

SBF 2011 A003 - Unrestricted

# Report

## **SIP - Rehabilitation of Infrastructure in Arctic Areas**

**New challenges for methods, tools and materials**

**Author**

Kristina Heilemann



Picture: Torgeir Jensen, 2009

# Report

## SIP - Rehabilitation of Infrastructure in Arctic Areas

New challenges for methods, tools and materials

**KEYWORDS:**

Keywords

**VERSION**

1

**DATE**

2010-11-09

**AUTHOR(S)**

Kristina Heilemann

**OPPDRAKSGIVER(E)**

NFR - The Research Council of Norway

**OPPDRAKSGIVERS REF.**

Jørn Lindstad

**PROJECT NO:**

3C0277

**NUMBER OF PAGES/APPENDICES:**

21

**ABSTRACT**

### Rehabilitation of Infrastructure in Arctic Areas - summary

It is likely that climate change is going to have significant impacts on existing Arctic infrastructure and on the development in the region. The consequences of increasing temperatures, thawing of permafrost, and melting of the sea ice cause damages on infrastructure and buildings. Regional and national economic growth depends on the stability and maintenance of transportation routes and industrial development.

The present report describes the challenges for the design, maintenance and rehabilitation of Arctic infrastructure. Some examples of new innovative building material and methods are given.

**PROJECT MANAGER**

Bjørn Ove Lerfeld

SIGN

**CHECKED BY**

Leif Sigurd Hafskjold

SIGN

**APPROVED BY (name, position)**

Arnstein Watn

SIGN

**REPORTNO.**

SBF 2011 A003

**ISBN****CLASSIFICATION**

Unrestricted

**CLASSIFICATION THIS PAGE**

Unrestricted

# Document history

---

VERSION	DATE	VERSION DESCRIPTION
1	2011-01-24	Final version

# Table of contents

<b>INTRODUCTION</b> .....	<b>5</b>
<b>1 The Arctic Climate Change</b> .....	<b>6</b>
<b>2 Permafrost</b> .....	<b>6</b>
<b>3 Infrastructure</b> .....	<b>7</b>
3.1 Buildings.....	8
3.2 Foundations and Embankments.....	9
3.3 Winter Roads.....	10
3.4 The Arctic Coastline.....	10
3.5 Natural Resources.....	11
<b>4 Innovative Methods and Materials</b> .....	<b>12</b>
4.1 Pipeline Coating Protection.....	12
4.2 Insulated Pipes and Pipe Fittings.....	13
4.3 Norfino Sealing System.....	13
4.4 Metallon Sandwich Panels.....	14
4.5 Polyguard - ReactiveGel™.....	15
4.6 Two-phase Thermosyphon.....	15
<b>5 Conclusion</b> .....	<b>18</b>
<b>6 References</b> .....	<b>19</b>
<b>7 Sources from the World Wide Web</b> .....	<b>20</b>

# SIP - Rehabilitation of Infrastructure in Arctic Areas

## INTRODUCTION

Advanced tools and innovative development of computers with increased processing power enable scientists to provide climate models with a high regional resolution. In 2004 the Arctic Impact Climate Assessment was published, so far the most detailed study for the Arctic region. The changing nature of the changing climate will influence the development of the society on a large scale. On one hand consequences of climate change will increase the appearance of natural hazards and will increase the danger for the population, the infrastructure and the environment. But on the other hand the changing climate opens new perspectives according to the use of the Arctic region, which attracts more and more the public notice, since the ice shield is melting.

The Arctic, the last intact region in the world, expects an invasion through the abutting nations. The geopolitical importance increases with melting of the ice shield. It is assumed that the continental shelf contains inestimable natural resources such as oil and gas in place, diamonds, gold and other precious metal, which will be easier accessible due to the melting ice cover. Russia, Canada, Denmark, the United States and Norway are highly interested in the Arctic. When Russian Researchers in 2007 dived deep with a submersible below the North Pole and located a flag in 4261 m water depth a new era started. The Russians want to show that the Lomonosov ridge, a 1.800-kilometer underwater mountain range extend to near the pole and is therefore a geological extension of Russia. This symbolic act points the increasing economic and environmental importance of the Arctic and is the beginning of the geopolitical race of the neighbouring countries.

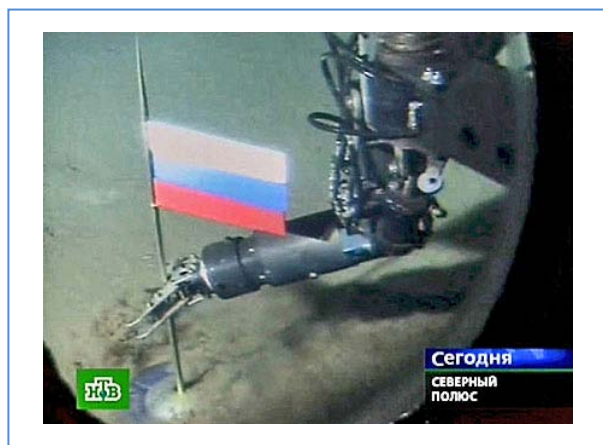


Figure 1: Russian flag located under the North Pole in 2007 (<http://www.nrhz.de/flyer/beitrag.php?id=13962>)

Due to the great commercial and environmental relevance of the region, it is of a vital importance to gain fundamental knowledge about the Arctic area and the ice-bearing seas. As a nation bordering the Arctic region, Norway has to play a significant role in the Arctic research. Substantial research in the field of oceanography, ice erosion and climatology has to be undertaken in the next decades.

The high relevance and importance of the Arctic region for the Norwegian state became recently visible during a press conference on March 12, 2010 in Tromsø, where the prime minister presented the government's new High North document named "New Building Stones in the North". The Norwegian ministry of foreign affairs underlined with their publication "The Norwegian Government's High North Strategy" that one of the most important priorities in the years ahead will be to take advantage of the opportunities in the High North. Some goals are to take advantage of the opportunities the Barents Sea presents as a new European energy province in accordance with the principals of sustainable development and to take environmental and climate considerations in everything what will be done.

## 1 The Arctic Climate Change

Extremes frame the dynamic nature of the Arctic climate: very cold winter temperatures, dominance of snow cover, and relatively low rates of precipitation. Essentially one frozen and one thawed seasons with abrupt transition between dominate the Arctic year. The winter lasts 7-10 month where an unfrozen surface is rare. Since the end of the "little Ice Age" after a medieval warm period the Arctic has warmed substantially (Hinzman et al. 2005).

Results of the analyses of the climate of the 20<sup>th</sup> century show an increase in temperature and precipitation over the past century, while the snow cover extent around the periphery of the Arctic and the sea ice extent have very likely decreased. Reconstruction of the Arctic climate over thousands to millions of years shows very rapid temperature variability from a few to several degrees over a century. The climate change in the Arctic is much larger than the change on the global scale (McBean et al., 2004).

## 2 Permafrost

Numerous climate change scenarios indicate that global warming will be most pronounced in the high latitudes, where many of the potential environmental and socioeconomic impacts are associated with permafrost.

Permafrost is defined as ground that remains below 0°C for more than two consecutive years. Approximately 24% of the terrestrial surface of the northern hemisphere is occupied by permafrost regions. There is only a little knowledge about subsea permafrost in the Arctic ocean and new occurrences continue to be found. Human infrastructure such as roads, bridges, buildings, utilities, and airstrips can be disrupted severely due to effects of climatic warming on permafrost and the seasonally thawed layer above (active layer) it. Long-term palaeographic records from Northern Alaska, Russia and Canada shows that climate warming can lead to increases in permafrost temperature, thickening of the active layer, and a reduction in the percentage of the terrestrial surface underlain by near-surface permafrost. Damages to infrastructure are the consequences of extensive ground settlement due to the described effects. (Harris 1987, US Arctic Research Commission 2003).

Climate change is possible to be a factor in engineering projects. Therefore, engineering design must address the problem of preserving infrastructure under projected future climate conditions. Areas of warm, discontinuous permafrost present one of the greatest challenges in order to find economic solutions to address the impacts on foundations and structures (Instanes et al., 2004).

### 3 Infrastructure

Although the Arctic area is known as a mostly unpopulated and undeveloped wilderness the occurrence of large reservoirs of fossil fuels and ore deposits led to substantial development of infrastructure in northern Scandinavia and to several cities with populations of more than ten thousand which are located in the contemporary zone of sporadic permafrost.

The consequences of increasing temperatures, thawing of permafrost and melting of the sea ice cause damages on infrastructure and buildings. The changing "face" of the Arctic poses a special challenge for infrastructure. In several areas railway tracks already deformed, landing runways and roads are in bad condition. In addition storms, mudslides, landslides, avalanches and floods cause tremendous damages.

The thawing of permafrost can produce dramatic socioeconomic impacts illustrated by a disaster in Norilsk, Siberia in 1966 where a building affected by differential thaw collapsed and killed 20 people. Also Yakutsk, a Russian city built over permafrost in central Siberia has suffered severe damages on its infrastructure through the thawing of ice-rich layers which caused differential settlement. Damages on a local power generating station resulted in a temporary loss of electrical service. In 1998, Yakutsk was declared a natural disaster area. Substantial investments became necessary to prevent catastrophic consequences arising from damages to buildings and other engineered works (Nelson et al. 2002).

The regional and national economic growth depends on the stability and maintenance of transportation routes and industrial development. It is likely that climate change is going to have significant impacts on existing Arctic infrastructure and on the development in the region. The uncertainty of future climate impacts demands new engineering solutions and can in most cases increase the costs of new projects in the Arctic. The future climate change may increase the environmental stresses structures are exposed to and cause increased risk and damage to infrastructure and threat to human lives. Adaptation, mitigation and monitoring techniques are necessary to minimize the potential impacts to infrastructure like schools, hospital, various types of buildings and structures, facilities such as roads, railways, airports, harbours, power stations, power, water, and sewage lines (Instanes et al., 2004).

Most of the Arctic facilities are built due to population concentrations, extraction of natural resources, or military activities. Industrial and military facilities include typically industrial buildings, warehouses, crew and worker quarters, embankments for roads and airports, pipelines and excavation of different types. Concerning human settlements the infrastructure includes public transportation systems, utility generation and distribution facilities, and residential and business buildings.

Increasing air temperature and thawing of permafrost are likely to affect engineering projects. Frost heave and thaw settlement are likely to affect the Northern pipelines. Possible acceleration in settlement of shallow pile foundations in permafrost over the design life of a structure have to be considered. The availability of winter roads is likely to decrease due to the reduction in the duration of the freezing season. Minor thickness of Arctic sea-ice cover might affect the design of offshore structures for ice loadings. Changes in precipitation are very likely to alter runoff patterns, and possibly the ice-water balance in the active layer. This might have effects on structures such as bridges, pipeline river crossings, dikes, or erosion protection measures. The stability of steep slopes of open-pit mine walls in permafrost might be affected.

The recent infrastructure was designed for current climate conditions and it is possible that appreciable warming will introduce different settlement beneath them (Instanes et al. 2005).

### 3.1 Buildings



Figure 2: Pillars prevent the building from damage due to thawing permafrost- BP operation center, Prudhoe Bay, Alaska ([www.klimanotizen.de](http://www.klimanotizen.de))

Nowadays several foundation systems are in use for industrial, commercial, and residential structures located in the Arctic. When buildings are underlain by permafrost thawing of the ground must be avoided due to elevating the buildings above the ground surface on a pile or adjustable foundation system. The airspace in between ensures that the heat from the building will not induce permafrost warming. Structures ranging from single-family residences to large living quarters and apartment blocks are currently supported on pile foundations. However, many Siberian buildings are showing significant rates of structural failure that may be connected to thawing of permafrost.



Figure 3: How thawing permafrost can destroy a building (Chersky, Russia) ([www.klimanotizen.de](http://www.klimanotizen.de))

The type of frozen soil such as clay, silt, or sand determines the bearing capacity of piles embedded in permafrost. A safe pile design depends on the calculated maximum temperatures of the frozen along the embedded pile length. The pile foundations are particularly sensitive to permafrost temperatures and an increase in ground temperature along an existing pile is very likely to reduce its bearing capacity or increase the rate of its settlement.



Future temperature increase and thawing of permafrost have to be considered when designing future buildings founded on piles. The pile design has to be adjusted to the estimated useful lifetime of the structure and should preferably be based on projected temperature conditions at the end of its lifetime. Longer pile length and increased costs for any particular pile type are likely to be the consequence.

Pile foundations can be sufficient for residential buildings and lighter structures. For industrial buildings bearing heavy loads pile foundations are sometimes too costly. Insulation installed beneath the floor or some kind of cooling system can prevent heat transfer and thawing of underlying permafrost (Instanes et al. 2005).

### 3.2 Foundations and Embankments



Figure 4: Thawing permafrost under roads and railway tracks

(<http://www.futurity.org/earth-environment/stream-water-may-signal-permafrost-thawing/> and [http://nasadaacs.eos.nasa.gov/articles/2005/2005\\_permafrost.html](http://nasadaacs.eos.nasa.gov/articles/2005/2005_permafrost.html))

Infrastructure such as roads, railways, airstrips, pipelines, buildings, and other structures are mostly placed on the upper layers of the ground. A cooling trend will not necessarily affect the performance of foundations unless different heaving occurs. Existing foundations are designed with only a limited safety factor to cope with unusually warm years and are certainly not built to cope with the effects of climate change. Small increase in temperature would produce structural failures in foundation due to the reduction of load-bearing strength, whereat larger temperature increase would mean that almost all of the structures would have to be rebuilt.

Increasing temperatures are likely to affect embankment performance and it is very likely to result in increased failure rates and higher maintenance costs for roads, railways, and airports. The effects of projected temperature increases have to be incorporated in future embankment design. In addition the natural temperature increase embankment construction often produces a significant alteration of the surface microclimate that results in an increase in mean annual surface temperature of several degrees as compared to natural conditions. It is a minor problem in the continuous permafrost zone, where the permafrost layer and surface conditions are generally colder. The surface warming due to embankment construction can usually be accommodated using well-established design practices (Harris 1987).

### 3.3 Winter Roads



Figure 5: Winter roads with potential risk for traffic (<http://englishrussia.com/index.php/2007/11/28/road-went-wrong/>)

Winter transportation routes have played an important role for the industrial development in the Arctic area. During the winter period the ice provides new roads and bridges which enables material and food supply to remote colonies. Ice roads consist of frozen lakes, rivers, and tundra. In some cases the use of ice roads is limited by the duration of exploration activities. In other cases permanent ice corridors have been established especially for community supply. In comparison to gravel roads the environmental impact of ice roads is very small; eventual removal after oil and gas exploration activities is not necessary. The construction of winter ice roads is affected by a number of climate factors, including air temperature, accumulating air freezing index and snow fall. The underlying frozen base material ensures the structural integrity. A significant period of freezing temperatures must occur each autumn before the construction of ice roads can begin. For water crossings the thickness of the ice formation must reach minimum critical values before vehicles can use the winter roads safely. In tundra areas it is important to protect the sensitive vegetation. A sufficient frozen layer has to be established, which can support significant loads without harming the underlying vegetation, before the roads can be opened for the traffic. The opening and closing are determined by climatic conditions. Reduction in the annual air freezing index and an increasing in air temperature are very likely to have a negative impact on the duration of the winter road season. (Arctic Climate Change Impact, 2005).

### 3.4 The Arctic Coastline

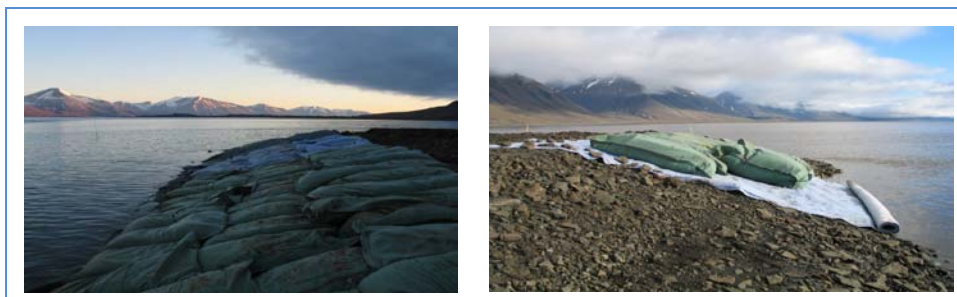


Figure 6: Erosion protection with geotextile bags (SINTEF, GISSAC project)

The use of the Arctic coastline plays an important role in the development of the economy and the social well-being of all Arctic residents. A warmer climate would increase the season for open-sea operations and probably

modify the zones of the different ice types (landfast ice, polar pack ice, seasonal ice) in the offshore areas. The movement patterns of ice islands and icebergs from the far North would change and influence the design requirements for offshore structures such as platforms and shipping terminals. The presence of permafrost affects often the coastal dynamics directly or indirectly. The ice beneath the seabed and shoreline melts from contact with warmer air and water and the unconsolidated soil is exposed to wave induced erosive processes. Flood barriers, dikes breakwater and erosion control measures may not be able to reduce erosion rates sufficiently. The combination of increased wave action, sea level rise, and thermal erosion are challenges for engineering solutions to face the impacts of a warming climate (Harris, 1987, Instanes et al. 2004).

### 3.5 Natural Resources

The mining industry in the Arctic is an important part of national economies. Offshore oil exploration and production is likely to benefit from less extensive and thinner sea ice due to decreased costs for the construction of platforms that have to withstand ice forces. An increase in mining and exploration activities would require expansion of air, marine and land transport systems. Reduced sea ice enables a longer shipping season in all Arctic areas, with the possibility of better transit through the Northern Sea Route and Northwest Passage for at least part of the year. Sea level rise would provide deeper drafts in harbours and channels. A thinner ice cover reduces the need for ice strengthening of ship hulls, offshore oil and gas platforms and the need for icebreaker support.

However, the impacts of climate change bear not only benefits for the mining and exploration industry. Mining facilities which are depended on road on permafrost will experience increasing maintenance costs with permafrost thawing. Increasing temperatures would reduce the strength of the permafrost. Underground mines are forced to use larger rock pillars to support the roofs of the workings. The risk of rock bursts and flooding from unfrozen layers in the permafrost soil would increase and the cost of air cooling in deep mines would rise (Harris, 1987; Instanes et al, 2004).



Figure 7: Russian pipeline in thawing permafrost areas (<http://www.desdemonadespair.net/2009/11/permafrost-thaw-threatens-russia-oil.html>)

## 4 Innovative Methods and Materials

The recent extreme weather conditions and a changing climate in the Arctic are a challenge for the design of buildings and infrastructure. Rising temperature will lead to melting permafrost with instable underground condition, to stronger waves which will increase the shore erosion. New solutions for fundamentals and embankments, for isolation of buildings and erosion protection along the coast have to be developed. Existing design of buildings and infrastructure which are sufficient in temperate zones might not be sufficient under extreme low, temperature. New materials, technologies and structures have to be developed to prevent the deformation of railway lines, airport runways, pipelines and building fundamentals. As global warming increases stronger effects of melting permafrost are expected and actions to preserve existing buildings and infrastructure have to be taken today.

However, only minor knowledge about the performance of building material and methods used under extreme low temperatures and in areas of melting permafrost exist. Until now only few companies have specialised on products and services for the Arctic. Most recent building activities are related to the offshore industry, neglecting urban infrastructure.

Intensive research in the Arctic is important to design, develop and maintain Arctic structures which have to cope with the effects of climate change. The lack of local building material requires special modern techniques and environmental friendly use of "imported" construction material. There is a need to develop construction materials and methods and structures to meet the requirements of an environmental and sustainable handling of the sensitive Arctic region.

The following chapter presents some examples for innovative materials and methods sufficient for the extreme Arctic conditions.

### 4.1 Pipeline Coating Protection

[\(http://pipelinesinternational.com/news/providing\\_coating\\_protection\\_in\\_arctic\\_tundra/043735/\)](http://pipelinesinternational.com/news/providing_coating_protection_in_arctic_tundra/043735/)

926 km pipeline runs between China and Russia while crossing boreal forests and Arctic tundra. To mitigate the risk of forest fires the Chinese government limited the construction period to the winter season. Traditional shrink sleeves which fit around pipeline joints need to be heated and can only be applied in minimum temperatures of -5 degrees Celsius.

In addition, the extremely low temperatures require a special coating to ensure appropriate function conditions. Traditional insulation and protection measures are in that case not suitable. The Dutch company SPOPAQ developed a wrapping band which is covered with polypropylene outer wrap. 36 special coating employees were busy to coat 24 300 joint in a period from May 2009 until December 2010.



Figure 8: Pipeline coating, STOPAQ, (<http://www.stopaq.com>)

## 4.2 Insulated Pipes and Pipe Fittings

([http://www.arcticinsulation.net/pipe\\_and\\_fittings.htm](http://www.arcticinsulation.net/pipe_and_fittings.htm))

The Arctic Insulation and Manufacturing company located in Alaska produces since more than 25 years factory pre-insulated piping and fittings for above and below ground applications for water, sewer, steam, and condensation. Polyurethane foam ensures best insulating values.



Figure 9: Insulated pipe and pipe fittings

## 4.3 Norfino Sealing System

([http://www.beele.com/web/index.php?option=com\\_content&task=blogcategory&id=143&Itemid=291](http://www.beele.com/web/index.php?option=com_content&task=blogcategory&id=143&Itemid=291))

Vessels and Offshore installations operating in the Arctic are exposed to a higher risk for damages and accidents due to extreme weather conditions, ice, darkness and fog. NORFINO provides a sealing system for metallic pipes and or cables based on the NORFINO rubber that has excellent properties regarding exposure to excessive temperatures.

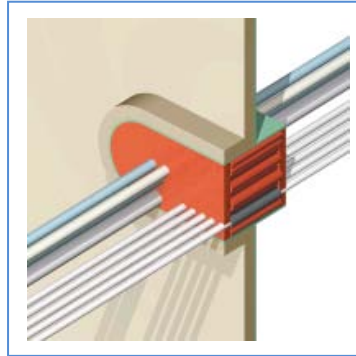


Figure 10: NORFINO sealing system for pipes and cables

Combined penetrations for metal and plastic pipes as well as cables can be sealed with NORFINO within the shortest installation times and maintenance friendly. The system is approved for any combinations of cable, metallic, or plastic pipes and has a service life of over 20 years. NORFINO is used for shipbuilding and retrofitting, offshore installations, building and construction, and other environments where the safety of people and installations has to be guaranteed.

#### 4.4 Metallon Sandwich Panels

([http://www.oilandgaseurasia.com/news/p/2/news/1396/our\\_partners/advertising/](http://www.oilandgaseurasia.com/news/p/2/news/1396/our_partners/advertising/))

Metallon, a production and construction company, developed for the "hard-to-reach" areas in Russia a material that is easily transportable to construction sites and makes construction of facilities as quick as possible. Metallon's sandwich panels are economic efficient, light weight and have high heat saving indices. The panels consist of metal, fiber building board, insulant, and metal again with a core of mineral wool or foam polystyrene and a casing of galvanised sheet steel with protective decorative coating.

Sandwich panels can be used for the construction of commercial and industrial complexes, sport facilities, food industry facilities, filling stations, freight handling and port terminals, and warehouses. Three-layer frameless metal sandwich panels are designed for walls and roofs of civil housing and industrial construction buildings for temperatures between -65 and + 75 degrees Celsius.



Figure 11: Metallon sandwich panels

#### 4.5 Polyguard - ReactiveGel™

(<http://www.reactivegel.com/History.htm>)

In order not to disturb the fragile permafrost oil and gas pipelines in North America and Russia are aboveground which need to be insulated. The potential for very large corrosion under insulation and spills in the sensitive environment makes the engineers extremely concerned.

The company Polyguard developed a unique material called ReactiveGel® whose chemical elements reacts within a short time with the elements in the steel surface and forms an ultra-thin glasslike mineral surface. On that way the pipeline is protected against corrosion.



Figure 12: "above the Arctic circle" application: corrosion under insulation.

#### 4.6 Two-phase Thermosyphon

([http://www.arcticfoundations.com/index.php?option=com\\_frontpage&Itemid=1](http://www.arcticfoundations.com/index.php?option=com_frontpage&Itemid=1))

Arctic Foundations, Inc. provides since more than 35 years solutions to geotechnical problems through the application of their proprietary ground freezing technology and analyses, designs, manufactures, installs, and operates heat transfer and ground freezing systems that enhance the engineering characteristics of soil and rock.

The technology is based on two-phase thermosyphons, passive refrigeration devices, which transfer heat against gravity.

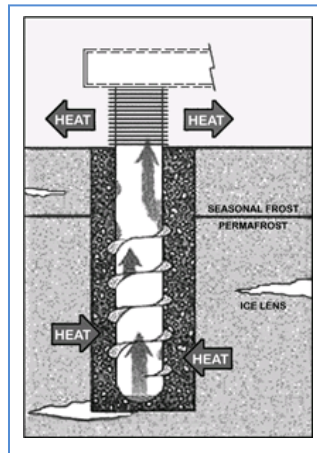


Figure 13: Two-phase Thermosyphon

The construction consists typically of a closed ended tubular vessel charged with a two-phase working fluid while the vapor phase of the working fluid fills the majority of the interior of the vessel, with the liquid phase filling the minority of the volume.

Arctic Foundations: "Thermosyphons have typically functioned passively in cold climates during the winter months, at which time the above-ground portion is subjected to cold ambient air which cools and condenses the working fluid. The condensed fluid gravitates to below-ground level. Below ground, subjected to warmer temperatures, the working fluid warms, vaporizes, and rises upward to repeat the cycle. This continuous recycling is irreversible because the cycling ceases in the summer when the air temperature is above the soil temperature. This closed two-phase process should not be confused with the open two-phase process whereby liquid nitrogen is used in ground freezing applications. The latter process simply releases the nitrogen gas to the atmosphere having gained sufficient heat from the soil to vaporize the liquid nitrogen."

The technology has been in use since 1960 on over 900 installations.

Technologies:

- Thermopiles



Figure 14: Thermopiles



Thermopiles are load bearing two-phase thermosyphons used for structures which are situated on permafrost soil.

- Thermo Helix-Piles



Figure 15: Thermo Helix-Piles

Thermo Helix-Piles are used to support greater loads and where consequences of foundation movement are high. Helical shear rings are attached to the common two-phase thermopiles.

- Helix-piles



Figure 16: Helix-Piles

The Helix piles with a helical shear ring support greater loads than similar size conventional piling and require shorter embedment depths than usual piles. The Helix piles are mostly used to support high loads and provide high redundancy factor when the benefits of thermo-cycling are not required.

## 5 Conclusion

Uncountable climate scenarios predict a changing climate in the Arctic. Observations over the last decades show that the climate change occurs more rapidly than in temperate zones. The consequences of climate change are an increase in temperature, melting ice shields, changed movement patterns of icebergs, increased coastal erosion due to the lack of sea ice, increased river and shore erosion, intensified wave dynamics and loads, increased storm intensity and frequency, and melting permafrost. All these parameters are likely to influence the performance of existing infrastructure and will cause huge damages on roads, railway tracks, airfields and buildings. Due to the melting permafrost and the increased threat for landslides, avalanches, and floods relocation of buildings might be necessary. If the warming trend continues enormous costs for design, maintenance and rehabilitation of infrastructure will occur. The aspect of a changing climate within the next decades has to be considered when new constructions are going to be designed.

In addition to the harsh environment the lack of sufficient, local building material poses another challenge to the building and construction sector. Innovative methods which enable the construction to use local material for building and erosion protection measures have to be developed. Since the Arctic environment is extremely sensitive all "imported" material must be chosen carefully and tested before using.

Detailed knowledge about the environment, the ecologically friendly handling of natural resources, and sustainable building is required. Comprehensive research is the fundament for an economical and considerate exploitation of the Arctic.

## 6 References

Arctic Climate Impact Assessment (2005), Cambridge University Press ISBN-13 987-0-521-86509

Arctic Climate Impact Assessment (2010),

Harris, S.A. (1987) Effects of Climatic Change on Northern Permafrost

Northern Perspectives, Volume 15, Number 5, ISSN: 0380-5522, Published by the Canadian Arctic Resources Committee

Hinzman, L.D., Bettes, N.D., Bolton, W.R., Chapin, F.S., Dyurgerov, M.B., Fastie, C.L., Griffith, B., Hollister, R.D., Hope, A., Huntington, H.P., Jensen, A.M., Jia, G.J., Jorgeson, T., Kane, D.L., Klein, D.R., Kofinas, G., Lynch, A.H., Lloyd, A.H., McGuire, D., Nelson, F.E., Oechel, W.C., Osterkamp, T.E., Racine, C.H., Romanovsky, V., Stone, R.S., Stow, D., Strum, M., Tweedie, C.E., Vourlitis, G.L., Walker, M.D., Walker, D.A., Webber, J., Welker, M., Winker, K.S., Yoshikawa, K. (2005): Evidence and implications of recent climate change in Northern ALASKA AND OTHER Arctic Regions. *Climatic Change* (2005) 72: 251–298, DOI: 10.1007/s10584-005-5352-2

Instanes, A., Anisimov, A.O., Brigham, L., Goering, D., Ladanyi, B., Larsen, J.O., Khrustalev, L.N. (2004): Climate Change and Arctic Infrastructure (ACIA Chapter 16), ACIA International Symposium on Climate Change in the Arctic Reykjavik, Iceland, 9-12 November 2004

Instanes, A., Anisimov, A.O., Brigham, L., Goering, D., Khrustalev, L.N., Ladanyi, B., Larsen, J.O., (2005): Infrastructure: Buildings, Support Systems, and Industrial Facilities, Arctic Climate Impact Assessment, Chapter 16, Cambridge University Press ISBN-13 987-0-521-86509

McBean, G.A., Alekseev, G., Chen, D., Førland, E., Fyfe, J., Groisman, P.Y., King, R., Melling, H., Vose, R. and Whitfield, P.H. (2004): The Arctic Climate: – Past and Present (ACIA Chapter 2), ACIA International Symposium on Climate Change in the Arctic Reykjavik, Iceland, 9-12 November 2004

Nelson, F.E., Anisimov, O.A., Shiklomanov, N.I. (2002): Climate Change and Hazard Zonation in the Circum-Arctic permafrost Regions, *Natural Hazards* 26: 203–225, 2002., © 2002 Kluwer Academic Publishers. Printed in the Netherlands.

U.S. Arctic Research Commission Permafrost Task Force (2003) *Climate Change, Permafrost, and Impacts on Civil Infrastructure*. Special Report 01-03, U.S. Arctic Research Commission, Arlington, Virginia.

## 7 Sources from the World Wide Web

Chapter	Source
INTRODUCTION	<a href="http://www.nrhz.de/flyer/beitrag.php?id=13962">http://www.nrhz.de/flyer/beitrag.php?id=13962</a>
Buildings	<a href="http://www.klimanotizen.de">www.klimanotizen.de</a>
Foundations and Embankments	<a href="http://www.futurity.org/earth-environment/stream-water-may-signal-permafrost-thawing/">http://www.futurity.org/earth-environment/stream-water-may-signal-permafrost-thawing/</a> <a href="http://nasadaacs.eos.nasa.gov/articles/2005/2005_permafrost.html">http://nasadaacs.eos.nasa.gov/articles/2005/2005_permafrost.html</a>
Winter Roads	<a href="http://englishrussia.com/index.php/2007/11/28/road-went-wrong/">http://englishrussia.com/index.php/2007/11/28/road-went-wrong/</a>
Natural Resources	<a href="http://www.desdemonadespair.net/2009/11/permafrost-thaw-threatens-russia-oil.html">http://www.desdemonadespair.net/2009/11/permafrost-thaw-threatens-russia-oil.html</a>
Pipeline Coating Protection	<a href="http://pipelinesinternational.com/news/providing_coating_protection_in_arctic_tundra/043735/">http://pipelinesinternational.com/news/providing_coating_protection_in_arctic_tundra/043735/</a> <a href="http://www.stopaq.com">http://www.stopaq.com</a>
Insulated Pipes and Pipe Fittings	<a href="http://www.arcticinsulation.net/pipe_and_fittings.htm">http://www.arcticinsulation.net/pipe_and_fittings.htm</a>
Norfino Sealing System	<a href="http://www.beele.com/web/index.php?option=com_content&amp;task=blogcategory&amp;id=143&amp;Itemid=291">http://www.beele.com/web/index.php?option=com_content&amp;task=blogcategory&amp;id=143&amp;Itemid=291</a>
Metallon Sandwich Panels	<a href="http://www.oilandgaseurasia.com/news/p/2/news/1396/our_partners/advertising/">http://www.oilandgaseurasia.com/news/p/2/news/1396/our_partners/advertising/</a>
Polyguard - ReactiveGel™	<a href="http://www.reactivegel.com/History.htm">http://www.reactivegel.com/History.htm</a>
Two-phase Thermosyphon	<a href="http://www.arcticfoundations.com/index.php?option=com_frontpage&amp;Itemid=1">http://www.arcticfoundations.com/index.php?option=com_frontpage&amp;Itemid=1</a>



Technology for a better society  
[www.sintef.no](http://www.sintef.no)