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# Report 1

## Case study objects in PCCH-Arctic

Selection criteria, list of the structures, and desktop data collection

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# PCCH-Arctic Report Nr. 1

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**ABSTRACT**

This report presents selection criteria and extended list of structures for the case studies at the PCCH-Arctic project. Several structures from this list will be chosen for the case studies. Selection is based on suggestions of the project participants, discussion at the kick-off meeting, and feedback from the project partners and discussions withing the project.

The repost also presents desktop collection of relevant data.

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*Cover image: Researchers on a field survey along the cableway Line 5-6 in Longyearbyen.*
*Image: © SINTEF AS, photographer: Anatoly O. Sinitsyn (early September 2022, processed picture).*

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## Introduction

The project "Climate and Cultural Heritage – Preservation and Restoration Management" (PCCH-Arctic, "the project"), [1], creates a knowledge base for sustainable safeguarding and future use of cultural heritage in the Arctic in conditions of changing climate and demography.

One of the project tasks is to design management plans of selected cultural heritage, which is under the responsibility of the user-partners, i.e. Longyearbyen Lokalstyre, Store Norske Spitsbergen Kulkompani AS and Kings Bay AS. Methodological developments performed within the project will be utilised for this purpose. This will be done, on the one hand, to contribute to solving the challenges the user-partners experience, and on the other hand to test out and demonstrate the PCCH-Arctic methodology for decision-making and for risk-based geotechnical design in permafrost.

On the one hand, selection of the case study objects is based on the lists of prioritized objects provided by the user-partners, and considerations and suggestions provided by the members of the reference group (see Ch. 1). On the other hand, selection is based on several criteria reflecting the value of the objects from cultural and historical perspectives, applicability of methodological developments within the project, an urgency for restoration of a specific object, practical considerations, etc. (see Ch. 2).

The extent of the case studies may vary for different objects.

## 1 Initial lists of objects for the case studies

Objects proposed by the user-partners and the members of reference group are presented in Table 1, where most of the objects are historical heritage, while some of them are cultural heritage (as the Titan crane).

**Table 1. List of the objects proposed for the case studies.**

| | **Longyearbyen** | **Object ID in Askeladden*** |
|---|---|---|
| 1. | System of the cableway posts, 1907–1960 (*Taubanebukker*, Norwegian):<br>• Cable car line 1b (*Taubanelinje 1b*)<br>• Cable car line 2b (*Taubanelinje 2b*)<br>• Cable car line 3 (*Taubane 3)*<br>• Cable car line for mines 5 and 6 (*Taubane delstrekning gruve 5 og 6*) | <br>158657<br>158986<br>158619<br>87889 |
| 2. | The Titan crane, 1953 (*Titankrana*, Norwegian) | NA |
| 3. | The old coal cableway centre in Longyearbyen, 1957 (*Taubanesentralen i Longyearbyen*) | 87889-6 |
| 4. | Mine 2b, 1937 (*Gruve 2B*) | 136716 |
| 5. | Mine 5, 1959 (*Gruve 5*) | 87889-4 |
| 6. | The coal cableway station in Hiorthhamn, 1917 (*Taubanestasjonen i Hiorthhamn*, Norwegian) | 93040-6 |
| | **Ny-Ålesund** | |
| 7. | The airship mast in Ny-Ålesund, 1926 (*Luftskipsmasta*) | 158506-2 |
| 8. | The White house, 1919 (*Hvitt hus*) | 159 781 |
| 9. | The Tronderheimen house, 1945 (*Trønderheimen*) | 159 772 |
| 10. | The London houses, 1912/1950 (*Londonhusene*) | 159807-1<br>159804-1<br>159806-1<br>159802-1 |
| 11. | The Green Harbour-house, 1909 (*Green Harbour-Huset*) | 159759-1 |

**Notes:**
* – Askeladden [2], national heritage database in Norway.
NA – not applicable.

## 2 Selection criteria

The following selection criteria are proposed:

1. A need to preserve and/or restore the given objects of cultural heritage *at the current time*.
2. Technical possibilities of the project to handle challenges towards specific objects of cultural heritage.
3. Potential for using the given objects of cultural heritage for some other purposes/future use.
4. Opportunities for cooperation with parallel ongoing research projects.
5. Transfer value of knowledge and experience to other objects of cultural heritage in Svalbard and other polar regions.

The following categories of relevance to the criteria 1 to 5 are suggested: low (1), normal (2), high (3), extremely high (4).

It may be assumed that each criterion has an equal importance. At the same time the criterion "1" (i.e., "a need to preserve and/or restore given objects of cultural heritage at the current time") may have somewhat higher weight as it reflects the risk of total loss of an object.

Ascription of a score reflecting fulfilment of each criterion was performed for demonstration purposes (see Table 2 in Ch. 4). Proposed criteria 1 to 5 may require discussion within the project, and a workshop session with a questionnaire to the project participants may be suggested for a more objective selection of the case study objects.

Considerations regarding criteria 1 to 5 are presented below.

1. A need to preserve and/or restore given objects of cultural heritage *at the current time.* Such need may be defined based on the following:
    a. Cultural and historical value of an object
    b. Technical state of an object
    c. Manifestation of natural (as rot decay, corrosion of steel elements) and geo-hazards towards an object and an area of its location (such as degradation of permafrost[1]), slope processes, coastal erosion, riverine scour and erosion, sea and riverine flooding, etc.)
    d. Sensitivity of natural and geo-hazards to climate change

    *Comments*

    Points "c." and "d." may somewhat overlap as climate change, during the lasts decades already affected natural hazards and conditions of various building materials. At the same time, one may expect that the climate change impacts may continue to increase in the future.

    The need to preserve and/or restore objects of cultural heritage may be expressed in terms of risk, defined for instance in accordance to Boro and Hermann (2020). Obviously, high cultural and historical significance, poor technical state (requiring intervention for saving an object), significant manifestation of natural geo-hazards, and high sensitivity to climate change will define a high need for preservation and restoration.

2. Technical possibilities of the project to handle challenges towards specific objects of cultural heritage, which is governed by:

[1] **Permafrost** – ground (soil or rock and included ice and organic material) that remains at or below 0 °C for at least two consecutive years (van Everdingen, 1998). **Permafrost degradation** – a naturally or artificially caused decrease in the thickness and/or areal extent of permafrost (van Everdingen, 1998).

a. Applicability of the project methodology, including simulations of the future ground thermal state
b. Sufficient background data (such as historical, technical, site conditions (i.e., geo-cryo-hydrological conditions)

*Comments*
Point "a." – methodology to manage the risks associated with the natural and geo-hazards (with placing focus on permafrost degradation) is the anticipated scientific advances of the project in the engineering domain. The methodology will be suitable to assessment of portfolios of the objects of similar structural type (with focus on the foundation solutions), yet it will be applicable to a singular object. The methodology will involve two steps. At the first step, "coarse" risk analysis due to various natural hazards will be performed, followed by the second step with a more detailed assessment. Core component of the methodology will be detailed risk analysis of foundation stability due to permafrost degradation, which will be performed at the second step.

Permafrost degradation is mostly relevant to the conditions of *unlithified* sediment (sand, silt, clay) containing ground ice. Lithified sediment (rock) is, in engineering terms, not affected by permafrost degradation unless it contains ground ice.

Typical types of foundations of cultural heritage on lithified and unlithified sediment in permafrost are (Figure 1):

- Shallow foundation "sitting" above permafrost table[2] or within the active layer[3] – typical situation for small houses/cabins
- Shallow/deep foundation "sitting" below the active layer.

Therefore, the project is mostly aiming to the challenges associated with foundations in unlithified sediment in permafrost.

[2] **Permafrost table** – the upper boundary surface of permafrost (van Everdingen, 1998).
[3] **The active layer** – the layer of ground that is subject to annual thawing and freezing in areas underlain by permafrost", (van Everdingen, 2005).

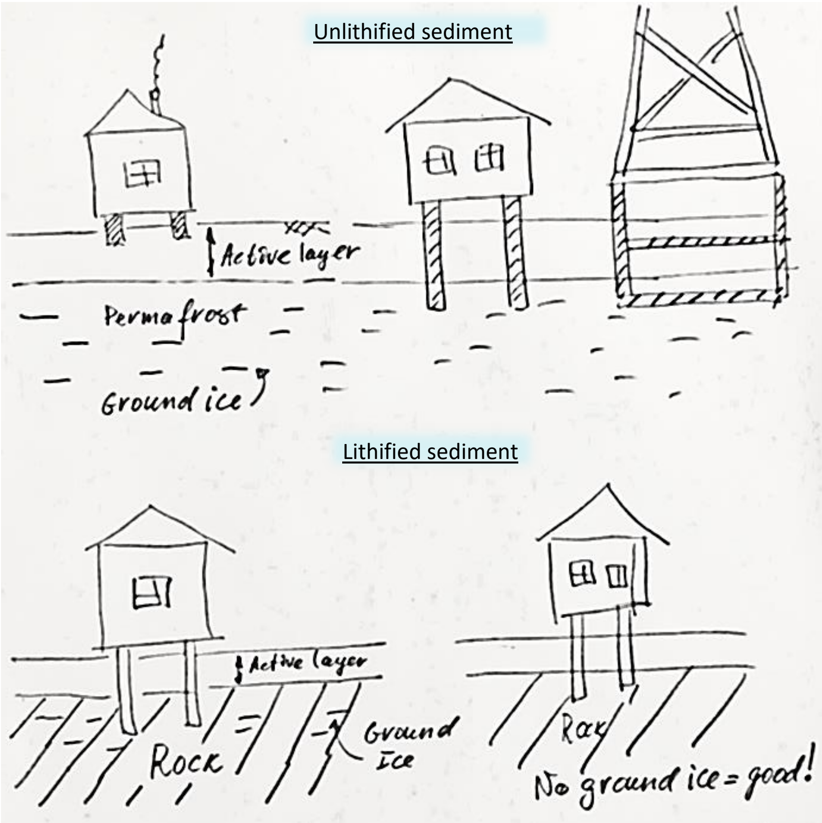


**Figure 1. Typical foundation types in permafrost.**

Following the considerations above, the following structural types are suggested:

- Type 1 – shallow foundations within the active layer (i.e., above the permafrost table). Houses in Ny-Ålesund and in Hiorthhamn (for example *Boligbrakke G*) represent the Type 1.
- Type 2 – foundations located within the permafrost, i.e. lower part of foundations is resting on frozen soil. One can assume that most of the cableway posts represent this type.
- Type 3 – objects with special foundations. This type is similar to the Type 2, but is singled out in a special category due to cultural and historical value of the particular structures. The old coal cableway centre in Longyearbyen, the cableway station in Hiorthhamn, the airship mast in Ny-Ålesund represent the Type 3.

Another important consideration when it comes to the natural hazards is that sometimes several various natural hazards are present on the site. Yet, it is easier to analyse the results of a somewhat idealized situation when only one natural hazard is present, i.e. permafrost degradation. Hence, the latter settings when it comes to selection of the case study objects may be prioritized.

It is also known that in Longyearbyen, a large number of the cableway posts are affected by the process of solifluction[4]. Such a situation (Figure 2), should those objects be selected, would require involvement of special engineering considerations (as for instance presented in [4]) for assessment of foundation stability on sloping terrain in permafrost.

[4] **Solifluction** – slow downslope flow of saturated unfrozen earth materials (van Everdingen, 1998).

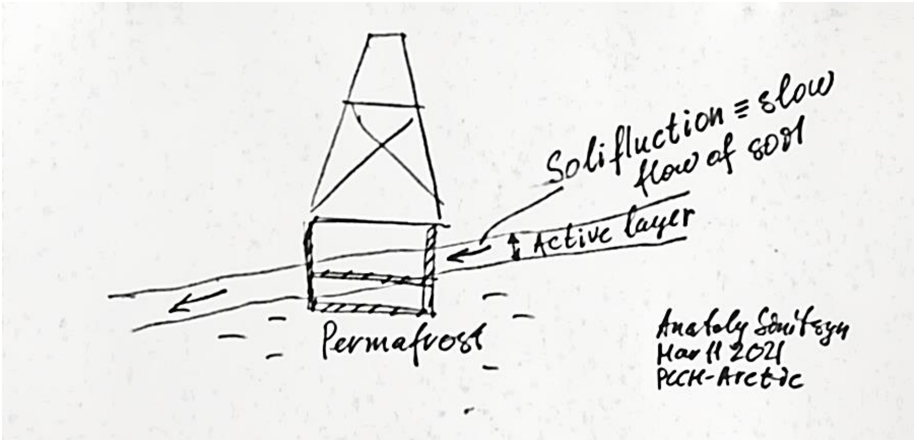


**Figure 2. Solifluction and foundation of a cabelway post.**

Point "b." – acquisition of field data (such as technical surveys, site data, geo-cryological conditions) is expensive in remote Arctic areas. Hence, the project aims to utilize existing data as much as possible.

3. Potential for enrolment of given objects of cultural heritage in the future use, which may be defined based on the following factors:
   a. Technical considerations, i.e. acceptable loads from the users.
   b. "Preparedness" towards the future use, such as existing managing strategies, developed and approved by the authorities plans, etc.
   c. "Potential" for interest among the users (historical and cultural values, potential for acquisition of experience, etc.)

*Comments*
Point "a." – defining acceptable loads may be a challenging task, including loads on various subjects, such as landscapes (vegetation cover), "wear and tear" of interiors of the buildings and structures, and even a visual load by tourists/vessel in pristine Arctic environment.

Point "c." – future use of cultural heritage may be useful for local societal (widening of cultural science and, when applicable, urban developments) and economic developments. Hence potential for such elements should be estimated. Moreover, enrolment in future use may also be useful for some other (which may be based on digital solutions) developments. Experience obtained from various types of new use may further on be transferred to other Polar areas. Overall, cultural heritage may contribute in sustainable development in terms of economic, social, and environmental productivity in communities [5].

4. Opportunities for cooperation with parallel ongoing research projects.

*Comments*
This may contribute to and enable holistic assessment of given objects of cultural heritage taking into account set of various factors providing impacts on cultural heritage. For example, other types of vital data (in addition the impacts of climate change on foundations), may include detailed data and knowledge on the natural hazards (such as rockfalls, landslides, and avalanches), fungal decay of timber in conditions of cold climate, on the impacts of the tourist traffic, indoor climate in the buildings, etc.

Examples of such ongoing parallel projects include the *ArcticAlpineDecay* ([6]) and the *CULTCOAST* project ([7]).

5. Transfer value of knowledge and experience to other objects of cultural heritage in Svalbard and other polar regions.

   *Comments*
   Transfer value for some, more common, objects may be higher than for other, more unique objects. For example, transfer value for small houses/cabins on shallow foundations may be higher across the Arctic.

# 3 Methodological aspects towards the case study objects

The discussion in this chapter somewhat extends considerations presented in Ch. 2 for the criteria 2 ("Technical possibilities of the project to handle challenges towards specific objects of cultural heritage") and 5 ("Transfer value of knowledge and experience to other objects of cultural heritage in Svalbard and other polar regions"). This discussion presents considerations for the best use of the case study objects in light of: i) direct applicability of the results for needs of the user-partners, and ii) in the light of knowledge transfer.

Case study objects will be organized/considered in 4 groups:

1. "Focus" objects or the main cases
2. "Secondary" objects
3. "Comparable" objects
4. "Special" objects

## 3.1 Focus objects

Focus objects or the main cases are the most important objects, which will be studied in detail. The following data will be collected for these objects:

a. Geotechnical data
b. Climate data and climate projections
c. Structural data
d. Data on relevant previously performed restoration projects (for example as the cableway post reconstructed in 2007 in proximity to the office of the Governor of Svalbard)
e. Historical and cultural documentation
f. Other publicly available data.

These objects can be important from other perspectives, i.e. safety issues and cooperation with other ongoing projects. Conclusions should be transferable to other objects in comparable environmental conditions.

Focus objects may represent several typical geo-cryo-morphological conditions, i.e. flat terrain with ice-rich permafrost, sloping terrain, shallow rock with ice-poor permafrost, and riverine settings with increased degradation of permafrost.

In this project the focus objects are largely defined by the degradation of permafrost under global warming.

## 3.2 Secondary objects

Secondary objects should be structurally similar to the focus objects and located in "similar" microclimate- (i.e., within the extents of the studied areas) and geo-cry-morphological conditions). For practical reasons, we assume that micro-climate remains the same on the distances of several hundred meter to first kilometres. Another practical aspect is that these objects should be located within the grid cell or in neighbouring grid cells for the climate modelling to assure relevance of climate modelling (made for the focus objects) to secondary objects. Conclusions from the focus objects may be extrapolated to the "secondary" objects.

## 3.3 Comparable objects

Such objects are structurally similar to the main objects (the type of foundations and the upper structure) and are located in "comparable" climate- and geo-cryo-morphological conditions. In this case, "comparable" implies a coarser degree of likeness than for "similar" when defining secondary objects. "Comparable" climate- and geo-cryo-morphological conditions could be found in Svalbard or in other polar regions.

Conclusions obtained for the focus and the secondary objects may be qualitatively transferred to these objects by means of: i) qualitative expert judgement and experience; 2) modelling (climate, cryological and geotechnical).

Qualitative transfer of conclusions should be supported by experience/filed observations. For instance, the answers to the following questions may support qualitative transfer of conclusions related to shallow foundations of small houses/cabins:

- How do small cabins on shallow foundations practically settle in warming permafrost?
- Do all cabins on shallow foundations within the active layer and with ice-rich permafrost settle?
- Do they all have differential settlements? Do we always need to handle differential settlements?
- How do we normally handle differential settlements of shallow foundations?

## 3.4 Special objects

Such objects may be characterized by a pressing/urgent need to take actions to save them. They are of high conservation value and relevant risks are high or extremely high. These objects may not necessarily be threatened by the hazard of permafrost degradation (which largely defines the focus objects), but may be threatened by some other hazards (as slope instability hazards, rot decay, coastal erosion). General approaches and specific (if possible) solutions will be proposed by the project to protect such objects.

# 4 Case study objects

## 4.1 Notes for selecting case study objects

Based on selection criteria from Ch. 2 and Ch. 4, several points were elaborated when selecting the case study objects. These are presented in the notes below.

*Note 1 – input based on discussion in the kick-off meeting*

Preliminary suggestions identified, based on discussion in the kick-off meeting, for the case studies include:

- Whole or part of the system of the cableway posts in Longyearbyen, as an example of structures founded in permafrost.
- Representative house or cabin in Ny-Ålesund, as an example of structure founded above permafrost table.

- Landmark structures (Amundsen-mast, Taubanesentralen, and/or cableway posts, which serve this role as well). General impact of climate change due to permafrost degradation may be assessed for such structures. This would ideally require a detailed knowledge on soil profiles and other comprehensive investigations. Availability of existing data on soil profiles and permafrost temperatures would significantly ease this analysis. In addition, suggestions for the future use of such structures may be elaborated based on a demographic assessment.

*Note 2 – selection of study objects and considerations about modelling*
The following objects are primarily selected, but a certain flexibility is still maintained:

- The whole system of cableway posts in Longyearbyen:
    - An ideal case to test decision-making and risk-based methodologies of WP4
    - An object of interest of several actors (Store Norske and Longyearbyen Lokalstyre and Visit Svalbard) concerning management (including safety issues) and use of the structures as a landmark and identity object of Longyearbyen as a touristic attraction.
    - It is the major technological challenge to the responsible organization to deal with this.
      The whole system, consisting of approximately 200 objects, will be divided in the groups depending on the type of prevailing natural hazards. Representative subjects from the different groups will be selected. One object from each category may be studied. Selection will be coordinated with the ArcticAlpineDecay project. For example, the cableway posts, which are within the town area may be the most important objects as they are a part of the town identity and may pose some safety issues.
- Houses in Ny-Ålesund – the focus is placed on the needs of management and new usage needs. Two different houses should be investigated – one where people live in and another where people do not live in. Examples include the Green Harbour house which is not occupied and the London houses which are in use. Management aspect with the snow removal should be considered within the project for evaluating the efficiency of maintaining/cooling permafrost by removing snow cover (cleaning ground surface from snow). Scenarios when (in cold periods) to clean the snow should be investigated. Accounting for temperature regimes inside of the houses may be important when simulating permafrost regime. It could be an idea to install sensors (in shallow boreholes) measuring ground temperatures under the houses to adapt the management strategies. Such sensors may also help to identify alarming situations should warming of permafrost go too fast.
- The old coal cableway centre in Longyearbyen – perhaps the aspects of "new" use and monitoring (settlements) mostly relevant here. Assessment of climate impacts is somewhat hampered by the need to run detailed geotechnical investigations and detailed modelling (settlements of the structure, slope stability).
- Landmark structure in Ny-Ålesund – The airship mast.

*Note 3 – opportunities for cooperation with parallel ongoing research projects (criteria #4 in Ch. 2)*
Based on discussions with the *ArcticAlpineDecay* project, the following objects were identified as candidates, which may serve at some degree both of the projects:

- Several cableway posts within the urban area in Longyearbyen
- Green Harbour House in Ny-Ålesund

Cableway posts within the urban area in Longyearbyen constitute a unique landscape in the town, and exposed more, compared to the ones located for instance in Adventdalen, to the visual experience of locals and tourists. Some of these posts were studied, restored, or completely renovated from before; hence this experience may be analysed. Also, some of them are the tallest among the whole system, and at the same time may already be unsafe due to rot of foundations; hence there is a need for their restoration. At the same time, present restoration techniques require improvements to ease technical operations and to decrease the costs.

These posts are easily accessible from a logistical point of view. Also, some of the posts experience different types of natural hazards acting on them (as solifluction, landslides, rockfalls and avalanches), which is interesting example for testing the first step (i.e., "coarse" risk analysis) of the PCCH-Arctic methodology.

The Green Harbour House in Ny-Ålesund is the oldest building in town, which was never restored from before, and at the current time requires restoration due it is technical conditions.

*Note 4 – cultural heritage in Hiorthhamn*

Hiorthhamn is an old mining settlement located in the vicinity of Longyearbyen. It has several objects of cultural heritage, including buildings, remains of a locomotive, the old cableway centre, and other objects, [8]. Hiorthhamn settlement is automatically protected[5], and it is a unique object that has a high conservation value as it is almost a complete mining facility from the beginning of the 20$^{th}$ century [9].

The latest assessment [9] points out that the natural hazards of timber rot, slope processes, coastal erosion and the impacts of local human loads pose extreme risk on the cultural environment i Hiorthhamn. The risk imposed by coastal erosion to the old cableway centre and some other objects was extremely high for the year 2020, and this risk was found unacceptable. It is recommended to apply temporal measures to mitigate the coastal erosion and to develop a permanent solution in the meanwhile. Rates of coastal erosion and geomorphology in the area, as well the needs for continued monitoring and sustainable management of cultural heritage were reported by Nicu, et al. (2020).

One may conclude that an input for solving the challenges in Hiorthhamn may be of relevance to the managing authorities and may contribute to the areas of interests of various users such as locals, visitors and various professionals. Further activities supporting management of cultural heritage in Hiorthhamn may include discussions (relevant to work package 2 in the PCCH-Arctic project) towards the depth and extent of applicable approaches in taking care of Svalbard's cultural monuments. Such discussion may embrace the areas such as technology, economy, climate change, law and protection philosophy.

*Note 5 – special cases and research issues, which are beyond the scope of the project*

It may be suggested to allocate the following structures in *special cases*:

- The old coal cableway centre in Hiorthhamn – as the challenges there are rooted in the hazard of coastal erosion, which largely is beyond the research scope of the project.
- The airship mast in Ny-Ålesund – the challenges related to foundations should be considered in a "normal" manner as they correspond to the goals of the project. The challenges related to structural stability of the upper structure are outside of the project goals.
- System of the cableway posts similar to the airship mast in Ny-Ålesund, the challenges related to foundations should be considered in a "normal" manner as they correspond to the goals of the project. The challenges related to structural stability of the upper structure are somewhat outside of the project goals.

## 4.2 Selection of the case study objects

Based on criteria 1–5 from Ch. 3, an attempt of assessment of the proposed objects for being selected as case study objects is presented in Table 2. The results presented in Table 2 are somewhat subjective and

[5] According to the Svalbard Environmental Protection Act, all cultural monuments from before 1946 are automatically protected.

should selection be performed in such a way, then ascription of the scores should be done by a panel of various experts.

**Table 2. First draft for selection of the case study objects**

| | | Relevance | | | | |
|---|---|---|---|---|---|---|
| | Criteria | Need to preserve | Technical possibilities | Potential for future use | Opportunities for cooperation | Transfer value |
| # | **Longyearbyen** | | | | | |
| 1. | System of the cableway posts, 1907–1960 (*Taubanebukker*) | **4** | **4** | 3 | **4** | 2 – 3 |
| 2. | A Titan crane, 1953 (*Titankrana*) | 1 – 3 | 1 – 2 | 3 | 1 | 2 |
| 3. | The old coal cableway centre in Longyearbyen, 1957 (*Taubanesentralen i Longyearbyen*) | 2 – 3 | 1 – 2 | 4 | 1 | 2 – 3 |
| 4. | Mine 2B, 1937 (*Gruve 2B*) | 3 | 1 | 3 | 1 | 2 |
| 5. | Mine 5, 1959 (*Gruve 5*) | 3 | 1 | 3 | 1 | 2 |
| 6. | The old coal cableway centre in Hiorthhamn, 1939 (*Taubanestasjonen i Hiorthhamn*). And possibly other objects of cultural heritage in Hiorthhamn. | **4** | 1 – 2 | **4** | 2 – **4** | 3 – **4** |
| | **Ny-Ålesund** | | | | | |
| 7. | The airship mast in Ny-Ålesund, 1926 (Luftskipsmasta) | **4** | 2 – 3 | **4** | 1 | **4** |
| 8. | The White house, 1919 (*Hvitt hus*) | 3 | 2 – 3 | 3 – 4 | 2 | 3 – 4 |
| 9. | The Tronderheimen house, 1945 (*Trønderheimen*) | 3 | 2 – 3 | 3 – 4 | 2 | 3 – 4 |
| 10. | The London houses, 1912/1950 (*Londonhusene*) | 3 | 2 – 3 | 3 – 4 | 2 | 3 – 4 |
| 11. | The Green Harbour-house, 1909 (*Green Harbour-Huset*) | **4** | 2 – 3 | 3 – **4** | **4** | 3 – **4** |

**Note:**
Scores for relevance for different criteria: low (1), normal (2), high (3), extremely high (4).

Following the categorization proposed in Ch. 3 and foundation types suggested in criterion #2 in Ch. 2, the above suggestions can be combined based on discussions within the project meetings and "results" of the selection based on the criteria from Ch. 2 (see Table 2). The outcome is presented in Table 3.

**Table 3. Categorization of proposed objects for the case studies.**

| | | Foundation types | | | Object types | | | |
|---|---|---|---|---|---|---|---|---|
| | | Type I | Type 2 | Type 3 | Focus | Secondary | Similar | Special |
| | **Longyearbyen** | | | | | | | |
| 1. | Some cableway posts **within** Longyearbyen urban area | | ● | | **V** | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Cableway posts **outside** of Longyearbyen urban area | | ● | | | **V** | | |
| 2. | The Titan crane | ● [B] | | | | | **(V)** | |
| 3. | The old coal cableway centre in Longyearbyen | | | ● | | | | **(V)** |
| 6. | The old coal cableway centre in Hiorthhamn | | | | | | | **V** |
| | Barakk G in Hiotrhhamn (*Boligbrakke G*) | ● | | | | **(V[A])** | | |
| | **Ny-Ålesund** | | | | | | | |
| 7. | The airship mast in Ny-Ålesund | | ● | | | | | **V** |
| 8. | The White house | ● | | | | **V** | | |
| 9. | The Tronderheimen house | | | | | **V** | | |
| 10. | The London houses | ● | | | | **V** | | |
| 11. | The Green Harbour-house | ● | | | **V** | | | |

**Notes:**

(V) – brackets signalize that the object will be considered for analysis after a pilot application of the PCCH-Arctic methodology is performed for a simpler structure.

[A] – restoration of this object is strongly recommended by the authorities. Including of this object in the project studies requires further discussions within the project.

[B] – assumption based visual observation of foundationы of the Titan crane, which is railway sleepers resting on the ground surface.

The project also proposes to begin testing the project methodology (in other words to consider as the case study objects) on smaller and structurally simpler objects and then move towards more comprehensive structures as far as the funding permits.

# 5 Special cases – the cableway station in Hiorthhamn

Following *Note 5* in Ch. 4, key points from historical perspective are presented in Table 4.

**Table 4. Key points concerning the situation at Hiorthhamn from the managerial perspective of cultural heritage.**

| |
|---|
| Hiorthhamn settlement is automatically protected, and it is a unique object that has a high conservation value as it is almost a complete mining facility form the beginning of 20th century, [9]. Flyen and Boro [9] point out that the risk imposed by the coastal erosion to the Old cableway station and some other objects is extremely high for the year 2020, and this risk is unacceptable. It is recommended to apply temporal measures to mitigate the coastal erosion and to develop in the meanwhile a permanent solution. |

**Coastal erosion in the area**

The natural hazard of coastal erosion is normally characterized by the rates of coastal erosion, expressed in m/yr, where negative values indicate erosion. Nicu, et al. (2020) investigated the position of 1.3 km of the Hiorthhamn shoreline and reported average erosion rates of -0.21 m/yr for the 92-year period and pointed out the needs in continued monitoring and sustainable management of cultural heritage at the site. More importantly, it was found that erosion rates at the old coal cableway station have the values of -0.57 to -0.76 m/yr. The authors classify these rates as "very high". It is important to note that only two shoreline positions were analysed by the study, i.e. from 1927 and 2019. The latter leaves room to hypothesize that erosion rates in the last decades may be even higher than the reported long-term values. Such a situation may be possible due to longer periods of wave activity and possibly stronger wave climate in the last decades, yet such assumptions shall be clarified by a hydro-meteorological analysis. Distance from the cable to the crest of coastal bluff is 2 m as of 2020, [9].

# 6 Desktop data collection

Analysis of the case study objects will require data collection (for the main types of data see Ch. 3.1). Data collection will be performed through the following steps:

1. Desktop data collection, i.e. this chapter.
2. Field data collection – data collection from field surveys and from instruments installed in the field.
3. Modelling – this type of data will be produced by meteorological, geocryological, geotechnical and other types of modelling.

## 6.1 Cultural and historical data

### 6.1.1 Some general sources of information on cultural heritage in Norway

- The Directorate for Cultural Heritage in Norway (Riksantikvaren) [11].
- Askeladden, [2] – national heritage database in Norway.
- Kulturminnersøk, [12] – web page for search for cultural heritage in Norway. This web page provides basic data about the objects of cultural heritage – their ID number, year of construction, history of use, and in some cases, current state of the objects (which may include information about conditions of foundations).
- Riksantikvarens kartportal, [13] – map portal of Riksantikvaren.

### 6.1.2 General sources of information about cultural heritage in Svalbard

- Report "Teknisk industrielle kulturminner i Longyearbyen med omegn. Verneverdi og forvaltning" (*"Technical industrial heritage of Longyearbyen and its surroundings. Protection value and management"*), Sysselmannen på Svalbard (2010).
- Report "Katalog prioriterte kulturminner og kulturmiljøer på Svalbard. Versjon 1.1 (2013)" ("*Catalogue of the cultural heritage sites with high priority in Svalbard. Version 1.1 (2013"*), Skauen Sandodden, et al. (2013).
- "Kulturminneplan for Svalbard 2013–2023" ("*Plan for the management of cultural heritage in Svalbard from 2013 to 2023*), Sysselmannen på Svalbard (2013).
- Booklet "Longyearbyen. From company to modern town", Reymert (2013).
- Report "Miljøovervåking av kulturminner på Svalbard. Eksisterende og tidligere overvåkningssystemer på Svalbard" (*"Environmental monitoring of cultural monuments on Svalbard. Existing and previous monitoring systems on Svalbard"*), Flyen (2016).

  *An overview of the sources of environmental monitoring (projects, systems, and measures) relevant to cultural heritage in Svalbard can be found in this report.*

- Book "Svalbards historie" (*History of Svalbard, in Norwegian*), Arlov (2003).
- CULTCOAST project, [7].

### 6.1.3 Cultural heritage in Longyearbyen

**Taubanesentralen in Longyearbyen**

- Report "Taubanesentralen", Multiconsult Norge AS (2018).

  *Some facts about foundation of the old coal cableway centre in Longyearbyen can be found in this report.*

- Drawing "Taubanesentralen. Øvre plan" (*"Plan of the upper floor"*). A1/A3=1:100/1:200", Multiconsult Norge AS (2019).

**Cableway posts in Longyearbyen**

- Report "Rapport om vedlikehold av taubanebukken ved sykehuset" (*"Report on maintenance of the cableway post at the hospital"*), Håvelsrud (2016).

  *The report describes restoration process at the cableway post nr 5, Line 5–6 (ID number 87889-13). It, in particular, points out that in this particular case the lower foundation part, i.e. horizonal beam, is located at 2.5 m below the ground surface.*

- Application "Søknad om revidert innfestingsmetode ved sikring av taubanebukker" (*"Application for a revised fastening method when securing cableway posts"*) og Notat "Stabilisering av taubanebukker. Refundamentering med peler" (*"Stabilization of cableway bucks. Refoundation with piles"*), Store Norske Spitsbergen Kulkompani AS (2017).
- Decision on dispensation "Longyearbyen - Svalbard - vedtak om dispensasjon for stabilisere tiltak på automatisk fredete taubanebukker, ID 158657, 158986, 158619 og vedtaksfredete taubanebukker, ID 87889 - jf. Svalbardmiljøloven § 44 første of siste led" (*"Longyearbyen - Svalbard - decision on dispensation for stabilizing measures on automatically protected cableway bucks, ID 158657, 158986, 158619 and decision-protected cableway bucks, ID 87889 - cf. Svalbard Environment Act § 44 first and last paragraph"*), Riksantikvaren (2019).

  *This decision for dispensation, in particular, presents restoration measures for cableway posts. Attachment 1 of the decision for dispensation presents an overview of conditions of cableway posts at the Lines 5-6, 6, 1b, 2b, and 3. The following classes of conditions are defined:*
    - *TG 1 – normal need for restoration (new structure).*
    - *TG 2 – moderate need for restoration.*
    - *TG 3 – significant need for restoration.*
    - *TG 4 – structure is lost/dismantled.*

- Report "Bevaring av teknisk industrielle kulturminner. Reparasjon av taubanebukker i Longyearbyen" (*"Preservation of technical industrial cultural monuments. Repair of cableway posts in Longyearbyen"),* Flyen and Mattsson (2018).

  *In particular, the report presents discussion on the risks associated with fungal decay, it suggests two principal foundation types (foundation anchored in the ground and concrete blocks), and describes methods for rehabilitation, and provides general sketch of a foundation.*

- Report "Rapport om restaurering av taubanebukk Gruve 5-6 bane ved Alpinbakken. Askeladden ID 158986 (*"Report on restoration of cable car buck Mine 5-6 track at Alpinbakken"*), Guhl (2019).

  *Pictures and drawings of foundations of cableway posts can be found in this report.*

- Report "Rehabilitation of Cableway Post. Pre-project for master thesis", Enevoldsen (2021).

*This report evaluates safety when replacing the upper structure of cableway posts to new foundations. Only a specific approach for replacement operation is considered.*

- MSc thesis "Rehabilitation of Cableway posts", Enevoldsen (2022).

  *An outline of foundations of cableway posts is provided in this thesis.*

- Some pictures taken during restoration of foundations of the Cableway post Nr. 7 at the Line 5-6 are presented in Appendix 1.

**Mine 2B in Longyearbyen**

- Report "Daganlegget Gruve 2B. Restaurering 2011-2013" [29].
- Note "Dagalegg Gruve 2B - Tilstandsrapport. Vedlegg til søknad" (*"Site facilities for Mine 2B - condition report. Attachment to proposal"*), Spjudvik and Flyen [30].
- Report "Tilstandsanalyse av skredfare mot gruve 2b" (*"Condition analysis of landslide hazard against mine 2b"),* Hannus and Ripman Sletten (2019).

  *Probabilities for snow avalanches and landslides, and evaluation of rockfalls at the Mine 2b can found in this report.*

- Report "Gruve 2b, Longyearbyen. Tiltak og kostnadsoverslag" *("Mine 2b, Longyearbyen. Measures and cost estimates"*), Hannus and Ripman Sletten (2020).
- Attachement to proposal "Tiltaksplan for sikring av området bak Gruve 2B" ("*Action plan for securing the area behind Mine 2B"*), Store Norske Spitsbergen Kulkompani AS (2020).

**Mine 5**

- Report "Rapport fra befaring til Gruve 5 i Endalen nær Longyearbyen på Svalbard 26. Juli 1988" (*"Report from an inspection of Mine 5 in Endalen near Longyearbyen on Svalbard 26 July 1988"*), Bergmesteren for Svalbard (1988).

  *The report presents a short note about coal-mining infrastructure of the Mine 5 in Endalen, Svalbard.*

**Mine 6**

- Report "Tilstandsvurdering av teknisk-industrielle kulturminner. Gruve 6, Adventdalen på Svalbard" (*"Condition assessment of technical-industrial cultural monuments. Mine 6, Adventdalen on Svalbard"*), Flyen, et al. (2018).

**Cultural heritage in Hiorthhamn**

- Booklet "Hiorthhamn – kulldrift under vanskelige forhold" (*"Hiorthhamn – coal mining under difficult conditions"*), Johannessen (2006).
- Report "Gruveminner i Longyearbyen og Hiorthhamn. Fredete taubanebukker: Tilstand og bevaring" (*"Mining monuments in Longyearbyen and Hiorthhamn. Protected cableway posts: Condition and conservation"*), Flyen and Mattsson (2013).
- Report "Svalbard: Hiorthhamn Kulturmiljø. Kulturminner og klima – risikovurdering og planlegging av tiltak. En del av prosjekt Adapt Northern Heritage 2020" (*"Svalbard: Hiorthhamn Cultural environment. Cultural monuments and climate - risk assessment and planning of measures. Part of the Adapt Northern Heritage 2020 project"*), Flyen and Boro (2020).

  *Foundation type for the barack "Boligbrakke G" in Hiorthhamn can be found in this report.*

- Article "Coastal Erosion Affecting Cultural Heritage in Svalbard. A Case Study in Hiorthhamn (Adventfjorden) – An Abandoned Mining Settlement", Nicu et el. Nicu, et al. (2020).

### 6.1.4 Cultural heritage in Ny-Ålesund

- Report "Helhetlig plan for miljøtiltak i gruveområdet i Ny-Ålesund (Kings Bay) – Perspektiv på historie, kulturminner, industrielle etterlatenskaper, forsøpling og forurensing" (*"Comprehensive plan for environmental measures in the mining area in Ny-Ålesund (Kings Bay) - Perspective on history, cultural monuments, industrial remains, littering and pollution"*), Bjartmann Bjerck, et al. (1999).
- Report" Ny-Ålesund. Forvaltningsplan for de fredete bygningene i tettstedet" (*"Ny-Ålesund. Management plan for the listed buildings in the settlement"*), Hoem and Paulsen (2008).

  *Details on foundation types and suggested approaches of restoration of foundations can be found in this report. It is, for instance, suggested to make longer wooden piles to meet the impacts of climate change on permafrost.*

- Report "Ny-Ålesund. Verdens nordligste gruveby" (*"Ny-Ålesund. The world's northernmost mining town"*), Reymert (2016).

- Report "Tilstandsrapport med behandlingsforslag Amundsenmasta i Ny Ålesund" (*"Condition report with treatment proposal for Amundsen's mast in Ny Ålesund"*), Brennsund (2019).

  *General information (without exact dimensions) of foundations, and the natural hazards (i.e., riverine erosion) which may impact the structure can be found in this report.*

- General description of foundations of the case study objects in Ny-Ålesund was provided to the project by Per Kyrre Reymert; this description is presented in Table 5.

**Table 5. General description of foundations in Ny-Ålesund provided by Per Kyrre Reymert.**

1. **The airship mast**. Four men blasted the permafrost ground and made the three concrete fundaments for the supporting wires. Each is 40 tons of concrete. The sand was blasted in the shore close to the bay and taken to the community to dry. With warm water from the community and some small stones, it was mixed on site. The work was finished on December 5$^{th}$, 1925 after working around the clock in temperatures of -20 °C, in darkness and strong winds. Still standing.

2. **Hvit Hus** was built in 1919 on a concrete foundation. The living quarters of the mine manager. Has been used ever since, except for four years during the war.

3. **Trønderheimen**, a barrack of readymade elements put up in 1945. Stands on the site of a house burned during the war. The middle part of the foundation is the concrete foundation of that house. Regular use in summers. To be refurnished.

4. **Londonhusene,** built in 1912 in Piersonhamna on Blomstrandhalvøya by the British mining company NEC. In 1949-50 the four houses were moved across the fjord to Ny-Ålesund to be used as living quarters. Nr.1 rehabilitated inside in 2008-09, outside – in 2012. Nr. 2 got new foundation in 2013 and Nr. 3 and Nr. 4 in 2015 and rehabilitation inside in 2016.

5. **Green Harbour-Huset**. Put up by the mining prospectors *Chr. Anker Green Harbour* in 1912 and 1913. Moved to Ny-Ålesund in 1917 or 1918 as it is online with houses built in those years. The small wooden house stands on a foundation of wood and has two small annexes.

- Several restoration projects were completed in Ny-Ålesund since the report by Hoem and Paulsen (2008) was released, i.e. in the period 2008–2022. Overview of implemented solutions and some notes on performance of foundations of historical buildings and some of the modern buildings in Ny-Ålesund is presented in Table 6. This overview includes description from Table 5. The overview will be helpful to generalize the findings obtained from the case study objects on a wide array of buildings in Ny-Ålesund.

**Table 6. Overview of foundations of historical and some of modern buildings in Ny-Ålesund, prepared by Espen Blix, Kings Bay AS (punctuation preserved).**

| #[1] | Building and year of construction | Original foundation | Restored foundation and notes on site conditions as of spring 2022 |
|---|---|---|---|
| 1 | Green Harbour-house (*Green Harbour-Huset*), 1909 | Most probably wooden grill laying on the ground surface.<br><br>"Green Harbour-Huset. Put up by the mining prospectors Chr. Anker Green Harbour in 1912 and 1913. Moved to Ny-Ålesund in 1917 or 1918 as it is online with houses built those years. The small wooden house stands on a fundament of wood and has two small additions", [41] (see Table 5). | Still on original foundation.<br><br>Signs of ground settlements and heave of soil around the house. |
| 2 | The London houses (*the London husene*), 1912 | "Londonhusene, built in 1912 in Piersonhamna on Blomstrandhalvøya bythe British mining company NEC. In 1949-50 the four houses were moved across the fjord to Ny-Ålesund to be used as living quarters. Nr.1 rehabilitated inside in 2008-09, outside – in 2012. Nr. 2 got new fundament in 2013 and Nr. 3 and Nr. 4 in 2015 and rehabilitation inside in 2016", [41] (see Table 5). | Wooden blocks on ground surface.<br><br>The wooden blocks are sinking in the ground. The best solution in this area of town is steel piles to bedrock. |
| 2 | London 4 | Wooden blocks on ground surface with skirt. | New wooden blocks in 2015. |
| 3 | London 3 | Wooden blocks on ground surface with skirt. | New wooden blocks in 2015. |
| 4 | London 2 | Wooden blocks on ground surface with skirt. | New wooden blocks in 2013. |
| 5 | London 1 | Wooden blocks on ground surface. | New wooden blocks in 2013. |
| 6 | School (*Skolen*), 1917 | Wooden blocks on ground surface with skirt. | Still on original foundation. |
| 7 | Telegraf (*Telegrafen*), 1918 | Wooden blocks on ground surface with skirt. | Still on original foundation, but some repair was done in 2013. |
| 8 | Museum (*Meseet*), 1917 | Concrete foundation, depth unknown. | Still on original foundation, some repair was done under the floor in 2012-2013. |
| 9 | Museum cabin, light green (*Museum/Museum shytta/hytte lysegrønn*), 1918 | Unknow, the cabin was moved in the 80-ies to today's position. | Piles installed into the bedrock (total 6 meters piles, 3 meters from ground level to bedrock), and timber skirt was installed, as required by the authorities. |
| 10 | Veteran cabin, light blue (*Veteranhytta/hytte lyseblå*), 1918 | Wooden piles. | Still on original foundation. |
| 11 | Sysselbu, 1918 | Wooden blocks on ground surface. | Still on original foundation. |

| | | | |
|---|---|---|---|
| 12 | Museum, 1918 | Concrete foundation. Depth unknown. | Still on original foundation. |
| 13 | Amundsen villa (*Amundsenvillaen*), 1918 | Concrete piles. Depth unknown. | Still on original foundation. Some movements in the fundament. |
| 14 | North Pole hotel (*Nordpolhotellet*), 1918 | Concrete foundation and some concrete piles. Depth unknown. | Still on original foundation. |
| 15 | Gult hus, 1919 | Concrete foundation. | Still on original foundation. |
| 16 | The White house (*Hvitt Hus*), 1919 | "Hvit Hus was built in 1919 on a concrete fundament. The living quarters of the mine manager. Has been used ever since, except for four years during the war", [41] (see Table 5). | Still on original foundation.<br><br>Signs of settlement of ground surface (left-hand wall when looking from the front site)<br>Small cracks in the original foundation. |
| 17 | Blått hus, 1919 | Concrete foundation. Depth around 1 m. | Still on original foundation. |
| 18 | Mellageret, 1919 | Concrete piles. Depth unknown. | Still on original foundation. |
| 19 | Post office (*Posthuset*), 1920 | Wooden blocks on ground surface with skirt. | Still on original foundation. |
| 20 | The iron warehouse (*Jernlageret*), 1927 | Concrete plate. | Still on original foundation. |
| 21 | Sætra, 1919-1945 | Unknow, the cabin was moved from the mining area. | Still on original foundation. |
| 22 | Båtnaust, 1st operation period | Wood straight on soil. | Still on original foundation. |
| 23 | Båtnaust, before 1921 | Wood straight on soil. | Still on original foundation. |
| 24 | Båtnaust, 1st operation period | Wood straight on soil. | Still on original foundation. |
| 25 | The Tronderheimen house (*Trønderheimen*), 1945 | Shallow foundation and posts.<br><br>"Trønderheimen, a barrack of readymade elements put up in 1945. Stands on the site of a house burned during the war. The middle part of the fundament is the concrete fundament of that house. Regular use in summers. To be refurnished", [41] (see Table 5). | Still on original foundation. |
| 26 | Mexico, 1945 | Shallow foundation and posts.<br><br>"Mexico", a barrack of readymade elements put up in 1945. Stands on the site of a house burned during the war. The middle part of the fundament is the concrete fundament of that house. | Still on original foundation. |
| 27 | Hospital (*Sykehuset/Skutergarasjen*), 1945 | Shallow foundation and posts.<br><br>"Sykehuset", a barrack of readymade elements put up in 1945. Stands on the site of a house burned during the war. The middle part of the fundament is the concrete fundament of that house. | Steel frame with steel piles drilled 2m in the bedrock. Depth 9-10 meters from ground level to bedrock. |
| 28 | Samfunnshuset, 1945 | Wooden blocks. | Still on original foundation. |

| | | | |
|---|---|---|---|
| 29 | Saga, 2nd operation period | Wood straight in the soil. | The soil was exchanged with draining gravel in 2018. |
| 30 | Gamle kraftstasjonen, 1949 | Concrete foundation, unknow if it is standing on bedrock or in the soil. | Still on original foundation.<br><br>Still stable, no cracks in the walls, probably funded in the rock. |
| 31 | Hundegården, 1949 | Wood straight in the soil. | Still on original foundation. |
| 32 | Dokkehus, 1953 | Wooden Blocks on ground surface. | Still on original foundation. |
| 33 | Transformatorhus, 1956 | Concrete plate. | Still on original foundation. |
| 34 | Servicebygget, 1957 | Concrete foundation – 0.5m depth under the ground level. | Steel piles (2020) (all piles are drilled 3 meters into bedrock).<br><br>Piles funded in the rock. |
| 35 | Vaskeriet, 1957 | Concrete foundation – 0.5m depth under the ground level. | Still on original foundation.<br><br>Condemned. The building will be closed during 2022 pending founding for a new building. |
| 36 | Dasan/Rabot, Ungkarsheimen I, 1957 | Concrete foundation. Depth unknown. | Still on original foundation. |
| 37 | Verkstedet, 1957 | Concrete foundation, unknow if it is standing on bedrock or in the soil. | Still on original foundation. |
| 38 | Fjøset, 1957 | Concrete on bedrock. | Still on original foundation. |
| 39 | Yellow River station, Ungkarsheimen II, 1958 | Concrete foundation. Depth unknown. | Still on original foundation. |
| 40 | Snekkasjen, 1959 | Concrete foundation, unknown whether it is standing on bedrock or in the soil. | Still on original foundation. |
| 41 | Renseverket, 1960 | Concrete foundation, unknown whether it is standing on bedrock or in the soil. Probably founded in the rock. | Still on original foundation.<br><br>Still stable, no cracks in the walls, ice in the two basement floors. |
| 42 | Kullkaia, 1960 | Steel piles, depth unknown. | Still on original foundation. |
| 43 | Amsterdam / The Netherlands, 1962 | Concrete piles, depth unknown. | Still on original foundation. |
| | The airship mast in Ny-Ålesund (*Luftskipsmasta i Ny-Ålesund*), 1925 | "Four men blasted the permafrost ground and made the three concrete fundaments for the supporting wires. Each is 40 tons of concrete. The sand was blasted in the shore close bay and taken to the community to dry. With warm water from the community and some small stones it was mixed on site. The work was finished on December 5th1925 after work around the clock in temperatures -20 °C in darkness and strong winds. Still standing", [41] (see Table 5). | New steel anchors for supporting lines finished 2021. |

| | | | |
|---|---|---|---|
| 63 | Research Laboratory (Marinlaboratoriet) | | Still stable, probably funded on the bedrock. |
| — | Veksthuset 2018-2019 | | Steel frame(?) and piling into the rock, 6-9 m in permafrost and 3 m into the rock.<br><br>Part of soil is unfrozen, appearance of ground water |
| 66 | Kongsfjordhallen, 2015 | Foundation in direct contact with the ground. | Steel frame with concrete on top and steel piles drilled 3 meters in the bedrock. Depth to bedrock 0-7 meters |
| — | Gruvebadet | Concrete piles. | Steel piles drilled 2m in the bedrock.<br><br>4 m of ground ice between the soil and the bedrock. Ground level are sinking every year. In 2021 a sinkhole was opening downside the building. |
| 65 | Lagerhall, 2010 | Probably founded in the rock. | Still stable, no cracks in the walls. |

**Notes:**

[1] – Ordinal numbers and color legend are according to Reymert (2016): **red** – houses built before 1916; **orange** – 1st operating period; **blue** – Swedish barracks 1945; **light blue** – 2nd operating period 1945–1963, **grey** – buildings built after 1963.

### 6.1.5 Fungal decay of timber in Svalbard

- Article "Wood-decaying fungi in protected buildings and structures on Svalbard", Mattsson et al. [42].
- Report "Håndtering av råteskader i kulturminner på Svalbard. Skadeårsaker og løsningsmetoder (*Handling of rot damage in cultural monuments on Svalbard. Causes of damage and solution methods*)", Flyen and Mattsson [43].
- Report "Råtekontroll av taubanebukker på Hiorthhamn, Svalbard" (*Decay control of trestles on Hiorthhamn, Svalbard*), Flyen and Mattsson [44].
- PhD thesis "The impact of microclimate on biodeterioration of wood in historic buildings", Mattsson [45].
- ArcticAlpineDecay project, [6].

### 6.1.6 Foundations of modern buildings in Svalbard

Selected references on foundations of modern buildings in Svalbard:

- Article "Pile design in saline permafrost at Longyearbyen", Instanes and Instanes (1999).
- Article "Permafrost temperature to be used in design of infrastructure in Svalbard", Instanes (2000).
- Article "Permafrost in Svalbard: a review of research history, climatic background and engineering challenges", Humlum, et al. (2003).
- MSc thesis "Foundation behaviour in Longyearbyen, Svalbard", Nokken (2009).
- Some strength properties of artificially prepared saline permafrost from Longyearbyen are presented in the following articles: [50-52].
- Article "Incorporating climate warming scenarios in coastal permafrost engineering design – Case studies from Svalbard and northwest Russia", Instanes (2016).

*Evaluation of permafrost degradation in Longyearbyen can be found in this article.*

- Series of reports for Statsbygg (the Norwegian government's building commissioner) about expected climate change impacts on buildings in Svalbard:
    - Summary report "Forventede klimaendringers langsiktige konsekvenser for bygging og forvaltning på Svalbard. Samlerapport ("*Long-term consequences of expected climate change for construction and management on Svalbard. Summary report*)", Rongved, et al. (2018).
    - Report "Delrapport 1: Klimascenarioer for Longyearbyen-området, Svalbard ("*Climate scenarios for the Longyearbyen area, Svalbard*")", Isaksen, et al. (2017).
    - Report "Delrapport 2: Forventede klimaendringers påvirkning på byggegrunn i Longyearbyen-området ("*Subreport 2: Expected climate change impact on building land in the Longyearbyen area*")*",* Instanes AS (2017).
    - Report "Delrapport 3: Forventede klimaendringers langsiktige konsekvenser for bygging og forvaltning på Svalbard ("*Subreport 3: Expected long-term consequences of climate change for construction and management on Svalbard*")", Instanes AS og Rambøll AS (2017).
- Article "The MonArc Project: Monitoring Programme for Foundation Settlements and Initial Results" Sinitsyn, et al. (2020), and corresponding reports ([59, 60]).

*Settlements of UNIS Guest House measured in 2017–2019 are presented in this article. Combined with data on soil profile [61], this data may be utilized for calibration of numerical models of foundations in permafrost in Longyearbyen.*

- Report " Impact of Climate Change on Infrastructure in Longyearbyen. Case Study of pile foundations on sloping terrains", Bekele and Sinitsyn (2020).
- PhD thesis "Mechanical behavior of frozen saline clay: laboratory, field and numerical investigation", Lyu (2021).

*Thesis is dealing with physical and mechanical properties of saline clay from Longyearbyen.*

- "Grey" literature – there are numerous reports on geotechnical investigations, which were produced by the consultancy for design of foundations of new buildings in Longyearbyen and Ny-Ålesund. It can be useful to inquire such reports should the locations be relevant to the cultural heritage in question.

### 6.1.7 Missing information

It is believed that the archive drawings of upper structures and foundations of the cableway posts in Longyearbyen are stored in the state archive in Tromsø. The project had unfortunately no opportunity to perform search in the archive of these documents. There are also drawings of cableway posts in a private collection, which belongs to the inheritors of the company *Ole Mørkved* i Namsos. This company was delivering and assembling the cable posts in Longyearbyen.

## 6.2 Geomorphological and other relevant types of maps

There are several geomorphological maps for Longyearbyen and Ny-Ålesund, which are summarized below:

- Adventdalen, Geomorphological and Quaternary geological map, Svalbard (1:100 000), Tolgensbakk, et al. (2000).
- Geomophlogical map and map of ground ice in Advendalen (1:100 000), Härtel and Christiansen (2014, unpublished dataset).
- Landscape forms and loose materials (quaternary geology) from Bjørndalen to Vestpynten (1:10 000), Rubensdotter, et al. (2015).
- Longyeardalen, Løsmasser og landformer med fokus på skråninger (*Longyeardalen, soils and landforms with a focus on slopes*), Rubensdotter (Kartutkast 2019).

- A Quaternary geological map of Endalen, Svalbard, Scale 1:10 000, Gerland [67, 68].
- Landforms and sediments in Todalen and upper Gangdalen and Bødalen, Svalbard. Scale 1:25 000, Rubensdotter, et al. (2015).
- Geomorphological map "Yttre Todalen (*"Outer Todalen"*). 1:10 000", Rubensdotter (2022, draft).
- Geomorphological and surface sedimentological study in Hiothhamn, Solberg Hergot (2021).
- Map of Svalbard Norwegian Polar Institute. TopoSvalbard (2018).
- Svalbardkartet (*"Svalbard map"*) [73].

  *This interactive map presents, for example, geological data.*

**Ny-Ålesund**

- Article and supplementary material "Analysis of the paraglacial landscape in the Ny-Ålesund area and Blomstrandøya (Kongsfjorden, Svalbard, Norway)", Berthling, et al. (2020).
- Article "Geomorphological features of the Kongsfjorden area: Ny-Ålesund, Blomstrandøya (NW Svalbard, Norway), Miccadei, et al. (2016).
- Map "Carte Géomorphologique de reconnaissance de la presqu'île de Brögger (Spitsberg) (*Geomorphological reconnaissance map of the Brögger peninsula (Spitsbergen*)", Joly (1969).

  *Geomorphological map for the area of the Bayelva river (proximity of Ny-Ålesund) can be found in this map. This map is also used in [77], metadata from this map is presented by May and Boike (2014).*

- MSc thesis "Land cover and landform classification upscaling of soil organic carbon stocks in the Brøgger Peninsula, Svalbard", Wojcik (2015).

  *Some geomorphological data for the area of Ny-Ålesund can be found in this thesis.*

## 6.3 Geotechnical and cryological conditions

**Svalbard**

- Report "Climate in Svalbard 2100 - a knowledge base for climate adaptation", Hanssen-Bauer, et al. (2019).

  *In particular, the report presents data sets for permafrost conditions, and evaluation of climate change impacts on permafrost conditions in several locations in Svalbard.*

**Longyearbyen area**

- Report "En sammenstilling av grunnundersøkelser i Longyearbyen" (*"A compilation of soil investigations in Longyearbyen"*), Pedersen and Hellum (2007).

  *Soil investigations in Longyearbyen up to the year 2007. References on reports of NGI, which contain geomorphological map and a soil profile along the Longyearelva river.*

- TSP NORWAY: Thermal State of Permafrost in Norway and Svalbard. Home page [81].

  *Thermal state of permafrost in Svalbard.*

- Article "The Role of Interannual Climate Variability in Controlling Solifluction Processes, Endalen, Svalbard", Harris, et al. (2011).

  *Soil profile and permafrost temperatures in Endalen.*

- MSc thesis "Sedimentology and geocryology of an Arctic fjord head delta (Adventdalen, Svalbard)", Gilbert (2014).

  *In particular, deep soil profile at the Old Aurora station in Adventdalen.*

- Technical Note "NGTS Permafrost 2016-1 Selection of sites", Instanes (2016).

  *Geo-cryological conditions at the NGTS permafrost sites.*

- Article "Characterization of two sites for geotechnical testing in permafrost: Longyearbyen, Svalbard", Gilbert, et al. (2019).

  *Soil profiles and ground temperatures at the Adventdalen and the UNIS East permafrost sites of the NGTS project.*

- Course report "SINTEF site - soil investigation", Kalland, et al. (2021).

  *Soil profile at UNIS Guest House.*

- PhD thesis "Holocene landscape history and ground ice distribution in Svalbard and NE-Greenland", Cable (2017).

  *Ground ice distribution in Adventdalen valley can be found in this thesis.*

- The ongoing *PermaMeteoCommunity* project at UNIS, [87].

  *This project may have new data sets on geotechnical conditions in Longyearbyen.*

## 6.4 Natural hazards

### 6.4.1 Permafrost degradation

**Svalbard**

- Article "Modeling the temperature evolution of Svalbard permafrost during the 20th and 21st century", Etzelmüller, et al. (2011).
- Report "Climate in Svalbard 2100 – a knowledge base for climate adaptation", Hanssen-Bauer, et al. (2019).

  *Climate projections and assessment of permafrost degradation presented in this report include Longyearbyen and Ny-Ålesund.*

**Longyearbyen**

- Article "Incorporating climate warming scenarios in coastal permafrost engineering design – Case studies from Svalbard and northwest Russia", Instanes [53].
- Delrapport 3: Instanes AS og Rambøll AS, Forventede klimaendringers langsiktige konsekvenser for bygging og forvaltning på Svalbard [57].

  Projections for permafrost degradation at selected locations in Longyearbyen.

- Seasonal dynamics of a permafrost landscape, Adventdalen, Svalbard, investigated by InSAR, Rouyet, et al. (2019).

**Ny-Ålesund**

- Article "A 20-year record (1998-2017) of permafrost, active layer and meteorological conditions at a high Arctic permafrost research site (Bayelva, Spitsbergen)", Boike, et al. (2018).
- Article "Surface temperatures and their influence on the permafrost thermal regime in high-Arctic rock walls on Svalbard", Schmidt, et al. (2021).
- Article "Modeling the impact of wintertime rain events on the thermal regime of permafrost", Westermann, et al. (2011).

### 6.4.2 Slope hazards

Under "slope hazards" we define mass-movement processes on slope terrain such as solifluction, landslides, mud flows, rockfalls and snow avalanches.

- PhD thesis "Snow avalanches in central Svalbard: A field study of meteorological and topographical triggering factors and geomorphological significance", Eckerstorfer (2013).
- Article "The geomorphological effect of cornice fall avalanches in the Longyeardalen valley, Svalbard", (2013) Eckerstorfer, et al. (2013).
- MSc thesis "Snow Avalanches on Svalbard: Investigating changes in depositional patterns and their palaeoclimatic significance", Berg Lofthus (2020).
- Report "Report on the 14-15 October 2016 mass movement event in the Longyearbyen area", Christiansen, et al. (2016).

  *The report describes landslide in Longyeardalen, which happened in the fall of 2016 due to a heavy rain event.*

- Report "Skredfarekartlegging i utvalgte områder på Svalbard" (*"Landslide hazard mapping in selected areas on Svalbard")*, Hannus [97].

  *Slope hazards in selected areas in and around Longyearbyen. The article presents references for earlier reports on evaluation of natural hazards in Longyearbyen.*

- Report "Skredrapport Sukkertoppen. Dimensjonerende skred fra Sukkertoppen og faresoner for Lia under Sukkertoppen" (*"Landslide report Sukkertoppen. Dimensioning landslides from Sukkertoppen and danger zones for Lia under Sukkertoppen"*), Gundersen, et al. (2018).

- Report "Impact of Climate Change on Infrastructure in Longyearbyen. Case Study of pile foundations on sloping terrains", Bekele and Sinitsyn (2020).

  *The natural hazard of solifluction and its impacts on structures in Longyearbyen.*

- Preliminary assessment of thaw slump hazard to Arctic cultural heritage in Nordenskiöld Land, Svalbard, (2021) Nicu, et al. (2021).
- The Arctic Safety Centre, UNIS [100] has several on-going activities concerning natural hazards in Longyearbyen.
- Research project "ARCT-RISK – Risk governance of climate-related systemic risk in the Arctic", [101].
- 2022' assessment of natural hazards in Longyearbyen, [102].
- Data set on landslide susceptibility in Adventdalen, Rubesdotter (Unpublished).

### 6.4.3 Coastal erosion

- PhD thesis "Erosion of Permafrost Affected Coasts: Rates, Mechanisms and Modelling", Guegan (2015).

  *Assessment of coastal erosion in Vestpynten, Longyearbyen area.*

- Coastal Erosion Affecting Cultural Heritage in Svalbard. A Case Study in Hiorthhamn (Adventfjorden)-An Abandoned Mining Settlement, Nicu, et al. (2020).

  *Assessment of coastal erosion at Hiorthhamn, references to other coastal assessments in Svalbard.*

- An open access data gateway "SVALCOAST Science Hub. Maps, data and research results related to coastal processes, sediments and landforms on Svalbard", [105].

  *The DynaCoast map-dataset of Isfjorden and some other open access data related to coastal zone research on Svalbard.*

- Large part of coasts in Svalbard are "rocky coasts", the main reference study for rocky coasts in Svalbard are [106-108].
- Article "High Arctic coasts at risk—the case study of coastal zone development and degradation associated with climate changes and multidirectional human impacts in Longyearbyen (Adventfjorden, Svalbard), (2018), Jaskólski, et al. (2018).

  *Examination of degradation of coastal zone in Longyearbyen.*

- Ongoing work of University of Oslo on coastal bluffs in Kvadehuken (Ny-Ålesund area), laser scans of coastal bluffs in Ny-Ålesund, reference persons – Sebastian Westermann, Juditha Aga.

### 6.4.4 Riverine flooding

- Report "Climate in Svalbard 2100 – a knowledge base for climate adaptation", Hanssen-Bauer, et al. (2019).

  *In particular, the report presents data sets for hydrological conditions in Svalbard.*

- Monitoring program "Hydrology, sediment transport and erosion in Longyeardalen", [110].

  *A long-term monitoring of Longyearelva (hydrology, sediment transport, erosion) and Longyeardalen (geohazards).*

- SvalDEM. A database of glacier fronts and their forefields digital elevation models in the changing Arctic, [111].

  *In particular, the project presents 3D maps of the glaciers Longyearbreen and Larsbreen, which feed Longyearelva.*

- Presentation "Oppsummering og observasjoner. Feltsesong 2020, Longyearelva", [112].

  *The presentation presents results of fieldwork on measurements of water flow, measurements of riverbank erosion and sediment transport in Longyearelva.*

- MSc thesis "The Longyearelva River-to-Ocean System. Monitoring an anthropogenic arctic fluvial system in changing climate over short and long timescales", Dalheim Ottem (2022).
- MSc thesis "Sediment source-to-sink in a warming Arctic. Thawing moraines, slope processes and river erosion in Longyeardalen, Svalbard", Pallesen (2022).

## 6.5 Climate data

### 6.5.1 Existing data set on historical records

Meteorological observations relevant for the study objects include the stations in Ny-Ålesund since 1969 (station number 99900 and 99910), Svalbard airport and Adventdalen. Observational data is available via the seKlima website ([115]) as well as the Frost API ([116]). Long-term climatological analysis can be put in context with, in particular, the long homogenized timeseries by Nordli, et al. (2014), which goes back to 1898. Re-analysis products, in particular the high-resolution (2.5 km) Copernicus Arctic Regional Reanalysis Service ([118]) is also available for the study areas.

### 6.5.2 Existing climate projections for Svalbard

The list of available future climate projections for Svalbard is quite short, and most are rather coarse in spatial resolution or have short temporal extent, both of which make it difficult to assess future climate change for individual case study objects.

Climate projections for Longyearbyen are presented in Isaksen, et al. (2017).

Dobler, et al. (2020) presented high-resolution (2.5 km) simulations using the COSMO-CLM regional climate model, downscaling from the global model MPI-ESM-LR for the RCP8.5 scenario from phase five of the Coupled Model Intercomparison Project (CMIP5). These downscaled simulations consist of two 30-year periods (1971–2000 and 2071–2100).

The Arctic Coordinated Regional Climate Downscaling Experiment (Arctic CORDEX) has a small ensemble of Pan-Arctic model simulations available downscaled from CMIP5 models. At coarser resolution: for ~50 km, there are 1, 6 and 12 simulations for the RCP2.6, RCP4.5 and RCP8.5 scenarios, respectively. For ~25 km~, there is one simulation with each of the RCP4.5 and RCP8.5 scenarios, both produced by the CCCma-CanESM2 regional model. Arctic CORDEX data is available via the Earth System Grid Federation data nodes.

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## Appendix 1 Pictures of foundations of cableway posts

Pictures below depict foundations of a cableway post, which were acquired during restoration project of cableway post Nr 7, Line 5-6 (Askeladden ID 87889-15).

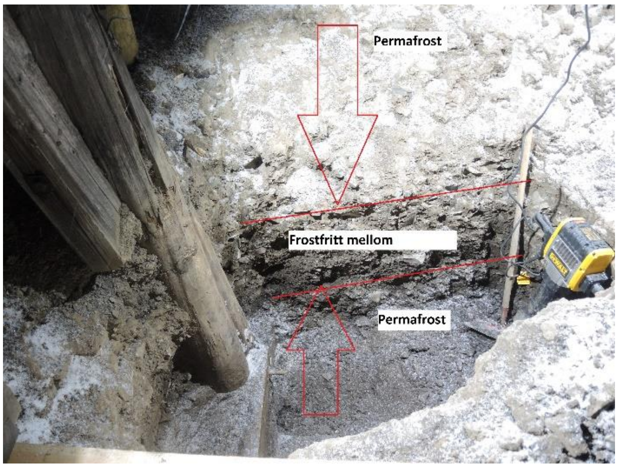


**Figure 3. Reconstruction of foundation of cableway post Nr. 7, Line 5-6. Copyright: © Store Norske Spitsbergen Kulkompani.**

**Figure 4. Reconstruction of foundation of cableway post Nr. 7, Line 5-6. Copyright: © Store Norske Spitsbergen Kulkompani.**

**Figure 5. Reconstruction of foundation of cableway post Nr. 7, Line 5-6. Copyright: © Store Norske Spitsbergen Kulkompani.**

**Figure 6. Reconstruction of foundation of cableway post Nr. 7, Line 5-6. Copyright: © Store Norske Spitsbergen Kulkompani.**