ADAPT
NORTHERN HERITAGE
TOOLKIT

Conservation factsheets

for managing northern historic places affected by climate change

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Cover image

The Røros Museum Preservation Centre is responsible for the restoration and conservation of the museum's historical buildings and provides restoration services for individuals and institutions nationwide. It contributes to increased expertise in heritage conservation and organizes courses and seminars, some of them in cooperation with universities and colleges.

1 INTRODUCTION

Conservation of historic places is about minimising any adverse impacts on those parts of a historic place which constitute its cultural significance. Environmental impacts are a significant factor in this, as are the impacts caused by human activity. Climate change influences these environmental impacts – be this in the form of changes to weather patterns, natural hazards or geological or hydrological conditions.

How climate change affects conservation practices is explored in these Conservation Factsheets, which are part of the Adapt Northern Heritage toolkit. The Factsheets, with their general advice and references to further information, especially support the use of the project's tool *Assessing Risks and Planning Adaption: Guide on Managing the Impacts of Climate Change on northern Historic Places*. In these six factsheets, the Norwegian Institute for Cultural Heritage Research discusses state-of-the-art conservation practices and climate change effects regarding fungal decay, coastal processes, flooding, frost and salt deterioration, landslides and snow load and avalanches.

2 BIOLOGICAL DETERIORATION DUE TO FUNGAL DECAY

A warmer and more humid climate increases the risk for fungal decay, which will create more deterioration in wooden cultural heritage.

Facts

What is fungal decay?

Rot is a form of fungal decay. Rot breaks down wood and can cause major damage to wooden buildings and wooden structures.

Deterioration of wood and other materials due to biological damage occurs naturally over time and funcal decay is one of the main reasons. The natural rate of deterioration varies widely by several factors, including the features of the material, exposure for climate conditions and maintenance.

Image 1 Storholmen Kongsfjorden. Photo: NIKU

What can happen to the cultural heritage object/environment?

The components of the wood material break down due to the enzymes that the fungus produces. If the moisture level exceeds 20% of the moisture content in the materials, there is a risk of developing rot. Wooden materials that are subject to prolonged humidification can be damaged by rot. Rot usually develops over a long period of time, but with increased moisture load, the rot develops faster, and the damage can therefore be extensive. With favourable growth conditions the rot can also develop extremely quickly, within six months

Examples of factors that can cause fungal growth:

- Condensation due to large difference between outdoor and indoor temperature
- Rain or wet snow
- Moisture during construction period / moisture in the building materials
- Leakages in installations connected to water and drainage
- Insufficient moisture projection

Image 2 Rot damages. Often, the inner parts of the logs are attacked, while the surface is relatively intact. Photo: Mycoteam

Why does it occur?

In nature there are many fungal species and they get their nutrition from the decomposition of wood. Damaged wood, due to fungal decay, quickly loses strength and already at approximately 10% weight loss of the wood there is approximately an 80% reduction in rupture strength.

Fungus, insects and biological growth are examples of biological deterioration. The rate of deterioration and thereby the life of a material, is strongly dependent on the exposure it is subjected to. Rot and fungus depend almost exclusively up on access to water, moisture and temperature, and therefore climate plays a significant role in this context. Climatic differences within one country, differences between the northern to southern part of the country, and between coast to inland, are of great importance for the risk of biological deterioration of our cultural heritage.

Fungal decay is most common on exposed building elements and structures, such as roofs and exterior walls. Extreme weather with strong winds and frequent heavy rainfall drives more moisture into building structures and allow less time for drying out. Most rot fungi are active between 5-30 degrees and grow the fastest between 20-22 degrees. There are always favourable temperatures for the development of rot in a heated modern building. Old constructions with no thermal insulation and natural ventilation have a slow development of rot damages over 20-30 years or significantly more. Modern constructions with thermal insulation and vapor barrier can have a quick damage development over 2-3 years (or faster!).

Brown rot is the term for the rot type where only the cellulose in the wood breaks down and leaves a brown and cracked wood structure in characteristic smaller or larger cracked cubic blocks. The wood can also be delaminated (i.e., it cracks up in the longitudinal direction of the wood). This type of rot occurs most commonly in conifers. The damage can be caused by several different types of rot fungus, for example dry rot (Serpula lacrymans). Determining the type is done by microscopic analysis. The wood that is damaged by brown rot can locally be severely weakened, and species such as dry rot also have a great ability to spread. Replacement of the damaged material with a security zone in the healthy wood is necessary.

White rot is formed by fungus that decomposes both lignin and cellulose. The wood becomes soft and fibrous.

How is it related to climate change?

A warmer and more humid climate increases the risk for fungal decay. Increased precipitation gives an increased risk of acute water damages (floods, leaks) and higher relative humidity. An increase in the average temperature combined with higher relative humidity will give some fungus more optimal living conditions, and the damages can therefore occur more frequently or in areas where they previously have not caused any problems. Another consequence may be that as a result from increasing temperatures, the season for external rot damage will be extended.

In extreme weather, there will be excessive effects from temperature and particularly water and moisture impact. This often has a dramatic direct impact on the development of fungal decay. In a matter of days and weeks you can see that large and serious damages occur.

Examples are:

- Long periods (weeks – months) with of warm weather. This quickly increases the moisture impact in cellars, basements and other cool constructions. For example, outbreaks of moulds often come within a few weeks.
- Long periods (weeks - months) with heavy rainfall. This results in a generally increased moisture impact, both in direct humidification and high relative humidity in materials. The result may be the growth of moulds and, to some extent, rot fungus. Indoor, increased relative humidity may give moulds better opportunities to grow.
- In the case of flooding, the moisture load will provide a favourable growth basis for fungal decay, extensive mould damage will occur within a few days and weeks of moisture impact.

Measures

Condition survey

By performing a condition survey, the present state of the building or construction can be established and from there the correct measures can be implemented. The condition survey should include information about legislation, historic description of the most important structural work or changes to the cultural heritage, and a description of the structural engineering. Also, a description of the state of the different building parts, which should be supplemented with photos. Finally, an assessment of the state of the cultural heritage and recommendation of measures is undertaken.

Make a general description of the building and the location of the damage in the building. Describe the visible extent of the damage and estimate the possible hidden extent of the damage. Because damages from fungal decay develop inside the materials and in structures that are hard to reach, many damages are overlooked. Often, different symptoms like moisture stains, efflorescence, flaking of paint and/or deformation of the wood surface indicate the presence of damages even if they are not directly visible. Such signs can therefore be used as a basis for assessing further exposure. When the damage is well developed, the signs will eventually become so clear that there is no doubt about the conditions.

In cases of internal damage and an undamaged exterior, rot damage can be difficult to find. Knocking on the materials to listen for a "hollow" sound can be effective, but it is more effective to use a rot drill. It is an instrument that drills a thin steel probe (about 1.5 millimeters in diameter and 400 millimeters long) into the wood while measuring the physical resistance. Any soft parts in the inner parts of the wood will appear on the printout from the control.

Having made an initial check and assessment, it often turns out that it is necessary to take down exterior coverings to get to the damaged materials. Loosening panels, wallboards, etc. often makes it very clear. In other cases, one can gain access to the vulnerable construction via inspection hatches and even very confined spaces, such as cellars, are often possible to inspect.

When making a registration of the damages, summarized the following information should be collected:

- General description of the building and relevant history
- Location of the damage in the building and construction
- Description of the appearance of the damage (rot structure, holes and so on)
- Clarification of which fungi, woodboring insects, and possibly other organisms that occur. Samples and tests may be necessary.
- Extent of visible outbreak
- Assessment of possible hidden parts of the damage
- Possible sampling of damaged wood for analyses
- Measurement of the moisture in the wood. Moisture measurements can either be done by instant measurements or by logging over time. In many cases, instant measurements are enough. In a follow-up control of a drying process, for example, or an extreme weather situation, logging may be appropriate to monitor the development. Decomposed wood has weakened strength. This can often be easily examined with a regular knife. By grading the deterioration on a four-part scale (0 = no damage, 1 = incipient damage, 2 = moderate damage and 3 = severe damage), it is easy to clarify the need for any action. The use of a hammer electrode is also recommended, which is connected to a moisture meter. It leads electrical currents into the wood, that allows you to read the level of conductivity.
- Moisture sources and causes
- Suggestions for further work, monitoring and possible adaptation

The cause and extent of a damage, together with the definition of the fungus type, form the basis for the assessment of relevant measures. Clarify the source of the moisture and possible causality between it and the damage.

Image 3 Mapping of rot damages in a timber wall. Photo: Mycoteam

Preventive measures

When it comes to preventing rot, it is important to have regular inspections focusing on moisture protection and drainage. Moisture protection of a building should prevent water and moisture from entering the structures and prevent water from being left near the building. By making relevant measurements of moisture, the exposure and the condition of the wood can be clarified. Measurements of the relative humidity and temperature can provide important information, but a direct measurement of the moisture in the wood gives a better understanding of the damage.

Regular maintenance is important. This may include securing built heritage against water and moisture, ensuring that wet building parts can dry up quickly, ensuring good drainage and regular cleaning of gutters and roof drains.

Image 4 Wood moisture meter. Photo: Mycoteam

Other measures

In case of rot, humidity can be avoided by means such as ventilations, repairs of leaking pipes, insulation, and repair to or replacement of unfortunate construction solutions.

Having rot damage, the following measures should be carried out:

- Stop the moisture supply and dry the materials to under 20% moisture content.
- Identify the deterioration phenomenon
- Assess the need to reinforce or replace weakened materials, repair leaks, and repair adverse construction solutions

If there is dry rot, you must also do the following:

- Remove all damaged wood with up to 0.5 meters safety zone
- New woodwork should be pressure-impregnated if it is acceptable by antiquarian standards
- Remove all surface growth
- Consider the possibility of chemical treatment of any infected masonry, with a safety zone of at least 0.5 meters into the affected area

A large part of the damages can be avoided by keeping the RH under 70% (indoors). Using a wood moisture meter, you can examine whether there is potential danger for further fungus growth in the wood.

Some fungus can survive dehydration for several years, and it is important to keep up with developments so that new water / moisture does not cause an outbreak again by monitoring. An important and general measure, if damage has not yet occurred, is preventative treatment, that is, to ensure that moisture is not applied to the building / structure.

3 COASTAL PROCESSES

Coastal erosion will increase and may create more deterioration on cultural heritage situated by the shoreline.

Facts

What are coastal processes?

Carrying away rocks, soils and/or sand along the coast is called coastal erosion. The erosion develops due to rising local sea levels, strong waves or coastal flooding.

Image 5 Hiorthamn.Svalbard. Coastal erosion. Photo: Anne Cathrine Flyen, NIKU

What can happen to the cultural heritage object/environment?

Coastal processes can cause direct or indirect damage to a heritage site. An example of direct damage to a heritage site may be that it dismantles or disappears after a single event, because erosion has destabilized the ground in the immediate vicinity of the heritage site. An example of indirect damage is that a site gradually erodes away over time due to waves, storm surges or spring floods.

Why does it occur?

Coastal processes are natural processes that take place at different timescales. Changes over a long period of time are due to climate change and geological processes. The consequences of sea level rise grow, the flatter the coastal areas are. If larger adjoining lands are located rather low above sea level, only a few cm average sea level increases will cause storm surges or high waves to flush tens of meters further inland and put larger areas under water.

How is it related to climate change?

In some regions, an increase in temperature will result in higher sea levels and greater and more frequent storms which will cause coast lines to erode. Ocean temperature, waves, tides, ocean currents and wind all contribute to form and shape the coast. So does the presence or absence of sea ice.

For impacts on erosion, the biggest changes come from absence or lack of sea ice and permafrost in addition to sea level rise and more wind. When a coastline is not protected by permafrost or sea ice, it is more exposed to storms and thus more prone to erosion.

Sea level rise is mainly caused by global warming, and it is accelerating. Water above 4 °C has an increase in volume when the temperature rises. The ocean's heat absorption from the atmosphere leads to an increase in volume that contributes to well over half the sea level rise. The rest is due to melt water from ice: the polar land areas (Greenland, Antarctica) and glaciers elsewhere in the world.

Measures

Condition survey

By performing a condition survey, the present state of the building or construction can be established and from there the correct measures can be implemented. The condition survey should include information about legislation, historic description of the most important structural work or changes to the cultural heritage, and a description of the structural engineering. Also, a description of the state of the different building parts, which should be supplemented with photos. Finally, an assessment of the state of the cultural heritage and recommendation of measures is undertaken.

In case of damages make a general description of the cultural heritage site and the location as well as a description of the appearance of the damage. Describe the visible extent of the damage and estimate the possible hidden extent of the damage.

Preventive measures

Erosion-reducing measures in the shorelines are either wave attenuation, stabilization of erosion-exposed unconsolidated deposits by planting mass-stabilizing vegetation or constructing erosion-damping structures. Preventive measures may also include relocating the object and/or extensive documentation of sites.

4 FLOODING

According to most precipitation projections, the total precipitation will continue to increase in the future which will create a higher risk for flooding and damages on cultural heritage situated in the flooding areas.

Facts

What is flooding?

Flooding is when the water level is so high that it rises and begins to do damage. It is a natural phenomenon and cannot be prevented. Flooding can come from rivers, lakes and the sea, and leads to an excess of water on land that is usually dry.

There are many different types of floods. The combination of rain and snowmelt can cause major floods. There is a greater risk of big floods when the snow melt starts in late spring. Flash floods are a rapid type of flooding that is most often caused by extremely heavy rainfall from thunderstorms. Glacial outbursts are an excessive flow that occurs when the dam of an ice lake breaks. River flooding occurs when a river floods its banks. Urban flooding is flooding in a built environment, caused by rainfall that overwhelms the capacity of the drainage.

Image 6 Expansive flooding can lead to substantial damages on heritage properties. Photo: Oddleif Løset, NRK

What can happen to the cultural heritage object/environment?

Expansive flooding can lead to substantial damages on heritage properties, infrastructure, sites and landscapes.

Floods often lead to erosion in streams and rivers and can lead to landslides and mudslides. The damage caused by floods depends on the type of flood that the site is exposed to.

Flooding can cause the heritage object or site to get filled with water or mud, or completely or partly washed away. Damages to a heritage object or site can also come from repair work undertaken after a flood, this applies mainly to buildings where the wrong measures have been implemented.

Why does it occur?

The most common causes of flooding are snow smelt and rain. Often in combination with high soil moisture content. High soil moisture content can lead to great overflow even with low intensity rainfall. Floods will usually be worse in urban areas with a high number of dense surfaces.

How is it related to climate change?

According to most precipitation projections, the total precipitation will continue to increase in the future. There will be more and heavier episodes of precipitation than before and they will increase in the winter, spring and autumn.

Measures

Condition survey

By performing a condition survey, the present state of the building or construction can be established and from there the correct measures can be implemented. The condition survey should include information about legislation, historic description of the most important structural work or changes to the cultural heritage, and a description of the structural engineering. Also, a description of the state of the different building parts, which should be supplemented with photos. Finally, an assessment of the state of the cultural heritage and recommendation of measures is undertaken.

Make a general description of the building and the location of the damage and a description of the appearance of the damage. Describe the visible extent of the damage and estimate the possible hidden extent of the damage.

Preventive measures

At a local level, inspections should be carried out in line with the established scenarios for that area. This can help show which cultural heritage is exposed to risk. Near a cultural heritage site, protective measures against flood damage should be carried out. Such measures should consist of securing rivers and streams against erosion, as well as the construction of flood walls. It is important that the security measures do not lead to secondary damages on the heritage site. Furthermore, physical planning should ensure that floodplains are not dismantled so that floodplains can absorb floods and avoid damage to cultural sites.

Regular maintenance is important. It may include securing built heritage against water and moisture, ensuring that wet building parts can dry up quickly, ensuring good drainage and regular cleaning of gutters and roof drains.

Maintaining and recreating green areas and further planting trees and other vegetation, can be used as a measure to counter future increased precipitation. Green areas absorb and infiltrate water as opposed to paved areas which instead increase the risk of surface water and flooding. Furthermore, vegetation, such as trees with large root systems, can stabilize soil masses and safeguard them against erosion. Examples of considerations and measures may be to keep streams, marsh areas and not to build over them. It may be appropriate to reopen streams that have previously been laid in pipes.

It is often important to have a warning system and flood protection for both individual buildings and cultural environments. Flood protection is constructed with modern materials and methods and may be constructed both as permanent ramparts and as temporary ones.

Other measures

If there is cultural heritage site or object within the area affected by flooding, these should be inspected to see if the heritage is damaged. Preservation / restoration measures should be carried out if there is damage to the heritage.

It is essential to prevent water from getting close to building materials that can develop moisture-related damages. Other examples of measures after flooding are to:

- Conduct frequent and systematic supervision and monitor technical condition of sites
- Provide good ventilation to prevent mold
- Perform continuous preventive maintenance work
- Securing buildings against water and moisture, and ensuring that wet building parts can dry up quickly
- Ensure good drainage from the building

It also important to follow up on weather forecasts and developments; the weather can progress quickly.

5 FROST AND SALT DETERIORATION

It is expected that frost and salt deterioration will increase in some regions and decrease in other due to climate change with more frequent zero degree-passages and more precipitation. This will create higher risk for deterioration of cultural heritage.

Facts

What is frost and salt deterioration?

When water freezes to ice it expands. If water enters cracks and/or pores of the material and then freezes into ice, the expansion will cause the materials to burst. This is called frost deterioration.

When salts move from liquid to solid form, the salts crystallize and expand, which puts more pressure on materials, causing them to burst.

Salt crystallization causes damage when the salts move from liquid form to solid form. This process crystallizes and expands the salts, which causes increased pressure on the surrounding building materials that can break both mortar and stone into pieces with great force. Salt crystallization can be divided into four phases:

- In phase I, the salt crystals grow inside the pores.
- In phase II the crystals have broken through the pore walls.
- In phase III the crystals have become so large that holes are formed inside the building material, and this gives more evaporation and an accelerating crystallization.
- In phase IIII the crystals have made clear damage in the form of flaking and cracks in stone and mortar.

Image 7 Frost damaged masonry at Mo church ruin, Valdres, Norway. Photo: NIKU

Image 8 Damages from salt crystallization inside Skoger old church In Buskerud, Norway. Photo: NIKU

What can happen to the cultural heritage object/environment?

One effect of frost deterioration is the breaking of building joints and stone and peeling-off plaster. Whether it is the building joints or stones that freezes into pieces is determined by the components of the individual mortar and stone types, such as pore structure, moisture suction and drying components.

Structures with masonry exposed to moisture will be vulnerable to this type of damage. Surfaces with poor drainage, broken building joints and damaged plaster are examples of parts of masonry structures where such damage can easily occur. The exposure of water that freezes to ice and thaws repeatedly, increases the structure’s vulnerability.

The following are examples of damages to the structure that allows water to enter:

- Leakage / damage to the ceiling
- Poor drainage
- Leakages in downpipes / gutters or under-dimensioned downpipes / gutters
- Leakages in fittings such as metal
- Damage to masonry
- Damage in plaster

The following are examples of building components or elements that may be exposed to an increased risk of frost deterioration, or which may contribute to increasing the vulnerability of frost damages in other parts of the building:

- Foundations of masonry
- Exterior walls of masonry
- Free-standing masonry
- Chimney in masonry
- Roofing
- Drainage System
- Gutters and downpipes

Frost deterioration is probably one of the most severe forms of physical deterioration that built archaeological cultural heritage in stone is exposed to, at least in the Nordic countries. Ruins are more vulnerable to this type of physical disaggregation than buildings, because ruins lack a protective roof.

Why does it occur?

Frost deterioration occurs when the temperature goes below zero and water freeze to ice and thereby expands. If there is water inside a material or construction the expansion makes it crack and deteriorate.

For salt to crystallize, the relative humidity needs to be less than the "equivalent relative humidity" of the salt (RHeq). For example, some chlorides only crystallize when the relative humidity of the environment goes below 35% at 20 °C, while some sulfates already crystallize when the relative humidity goes below 95% at the same temperature.

How is it related to climate change?

It is expected that frost deterioration will increase in some regions and decrease in other due to climate change and more frequent zero degree-passages. Water that enters the structure will freeze and thaw repeatedly during the winter and cause more frost damage than before. It is expected that salt crystallization in stone and mortar will increase due to more precipitation and thereby changing moisture conditions in the materials.

Increased temperatures will reduce the risk of frost deterioration of archaeological heritage in stone in some regions, whereas in other regions with lower temperatures, for example higher altitude regions, the risk will be extensive. Archeological heritage sites in stone located in coastal areas where the temperature is expected to rise are likely to be exposed to less frost damages towards end of this century.

Measures

Condition survey

By performing a condition survey, the present state of the building or construction can be established and from there the correct measures can be implemented. The condition survey should include information about legislation, historic description of the most important structural work or changes to the cultural heritage, and a description of the structural engineering. Also, a description of the state of the different building parts, which should be supplemented with photos. Finally, an assessment of the state of the cultural heritage and recommendation of measures is undertaken.

Make a general description of the building and the location of the damage and a description of the appearance of the damage. Describe the visible extent of the damage and estimate the possible hidden extent of the damage. If necessary, a clarification of types of salts should be done by tests. Finally, and if possible, the reasons for the damages should be explained.

Preventive measures

Practical measures to reduce the risk of frost damages to stone and mortar should be carried out by first assessing if there is an increased risk of frost damages due to expected climate change. Then the condition of the relevant part is studied, an analysis is made of the reasons for any increased risk and finally measures are recommended.

An assessment of any increase in the number of frost cycles in the area, as well as any increase in precipitation, is made by analyzing the site in relation to likely exposed areas. In addition to geographical location, height above sea level should be considered. For example, location on a ridge in relation to the average level in the area can provide colder climates than the more general geographical considerations. In addition, shaded areas, local areas with relatively cold or warm and protected climates may deviate from the more general geographical trends.

Preventive measures to reduce the risk of salt crystallization should also be directed towards stopping water from entering the structure, such as new and/or repaired drainage solutions and moisture protection as well as conscious choices of building materials. Building materials should prevent moisture from entering and allow for rapid drying out. Respond with new and/or improved drainage solutions and moisture protection as well as deliberate choice of building materials.

In some masonry structures it is difficult to stop moisture from entering, in that case the materials should be as frost resistant as possible. Another response may therefore be to ad or replace some materials in the building structures.

It is important that roofs, drains, walls, drainage etc. are in good condition. Moist building elements must be able to dry up quickly again.

Other measures

The following are examples of practical measures for both frost damages and salt crystallization:

- Repair of roofing
- Improvement of drainage, downpipes and gutters
- Repairs to covers / fittings
- Repair of plaster damage with adequate materials
- Masonry repairs that ensure water drainage
- Monitoring of symptoms, i.e., regular photo recording or laser scans
- Ensure that the moisture that gets into the construction quickly has the possibility to dry out
- Choices of building materials that avoid moisture from entering and allow for rapid drying out

Detect changes by continuous monitoring. For example, photo registration could be used for monitoring damages if it is unclear whether the damage should be repaired or how quickly the development progresses. In addition, photo-registration should be done before and after the implemented measures.

6 LANDSLIDES

Landslides are often triggered by heavy precipitation and as the climate becomes milder and precipitation increases, it is likely that there will be more landslides. For a cultural heritage object or site, the consequences of landslides can be catastrophic.

Facts

What is a landslide?

A landslide is when stone or soil moves or slides down the side of a mountain or valley. It occurs when the ground material changes from stable to unstable.

There are different types of landslides. When soil (including rocks, sand and clay as well as masses deposited by humans) overlies a rock or mountain, it may cause what is known as a 'landslide in soil'. Differences between these types of landslides are related to the grain size in the soils, the shape of the terrain and the water content.

Image 9 Fredheim, Sassenfjorden, Svalbard. Photo: NIKU

What can happen to the cultural heritage object/environment?

For a heritage object or site, the consequences of landslides can be catastrophic. A heritage site can be demolished or covered by mud or soil, entire buildings can be moved by a landslide or get lodged completely or partly beneath it.

Landslides can also cause minor damages, for example to the foundation of a building.

An indirect consequence can be that a landslide forces a river to change its course, redirecting the water towards a heritage object or site.

Why does it occur?

Landslides are often triggered by heavy precipitation or heavy snowfall. Many landslides are also caused by earthquakes.

How is it related to climate change?

Climate change has already led to a change in today's landslide pattern. That is, both the types of landslides and the geographical occurrence of landslides has changed. As the climate becomes milder and precipitation increases, it is likely that we will see more landslides where water and water pressure are the triggers.

Measures

Condition survey

If there is any kind of cultural heritage in an area exposed to landslide, a condition survey should be performed on the construction/building.

By performing a condition survey, the present state of the building or construction can be established and from there the correct measures can be implemented. The condition survey should include information about legislation, historic description of the most important structural work or changes to the cultural heritage, and a description of the structural engineering. Also, a description of the state of the different building parts, which should be supplemented with photos. Finally, an assessment of the state of the cultural heritage and recommendation of measures is undertaken.

Make a general description of the building and the location of the damage and a description of the appearance of the damage. Describe the visible extent of the damage and estimate the possible hidden extent of the damage.

Preventive measures

Landslides can be led away by constructing a type of protective wall. In the outlet area, steel wire rope can be used to prevent the landslide from reaching the heritage site. Before such preventive measures can be implemented, it is important to consider which part of the heritage site is to be preserved and which part withstands larger protective structures. These measures are often expensive. Risk assessment and planning of risk reducing measures should be done by experts.

Studies that show which building is exposed within each zone should be carried out. Near the exposed building or heritage sites, protective measures should be made. Such measures should consist in securing rivers and streams against erosion, as well as making drainage routes so that the soil is not saturated with water.

7 SNOW LOADS AND AVALANCHES

Generally, it is expected that the climate will be milder and that there will be more precipitation, largely higher temperatures and more often extreme weather. This will increase the risk for both avalanches and heavy snow loads, which may cause serious damage to cultural heritage.

Facts

What are snow loads and avalanches?

Snow load is the weight of accumulated snow and ice on a structure. If the snow load exceeds the weight that the structure can carry, the entire structure can collapse.

An avalanche is a great amount of snow flowing down a mountainside. Avalanches usually start in a terrain steeper than 30°, and without forest or any other form of resistance.

Most avalanches tend to happen in wintertime. In some areas, avalanches detach each year, while in other areas there may be 10, 50, 100 or even more years between each avalanche.

Image 10 The roof of a building has collapsed due to snow load. Oppland, Norway. Photo: NIKU

What can happen to the cultural heritage object/environment?

Avalanches and heavy snow loads can result in serious material damage and to total collapse of a structure.

The following are examples of potential damages from snow loads:

- Collapse
- Partial collapse
- Weakening of the construction (difficult to detect)
- Damage to eaves / roof protrusions (where roof and wall meet)
- Damage to roofing (can be caused / worsened by shoveling the snow)

Damage to gutters and drainage (can be caused / worsened by shoveling the snow)

Why does it occur?

Geological factors, strong wind, warmer weather and the structure and amount of the snow exacerbates the risk for avalanches.

Snow loads can appear after a single snowstorm but also after a series of storms that together result in snow load on structures. Snow comes in many forms. Regional differences in season, altitude, humidity, and other variations result in a range of snow densities and weight.

How is it related to climate change?

The consequences of climate change are associated with a good deal of uncertainty regarding snow conditions. Generally, it is expected that the climate will be milder and that there will be more precipitation, largely higher temperatures and more often extreme weather. Climate scenarios are unpredictable when it comes to snow loads, they can only give us an overall picture. The climate variations also give large differences in snow load on roofs, depending on geographical location and local variations. In other words, it is difficult to provide particularly detailed overviews of expected snow loads.

The most central factors of importance for snow load on roofs are:

- The amount of snowfall
- Temperature and humidity during snowfall
- Temperature and humidity after snowfall
- Wind and wind direction and duration during snowfall
- Wind and wind direction and duration after snowfall
- Roof design / construction / use of materials
- Heat loss through the roof structure
- Local geography / topography

Several of the above-mentioned factors interact and can produce numerous effects. As local conditions vary, it is difficult to give anything but general considerations. The following situations can have an adverse effect:

- Wet, heavy precipitation
- Extensive precipitation
- Rain after precipitation - but not so much rain that the snow rains away
- Roofs where the snow remains (for example turf roofs, mild roof angle)
- Fluctuations above and below the freezing point after and during precipitation periods that form a lot of ice on the roof / eaves
- Roofs with a high rate of heat loss through construction (poorly insulated)

Measures

Condition survey

Before the snow season, a condition survey should be carried out. By performing a condition survey, the present state of the building or construction can be established and from there the correct measures can be implemented. The condition survey should include information about legislation, historic description of the most important structural work or changes to the cultural heritage, and a description of the structural engineering. Also, a description of the state of the different building parts which should be supplemented with photos. It is in addition important to calculate the possibility for the building / structure to manage the predicted snow loads and avalanches in the future. Finally, an assessment of the state of the cultural heritage and recommendation of measures is undertaken.

Make a general description of the cultural heritage object or site and the location of the damage, and a description of the appearance of the damage. Describe the visible extent of the damage and estimate the possible hidden extent of the damage.

Preventive measures

Knowledge about the roof framing system and preparation before a snow event is important to be able to reduce the risk.

Regular maintenance is important. Take special care of the supporting structures, and in particularly roof structures, roof / wall transitions, wall constructions and the transitions between wall / floor / foundation. Also check roofing. Regular maintenance also includes such measures as securing the buildings against water and moisture, ensuring that wet building parts can dry up quickly, ensuring good drainage.

Preventive measures to avoid the risk of damage during major snow load can be evaluated by assessing whether the structure in question will be exposed to an increased risk of larger amounts of wet snow due to expected climate changes.

Prepare an action plan with the responsibilities divided: a plan for organizing, including a division of responsibilities. Important measures may depend on rapid response, but small measures. And follow up on weather forecasts and developments; the weather may progress quickly.

Warning systems for avalanches and supportive structures that prevent triggering of avalanches are also examples of preventive measures.

Other measures

The recommended measures are characterized by the fact that the climate scenario is very unpredictable. The following measures should be considered:

- Assessment of any increase in heavy snow is made by analysis of the location compared to likely threatened areas. In addition to geographical location, height above sea level should be considered. Local cold areas or local areas with relatively sheltered and protected climates may deviate from the more general geographical trends.
- Be at the forefront; Avoid potential problems by performing a thorough condition-based assessment with the intention of detecting any damage. Focus on the supporting structures, and in particularly roof structures, roof / wall transition, wall constructions and transition wall / floor / foundation. Also check roofing. Set up a repair program.
- Be sure to make calculations of how much load the buildings in question can withstand. Regarding old building constructions it can be difficult, but an estimation related to what load the building already has withstand during the centuries may be a possibility. NOTE: Remember the aspect to resist snow load that comes in a short amount of time – snow does not always fall over a long period of time.
- Shovel the roof: A very practical measure. However, there are important factors to be aware of - consider the type of roof, both types of construction and roofing. Some surfaces such as tiles and slate withstand poor shoveling tools and being walked upon better than others. Unequal loads caused by one side of the roof being shoveled first, may cause total collapse even if the snow volume isn't large. In some cases, the solution may even be to not shovel the roof.
- Changes to the construction (permit required): If assessments show that a roof will not withstand snow loads that are beyond the current situation, one can consider the following solutions.
  - Protective structures
  - Reinforcements in ceiling and / or walls
  - Change the type of roofing
  - Change the roof
  - Remove snow peaks
  - Remove trees nearby, both for the fall of snow on the roof and for better access for wind. Must be balanced for wind exposure and wind direction.

It is also important to follow up on weather forecasts and developments; the weather can progress quickly.

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