The MonArc Project: Monitoring Programme for Foundation Settlements and Initial Results

Anatoly O. Sinitsyn, Pavel I. Kotov and Arne Aalberg

Abstract Initial results of the Monitoring of Arctic Infrastructure project (MonArc) are presented. The project surveys buildings in several small towns in Spitsbergen, in the Svalbard archipelago, focusing on vertical settlements of buildings and foundations. The survey programme comprises damage characterization and performs annual measurements of vertical foundation settlements by differential leveling. Ground conditions in Spitsbergen are characterized by continuous permafrost. The monitoring programme comprises measurements in the small towns of Longyearbyen, Barentsburg, Pyramiden, and Svea. Settlement developments for surveyed buildings in the period 2017–2018 are presented. The established data may serve as a reference for future comparison and long-term assessment of vertical movements, for instance by repeating the survey every 5–10 years. The study and the data may contribute to a better understanding of the practical consequences of climate change, with its impact on various infrastructures.

Keywords Arctic · Infrastructure · Permafrost · Climate change

1 Introduction

Climate change is considered one of the major global challenges for humanity in the twenty-first century. Projected climate changes are most pronounced in the polar regions. It is believed that the impacts on permafrost conditions in the Arctic may lead to significant damage to infrastructure. Consequences of a warmer climate include the warming and thawing of permafrost, an increase in active layer thickness, and

A. O. Sinitsyn (✉)
SINTEF Community, S P Andersens veg 5, 7031 Trondheim, Norway
e-mail: anatoly.sinitsyn@sintef.no

P. I. Kotov
Faculty of Geology, Lomonosov Moscow State University, GSP-1, Leninskie Gory 1, 119991 Moscow, Russian Federation

A. Aalberg
The University Centre in Svalbard (UNIS), Pb. 156, 9171 Longyearbyen, Norway

A. Petriaev and A. Konon (eds.), *Transportation Soil Engineering in Cold Regions, Volume 1*, Lecture Notes in Civil Engineering 49,
https://doi.org/10.1007/978-981-15-0450-1_12

reduction in soil strength, leading to an increased amount of settlements. As pointed out by [1, 2], the effects of construction and maintenance of infrastructure at a site may also significantly affect the local thermal regime within the permafrost ground and may add to issues regarding the stability of foundations.

Long-term field measurements are useful in the design and documentation of the performance of foundations. The results of systematic monitoring of vertical positions of foundations, in conjunction with records of hydrometeorological parameters and maintenance history of a building, may help to identify the primary factors causing severe damage to foundations or a decrease of building serviceability.

The Monitoring of Arctic Infrastructure (MonArc) project creates and facilitates research cooperation between Norwegian and Russian researchers in Svalbard. This is through a joint effort in monitoring of selected infrastructure, focusing on vertical settlements of foundations and the development over time. These may be the results of natural creep processes of frozen soil, and accelerated creep and deformations. This is due to warming by climate change and also the possible impact from human activities at the sites, increased amount of surface water, water accumulation, unintended effects of maintenance, heat transported into the ground from buildings, etc.

The MonArc project tasks consist of monitoring the elevations of installed points on certain parts of selected buildings—mostly foundation piles in the towns of Longyearbyen, Barentsburg, Svea, and Pyramiden.

Svalbard is well suited for the present study as the ground is characterized by permafrost, and several building types and foundation systems are easily accessible. At the same time, climate projections suggest significant climate warming towards year 2100 [3, 4]. Permafrost is continuous in Svalbard [5], with ground temperature at a depth of zero annual amplitude of approximately −2 °C in the proximity of the shoreline (as reported by [6] for Vestpynten near Longyearbyen), and approximately −5 °C in the valleys (for instance Adventdalen near Longyearbyen [7]). Permafrost is usually saline in the coastal zones in Svalbard, posing significant challenges for proper foundation designs.

2 Methods

The main operation during the geodetical monitoring of the chosen structures was collection of elevation data for points fixed on the buildings. This data can be used for assessment, analysis, and forecast of settlements of the structures. Methodology for data processing was presented in [8]. Changes of elevations of the monitoring points in relation to each other or in relation to stable reference points were the decisive parameters.

Vertical displacements of the monitoring points were determined. Vertical displacement was defined according to the standard [9], i.e., the movement of the monitored point relative to an anchored and stable reference point (a “fixed point”).

Two main parameters are controlled during the monitoring programme for newly built structures ([10], Table L.1): (i) settlements of foundations and (ii) relative difference of settlements. These parameters were represented by [9]

1. Absolute value of displacement:

$$S_{\mathrm{Hi}} = H_i - H_0, \tag{1}$$

H_0 elevation of monitored point in initial (zero) monitoring cycle.
H_i elevation of the same point in i- monitoring cycle

2. Relative difference of displacement of monitoring points:

$$\eta = \frac{(\Delta S_{\mathrm{nm}})_i}{L} \tag{2}$$

L distance between two monitoring points.
$(\Delta S_{\mathrm{nm}})_i$ difference between displacements of monitoring points n and m in one cycle of measurements i (unevenness of displacement), calculated as follows:

$$(\Delta S_{\mathrm{nm}})_i = (S_n)_i - (S_m)_i, \tag{3}$$

The initial elevations of the monitoring points on the building foundations were determined by performing a standard manual differential leveling. This basic method is widely used due to several advantages. It only requires simple and inexpensive equipment, allows measurements under difficult conditions, and provides high accuracy and rapid measurements. Requirements (procedures and tolerances) for such works are found in standards for monitoring of infrastructure [11, 12].

It was presumed that elevations of the reference points were constant in all annual cycles of the monitoring. The assumption requires verification; hence, several reference points were used in some locations, and the data were cross-checked. Ideally, the reference points should be on solid rock or rock-anchored fixed points, as sought in similar investigations on the mainland. This was not present near all the monitored sites in Svalbard. Another option would be to establish new reference points for deformation monitoring in permafrost following typical design presented in [13].

The elevations of the reference points were considered to be constant if the change of the excess between the reference points K was according to (4):

$$K < 2m_{\mathrm{CT}} \cdot 2n^{0,5} \tag{4}$$

n quantity of stations by one measuring way
m_{CT} mean square error of determining the excess of stative (station)

Assessment of settlements can be based on the comparison of results with maximum allowable deformations of foundation bases [10]. Depending on the type of frame, deformations can be accessed via:

1. Maximum allowable absolute settlement $s_{\mathrm{u}}^{\max}$.
2. Average settlement $\overline{s}_{\mathrm{u}}$.
3. Maximum allowable relative difference of settlements $(\Delta s/L)_{\mathrm{u}}$.

3 Description of Surveyed Buildings

The Digital Level Leica Sprinter 250 M instrument and a barcode staff Leica GSS 111 rod were used for the survey. Leveling between a reference point and a building was performed in forward and reverse directions using approximately equal distances. Leveling in two horizons, in closed leveling paths around each building was performed.

The following works were carried out in 2017–2018:

1. Identification and/or establishment of reference points (fixed ground points) in the vicinity of the buildings. These were points that could not develop significant vertical movement in a long-term (decades) perspective, for example, massive piled concrete foundations in the vicinity of the considered building.
2. Installation of monitoring bolts on the base or foundation structure of the buildings, in easily accessible positions. Bolts were installed on the foundations at the corners of the buildings and at points closely spaced along the building sides and on piles located under the buildings where it was technically possible. The bolts were drilled and hammered into piles or characteristic foundation points at every 4–5 m. The locations of monitoring bolts were chosen based on recommendations from [7].
3. Leveling of the reference points, leveling from the reference points to the buildings, and leveling of the monitoring bolts.

The precision of a level run is described in terms of a maximum allowable error of the closed leveling path. The survey was conducted in accordance with the allowable errors defined in [11].

In order to provide data on a range of foundation solutions, the survey covers new and old buildings. These comprise shallow strip foundations as well as deeper pile foundations. Geotechnical investigations and documentation for the buildings were not available for the project. However, one may assume that the foundations of all surveyed buildings are constructed with the aim “to maintain the existing thermal regime” according to [14], referred to as Principle 1 in [15]. Detailed descriptions of the reference points, the buildings chosen for the monitoring, and the drawings with monitoring points are given in [8]. An overview of the buildings surveyed in 2017–2018 is presented in Table 1.

Table 1 Buildings surveyed in 2017–2018

Town	Building	Address/location
Longyearbyen	The UNIS Guest House (UGH)	Road 229.05
	The building "Elvesletta Byggetrinn 1"	The junction of roads 500 and 503
Barentsburg	The three-storey residential building "Komplex GRZ"	Heliport
Pyramiden	The multi-purpose garage	–
Svea	The two-storey building for temporal residence Barack "Låven"	–
	The two-storey building for temporal residence "Barack (Brakke) 2002"	–
	The multi-purpose garage/storage, "Magnetittlageret"	–

3.1 Longyearbyen

In Longyearbyen, the apartment building UNIS Guest House and the building "Elvesletta Byggetrinn 1" (The Vault Hotel) were surveyed. The former is a two-storey wooden module building, standing on wooden piles deployed in the ground to a depth of ca. 9 m. Crawl space protected by decorative planks allows airflow below the building (sun shelter in summer, cooling in winter). The building is in plan of approximately 15 by 70 m. The building was constructed in 2009–2011.

The second building is a three-storey wooden building, founded on 140 by 140 mm square hollow steel sections deployed to a depth of ca. 18 m in drilled holes, with concrete fill. Crawl space here is also sheltered by decorative planks. The building is in plan approximately 16 by 30 m and was finished early 2018.

The leveling path was anchored to reference points at the base of the chimney of the power plant in Longyearbyen. One reference point was installed by Geological Survey of Norway and another one by Norwegian Polar Institute. Ground conditions at the power plant are rock; hence, it is expected that the reference points should be stable.

3.2 Barentsburg

The three-storey building "Komplex GRZ", constructed in 1975–1978, was selected for the survey. The building is approximately 50 by 15 m. It comprises a concrete frame constructed from concrete beams and columns, with infill and exterior brick walls. It is supported on concrete piles, with an estimated depth of 10 m into the ground. Airflow under the building is restricted by the exterior brick walls. The building has presently visible damage by surface cracks on the northern wall, likely caused by earlier settlements.

Two standard reference points (GUGK system), located on the pad of heliport, and one additional reference (a casing of an abandoned borehole) were used for survey.

3.3 Pyramiden

A multi-purpose garage built in 1981–1983 was selected for the survey. The building has brick walls and is supported on a concrete frame supported on pillars on concrete piles. Here, the piles are assumed to be 10 m long (standard for that time). The space below the building permits free airflow in the crawl space. The building has cracks on the walls facing west, north, and south.

Reference for the height was taken at three casings of abandoned boreholes and the foundation of the new meteorological station near the building.

3.4 Svea

In the mining city of Svea, the two-storey barracks “Barack 2002”, “Låven”, and a multi-purpose garage were surveyed. The first two buildings were constructed in 2002 and 2010, respectively, from prefabricated wooden modules supported on a beam frame, on wooden piles. Standard ventilated space and cover planks allow airflow below the building.

The main reference point of Svea, located at the entrance of main Store Norske Spitsbergen Grubekompani office, was used as reference in surveys.

4 Results

The initial results are built on the data sets for years 2017 and 2018. The data sets are reported in [8] and [16]. Assessment of measurement quality showed that the measurements in 2018 were more accurate (less errors in the leveling paths) than in 2017, for all monitored objects. In several cases, the measurements were with an outcome fulfilling the requirements of accuracy class 1, i.e., the highest (best) accuracy class for such works.

4.1 Longyearbyen

The reference points in Longyearbyen did not change their position relative to each other over the 2017–2018 (fixed points were stable). The survey from the reference points to the buildings fulfilled the requirements of a third-class accuracy in 2017 and first-class accuracy in 2018. The exact change of elevation of the monitored buildings in Longyearbyen in relation to the reference point is thus difficult to derive.

Absolute displacements at UNIS Guest House showed that the settlements were up to 7.1 mm, and heave of piles was up to 5.7 mm; maximum relative difference of monitoring points was 0.0007 mm/mm. At the building "Elvesletta Byggetrinn 1"—settlements were up to 2.3 mm, and heave up to 3 mm; only one value (as monitoring points were distributed in most cases more spaced than on neighbouring piles) of relative difference of monitored points was measured –0.0004 mm/mm. These values should be considered as estimates only. Confirmation and more accurate data will become available after the 2019 field season.

4.2 Barentsburg

Only a preliminary field survey was performed in Barentsburg in 2017. The results of this survey cannot serve as a solid baseline data set and be compared to 2018 data. More accurate results will come after survey in 2019 also.

4.3 Pyramiden

Two out of four reference points in Pyramiden were stable in 2017–2018. Absolute displacement of the monitoring points on the outer walls at the multi-purpose garage showed settlements in the range 0–5 mm. No heave displacement was detected. The largest displacements were found at locations where the drainage of water (collected on the roof) goes into the ground (found in the left corner of the south-facing wall). The relative difference of monitoring points at that corner was up to 0.0003 mm/mm. The former possibly signals that settlements on these foundations occurred together at the same time (due to leakage of hot water for instance) and stabilized afterwards. Another area showing significant settlements was the location where a heavy tank is installed inside on the building, corresponding to a large vertical load.

4.4 Svea

Displacements for the Barack “Låven” from 2017–2018 showed settlements up to 4.1 mm, and heave was detected only on one pile (0.4 mm). For the multi-purpose garage “Magnetittlageret”, the displacements showed settlements up to ca 14 mm, and heave was detected only at one location (ca. 3 mm).

5 Discussion

A comparison of obtained settlement data with maximum allowable deformations of foundation bases may be used to estimate the length of lifetime. This could be performed for the UNIS Guest House, the multi-purpose garage in Pyramiden, and the Barack “Låven” as these are structures placed on separate foundation grills supported by piles. This value will be 10–20 cm depending on the material and construction of bottom frame between piles and upper structure.

It appears reasonable to assume the initial phase of vertical displacements of the foundations to be finished for the chosen buildings. If the climate and ground conditions remain the same as today and further settlements develop more or less at a constant rate, one can estimate the following:

- UNIS Guest House—the maximum settlements will reach 20 cm by 2040.
- Multi-purpose garage in Pyramiden—the maximum settlements should have reached 15 cm by the year 2013.
- Barack “Låven”—the maximum settlements will reach 20 cm by ca. 2060.

Analysis for the building “Elvesletta Byggetrinn 1” is not given as it was recently built. Data for comparative analysis of the building in Barentsburg and Barack “2002” in Svea will be obtained in 2019. Combination of settlements of some piles with frost heave on others may make the deformations more severe. Note that the lifetime estimates above are very rough estimates, presented as inspiration for future research. Other concerns include the decay of foundation and pile material and accelerated climate change, which may have a more severe impact.

6 Conclusions

Data for the elevations of marked points on or near foundations of selected buildings in four towns in Spitsbergen were recorded in 2017–2018, and a simple analysis was performed. The recorded elevation data for the building foundations establish a present (“as today”) data set. Rather significant settlements were observed for some of the buildings in 2017–2018, while the settlements were moderate for others. The data will provide a basis for assessing long-time impacts of climate change on infrastructures in permafrost conditions in the future.

Data are stored in the project archive, which will be freely available from the project web page [17] and from the Research-In-Svalbard (RiS) database [18].

Acknowledgements The authors would like to thank The Research Council of Norway for the economic support through the POLARPROG programme (246757/E10). We also appreciate the contributions from the project partners Lomonosov Moscow State University, Longyearbyen Lokalstyre, Trust Articugol, Store Norske Spitsbergen Grubekompani AS, The University Centre in Svalbard, and SINTEF Building and Infrastructure.

References

1. Instanes A (2003) Climate change and possible impact on arctic infrastructure. In: Phillips M, Springman S, Arenson L (eds) 8th international conference on Permafrost. Balkema publishers, Zurich, pp 461–466
2. Anisimov O, Vaughan D (2007) Polar regions. In: Parry M et al. (eds) Climate change 2007: climate change impacts, adaptation, and vulnerability. Contribution working group II to the fourth assessment report of the intergovernmental panel on climate change, Cambridge University Press, Cambridge, pp 653–685
3. Benestad R et al (2016) Climate change and projections for the barents region: what is expected to change and what will stay the same? Environ Res Lett 11:1–8
4. Forland E et al (2011) Temperature and precipitation development at svalbard 1900–2100. Adv Meteorol 2011:1–14
5. Humlum O, Instanes A, Sollid J (2003) Permafrost in Svalbard: a review of research history, climatic background and engineering challenges. Polar Res 22(2):191–215
6. Guegan E (2015) Erosion of permafrost affected coasts: rates, mechanisms and modelling. Ph.D. thesis. Faculty of engineering science and technology, department of civil and transport engineering, Norwegian University of Science and Technology, Trondheim
7. Gilbert G (2014) Sedimentology and Geocryology of an Arctic Fjord Head Delta (Adventdalen, Svalbard). M.Sc. Thesis. Department of geosciences, faculty of mathematics and natural sciences, University of Oslo, Oslo
8. Sinitsyn A et al (2018) MonArc project report 2017. SINTEF, Trondheim
9. STO SRO-S 60542960 00043-2015 (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”). ROSATOM, Moscow
10. SP 22.13330.2016 (2016) “Osnovaniya zdaniy i sooruzheniy” (*Soil bases of buildings and structures*), Rosstandart, Moscow
11. GOST 24846-2012 (2011) “Grunty. Metody izmereniya deformatsiy osnovaniy zdaniy i sooruzheniy” (Soils. Methods of measuring the strains of structure and building bases). Rosstandart, Moscow
12. EM 1110-2-1009 (2002) Structural Deformation Surveying, in Engineer Manual. Department of the Army US Army Corps of Engineers, Washington, D.C
13. GKINP (GNTA)-03-010-02 (2012) “Instruktsiya po nivelirovaniyu I, II, III i IV klassov, (*Instruction for levelling of classes I, II, II and IV*). Roskartographiya, Moscow
14. Andersland O, Ladanyi B (2004) Frozen ground engineering, 2nd edn. Wiley, New Jersey
15. SP 25.1330.2012 (2012) “Osnovaniya i fundamenty na vechnomerzlykh gruntakh” (Soil bases and foundations on permafrost soils). Rosstandart, Moscow
16. Sinitsyn A, Kotov P, Aalberg A (2019) MonArc project report 2018. SINTEF, Trondheim
17. MonArc home page, http://www.sintef.no/prosjekter/monarc/. Last accessed on 27 Jan 2019
18. RiS database Home page, https://www.researchinsvalbard.no/project/8747. Last accessed on 27 Jan 2019