0,3900	-0,3899
				7,98	8,39	0,40		1,3641	1,7543	-0,3902		
	20	2-1	UGH1	8,37	7,35	1,02	1,01	1,1882	1,7157	-0,5275	-0,5274	-0,5274
				8,34	7,34	1,01		1,1872	1,7144	-0,5273		
										Error	-0,0004	0,0000

Calculations_Elevations of the monitorin

tation N	Monitoring point №	Distance, m: Between rods	Distance, m: From the reference point, m	Station № Forth/ Back	Height, m: Forth	Height, m: Back	Difference, m Between forth and back line	Average height, m	Correction of height, m	Adjusted height, m	Evelation relative to the reference point,m
	UGH1	0,00	0,00		0	0	0	0			8,1273
1	UGH2	15,83	15,83	1/20	0,5277	0,5274	0,0003	0,5276	0,00002	0,5276	8,6549
2	UGH3	16,13	31,97	2/19	0,3901	0,3900	0,0002	0,3901	0,00002	0,3901	9,0449
3	UGH4	15,72	47,69	3/18	0,1223	0,1221	0,0002	0,1222	0,00002	0,1222	9,1671
4	UGH5	24,70	72,39	4/17	0,8412	0,8427	0,0015	0,8420	0,00003	0,8420	10,0091
5		24,80	97,20	5/16	0,8515	0,8522	0,0007	0,8518	0,00003	0,8519	10,8610
6	UGH6	6,67	103,86	6/15	-0,4389	-0,4379	0,0011	-0,4384	0,00001	-0,4384	10,4226
7	UGH7	18,30	122,16	7/14	0,2987	0,2988	0,0001	0,2987	0,00002	0,2988	10,7213
8		9,09	131,25	8/13	-0,1186	-0,1194	0,0008	-0,1190	0,00001	-0,1190	10,6024
9	UGH8	36,45	167,70	9/12	-0,2679	-0,2694	0,0015	-0,2686	0,00004	-0,2686	10,3338
10	UGH9	20,84	188,54	10/11	-0,6588	-0,6588	0,0000	-0,6588	0,00002	-0,6587	9,6750

7 Results

7.1 Reference points

Use of benchmarks is required for the geodetic leveling. Existing benchmarks were used. However, there is, in general, a lack of benchmarks in Svalbard due to challenging geotechnical conditions. Hence it is planned to use existing infrastructure (buildings) as additional benchmarks. The following buildings will be considered for this purpose:

- Buildings which are designed for long life period (i.e. >50 years), designed values of allowable settlements of such buildings must be low. Such buildings shall not have any signs of deformations at the present time.
- Structures on the rock outcrops.
- Structures which shall be considered as stable due to their engineering function, i.e. wells of boreholes, etc.

Establishment of benchmarks suitable for monitoring of buildings is not planned due to economical limitations within the project.

List of benchmarks used in 2017 is presented in Attachment 0, **Error! Reference source not found.** . The list w ill be updated if new reference points will be established in 2018–2019.

7.2 Buildings in Longyearbyen

Existing reference point at the power plant was used as the reference point (see Appendix C, Figure 20–Figure 22).

Two buildings were surveyed in Longyearbyen: UNIS Guest House (UGH, Road 229.05) and the building "Elvesletta Byggetrinn 1" for a new hotel (crossing of the Roads 500 and 503). Route from the power plant towards UGH and the building "Elvesletta Byggetrinn 1" is presented in Figure 4. The distance between instrument and barcode staff was kept 25 m in most of the cases.

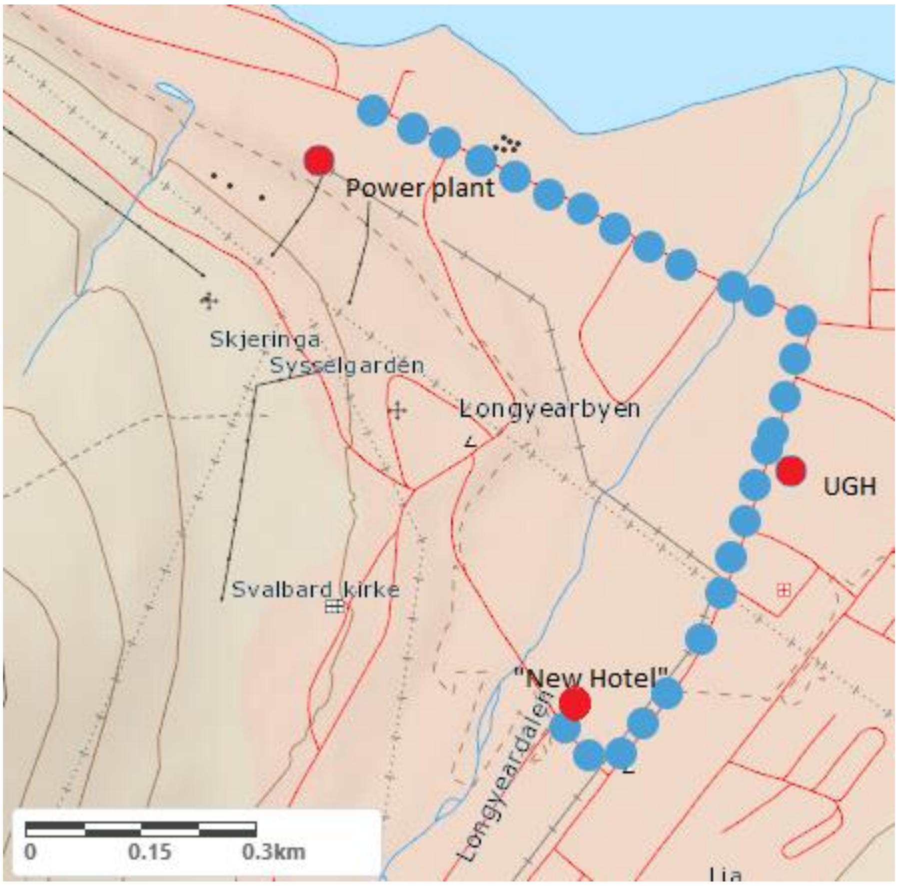

Figure 4. Way points for survey in Longyearbyen.

The UNIS Guest House

This building is a light-weight two-story wooden building (Figure 5) and the foundation is composed of wooden piles penetrating to a depth of ca. 9 m [17]. Crawl space is covered by decorative planks allowing free air flow below the building. Western side of building partially connected to road (Road 500) by ramp, partially disturbing the air flow. Dimensions of the building are approximately 15x70 m. The building was constructed in 2009–2011. The building is used for temporal accommodation.

Figure 5. UNIS Guest House.

Monitoring bolts were installed outside and under the building. Stations of the level and locations of the bolts are presented in Figure 6–Figure 7.

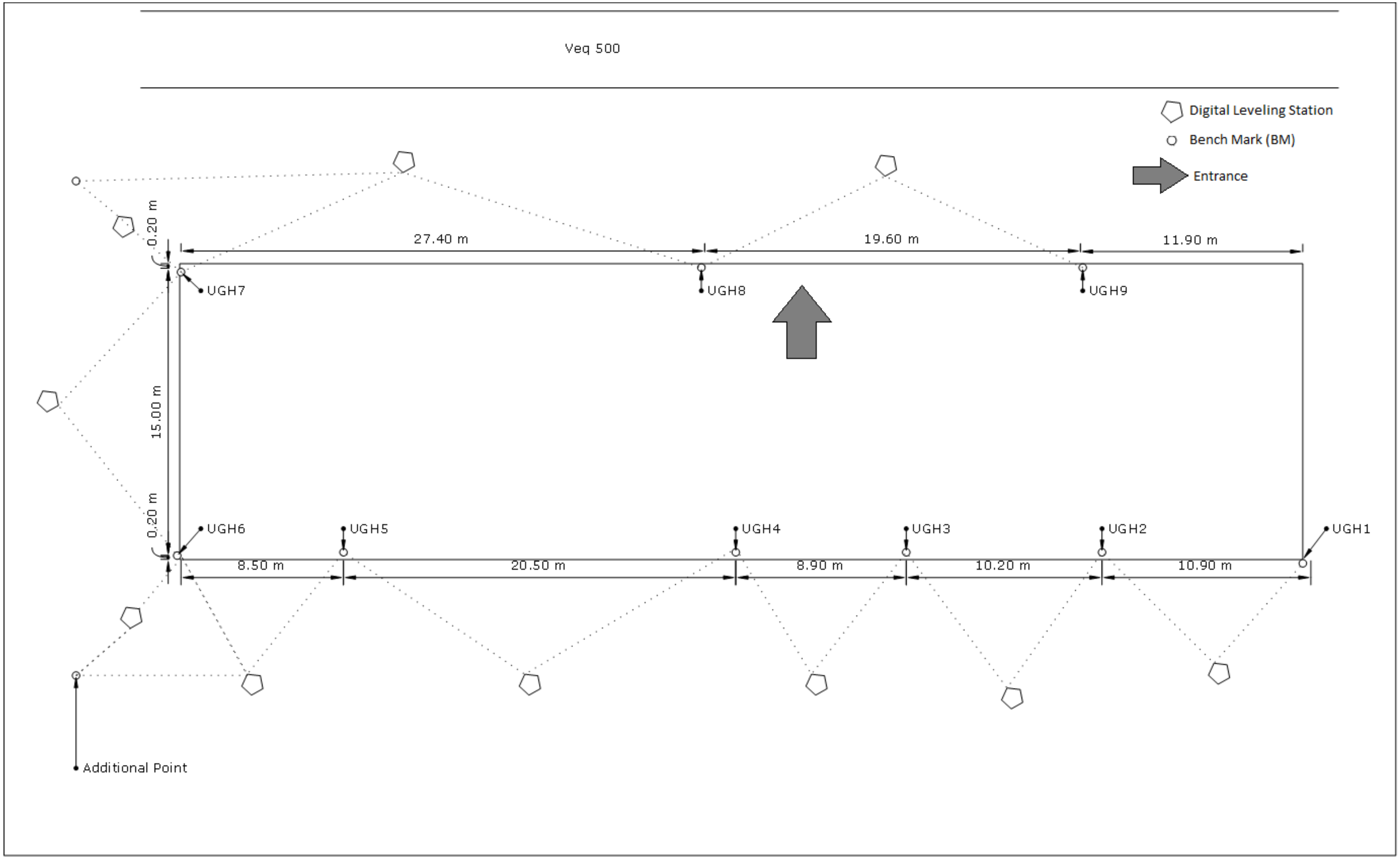

Figure 6. Sketch of the UNIS Guest House with locations of stations for leveling and locations of the bolts, installed on the outer piles.

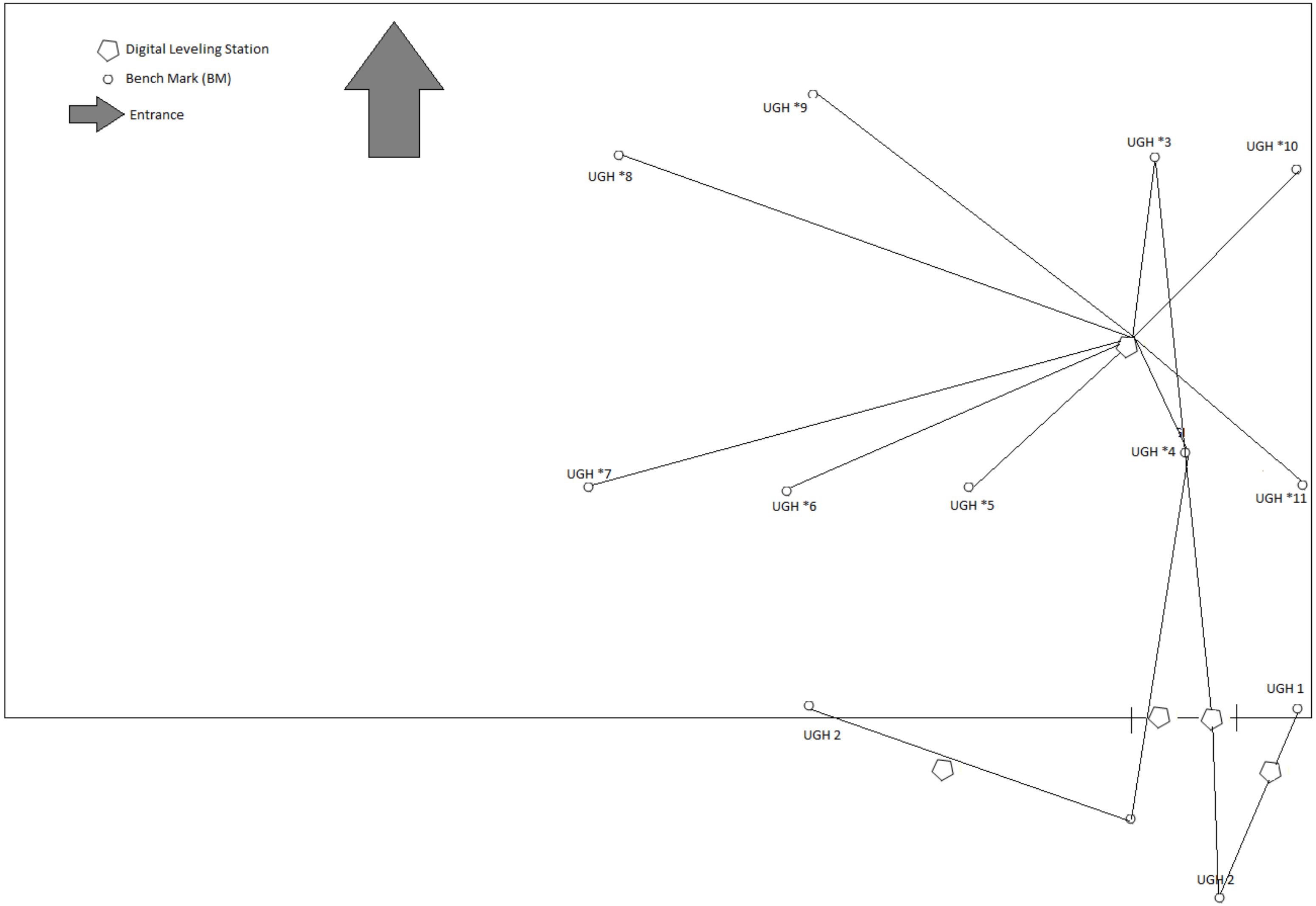

Figure 7. Locations of the bolts and leveling station beneath the UNIS Guest house.

Results of leveling are presented in Excel tables, which are attached to report. Description of all Excel tables with data is presented in Section 7.6, Table 4.

The building "Elvesletta Byggetrinn 1" for a new hotel

The building is a Light-weight three-story wooden building (Figure 8) and foundation is composed of steel piles (140-mm squire profile) penetrating to a depth of ca. 18 m. Crawl space is covered by decorative planks allowing for free air flow below the building. Dimensions of the building are approximately 16 x 30 m. The building was erected in 2016-2017. The building is used for temporal accommodation.

Remarks on special conditions: the building is located in proximity of the Longyear Elva. Icings (ca. 1 m thick, 50 m in diameter) were observed on the ground surface in the area next to the building (spring 2017).

Figure 8. The building "Elvesletta Byggetrinn 1" of a new hotel in Longyearbyen.

Monitoring bolts were installed outside and under the building, see Figure 9.

SINTEF

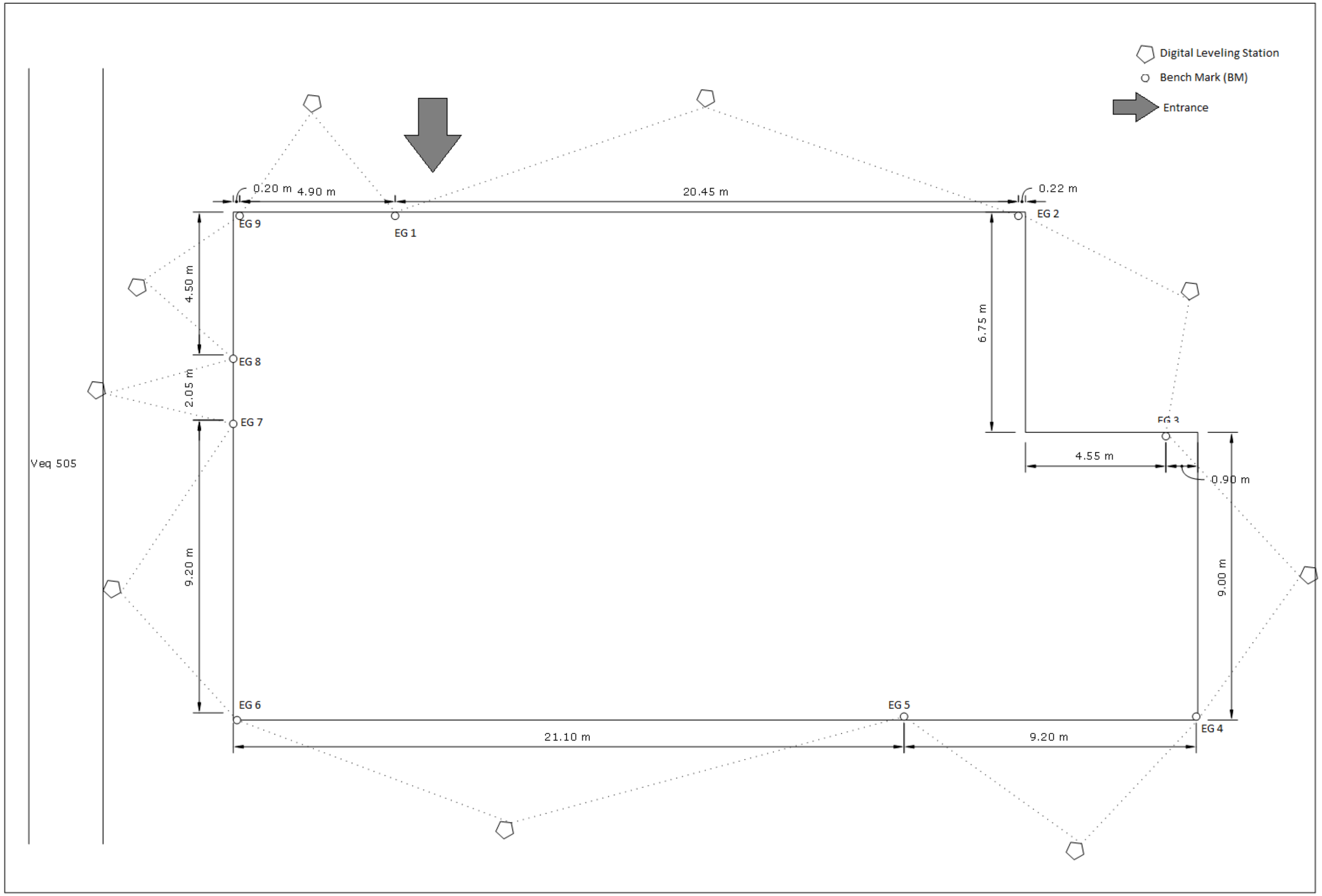

Figure 9. Sketch of the building "Elvesletta Byggetrinn 1" and locations of bolts and leveling stations.

Results of leveling are presented in Excel tables, which are attached to report. Description of all Excel tables with data is presented in Section 7.6, Table 4.

7.3 Buildings in Barentsburg

Reference points used in Barentsburg are presented in Appendix 0 (Figure 23–Figure 28). Reference points N1 and N2 (see Figure 24–Figure 27) were used for the survey.

Three-story building "Komplex GRZ", constructed in 1975–1978 was surveyed (Figure 10). Dimensions of the building are approximately 50 by 15 m. The building has brick walls installed on pillars, which are based on concrete piles. It is assumed that piles are 10 m long. Construction of basement prevents free flow of air in the crawl space. Cracks were observed in the wall facing the helipad. Reasons that caused the observed damage are unknown.

Monitoring bolts were installed on the outer wall of the building. Previously installed bolts were found on the wall surface, these bolts were also included into monitoring. Locations of the monitoring bolts are presented in Figure 11.

Figure 10. Building "Komplex GRZ" in Barentsburg.

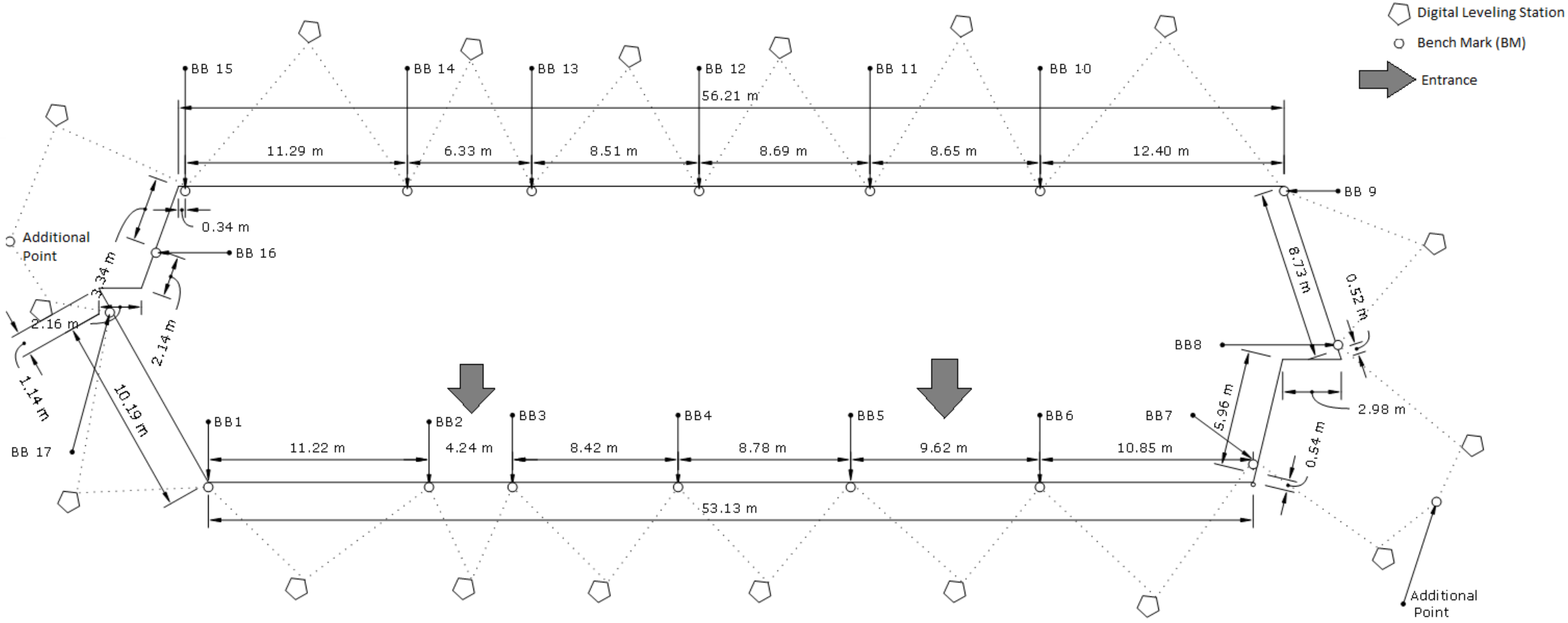

Figure 11. Sketch of the building "Komplex GRZ" in Barentsburg and locations of bolts and leveling stations.

7.4 Buildings in Pyramiden

Reference points used in Pyramiden are presented in Appendix 0,(Figure 29–Figure 33). Route from the reference points towards the surveyed building in presented in Figure 12.

Figure 12. Route from the reference points to surveyed building in Pyramiden (Picture: after [14]).

The building is a multi-purpose garage (Figure 13), which was built in 1981–1983. Brick walls of the building are installed on pillars, which are based on concrete piles. It is assumed that the piles are 10 m long, construction of the building permits free air flow in the crawl space. Cracks were observed on the western wall of the building.

Figure 13. The multi-purpose garage in Pyramiden.

Monitoring bolts installed outside (BP1–BP19) and under the building, locations of monitoring points are presented in Figure 14. Monitoring bolts were also installed on the left-hand side of road (if one goes from the building towards the port), these locations are marked as "Pole 1…Pole 7" on Figure 12.

Results of leveling are presented in Excel tables, which are attached to this report. Description of all Excel tables with data is presented in Section 7.6, Table 4.

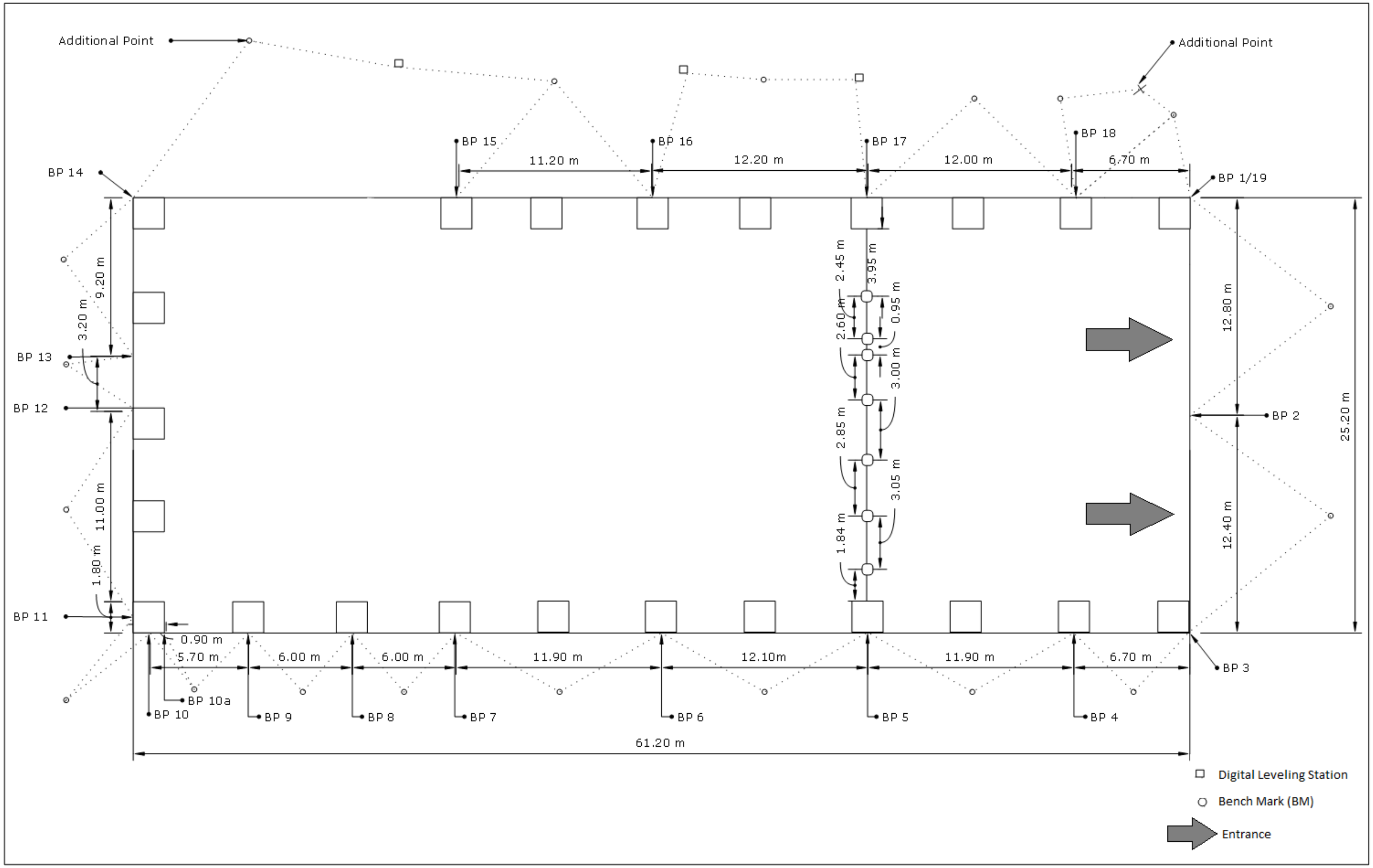

Figure 14. Sketch of the multi-purpose garage in Pyramiden and locations of bolts and leveling stations.

7.5 Buildings in Svea

Reference points used in Svea are presented in Appendix C (Figure 34–Figure 35). Route from the reference points towards the surveyed building in presented in Figure 15.

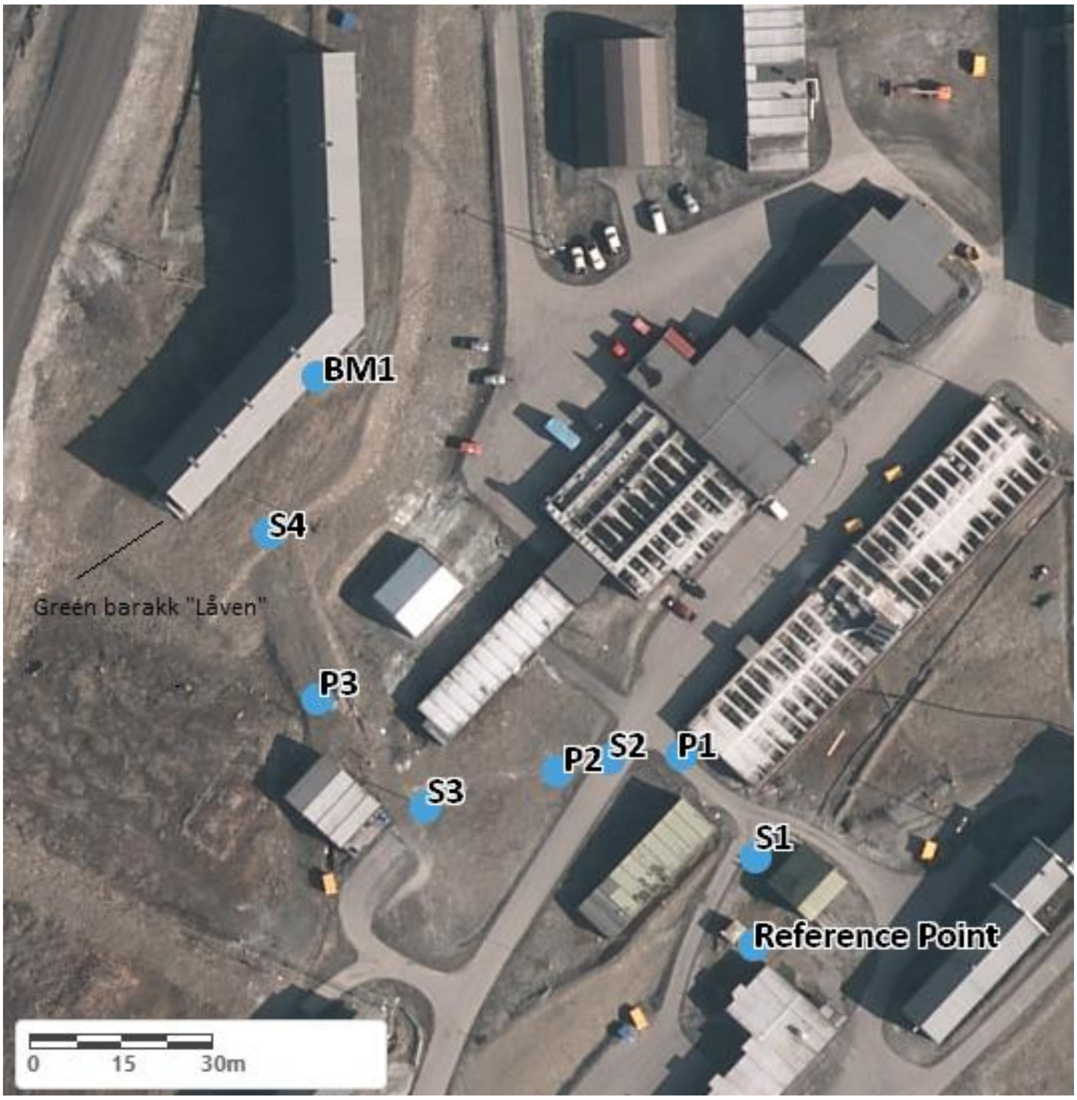

Figure 15. Map with the Låven barakk, way points, and reference points in Svea (Picture: after [14]).

Two buildings were surveyed: building of the Låven barakk (Figure 16) and a multi-purpose garage (Figure 18).

Figure 16. Building of the Låven barakk in Svea.

The building of "New green barrack "Låven"

The building of "New green barrack" was constructed in 2010. The building was used for short-term accommodation, build on wooden piles, crawl allows free air flow beneath the building. Small damages are presented on South-East and East side (only one visible damage due to building movements, others possible caused by snow scooters, snow clearance vehicles etc.). The northern side of the building is ca. 80 m long, the southern side is ca. 90 m, width of the building is 11 m. Two stair cases are located on the southern (front) side of the building, and one additional (fire exit) on the western side.

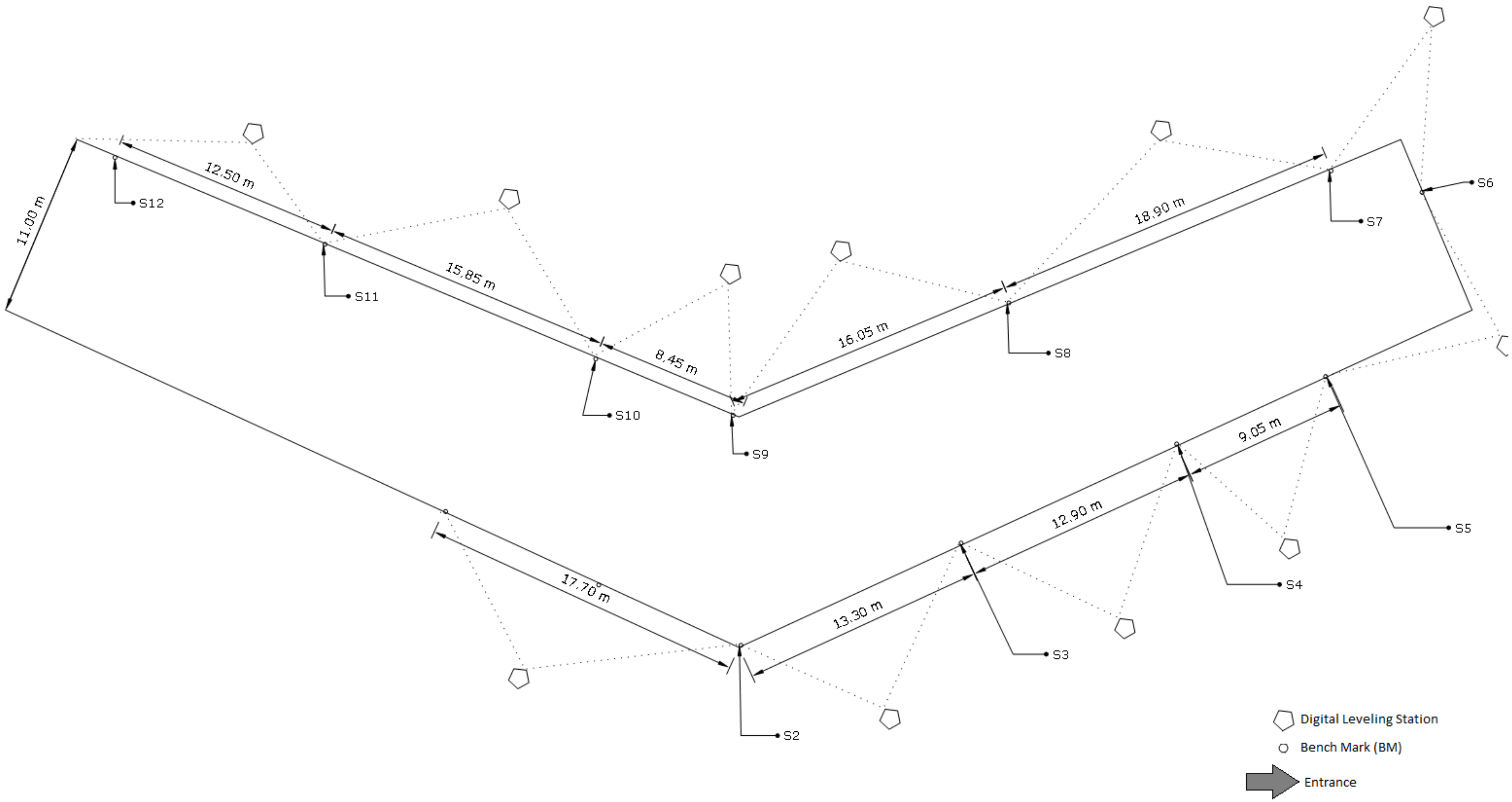

Figure 17. Sketch of the building of "New green barrack" in Svea and with locations of bolts and leveling stations.

As mentioned above, survey was performed from the main reference point, which is located at the entrance of Store Norske office. Way points followed the roads, and distances of 25 m between the level and a station was kept where it was possible. The distance was shorter in steep parts of the road. Monitoring bolts were installed into the wooden piles below the building on three sides (see Figure 17), the bolts were not installed on another side as piles there were hardly accessible for installation of bolts.

Multi-purpose garage

The Multi-purpose garage (Figure 18) is used as storage of vehicles and equipment. It is a lightweight building, which has walls composed from metal panels. The building is located on shallow concrete foundation, which has ventilation channels throughout the whole buildings' foundation. Free air flow in winter is possible. In summer, the channels are blocked with styrofoam blocks to shelter the frozen ground from getting into direct contact with the warmer air surrounding the building.

Figure 18. Multi-purpose garage in Svea.

Survey at the garage was carried out locally, i.e. elevations of its elements were not measured in relation to the reference point. Elevations of monitoring points were measured in relation to the building itself. The two long sides of the garage were surveyed (Figure 19). Survey on each side on the garage was performed in relation to the point located on the side, which was surveyed. Evelation of the foundation at each fifth ventilation channel was surveyed.

Figure 19. Survey on the multi-purpose garage in Svea.

Results of leveling are presented in Excel tables, which are attached to report. Description of all Excel tables with data is presented in Section 7.6, Table 4.

7.6 Overview of obtained data

All data are saved in Excel files. The files are stored internally at SINTEF Byggforsk in the project folder, and will be freely available for downloading from the RiS database ([18]). An overview of the data collected (Excel files) is presented in Table 4.

Table 4. Overview of collected data.

Names of Excel files	Description of data
Longyearbyen	
Longyearbyen_ Elvesletta Byggetrinn 1	Levelling of the building "Elvesletta Byggetrinn 1".
Longyearbyen_Reference points	Leveling the reference points near the Power plant.
Longyearbyen_Road_PS_UGH	Leveling of the road from Power plant to UNIS Guest House.
Longyearbyen_Road_UGH_Elvesletta Byggetrinn 1	Leveling of the road from UNIS Guest House to Elvesletta Byggetrinn 1.
Longyearbyen_UGH	• Sheet "Outside": leveling outside of the UNIS Guest House (UGH). • Sheet "Inside": levelling under the UNIS Guest House (UGH).
Pyramiden	
Pyramiden_Measurements under the garage	Leveling under the multi-purpose garage.
Pyramiden_Measurements at the multi-purpose garage	Leveling from reference point 1 to the multi-purpose garage.
Pyramiden_Reference points	Leveling from reference point N1 to the reference points N 2, N 3, N 4.
Barentsburg	
Barentsburg_Measurements on the Building	Leveling outside the building from reference point N1.

Barentsburg_Reference point	Leveling from reference point N1 to N2, and from N2 to N3.
Svea	
Svea	• Sheet "New green barrack Låven": leveling from the reference point N1 to the "New green barrack". • Sheet "Multi-purpose garage": leveling the garage from two stations ("station points").

7.7 Daily reports and results of surveys

Daily activities are presented in Table 5.

Table 5. Daily reports.

Date	Activity
	Works in Longyearbyen
07.08.2017	Installation of monitoring bolts at UGH and performance of first measurements.
08.08.2017	Leveling at UGH.
09.08.2017	HSE training.
10.08.2017	Leveling from the Reference Point to UGH.
	Works in Barentsburg
12.08.2017	Installation of monitoring bolts, leveling from the reference points towards the building, leveling at the building.
	Works in Pyramiden
17.08.2017	Installation of monitoring bolts, leveling from reference points, leveling at the building.
18.08.2017	Second set of leveling at the building and below the building.
	Works in Longyearbyen
20.08.2017	Leveling from UGH to "Elvesetta Byggertinn 1".
21.08.2017	Leveling at the building of "Elvesetta Byggertinn 1".
	Works in Svea
22.08.2017	Installation of monitoring bolts in Svea.
23.08.2017	Leveling from the reference point to the building of "New green barrack", leveling at the Låven barakk.
24.08.2017	Leveling at a multi-purpose garage in Svea.
	Works in Longyearbyen
26.08.2017	Final meeting: discussion on obtained results and reporting.

8 Data quality

Data quality of surveys in Longyeanbyen, Pyramida and Svea corresponds to the class III according to [8,9] (see Table 6). The error of closure was less than maximum allowable value. Hence, the data collected is suitable for comparison with the measurements, which will be obtained in the future. The latter will allow one to perform comparative study on influence of climate change on performance of foundations of surveyed infrastructure.

Data obtained in Barentsburg does not meet the quality requirements, and hence shall be disregarded. It was not possible to repeat the measurements due to time constrains. The reasons that led to these are associated with lack of time in the field. The measurements shall be repeated in 2018.

In one series in Longyearbyen and in one series in Piramiden, the errors of closure are higher than the maximum allowable errors, this data should not be used for comparative studies.

Obtained data makes it possible to monitor the road in Pyramiden.

Table 6. Assessment of the data quality.

Location	Line	Error of closure, m	Equation	Maximum allowable error, m
Barentsburg	Building	-0,0210	$\pm 1.5\sqrt{n}$	-0,0064
			$\pm 10\sqrt{L}$	-0,0068
	From reference point 1 to 2	-0,0251	$\pm 1.5\sqrt{n}$	-0,0054
			$\pm 10\sqrt{L}$	-0,0077
	From reference point 2 to 3	-0,0109	$\pm 1.5\sqrt{n}$	-0,0050
			$\pm 10\sqrt{L}$	-0,0073
Longyearbyen	UNIS Guest House	-0,0004	$\pm 1.5\sqrt{n}$	-0,0067
			$\pm 10\sqrt{L}$	-0,0043
	Byggetrin 1	0,0006	$\pm 1.5\sqrt{n}$	0,0075
			$\pm 10\sqrt{L}$	0,0048
	road from Power Station to UNIS Guest House	0,0016	$\pm 1.5\sqrt{n}$	0,0099
			$\pm 10\sqrt{L}$	0,0099
	road from UNIS Guest House to Byggetrin 1	0,0122	$\pm 1.5\sqrt{n}$	0,0076
			$\pm 10\sqrt{L}$	0,0075
Pyramiden	Garage	0,0078	$\pm 1.5\sqrt{n}$	0,0106
			$\pm 10\sqrt{L}$	0,0078
	From reference point 1 to 2	-0,0011	$\pm 1.5\sqrt{n}$	-0,0052
			$\pm 10\sqrt{L}$	-0,0051
	From reference point 1 to 3	-0,0110	$\pm 1.5\sqrt{n}$	-0,0064
			$\pm 10\sqrt{L}$	-0,0060
	From reference point 1 to 4	0,0020	$\pm 1.5\sqrt{n}$	-0,0073
			$\pm 10\sqrt{L}$	-0,0070
Svea	New" barakk	0,0044	$\pm 1.5\sqrt{n}$	0,0082
			$\pm 10\sqrt{L}$	0,0061

Note:
n – Number of stations;
L – Distance, km;

9 Planning of Fieldwork for 2018

9.1 Challenges during fieldworks in 2017

Darkness under the buildings (UGH and the garage in Pyramiden) precluded normal work of the digital laser level, use of additional flesh light improved the conditions.

9.2 General comments on planning of fieldwork in 2018–2019

1. Order tickets (to/from Svalbard) and plan transportation within Svalbard by taking into account possible adverse weather conditions, i.e. possible delays in transportation must be included into

the planning of field work. In addition, planned duration of stay in Barentsburg, Pyramiden and Svea shall include extra time taking into account adverse weather conditions (when performance of field work would not be possible).
2. Take pictures of the note book each time in the end of working day, this will ensure data safety.
3. Process data at the end of the day, or the next morning. This will ensure data quality, i.e. measurements can be repeated while being in the field (Barentsburg, Pyramiden and Svea).
4. Buy/rent all necessary equipment well in advance.

9.3 Recommendations for the fieldwork in 2018

The following is recommended to include in the field works in 2018:

- To initiate (within the project)[1] monitoring of openings of cracks in the brick walls in Barentsburg and Pyramiden. Instrumentation will consist of installation of thin steel palets (consisting of two separate pieces) across visible cracks, and subsequent monitoring of its opening.
- For the leveling survey, it is strongly recommended to break the distance from the reference point to the buildings in equal intervals (for instance 25 m), the latter helps to minimize the measuring error.

9.4 Acquisition of additional equipment for field work in 2018

Table 7. Additional equipment needed for field works in 2018.

	Equipment	Notes
1.	Base plate (5 kg)	To buy
2.	Drill bits for concrete (10 mm), type: for hammer drill.	To buy.
3.	"Write in the rain" note book.	Buy new one at UNIS reception in 2018.

Project information

The project is supported by The Research Council of Norway (the POLARPROG programme) and by partners of the project – Lomonosov Moscow State University, Longyearbyen Lokalstyre, Stiltelsen SINTEF, Store Norske Spitsbergen Grubekompani AS, The University Centre in Svalbard, and Trust Articugol.

[1] Measurements on openings of cracks were performed in Barentsburg and Pyramiden in previous years by Trust Arcticugol.

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Appendix A. Planning of fieldwork

Table 8. Schedule for fieldworks in 2017.

Week	Date	Activity
W30	M 26–F 30	AS: communication with LL, SNSK, UNIS, TA, SS.
W31	M 31	KB, AS: collection of equipment, work with field instruments.
W31 W32	T 1	KB, AS: collection of equipment, work with field instruments.
	W2	
	T 3	
	F 4	
	S 5	
	S 6	PK arrives in LYR
	M 7	KB and PK: Survey in LYR
W32 W33	T 8	KB and PK: Survey in LYR
	W 9	KB and PK: HSE; AS: LYR→BB (Meeting at Trust Arcticugol)
	T 10	KB and PK: LYR→BB
	F 11	Survey in BB
	S 12	Packing in BB; BB→LYR
	S 13	
	M 14	KB, PK, AS: LYR→PIR,
W33 W34	T 15	Survey in Pyramiden
	W 16	Survey in Pyramiden
	T 17	PIR→LYR
	F 18	KB, PK, AS: Survey in LYR
	S 19	
	S 20	
	M 21	KB, PK: Reporting
W34 W35	T 22	KB, PK, AA: LYR→Svea, Svea-Survey
	W 23	Svea-Survey
	T 24	Svea-Survey, Svea→LYR
	F 25	KB, PK: Reporting
	S 26	
	S 27	
	M 28	PK departs from LYR

Table 9. Abbreviations for fieldwork in 2017.

Acronym	Transcript
HSE	Health, Safery, Environment training at UNIS.
KB	Katharina Beuter
PK	Pavel Kotov
AS	Anatoly Sinitsyn
AA	Arne Aalbeg
LYR	Longyearbyen
BB	Barentsburg
PIR	Pyramiden
Svea	Svea
LL	Longyearbyen Lokalstyre
TA	Trust Arcticugol
SNSK	Store Norske
UNIS	The University Centre in Svalbard
SP	Svalpro AS
SS	Sandmo and Svenkerud

Appendix B. List of instruments and equipment

List of instruments for survey is presented in Table 10.

Table 10. List of instruments and equipment collected for field work in 2017.

	Equipment	Location
1.	Digital laser level Leica Sprinter 250M, long staff bar, short staff bar, tripod, Leica software, extra 2AA battaries, 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.	Total station Leica TCR1205 (5 sec), charger, extra battery, reflectors, pole, standard prism, mini prism, glue for reflectors.	Was not used in 2017, it is planned to use this instrument in 2018. Leica total station belongs to UNIS and stored at AG department. Reflectors and mini prism are stored at the office of Arne Aalberg.
3.	Hitachi hammer drill DH 360AL (2 pcs), DeWalt skrew driver.	UNIS AT department.
4.	Bolts for installation in wooden and concrete piles, accessories for installation of bolts (drills for wood/concrete).	"SINTEF storage room" on the third floor at UNIS.
5.	50-m measuring tape.	UNIS AT department.
6.	Three Zarges boxes (for transportation of equipment and food).	UNIS AT department.
7.	VHF radio (2 pcs), charger for VHF radio, satellite phone, emergency beacon, rifle and flair gun (2 kits), ax, jarvenduk (sleeping bag for emergency situations).	UNIS Logistics department.
8.	Tool box.	"SINTEF storage room" on the third floor at UNIS.
9.	"Write in the train" note book.	Buy new one at UNIS reception in 2018.
10.	Anchors for establishment of reference points in a rock outcrop.	"SINTEF storage room" on the third floor at UNIS.

Appendix C. List of reference points used during the survey

Longyearbyen

One of two reference points, installed on/at the pipe of the power plant (Figure 20–Figure 22) was used for survey. Reference points were installed at the entrance of pipe of the power plant in Longyearbyen by Norwegian Polar Institute (designated as LRP1 in present report) and Geological Survey of Norway (designated as LRP2 in present report). Approximate coordinates: 78.2252° N; 15.6183° E.

Figure 20. Location of the reference points in Longyearbyen: pipe of the power station**.**

Figure 21. Location of the reference points in Longyearbyen.

Figure 22. Circle points to the reference point at the entrance into the pipe of power plant in Longyearbyen. This point was used in the survey (LRP1).

Barentsburg
Two standard reference points were located on the pavement of the helipad were used for survey (Figure 23–Figure 28):

- Reference point N1 (BRP1) "GUGK 1356" (33 X 0481425, UTM 8669812)
- Reference point N2 (BRP2) "GUGK 190(1?)" (33 X 0481705, UTM 8669778).

In addition, several wooden structures called "pyramids" were noticed on a distance of 1–2 km uphill from the building. One may assume that the pyramids are installed to mark the standard reference points. Distance from the pyramids to the building was too large in to order to use them as reference points in the survey. Another pyramid termed as Reference point N3 "Pyramid at the sea coast" (33 X 0481948, UTM 8669832) is located in several hundred meters from the heliport and can be considered as a reference points for future surveys (Figure **28**).

Figure 23. Reference points in Barentsburg (satellite image is from [17]).

Figure 24. Katharina Beutner standing close to the Reference point N1 "GUGK 1356" (BRP1).

Figure 25. Figure 25. Reference point N1 "GUGK 1356" (BRP1).

Figure 26. Pavel Kotov staying next to the Reference point N2 "GUGK 190(1?)" (BRP2).

Figure 27. Reference point N2 "GUGK 190(1?)" (BRP2).

Figure 28. Reference point N3 "Pyramid at the sea coast" (BRP3).

Pyramiden

Four reference points in Pyramiden were used (Figure 12, Figure 29–Figure 33):

- Reference point N1 (PRP1), located at fence of oil tanks (33 X 0529579, UTM 8731566),.
- Reference point N2, located at an old steel borehole casing. It was decided in the end of fieldwork to excude this point from the consideration due to arised doubds in the stability of the casing.
- Reference point N3 (PRP2), located on the top of the casing of old borehole (33 X 0529651, UTM 8731808). Short (ca 15 cm) steel rod welded to the top of casing was used as actual reference point. Barcode staff was installed in the middle part of this rod.
- Reference point N3 (PRP3), located at the base of the weather station.


Figure 29. Reference point N1 (PRP1).


Figure 30. Reference point N1 (PRP1), finger pointing at the upper point of the platform, where the rod (barcode staff) was placed for performing the measurements.


Figure 31. Reference point N3 (PRP3), circle points the bolt, on which the bar staff was placed for surveying.

Figure 32. Reference point N4 (PRP4).

Figure 33. Reference point N4 (PRP4), arrow points on the bolt, on which the bar staff was placed for surveying.

Svea

Reference point at the Store Norske office was used in Svea (Figure 34–Figure 35).

Figure 34. Reference point in Svea.

Figure 35. Circle points out the bolt, which was used for survey at the Reference point in Svea.

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