THE CHALLENGES OF MITIGATION MEASURES IN LONGYEARBYEN SVALBARD

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ABSTRACT: The Arctic regions are facing changes in climate; warmer weather and more intense precipitations are thought to be the consequences. Longyearbyen in Svalbard is one of those places where warmer weather has been influencing the daily life of inhabitants. Changes in permafrost affects many building structures as the active layer and the temperature in the permafrost increases, so that the foundations lose their bearing capacity. It is unclear if climate change was the primary contributor to the dry snow avalanche in December 2015 which caused two fatalities, and in February 2017 with no fatalities in Longyearbyen. Structural damages were significant. The avalanche in 2015 was released from a small mountain side with about 80 m vertical drop, and damaged or destroyed 11 buildings. The avalanche in February 2017 came from Sukkertoppen mountain and hit and destroyed two buildings. After the two incidents with 14 months between them, the local and national authorities in Norway introduced a plan for mitigating measures during the spring of 2017, and shortly after a tender for the design of measures. The initial plan for mitigation measures was protection of the remaining buildings below Lia, as well as for the reclaim of the "lost" area. A snow drift fence was planned above the Lia and supporting structures in the starting zone. Permafrost and active layer have been a challenge for the design and construction of the mitigation measures. Frost heave, creeping of the active layer and bad rock quality has resulted in quite robust subsurface structures.

KEYWORDS: Svalbard, Longyearbyen, Sukkertoppen, Mitigation measures.

1. INTRODUCTION

The avalanche danger in Longyearbyen (Figure 1) has been known for a long time and has been described by Erik Hestnes and others in several NGI reports such as (Norges Geotekniske institutt NGI, 2001). There are several reasons why mitigating measures have not been carried out previously, but it will not be detailed here.

Two snow avalanches in Longyearbyen, one in December 2015, which caused two fatalities at the landmark "Spisshus" (pointed-gable houses) area, and one in February 2017 with no fatalities, hit the residence area located just above the center of town. Structural damages were significant, eleven buildings were damaged or destroyed in 2015 avalanche and two buildings in the 2017 avalanche.

The incidence in 2015 was a wake-up call for the local and national authorities to plan for increased safety for the inhabitants living in the run-out zone for snow avalanches, and slush- and debris flows.

In early 2016 the national authorities (Norwegian Water Resources and Energy Directorate, NVE) and local authorities (Longyearbyen lokalstyre, LL) called for tender for hazard mapping of the Longyearbyen area and the vicinity. Final document with a hazard map was released late in 2016 (Multiconsult AS, 2016). After the February 2017 incident a question was raised if the hazard zoning was reliable as the avalanche passed 1/1000 zone easily. At the same time in fall 2016 a case study on arctic design in Longyearbyen was released (Larsen, 2016). The case study proposed supporting structures in the starting zone in Lia and a snow drift fence above the supporting structures, similar mitigation solutions as NGI had proposed several times earlier.

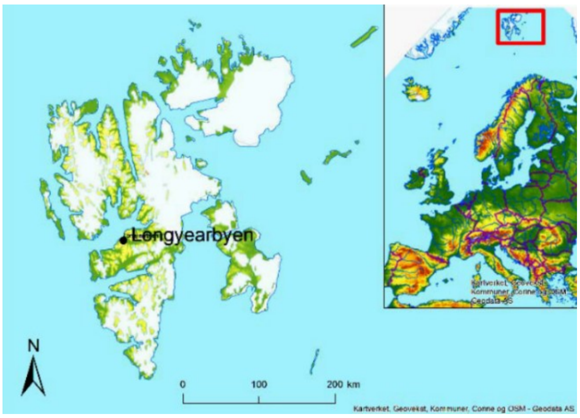

Figure 1. Red rectangle shows the location of Svalbard

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In early 2017 NVE called for tender for mitigation measures in Lia and referred to the case study as preliminary design of measures. NGI was awarded the contract and this paper summarizes the work which is described further in the project reports (Norges Geotekniske Institutt NGI, 2018a, 2018b).

2. THE CLIMATE

Longyearbyen is in one of the driest areas in Svalbard. The observed annual precipitation in the period from 1961-1990 was just about 300 mm, but in recent years the temperature has been increasing and less sea ice is observed which is thought to increase the moisture and precipitation. The monthly mean temperature on Svalbard has been over the normal from November 2010 to present (summer 2018). Figure 2 shows the annual mean temperature at Svalbard airport for the last hundred years and Figure 3 shows the Arctic anomaly compared to global anomaly.

It is becoming more common to see the average day temperature to rise over 0° C midwinter with periods of rain instead of snow. Such warm

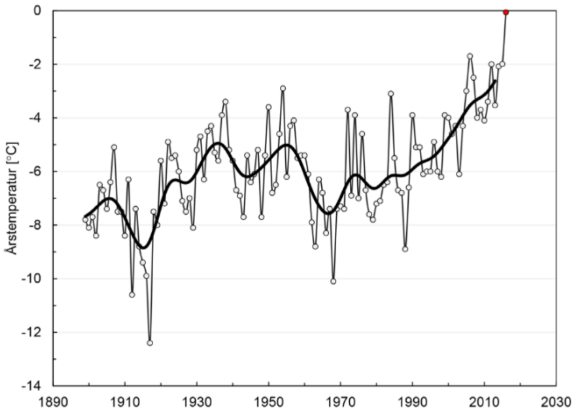

Figure 2. Annual mean temperature at Svalbard airport. The year 2016 is marked with red dot. Source: (Isaksen et al., 2017).

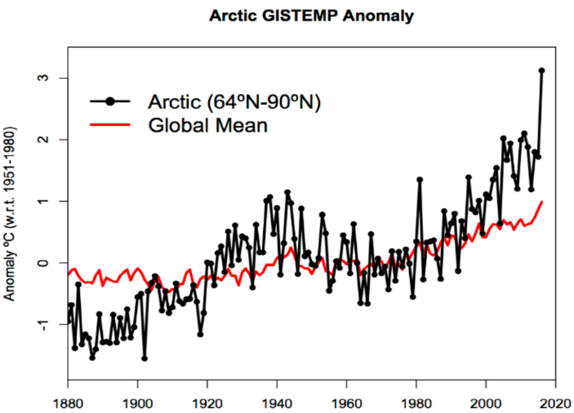

Figure 3. Arctic Anomaly. 2016 is the warmest on record in the Arctic. Source: K. Isaksen.

weather spells have caused slush flows down Vannledningsdalen, the last one in 2012. Wind observations indicate slight decrease in the frequency of strong winds over the last 40 years at Svalbard airport. There are large variations in wind between years. Model simulations indicate increased temperature on Svalbard next decades (Isaksen et al., 2017).

3. AVALANCHE PROBLEMS

Sukkertoppen mountain is a known avalanche site in Longyearbyen but in recent years avalanches have not, except for 2015 and 2017, hit the buildings located at the foot of the mountain. Accumulation of snow into release areas is primarily from South-East-winds out Adventdalen (walley), as shown in Figure 4.

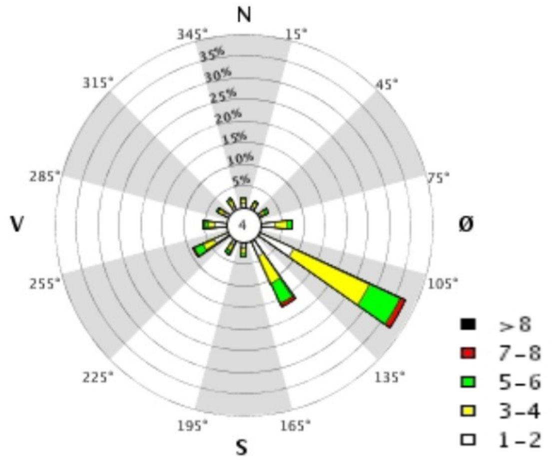

Figure 4. Wind frequency distribution at Svalbard airport during Nov.-April in the period 1975-2016. Wind force is shown on Beaufort scale. Source: (Isaksen et.al., 2017).

4. GROUND CONDITIONS

Svalbard is in the permafrost belt north of 64° N. During summertime the depth of the active layer is between 1 and 2 m in most places in Longyearbyen, and it is expected to increase in the order of tens of centimeters in the next decades due to warmer climate (Instanes AS, 2017).

In 1981 three “inclination” channels were installed close to Hilmar Rekstensvei (road) to monitor the creep of the active layer (the solifluction) in sloping terrain between 13° and 25°. The depth was 10 m. In 1995, after fourteen years, measurements showed a creep of 8 to 50 cm of the surface layer and diminishing creep to 3 m depth, where no creep was registered (Norges Geotekniske Institutt NGI, 1983).

Detailed and spatially distributed information on ground properties are essential for construction planning and design. The thickness of the active layer, depth to rock surface, ice content and material quality, are amongst the properties needed for the design of mitigation measures in Longyearbyen.

The area at the drainage canal and snow fence was accessible for a drilling rig but at the supporting structures the terrain was too steep for a drilling rig, and it was considered to be too expensive to use other drilling gear. Eighteen holes were drilled into ground to find the depth of the active layer and depth to rock (Sintef, 2017).

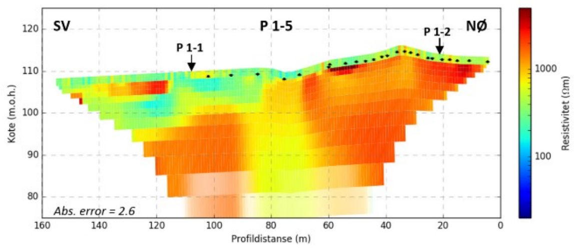

Figure 5. Resistivity values from the ERT-profile P1-5. Black dots are boundary layer from GPR interpreted as the permafrost table. Source: NGI, 2017.

Geophysical investigations comprising of Electrical Resistivity Tomography (ERT) and ground penetrating radar (GPR) were chosen for the supporting structure area (Norges Geotekniske Institutt NGI, 2017) but also for the other areas in order to compare and calibrate the geophysical results. Figure 5 shows resistivity values from the ERT-profile P1-5, which is the middle row of supporting structures.

The site investigation was carried out in middle to late September 2017 to ensure maximum thickness of the active layer.

5. MITIGATION MEASURES

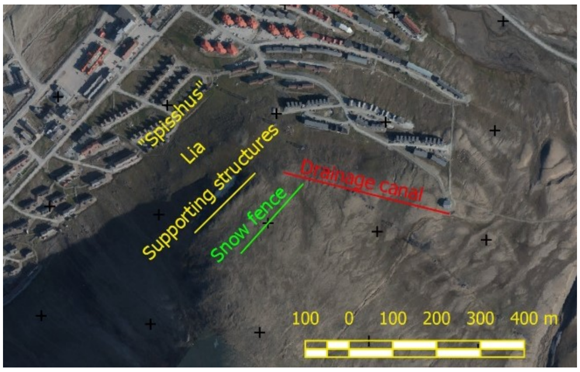

Figure 6. Schematic figure of location of mitigation measures. Aerial photo: Norwegian Polar Institute

The plan for mitigation measures was outlined in compendium prepared by Jan Otto Larsen (Larsen, 2016). The plan is more or less coherent with earlier proposals from NGI for the same area i.e. snow fences above the starting zone and supporting structures in the starting zone, Figure 6.

One of the design criteria from NVE was a S2 class i.e. frequency of incident should be less than 1/1000 a year after building of mitigation measures.

During the design phase NVE proposed a drainage canal below Sukkertoppen to collect ground- and surface water and divert it to east past the residential site.

5.1 Snow fences

Drifting snow is one of the main and increasing problems in Longyearbyen in wintertime and expected increase in precipitation due to climate change is considered to further increase the drifting snow problems as well as the frequency of other weather-related processes. The avalanche in December 2015 showed that it was time to consider mitigation to stop the drift into avalanche starting zones above the residential areas in Longyearbyen. The snow accumulation area above Lia is over 1000 m long, open and suitable for snow transport.

Figure 7. Snow fence under construction spring 2018. Photo: Eli Margrethe Solberg.

A plan for snow fences has been drafted before “somewhere” above the “Spisshus” starting zone. During the NGI work we found out that it was not possible to place the snow fence in “safe” area. Drafted plans for snow fence did either place the fence in snow avalanche prone area or the snow fence could increase the amount of snow in the release area for snow avalanches. In 2016 Multiconsult (Multiconsult AS, 2016) placed most of the snow drifting area in hazard zones 1/100 and 1/1000 due to risk for debris flows. It was possible to move the snow fence from the release area of snow avalanches, but it was not possible to move it out of possible debris flow area.

The terrain inclination at the snow fence varies from approx. 15° to approx. 25° and it has relatively even surface. During design the client asked for ski lift in the area which resulted in splitting the snow fence into two fences with approx. 20 m wide opening for the lift, Figure 7.

Concerns were raised about the snow fence material and expected lifetime. There was uncertainties related to the ground conditions, i.e. solifluction, depth of active layer, and thickness and properties of soil material above bedrock, plus climate, i.e. weathering and corrosion. The aim was to minimize the maintenance cost, so zinc coated steel material was chosen for the snow fence. The structure was founded on steel tube piles (Ø140x8mm) which are drilled into competent rock, acting as a cantilever beam to resist load from soil creep in the active soil layer.

To determine the embedded pile length for the snow fences and supporting structures, it was necessary to account for the upward loads (tension forces) from wind and snow acting on the snow fences, and uplift forces from frost heaving acting in the active layer. The thickness of the active layer was increased from 1-2 m (measured today) to 3 m to account for predicted climate change during the service lifetime of the structure. Based on this the design uplift force on a 140 mm pile was calculated to be 330 kN, approx. 10 times the upward loads from wind and snow. Steel rod anchors were drilled and grouted into competent rock, with a minimum depth 2.6 m below the pile tip, to account for the uplift forces. One of the main challenges for the contractor during installation was to determine the transition between frozen soil, low quality bedrock and competent bedrock. Due to the uncertainty associated with this, the pile was embedded minimum 4.5 m into the ground, to ensure a robust design.

The height of the snow fence is approx. 4 m and total length 217 m. Due to environmental issues the construction work had to be done while ground was frozen.

The contractor proposed 5 m wide elements without connecting elements. To compensate for variations in terrain inclination between elements and possible creep and damages it was decided to make opening of approx. 25 cm between elements.

5.2 Drainage canal

The purpose of the drainage canal (Figure 8) is to collect and divert ground- and surface water from Sukkertoppen past the habitation area along road 232 in Gruvedalen. It also helps to reduce the solifluction and risk for debris flow released below the drainage canal.

Several criteria that had to be considered while designing the drainage canal on this approx. 400 m long stretch. Limited options are to divert the water through the habitation and therefore it was essential to be able to divert the water from planned supporting structures above Lia to east past the cold-water tank and to existing small stream. A cultural heritage, an old coal cable way, is at the mountainside were the canal was planned and strict rules apply when working near it. The third criteria were aesthetic i.e. how visible the canal and small berm/access road would be from center of town. The fourth was to ensure "tight" canal i.e. how to prevent ground water in the active layer to seep through and how to consider warmer climate and increasing thickness of the active layer in the future.

To tighten the drainage canal, it was decided to excavate minimum two meters below planned canal bottom and minimum one meter into "future" permafrost layer to place a tight 1.5 mm thick polypropylen FPP membrane covered with fabrics on both sides for protection. The membrane trench will be backfilled with existing material.

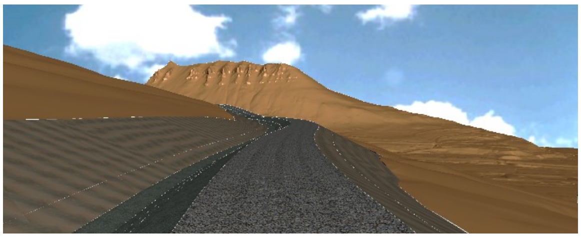

Figure 8. Simplified computer model of the canal (to the left) and berm (in the middle).

The depth of the canal is approx. 1 m from the berm/access road and bottom width is 1 m. The width of the berm is 3 m. All excavated organic material will be reused on berm- and canal side slopes for revegetation.

5.3 Supporting structures

Prior to the work on supporting structure there were limited information available on snow height in the starting zone. One measurement with unknown position had been done in Lia decades ago and it indicated snow height of approx. 5 m.

Few minutes before the release of the avalanche in the morning of December 22nd, 2015 photographer Tommy Dahl Markussen was taking pictures of the new snow that poured down during that night. His valuable photos have helped assessing the snow height in the northwestern part of the release zone. The observed snow height indicates some 5-6 m snow at northwest but snow height for the south east part is more uncertain, here it is estimated to be 1-2 m. It was estimated that the form of the slope hardly could accumulate more snow than approx. 6 m at the northwest part of the Lia. The estimation of max snow height for the southeast part is uncertain due to little available information, there it is estimated to be approx. 4 m.

The initial plan for supporting structures was three lines of Dk 5 m (perpendicular to surface) but after reevaluation the first row (the lowest one) was removed and instead decided to build a small catching dam in the run-out zone. During field trip to the site, a 56 m long line was added above previous topline at the southeast. Total length of supporting structures was 468 m.

It is not yet known how much effect the snow fences will have on the snow accumulation in the starting zone above the "Spisshus" but Dk 5 m for the supporting structures is considered to be on the safe side.

There is no experience with supporting structures in permafrost in Norway and therefore Stefan Margreth at the Institute for Snow and Avalanche Research SLF was contacted and asked for advice and pros and cons of different types used in the Alps.

One of the concerns in Longyearbyen was the visual effect of the structures so close to the center of town and how aging would visually affect the structures for instance if the solifluction would cause damages to parts of the structures. Another visual concern was the corrosion coating.

It was opened for two alternatives in the tender documents, rigid steel bridges and net constructions and both types were to be zinc coated. After

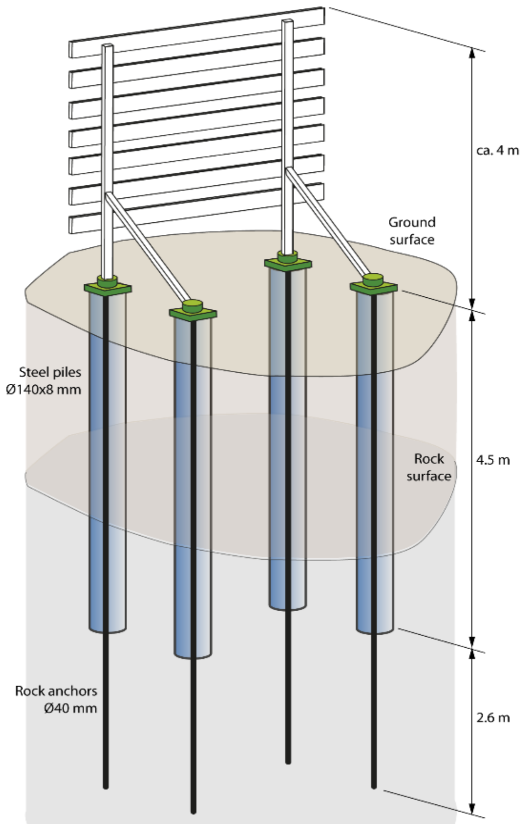

Figure 9. Snow fence and foundation support system with micropiles and anchors which are drilled and grouted in bedrock.

evaluation of the tenderer documents the conclusion was to build rigid steel bridges founded on micro-piles at upper and lower foundation, like the solution used for the snow fence. Total length of the steel tube piles (Ø90x8 mm) was 3 m, presuming at least 0.5 m depth in competent rock (Figure 9). Additional rock anchors (Ø32-Ø35 mm) was drilled and grouted into rock with a depth 4.0 m below the pile tip, to account for the tension forces. The foundation work was completed in mid-August 2018 and the superstructure will be completed by mid-October 2018.

6. NEXT STEPS

The work outlined here is only the first step of mitigation work in Longyearbyen. Next step is to protect the residential area under Sukkertoppen and alongside Vannledningsdalen. The planning and design work started late summer 2018 and will continue till late winter 2018/2019.

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