Foundation of infrastructure in Pyramiden and Longyearbyen

A comparative study of the types of foundation in the two cities, building damages, and a discussion of reasons for failures:

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1. Introduction

This report tries to give an overview about the foundations of infrastructures in two cities in Svalbard. Longyearbyen is the main Norwegian city situated in the southern part of the Isfjorden at the end of the Adventfjorden. It runs infrastructures like a normal city containing buildings for living, shopping centres, administrative buildings, airport, roads, pipelines and a lot more. The foundations of that infrastructure will be compared to that one left over in Pyramiden, which is an abandoned Russian mining city in the northern part of Isfjorden in the Billefjorden. Pyramiden was abandoned in 1998 and suffers from a continuous decay. In the last ten years no maintenance work was done until the Russian administration planned to reuse the city again recently.

We will have a look on the different types of foundations and some occurring damages also discussing reasons for failure.

2.Key Concepts

Frozen ground engineering includes construction and excavation works on permanent frozen soil, seasonal thawed soil or a combination of those two. Frozen permafrost soil at low temperature often shows greater strength than permafrost at higher temperatures. Soil with less strength is associated with poor drainage and thawing.

Many engineering tasks such as foundation take advantage of the mechanical properties of frozen soil but also suffer from the effects associated with thawing and creep. Ideal is to make installations in the permafrost body. The permafrost can be found at surface in high arctic regions or at depth under the active layer in lower arctic regions.

Since foundation is preferably situated in the permafrost, foundation design should include a strategy to preserve and facilitate permafrost. This can be done by *passive* approach or *active* approach. In the passive approach the design benefit from an existing permafrost body without any artificial energy transfer. In an active approach permafrost is introduced by artificial cooling devices. Creep occurs due to viscous properties introduced by ice in the soil. Creep can to some extent be avoided by pre-construction site investigations to exclude ice rich areas in early design and area planning.

2. Type of Buildings

A short look to both of the cities reveals great differences in the types of buildings. Generally the buildings in Pyramiden are much taller than in Longyearbyen. Housing in Pyramiden consists of several huge brick-buildings with up to four storeys, whereas most people in Longyearbyen live in smaller apartment houses or barracks with mostly only two storeys. Another big difference is the fact that almost all buildings in Longyearbyen are made out of wood instead of the brick and concrete constructions in Pyramiden. This also applies to the bigger public buildings. In both cities there are exceptions from these guidelines.

Wood might be a better construction material for permafrost regions due to its flexibility, lower thermal conductivity and smaller density, placing smaller loads on the permafrost soil compared to bricks and concrete.

Picture 1.1 Brick-buildings for housing in Pyramiden

Picture 2.2 Wooden houses in Longyearbyen

3. Type of foundations

The different infrastructures in Longyearbyen and Pyramiden are placed on specialized permafrost foundations. But like the types of buildings also the foundation construction varies a lot between both settlements.

5.1. Piled foundations

In both cities most of the buildings are placed on Piles. The main difference is, that the piles in Pyramiden are made of concrete mounted into a hole in permafrost, while most of Longyearbyen is placed on wooden piles hammered deep into the permafrost. They reach much deeper than the thickness of the active layer (down to 6-8m) and therefore are supported by enough adfreeze bonding. As well as in Pyramiden there are also in Longyearbyen some different forms of piles, e.g. steel or concrete piles.

Piled foundations keep the building away from the active layer and reduce the influence by the heat of the building. The air can circulate freely under the building to improve isolation between building and soil. Furthermore piled foundations offer good bearing capacities even in the permafrost.

Picture 5.1 Building on wooden piles in Longyearbyen

Picture 5.2 Concrete Piles used for foundations in Pyramiden

Picture 5.3 Hotel in Pyramiden on concrete piles

Picture 5.4 Construction site with wooden pile foundations in Longyearbyen

5.2. Slab foundations

Another technique is used for several public buildings (Shopping centre, town hall) in Longyearbyen and at least one building in Pyramiden (Headquarter of the mining company). These slab foundations support buildings with not more than 2 storeys. These foundations have a concrete slab on the bottom of the active layer, which is directly supported by the permafrost. These slab foundations need to be cooled because of the thermal impact of the building to the permafrost. Melting of the permafrost would lead to creep and settlement, which weakens the building or even leads to failure.

Picture 5.5 Næringsbygget in Longyearbyen

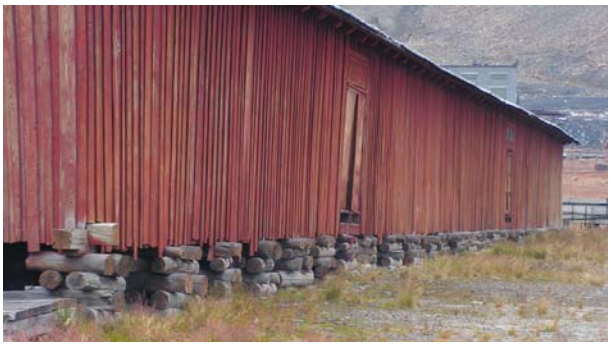
Picture 5.6 Shopping centre with slab foundation

5.3. Simple foundations

Few minor infrastructures in Longyearbyen and several wooden houses in Pyramiden are just built on top of the active layer. This technique is suitable for buildings where deformations due to settlement are not so important because of the function of the building. In Longyearbyen and Pyramiden wood is used as building material for such foundations.

On the other hand those simple foundations on the permafrost can easily be maintained and adjusted to settlements and permafrost creep. In Pyramiden these foundations can be found in a combination with piled foundations on some wooden residential buildings on the main place.

Picture 5.7 Combined Foundation of residential building



Picture 5.8 Storage building on wooden pillars (Pyramiden)

5.4. Refrigerated foundations

Large buildings introduce a lot of warmth into the ground. Thawing of permafrost can lead to big damages. Therefore the foundations of many large buildings are refrigerated. This can be solved in several ways: Active and controlled cooling of the concrete piles (old UNIS-building) or of the concrete slab; Passive systems like the headquarter building in Pyramides[5].

For active cooling of a slab foundation, the lower part of the concrete slab is refrigerated down to -10 C by cooling pipes and insulated from the upper part of the building. These systems require electricity and are therefore not common in Longyearbyen due to the small capacities of the power plant. Passive systems don't need any electricity but still at least yearly maintenance to work. Cooling liquids can pose a high environmental risk and can lead to permafrost thawing when leaking out of the system. Another possibility is cooling by air ventilation through pipes in the foundation (Waste depot in Longyearbyen).

Picture 5.9
Coal company Head-quarter Building in Pyramiden with passive re-frigeration not maintained for 10 years. The building already needed some steel support beams during its active period.

Picture 5.10 Slab foundation of the new cultural house in Longyearbyen during the construction. Cooled concrete slab below the thick insulation and building foundation.

6. Roads

Roads in Longyearbyen and Barentsburg are not constructed in a special way to withstand the permafrost forces. Proper foundation is in Longyearbyen compensated by permanent maintenance of the roads. Roads consist of a gravel filling of about 1 or 2 metres covered by asphalt (in Longyearbyen) or concrete (in Pyramiden). They are well exposed to erosion, which has led to total failure due to a lack of maintenance in some roads in Pyramiden. Fillings try to keep the ground below frozen to avoid settlements

Permafrost thaws near pipelines and along the roadsides, due to the snow insulation during winter and water intrusion leading to settlement, dipping lightposts and cracks in the road.

Picture 6.1 Street damaged by the Bertilriver in Pyramiden

Picture 6.2 Street in Longyearbyen with dipping Lightpoles

7. Pipelines

Pipelines pose a threat to frozen grounds. Heat from the pipelines thaws permafrost even through some insulation. Therefore all pipelines in Pyramiden are lifted from the ground on piles. In former times this was the same in Longyearbyen too, but many pipelines in Longyearbyen have been moved below the soil, being an obstacle for traffic and the nice appearance of the town.

In Longyearbyen the underground pipelines are buried in the active layer either directly with lot of insulation or within a bigger plastic tube allowing some ventilation for cooling. Leaking pipelines introducing steam or water into the permafrost can lead to severe thaw of permafrost.

Picture 7.1 Pipeline on concrete piles in Pyramiden

Picture 7.2 Underground pipeline next to a pipeline on wooden piles in Longyearbyen

8. Damage

In both cities we can observe several damages in the structures because of changes in the permafrost conditions or wrong foundations. In Longyearbyen there is not so much damage because of the ongoing maintenance work, which Pyramiden was lacking during the last ten years.

8.1. Permafrost creep and settlements

When a load is placed on permafrost ground, the elastic properties of ice lead to settlements. If the design of the building foundation is correct this primary creep can be compensated by the design of the foundation either by structural strength or possibilities for adjustment.

If there is more settlement than expected, the structure fails. In Pyramiden you can see several Houses with large cracks caused by differential settlements in different parts of the foundation just after the construction period.

Picture 8.1 Cracks due to primary creep in Pyramiden

Picture 8.2 Lateral creep dips the firehouse in Pyramiden

8.2. Thawing Permafrost

Another important reason for structure failure is thawing of permafrost. There can be several reasons for permafrost to thaw: Accidential insertion of water, steam or cooling agents can seriously change the permafrost conditions under a foundation. Heat impact from the builduings as well as the climate change also affects the thaw-depth and might inccrease the thickness of the active layer. This can result in a loss of bearing capacity and the stability of foundations. Shallow footings might loose their support and piled foundations loose bearing capacity due to less adfreeze bonding or might even be liftet up by frostjacking, if the piles are designed too short (6m-piles below the SAS-Hotel in Longyearbyen are lifted up).

A thicker active layer also amplifies the impact of lateral creep velocities towards the piles resulting in dipping foundations. When thawing of permafrost is recognized it is unluckily not so simple just to freeze it again, because frost heave could continue to damage the structures. Therefore one of the engineering goals is to keep the Permafrost in the state which it was in during the construction of the Building.


Picture 8.3 (left) River running into the foundation and leading to structural damage of the Madhouse in Pyramiden 2006
Picture 8.4 (right) A leaking pipeline thaws permafrost and leads to massive settlement next to Næringsbygget in Longyearbyen (Picture A. Instanes)

8.3. Lack of maintainence, exceeded lifetime or design errors

Some damages can be coupled to site specific condition and to liberate design as the SAS hotel in Longyearbyen. The hotel rest upon a standard foundation of piles 6-8 m deep, however the site is under the influence of historical and or present sea level. Salt in the pore water decrease freezing point hence reduces the ad freeze bounds. More extensive site investigation and more conservative design may have rendered a solid durable foundation.

Buildings are expected to experience settlements and damages after construction. In the design the magnitude of these changes within a certain time (the building life time) are estimated and somewhat compensated for or within the flexibility of the selected construction material. However the settlement continues if buildings are kept after the calculated lifetime. In such cases the construction facing settlements that most likely will exceed the settlements estimated for the design life and consequently failures and rapture of construction is frequent. This is the case for many of the buildings in Pyramiden but also in Longyearbyen where old buildings often are protected as cultural heritage.

8.4. Example: Kindergarden inPyramiden

The building of the kindergarden in Pyramiden shows strong damage. It seems to be based on shallow footings which experienced differential settlements between several pillars. The greatest damage can be found at the southeast corner of the building, where the pillars settled far more than the rest of the building.

Picture 8.5 Kindergarden in Pyramiden with differential settlements

The green grass on the eastern side of the building indicates a very wet area of Permafrost with less bearing capacity and even probably more insulating snow deposit thawing permafrost. Some pipelines leaving the building at that corner might also be a reason for permafrost thawing, reduced bearing capacity and differential settlements causing damage to the building. This damage is related to a lack of maintenance work in the last ten years.

Cracks occur at the weak points of the structure, for example in window corners.

9. Summary

The buildings Longyearbyen and Pyramiden show different strategies and different traditions to accomplish stable foundations. Foundations in Longyearbyen is traditionally made of wooden piles approx 6-8 meter deep and at some sites active cooling is used to preserve permafrost at sufficient depth during thawing season.

In Pyramiden several different foundations types were found: Surface piles, concrete piles, shallow foundations and wooden piles. Settlements and differential settlements were frequent. Cracks in buildings were observed at windows and doors as these often are weak points introduced in the building wall.

In Longyearbyen cables and pipelines have been put in underground trenches while elevated utility channels have been used in Pyramiden. Generally infrastructure in Longyearbyen is in a better shape than in Pyramiden because of ongoing maintenance works.

Picture 9.1 New building site with wooden piles already in the ground in Longyearbyen

10. References

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[4] Jan Otto Larsen, lectures during AT-301 at UNIS, Svalbard, 2009

[5] Andreas Umbreit, specialist on Pyramiden and Svalbard, 2009

Pictures:

5.9 Jan Otto Larsen; **8.4** Arne Instanes

All other pictures from Kristoffer Hallberg (2009) and Christian Katlein (2006, 2009)