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Erosion protection of a coastal cultural heritage in Svalbard; "Fredheim"

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ABSTRACT
This paper aims at identifying erosion hazards and possible measures to mitigate these hazards for one of the most known cultural heritage sites in Svalbard, "Fredheim". Three different studies, performed between 1987-2012, show that among other hazards, coastal erosion threatens Fredheim, a group of vulnerable houses situated on the boundary between Sassenfjord and Tempelfjord on the island Spitsbergen.

A study of the erosion at the site based on field work performed in 2010-2012 is presented in Tangen and Justad (2012). The erosion rates presented in the report are both yearly rates and calculated average rates based on manual and DGPS measurements. These measurements are used to calculate minimum and maximum possible lifetime for the group of houses at Fredheim.

Several hydrological and geological processes are present in the Fredheim area close to the river delta of Sassen River. Nivation melt water is transported in channels as groundwater creating subsurface transport of finer sediments thereby affecting the stability of the scarp. These processes are studied in order to understand the coastal erosion processes in permafrost soil at the site.

Results from the field work and analyses of collected data, lead to a proposal for protective strategies to reduce the risk of damage by erosion to the heritage site. These measures are designed to fit into the landscape as well as possible, and with the use of environmentally friendly construction materials such as timber, rock and local soils.

INTRODUCTION
Fredheim, see Figure 1, a cultural heritage site existing of four different cabins used by trappers in the early 19th century, is located in the inner part of Isfjorden, Svalbard, see Figure 2. The site undergoes active erosion and is interesting for research on coastal erosion rates and mechanisms of permafrost soils. A description of the geology of this area can be found in Sessford (2013).

Figure 1. Fredheim as seen from the west (Photo: SINTEF).

The Governor of Svalbard (Sysselmannen) is concerned about Fredheim and its retreating coastline, coming closer to the buildings each year. Based on this concern, SINTEF, along with UNIS, have worked to present environment friendly solutions by combining old and modern knowledge and techniques on coastal erosion processes and erosion protection. Fredheim can be protected from erosion hazards without having to physically move the buildings. Results from the above mentioned work and two previous projects (Johannessen, 1997, and Flyen, 2009) form the main basis of this paper.

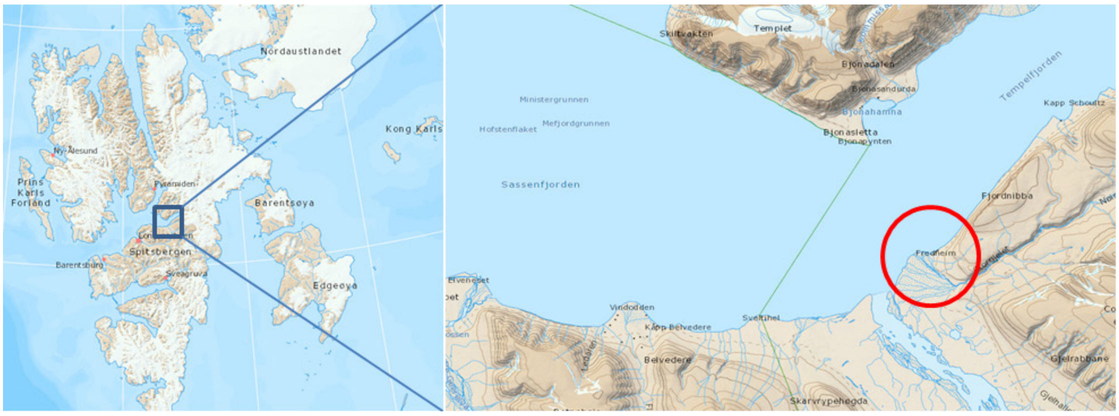

Figure 2. Map over Svalbard and Fredheim, where the investigated site are marked with red.

Figure 3. Nøis River delta in 1990. Brown line represents northern part of delta and escarpment edge in 2009. (Image adapted from Norsk Polarinstitutt image S90 2207).

The houses at Fredheim are located on the northern side of the Sassen valley, and in front of the Nøis River delta (Figure 3) which is continuously changing form and size. These deltaic changes will affect the coastal erosion situation at the site considering the role of sea waves as a part of the erosion process.

FIELD INVESTIGATIONS

Different methods have been applied for the field investigations at Fredheim, and the collected data used to forecast the possibility of future scenarios connected to erosion hazard for the buildings and to present different solutions for erosion protection. Ideally e.g. thermistor-strings for measurement of permafrost temperature and thermal regime should have been installed to give a better understanding of processes. For an area this close to a cultural heritage there is a strict regime on use of any machinery and equipment which can make any changes to the site. These restrictions prevented installation of thermistor-strings at the site.

To identify suitable local geological construction materials, some tests and analyses were carried out on the local soil deposits, both at the coastal bluff and for the sea-bed soils. Bag samples were taken by hand on shore and by grab sampler at the sea-bed. Samples were analysed in the laboratory to determine grain size distribution curves.

To monitor the coastal erosion rate for the site, DGPS, manual measurements and study of former reports (Johannessen, 1997, and Flyen, 2009) were carried out. Differential GPS was used to measure yearly erosion between the cabins and the bluff (Figure 4). An overview of performed investigations at Fredheim is presented in Table 1.

Table 1. Overview of performed investigations.

Purpose of investigation	**Approach**
Erosion rates	Geodetic measurements of coastline (Differential GPS: DGPS)
	Distance measurements between the coastline and houses (manual)
	Levelling
Evaluation local materials for erosion protection purposes	Rock Quality (Q-system as described by Barton and Choubey, 1977)
	Visual description of outcropped bedrock
	Grain size distribution from shallow samples on land and seabed sediments (sieving and hydrometer analyses)
Evaluating erosion rates and geohazard risk	Assessment of possible "geo-hazards" (landslides and erosion)
	Meteorological data

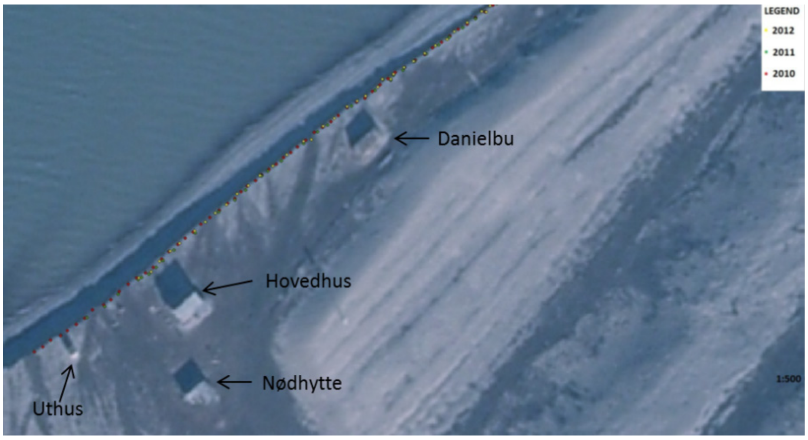

Figure 4. Presentation of DGPS measurements, 2010, 2011 and 2012
(Tangen and Justad, 2011, 2012).

FINDINGS

Coastal erosion mechanisms and erosion rates

The coastal retreat at the site has been monitored (not continuously) since 1986 (Bjerck, 1999), and the retreat rate has varied from year to year, see Table 2.

Erosion rates are calculated based on the manual measurements from three different studies (Johannessen 1997, Flyen 2009 and Tangen and Justad, 2011, 2012), and expected lifetime for the houses threatened by erosion hazard was estimated based on the calculated erosion rates on the coastal line.

Table 2. Results from measurements performed at Fredheim in the period 1987 to 2012. Measurements in meters are mainly performed with measuring tape between the north eastern corner of the individual buildings and erosion edge.

Year period	1987 Manual	1990 Manual	1993 Manual	1996 Manual	1998 Manual	2010 DGPS	2011 Manual	2012 Manual
Source	Bjerck 1999	Bjerck 1999	Bjerck 1999	Bjerck 1999	Bjerck 1999	Tangen, Justad 2012	Tangen, Justad 2012	Tangen, Justad 2012
Uthus	5.61	4.64	3.5	2.55	2.28	0.95[2)]	3.62	3.56
Nødhytte	No data	No data	No data	No data	No data	No data	27.63	27.26
Hoved-hus	17.7	16.64	15.88	No data	15.38	9.24	8.46	8.74[3)]
Danielbu	6.46	5.83	4.9	4.55	4.63[1)]	8.10[2)]	7.47	7.32

[1)] Error in manual measurements Danielbu in 1998.
[2)] Movement of the Uthus and Danielbu in this period.
[3)] Error in manual measurements Hovedhus in 2012.

Table 3. Estimated numbers of years before the buildings will be gone due to coastal erosion, dependent on constant erosion rates the following years.

Buildings	Johannessen 1997	Flyen 2009	SINTEF/UNIS (2010-2012)
Uthus	14 yrs	6 yrs	20 yrs
Nødhytte	109 yrs	48 yrs	156 yrs
Hovedhus	35 yrs	15 yrs	50 yrs
Danielbu	29 yrs	13 yrs	42 yrs

The tables above (Table 2 and Table 3) show that there are variations in erosion rates between the erosion edge and the individual houses. This can largely address the erosion mechanisms of Fredheim. It has previously been believed that the erosion was strongly linked to wave erosion, but the findings presented in this paper indicate that this might not be the case. Waves are a contributing factor, essentially as a carrier of already eroded soils. The main erosion process is melting and sliding of permafrost soil where nivation channels are probably the major contributor for this site (Figure 5). In these channels, fine grains are washed out and the bluff/coast line becomes more unstable in this area. This process makes the area between channels also become more unstable due to reduced lateral support.

Figure 5. Zone with water channels and leached soil.

The erosion rates vary significantly from year to year and from period to period. This can be seen in relation to air temperature, precipitation and the length of the ice-free season which change from year to year. Regarding annual variations, erosion rates have only been measured from one year to the next during 2010-2011 and 2011-2012. For these measurements there is a change in the erosion rate when the rate of the last period, measured in 2012, is only 1/7th of the rate measured in 2011. These changes in erosion rates are interesting in relation to the average summer temperature of Svalbard. In summer of 2012 the air temperature was relatively lower than average summer temperature in 2011 (Figure 6). Observations related to the presence of fjord ice between summer 2011 and summer 2012 show extreme long periods of ice-free sea, thereby leading to increased erosion activity at Fredheim (Figure 7, Figure 8 and Figure 9).

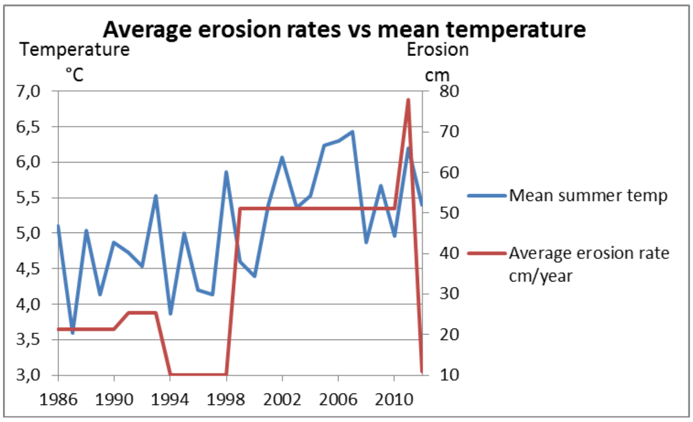

Figure 6. Erosion vs. mean air temperature. Temperature data from Svalbard airport (source: Norwegian Metrological Institute, 2012).

Another important factor for further study is the presence and effects of land ice, i.e. the part of the sea ice that is frozen in the coastal zone. Mechanisms around this, especially related to the dynamics associated with tides, can affect the erosion rate; in the same way that snow in the coastal zone will affect the temperature regime in the coastal permafrost, and thus affect erosion rates. All these factors are interesting and similar measurements and observations will be included in the 2013 field survey. Ice Map observations related to the ice in The Sassen Fjord and The Tempel Fjord are presented in Figure 7 and Figure 8.

Figure 7. Sea Ice Map 1st of February and 1st of March 2011
(source: Norwegian Metrological institute).

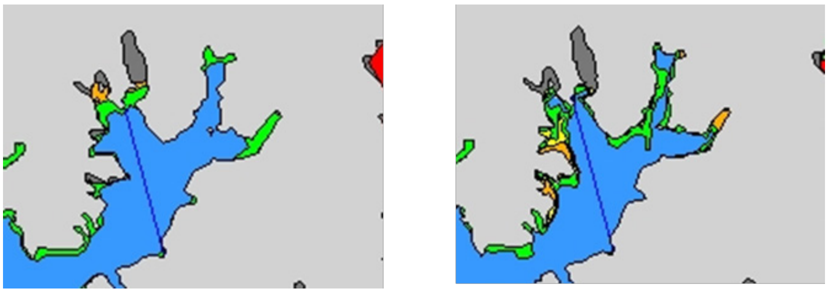

Figure 8. Sea Ice map 1st of February and 1st of March 2012.
(source: Norwegian Metrological institute).

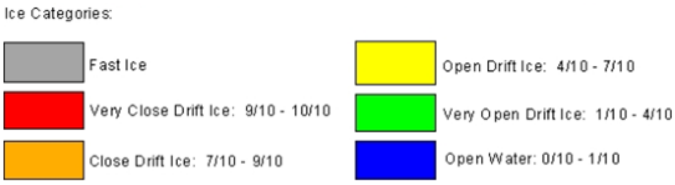

Figure 9 Explanation of the sea ice maps.
(source: Norwegian Metrological institute).

Soil parameters and rock quality

For recommendations of erosion protection methods and design, a number of different analyses were carried out in 2012 (Finseth et.al 2012). Grain size distribution was found for the soils (Table 4), while bedrock quality was tested and analysed by use of the Q-system (Table 5). Soil samples were taken both from the seabed and the bluff.

Table 4. Description of soil samples.

Sample	Number of samples	Description
Shallow water samples	5	Dominated by sand/silt
Samples 30cm from top of bluff	5	Gravel with some sand
Samples 100cm above the waterline in bluff	5	Gravel with ca 30% sand opening

Table 5.Q-value for Fredheim rocks.

	RQD	Jn	Jr	Ja	Jw	SRF	Q
OutcropTypical Range	40	1	0.5	2	0.33	5	0.165
Outcrop Most Frequent	30	4	1	4	0.33	5	0.231

Figure 10. Bedrock sample area.

POSSIBLE SOLUTION FOR EROSION PROTECTION

Timber has been favoured as the main construction material used in arctic coastal structures from an early stage. Findings in the project "Construction in the coastal zone at Svalbard – What do the quays of the past tell us of the constructions of the future" (Finseth and Lothe, 2011, in Norwegian) show that older erosion protections of woodwork are proven to have strong abilities to resist forces from sea and ice in the fjords of Svalbard, as observed in Pyramiden and Barentsburg. A timber structure alone, as a wall against the sea with active soil pressure may be exposed to large static and dynamic forces. In order to reduce the stress behind the wall due to the virgin and backfilled soil, it is proposed to combine wood with geosynthetics. The function of the geotextile is to deal with the active earth pressure reducing the moment on woodwork structure. . Geosynthetics are produced in numerous varieties and materials, specially designed to reinforce and absorb forces in the soil, or act as a separation layer to hold the soil in place where the water can flow freely through the sand and gravel. Figure 11 and Figure 12 is schematic diagrams of a possible design, also showing how the moment in the woodwork structure will be reduced by use of geosynthetics. The dimensions of the single elements in the wall are depending on design of the structure and are not dealt with in this paper. The active earth pressure was determined by hand calculation based on earth pressure theory, assuming worse case scenario where permafrost virgin soils are in unfrozen state. The earth pressure is analysed for a roughness ratio r=0.5 between the soil and wooden structure. A friction $\tan\varphi=0.7$ and a material coefficient $\gamma_M=1.4$ is assumed in the analyses.

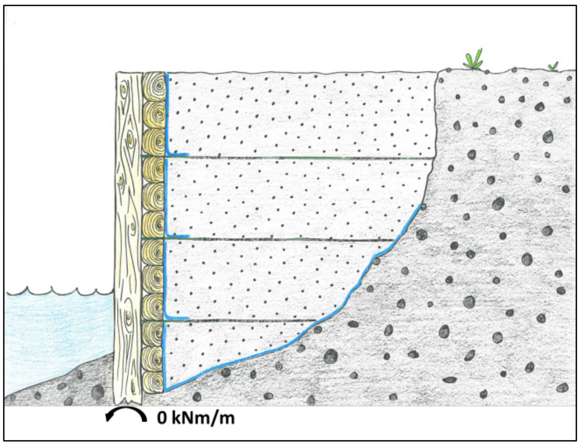

Figure 11. Cross section of a proposed method with wooden front, backfill of local soil in combination with horizontal layers of geosynthetics to reduce moment on the piles.

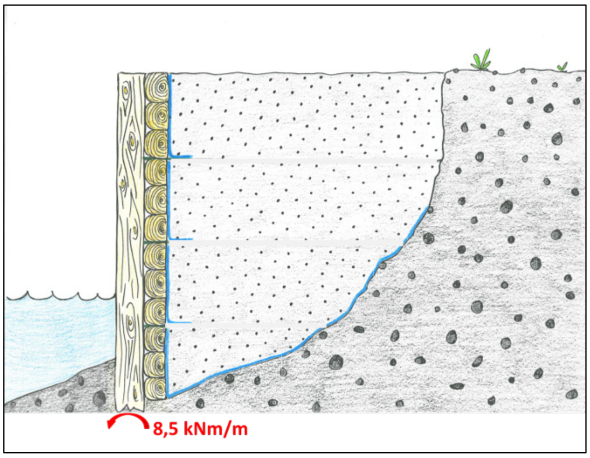

Figure 12. Cross section of a proposed method with wooden front without geosynthetic reinforcement.

A possible solution as described above would probably function well against the main mechanisms for erosion in Fredheim. On the other hand such a structure could create other challenges where the waves may become a more dominant cause for failure (Figure 12), as described by Dean and Dalrymple (2004). Possible sub erosion of the erosion protection could be a result, unless scouring of soil in front of the wall as illustrated in Figure 12 are taken into account for design.

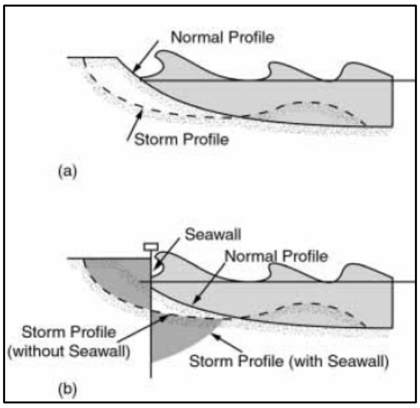

Figure 13. Normal profile and storm profile, with and without a protective seawall (Dean and Dalrymple, 2004).

Bedrock from the Fredheim area is not suitable for construction purposes, such as erosion protection measures. Results from soil analyses show that there is a possibility to construct a functional erosion protection measure for Fredheim site. The proposed method for erosion protection uses local soils which require a certain composition where permeability properties are an important factor. Samples taken from the sea bed indicate that these soils probably have a too low permeability for being used in the erosion protection structure. These soils are dominated by sand and silt which could possibly lead to building up of pore pressure behind the structure during melting period due to the permeability characteristics of the soil, thereby increasing the risk for instability of the structure.

Figure 14. Two different proposed designs for wooden erosion protection.

CONCLUSION

The studies performed at Fredheim since 1986 show a need for actions regarding protecting the cultural heritage from coastal erosion, although it is hard to estimate the life time. Erosion rates vary from year to year and most known driving agents are temperature and precipitation. Erosion mechanisms are connected to water flow in sub soil channels, creating unstable areas, and small ravines in the bluff along the coastline. These small ravines create a more unstable situation for the soil on the side, with reduced lateral support of the soil. Sampling, measurements and analyses show the potential of building an erosion protection where a combination of new and old technology can be used in order to create a structure that will both aesthetical fit in, and become a well-functioning measure. The study also shows the necessity of combining different disciplines in order to understand all on-going processes and challenges comprised by this project.

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