Kai Ryynänen

Handbook of Snow and Ice Construction

Photo: Niko Pernu

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Handbook of Snow and Ice Construction

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Foreword

This handbook is intended for the snow and ice construction industry. The target group consists of the authorities, designers and builders in the industry, not forgetting users of structures. I hope that this handbook becomes a tool shared by everyone engaged in the snow and ice construction industry.

This handbook discusses snow, ice and slush as a building material. This handbook has been divided into two parts. The first part provides instructions and recommendations for the design, construction and use of snow and ice structures. The second part consists of practical construction instructions.

The first edition of this handbook of snow and ice construction was and written based on snow and ice research conducted at Rovaniemi University of Applied Sciences (currently Lapland University of Applied Sciences). In the original version, companies and other parties engaged in the industry acted as technical specialists. Lauri Riikonen, one of the pioneers in the industry, made a significant contribution to the practical construction instructions discussed in this handbook.

At the time of writing the original handbook, snow and ice structures were studied and tested in practice during several winter seasons. Their use was also verified in a laboratory, especially with regard to the use of slush. The content of the field studies has been used in writing this handbook.

However, the industry has progressed, which is why it was more than necessary to update the handbook. This handbook of snow and ice construction was updated in the ProSnow project carried out in 2023–2025. The aim of the project was to develop the safety and climate resilience of snow and ice construction. The project included an interview study compiling tacit knowledge in the industry, the material of which was used in updating this handbook. Niko Pernu, Emilia Launne, Kari Moilanen, and Valtteri Pirttinen provided expert input into updating the content of the handbook.

The manual has undergone a round for comments, and the updated content has been commented on by the ProSnow project's steering group. I would like to thank everyone in the industry for their useful and professional comments. I would also like to thank all parties engaged in the projects. Without your input, significant information would have been left out of this handbook.

Rovaniemi, March 2025

Kai Ryynänen

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Introduction

Snow and ice construction is one of the special areas of expertise in tourism construction in Northern Finland. In a professional sense, snow and ice construction has been carried out for almost 30 years in various locations across Lapland. The design and construction of structures require a different approach from traditional construction, as the authorities and those undertaking construction projects do not always have sufficient information about snow and ice materials. The number of skilled building designers is also limited in the industry.

This handbook discusses snow, slush and ice as a building material. For writing this handbook, snow and ice structures were studied in field and laboratory tests during two winters. Research focused on the most common structural shapes and material combinations. To support the revision and supplementation of this handbook, tacit knowledge in the industry was obtained through interview studies, and best practices in safety were observed during site visits.

This handbook provides technical values for the design and construction of snow, ice and slush structures, as well as general design criteria, and presents commonly used type structures suitable for snow and ice construction. In addition, this handbook presents industry-related safety practices, rules and operating instructions, especially for current and future snow and ice builders. The starting point of the instructions is to ensure the safety of snow and ice structures and buildings, as well as their builders and users.

The final part of this handbook offers practical instructions for building proven snow, ice and slush structures. They are compression structures in which the forces that stress the structure tend to push the structure downwards. By combining ice, slush and snow, thinner structures can be built and new structural forms can also be developed.

1. Snow, ice and slush as construction materials

1.1 Research, development and innovation in snow & ice construction

At Lapland University of Applied Sciences (previously Rovaniemi University of Applied Sciences), long-term research and development have been conducted in several projects with industry organisations. In the research related to the preparation of this handbook, the current shapes of snow and ice structures have been studied at practical sites. In addition, material research has been conducted for ice and slush in experimental structures and laboratory conditions. Development related to updating this handbook has included interviews with various parties, site visits, cooperation with the authorities and companies, as well as the collection of tacit knowledge.

SNOW & ICE METHODS. The research and guidance project for snow and ice construction studied the behaviour of snow and ice structures in four different locations during two winters in 2008–2011. Twenty structures were studied, monitoring deformations, the development of material density, changes in the internal temperature of the structure and its impact on melting and load-bearing capacity. To verify the details of various phenomena affecting structural changes, the local weather in each location was measured at a weather station.

The impact of users on the snow and ice structures was studied by installing sensors that measure changes in indoor temperature and relative humidity in the upper parts of the structures' interiors. These measurements served to study whether users have an impact on the melting of snow. The measurement results were compared with previously published research results regarding snow, and it was investigated, for example, whether current snow structures behave in accordance with RIL 218–2002 "Snow constructions – General rules for design and construction" published by the Finnish Association of Civil Engineers (RIL). For ice and slush structures, the measurement results were used as the basis for the preparation of the dimensioning and construction instructions given in this handbook. In addition, a completely new three-layer structure was studied at a site outside the project during two winters. This handbook does not separately address the measurement results of the single research location. Measurement results obtained from different locations have been used as source material in the preparation of material-specific instructions.

The “Energiatehokas arktinen lumi” project carried out in 2019–2023 aimed to proactively respond to the challenges presented by snowless autumns by identifying the opportunities offered by Ounasvaara in Rovaniemi, especially from the perspective of winter sports, snow and ice construction, and athletic activities, and to increase Arctic climate expertise and business cooperation in the theme. The project studied aspects such as the storage of snow through preservation methods, uses and its profitability.

This handbook of snow and ice construction is also based on the ProSnow project carried out in 2023–2025 to promote the safety of snow and ice construction, especially considering climate change, which has a significant impact on the Arctic region. The project included updating this handbook of snow and ice construction, originally written in 2011, with most recent information in the industry. The project’s activities aim to provide clear updated instructions for the design, construction and use of snow buildings to support both builders and supervisory authorities. Through the other project publications, snow and ice builders are also provided with foresight and concrete support in solving the challenges brought by climate change.

1.2 Research on structures

Research on snow structures

In the SNOW & ICE METHODS project, the following snow structures were studied:

- a snow dome with a diameter of 12 m, connected to surrounding snow rooms (two winters)
- a snow corridor 3 m wide and roughly 3.5 m high
- a snow dome with a diameter of 12 m
- a snow dome with a diameter of 10 m
- an arch roughly 4.5 m high with a diameter of 3 m
- a straight-walled snow corridor 3 m wide with a sloping roof

Image 1. Studied dome-shaped snow structure (Ryynänen 2011)

Key research results on snow structures, which will be referred to later in this handbook:

- Snow structures in the shape of a catenary and a curve work well as a compression structure.
- Sagging is stable and controlled.
- The size of sagging depends on the snow and construction method used, as well as compacting during construction.
- The structures did not lose their load-bearing capacity or melted unusable during the period of use.
- Snow density developed during the period.
- The internal temperature of snow follows the outside temperature with a certain delay.

Research on ice structures

In the SNOW & ICE METHODS project, the following ice structures were studied:

- a 3 × 6 m ice log structure roughly 2.2 high

- a 3 × 4 m ice log structure roughly 2.2 m high
- an ice cone roughly 4.5 m high with a diameter of 4 m (two winters)
- an ice dome roughly 4.6 m high with a diameter of 5 m (Image 2)

Image 2. Studied ice structure (Ryynänen 2011)

In addition, the following ice structures were studied in laboratory conditions:

- two ice cones roughly 2 m high with a diameter of 2 m (image 3)
- two ice cones roughly 1.8 m high with a diameter of 1.8 m
- compression tests for pieces of ice
- freezing tests for pieces of ice

Image 3. Ice structures studied in laboratory conditions (Ryynänen 2011)

Key research results on ice structures, which will be referred to later in this handbook:

- Ice structures made of pieces of ice do not settle significantly during the period.
- An ice cone works well as a compression structure.
- Ice can be used as a load-bearing layer for other structures.
- The ice structure melts quickly as spring progresses.
- Ice is sensitive to wind-induced wear, i.e. erosion.
- The impact resistance of the ice structure is poor at low temperatures.
- Ice structures are “worse” than snow structures in terms of acoustics and thermal insulation.
- Ice density does not change notably during the period of use.
  The compressive strength of ice varies significantly, depending on the ice, the temperature and the compression method.

Research on composite structures

In the SNOW & ICE METHODS project, the composite structures used included slush structures, snow structures with more than 5% water added and structures with different layers of materials.

The following composite structures were studied:

- a dome 9.5 m high with a diameter of 16 m and with a snow wall structure 3 m high at the bottom and a frozen ice dome at the top
- a slush dome roughly 4.5 m high with a diameter of 5 m
- a snow and slush dome roughly 4.5 m high with a diameter of 5 m
- a snow and slush dome roughly 2.5 m high with a diameter of 3.2 m
- a snow and slush dome roughly 4.5 m high with a diameter of 5 m and with a thin wall
- a 10 × 15 m oval-shaped, three-layer ice, slush and snow structure roughly 4.9 m high (two winters, Image 4)

Image 4. Oval three-layer structure under construction (Ryynänen 2011)

Key research results on composite structures, which will be referred to later in this handbook:

- A composite structure, when built properly, is a well-functioning structure.
- A thin wall-like slush structure works well as a compression structure.
- A wholly frozen slush structure does not settle notably during the period of use.
- The sagging of a properly compacted snow structure is low when the structure contains large amounts of water.
- A three-layer structure enables the use of new structural forms.

1.3 Material properties

Snow as a building material

Snow and snow crystals are a combination of ice crystals condensed from water vapour in air. Usually a snow crystal appears as a hexagonal prismatic snowflake. The strength of the bonds between different parts of molecules formed by snow crystals and snowflakes are affected by the ambient temperature, for example. The size and shape of a snowflake and snow crystal vary significantly as shown in Figure 1. The shape of a snowflake and snow crystal changes throughout the lifecycle of snow.

Snow is affected by a physical phenomenon called metamorphosis. In nature, snow is light when it falls. As soon as snow accumulates on the ground or on the surface of a structure, it starts to change its shape. Snow crystals are first subject to a “destructive” metamorphosis, in which the crystalline structure of snow breaks when the internal bonds of the crystal break down. Snow particles become smaller and are rearranged. Snow crystals in the snow layer are compacted by their own weight and the effect of wind (Korhonen 1995).

As a result of destructive metamorphosis, the load-bearing capacity of the snow layer increases, resulting in “constructive”, or temperature-gradient, metamorphosis. In temperature-gradient metamorphosis, snowflakes form larger snow particles and the bonds of snow crystals become stronger. This increase in load-bearing capacity is affected by time, the outdoor temperature and the weight of the snow layer by volume (i.e. density) (Korhonen 1995).

When the outdoor temperature is 0 °C or higher, the outer surface of the snow layer starts to melt and water will form on the surface of the snow layer. When the outdoor temperature drops, the water on the surface of the snow layer starts to freeze, increasing the density and load-bearing capacity of the surface layer. This phenomenon is called melting metamorphosis (Korhonen 1995).

Figure 1. Different snow crystals and snowflakes (SnowCrystals 2011)

Snow density, or weight by volume, is the most important material characteristic that must be taken into account in snow construction. Snow density is not constant. Variation in density is influenced by three factors: the snow particles (size, shape, arrangement in the material), changes in strength (strength development as a time-dependent phenomenon), and the ambient temperature. Various density values have been measured and recoded for snow density (Table 1).

Table 1. Snow density values (RIL 2001, 52)

Snow density [kg/m³]	Description
50 – 80	Fresh natural snow
100 – 200	Packed natural snow
400	Fresh artificial snow / Minimum density according to RIL 218-2001
400 - 600	Snow density for structural design according to RIL 218-2001
> 800	Snow ice and ice

The density of the snow used in a structure changes throughout the lifecycle of the structure. In snow structures, sagging takes place during construction and use. The most significant sagging usually takes place during the first three days. Sagging depends, among other factors, on the initial density of the snow used in construction and the amount of compaction. For example, stored snow of a higher density usually settles less than fresh artificial snow. Due to changes in density and the effect of temperature, the density is indicated as follows:

$$\gamma = 600\frac{kg}{m^3}, T = -10°C$$

where the snow in question weighs 600 kg per cubic meter at -10 °C.

Table 2 summarises key material properties related to snow. These material property values are required, for example, in the design and quality control of snow structures. More detailed information about the material properties of snow and their use is available in various source materials, including the RIL 218-2001 guide. The material property values used in the design of snow structures are selected on a case-by-case basis by the structural engineer. In design, not all material values are always needed. Material values are affected by the temperature, snow quality, and snow and structural loading.

Table 2. Material properties of snow (RIL 2001 & Valtanen 2009)

Factor	Value	Unit	Additional information
Compression strength, f_{ck}	0 – 5	MPa	Value for artificial snow at -5 °C. Most crucial value for structural design. RIL218-2001 table.
Tensile strength, f_{tk}	0 – 1,4	MPa	Value for artificial snow at -5 °C. RIL218-2001 table.
Shear strength, f_{vk}	0 – 0,8	MPa	Value for artificial snow at -5 °C. RIL218-2001 table. Normal density at same time
Young's modulus, E_k	100 - 2900	MPa	Value for artificial snow at -5 °C. RIL218-2001 table. Snow is linearly elastic.
Creep, ε			Snow has fast creep. Can be categorized to reversible and irreversible.
Emissivity, ε	0.8		Age and purity of snow affects value
Absorption factor	0,1 – 0,6		Age and purity of snow affects value
Thermal conductivity, λ	0,2 – 1,1	W/m·K	Dependant of snow density
Specific heat capacity, Cl	2.1	kJ/kg °C	Dependant of temperature
Heat of fusion, S	335	kJ/kg	For water
Heat and freeze evaporation Hv	2835	kJ/kg	Snow can evaporate directly to air

Ice as a building material

Ice is made up of ice crystals. A single ice crystal is formed by the bonding of oxygen and hydrogen molecules. The position of the molecules gives the ice crystal its hexagonal shape. The size of ice crystals varies significantly. The size of the ice crystal depends, for example, on the freezing reaction and the number of oxygen molecules remaining in ice. Ice crystals form layers that overlap in the freezing direction (Figure 2) (Kilpeläinen & Mäkinen 2003, 5). As a result of the structure of ice, facets parallel to sheets are called basal facets, and the line perpendicular to sheets is called a crystal axis.

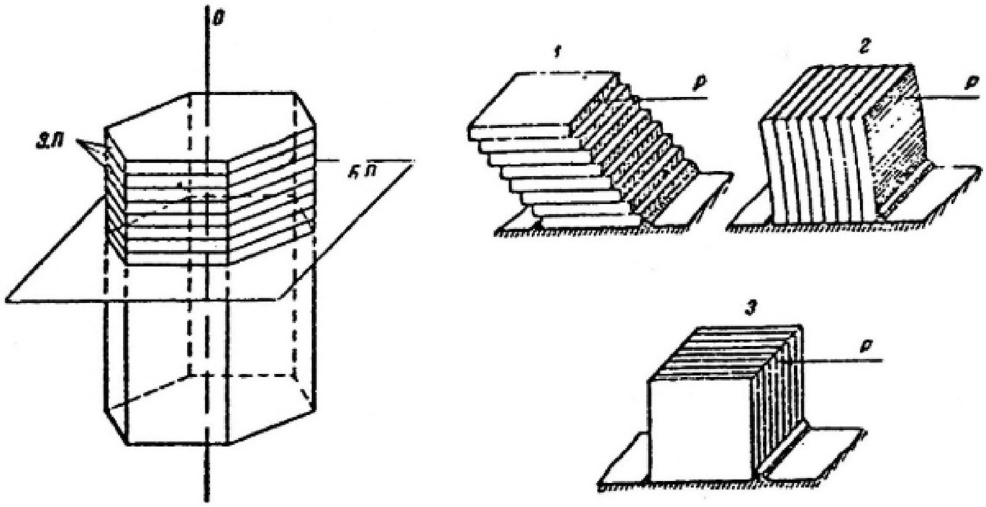


Figure 2. Ice crystal shapes (Kilpeläinen & Mäkinen 2003)

The shape of ice crystals varies. They may be boulder-shaped, elongated, i.e. needle-shaped, or sheet-shaped. The axes of ice crystals can be almost parallel, or they may be randomly oriented. Due to the different size, shape and layering of ice crystals, ice is a very heterogeneous material. As a result, the material properties of ice show significant variation.

When ice forms in natural waterbodies, air pockets are formed in ice due to water impurities and the structure of ice, which weaken the strength properties of ice. The size of the air pockets can vary significantly, which is why the strength of ice shows considerable variation. In natural waterbodies, ice is formed in layers (Image 5). At first, primary ice (clear ice) forms on the surface of water. Ice layers that form on top of clear ice are called snow ice. Snow ice is formed when snow accumulated on the ice surface mixes and freezes with water absorbed through cracks in clear ice.

The crystalline structure of ice is not constant due to loading and melting, for example. The properties of ice change according to the temperature of ice. The structural properties of ice are at their weakest at the temperature of 0 °C. As the temperature of ice rises, its strength decreases, while Young’s modulus, shear modulus and creep increase.

Image 5. Different layers of ice (Ryynänen 2011)

Table 3 summarises the material properties related to ice that are required in design and construction. In design, not all of the listed material values are always needed. Material values are affected by the temperature, ice quality and structural loading.

Table 3. Material properties of ice (Valtanen 2009, Kilpeläinen & Mäkinen 2003)

Factor	Value	Unit	Additional information
Density	917 – 920	kg/m³	Density changes with temperature.
Compression strength, f_{ck}	0 – 7	MPa	Not constant, depends from speed.
Tensile strength, f_{tk}	<0,8 - >2,4	MPa	Depends on structure and temperature. Arverage value 0,95 MPa.
Shear strength, f_{vk}	<0,4 - >1,2	MPa	Roughly half of tensile strength
Young's modulus, E	10	GPa	Value at 0 °C
Creep, ε			Jaetaan palautuvaan, viskoosiin ja viivästyneeseen.
Emissivity, ε	0.97		Value at 0 °C
Thermal conductivity	2.25	W/m·K	Depending on source
Specific heat capacity, C	2.13	kJ/kg·K	When ice temperature 0 °C.
Heat of fusion, S	335	kJ/kg	For water
Heat and freeze evaporation H	2500	kJ/kg	According to various sources: 0 °C on ice

Slush as a building material

Slush is a mixture formed as a combination of snow, ice and water. Snow and ice structures in which the amount of water added during the construction phase exceeds the recommendation of 5% of the amount of snow to be used given in RIL 218-2001 are called slush structures. During the construction phase, the original structure of snow and ice is completely transformed in slush to be fully wet. In the combination, the ratio between different materials is not evenly divided. Therefore, precise material values cannot be determined for slush.

The material properties of slush are affected by the properties of the snow and water used, the thickness of the slush layer, as well as the temperature of the slush formed and the ambient temperature. Slush structures do not require thick structures as those made of snow. Therefore, slush structures can be used, for example, in locations where snow is limited.

According to the studies conducted in the SNOW & ICE METHODS project at Lapland University of Applied Sciences in 2008–2011, the properties of slush are almost identical to ice when the slush is frozen. In the absence of long-term material research, it is not possible to provide more precise numerical values for the technical properties of the slush material at this point.

2. Structural design

2.1 General design criteria

The starting point for the design of snow, ice and slush structures is the safety of the people who use them. The instructions given in this handbook apply to structures that are of such size or purpose that a permit issued by the authorities is required for their construction. The design of structures in Finland is guided by the Building Act, the National Building Code of Finland, decrees and guidelines of the Ministry of the Environment, municipal construction guidance, and industry standards and guidelines. Since 2010, Eurocode-based design has served as the primary structural design standard.

Eurocodes EN 1990 (Basis of structural design and EN 1991-1-1 Eurocode 1 (Actions on structures – densities, self-weight, imposed loads for buildings) are applied in the design of snow structures. No Eurocode has been prepared for the design of snow structures, which is why the guidelines given in the RIL 218-2001 guide can be applied in the design of snow, ice and slush structures. The following dimensional calculations are required in the design of load-bearing structures:

- Ultimate limit states calculations; demonstrating the integrity of structures against cracking and falling.
- Serviceability limit state calculations; demonstrating the integrity of structures against deformation.

The partial safety coefficient method is used in the calculations. When using partial safety coefficients, reliable threshold values can be calculated for structural loading to predict deformations in structures and changes in loads during the period of use.

In ultimate limit calculations, the rated value of the load F_d is defined as follows for the integrity of a structure or structural part: (SFS-EN 1990, 88):

$$\left.\begin{matrix}1{,}15K_{FI}\\0{,}9\end{matrix}\right\}\sum_{j\geq1} G_{k,j} + \gamma P + 1{,}5K_{FI}\,Q_{k,1} + 1{,}5K_{FI}\sum \Psi_{0,i}\,Q_{k,i}$$

However, at least:

$$\left.\begin{matrix}1{,}35K_{FI}\\0{,}9\end{matrix}\right\}\sum_{j\geq1} G_{k,j}$$

Where:

K_{fi} = the load factor

$G_{k,j}$ = permanent loads

γ = Partial safety coefficient of a pre-load

P = the pre-load

$Q_{k,1}$ = the determining variable load

$\Psi_{0,i}$ = the combination factor for a variable load

$Q_{k,i}$ = other variable loads

In serviceability limit state calculations, the rated load F is calculated as follows: (SFS-EN 1990, 88):

Specific combination:

$$\sum_{j\geq1} G_{k,j} + P + Q_{k,1} + \sum \Psi_{0,i}\,Q_{k,i}$$

Regular combination:

$$\sum_{j\geq1} G_{k,j} + P + \Psi_{1,1}\, Q_{k,1} + \sum \Psi_{2,i}\, Q_{k,i}$$

Long-term combination:

$$\sum_{j\geq1} G_{k,j} + P + \sum \Psi_{2,i}\, Q_{k,i}$$

The impact of weather conditions on snow, ice and slush structures must be assessed. The RIL218-2001 guide can be used to assess weather conditions. If the construction site and structures are the same each year, weather data obtained from measurements carried out in previous years with sufficient reliability can be used to assess the behaviour of the structures.

In serviceability limit state calculations, threshold values are set for the structure. If they are met or exceeded, the use of the ice and snow structure must be suspended or stopped. Tilting and sagging values higher than the threshold values can be permitted for snow and ice structures, but in this case, they must be monitored more frequently and reliably than normal during the period of use. The original structural shape must be maintained in each case.

Threshold values in the serviceability limit state are:

- **Tilting:** for free-standing structures, when the ratio between the height of the structure (L) and the direction of tilting and the cross-sectional dimension of the structure’s base (H) is greater than 2.5 (Figure 3) (RIL 2001, 39). The threshold value is L/20 when L is the horizontal distance between the examined point from the lower edge of the structure (Figure 3) (RIL 2001, 40).
- **Sagging:** for free-standing structures, the threshold value is L/5 (RIL 2001, 40), when L is the vertical distance between the examined point from the lower edge of the structure (Figure 4). The reliability and stability of the examined point at the lower edge must be ensured.
- **The maintenance of the original shape of the structure** must be ensured especially for vault, arch and dome structures (Figure 5). If the structure loses its original shape, its use must be suspended until the conditions for continuing the use of the structure have been ensured. For example,

the deformation of an arch into a line always requires the use of the structure to be suspended.

- **Functioning of window and door openings**.

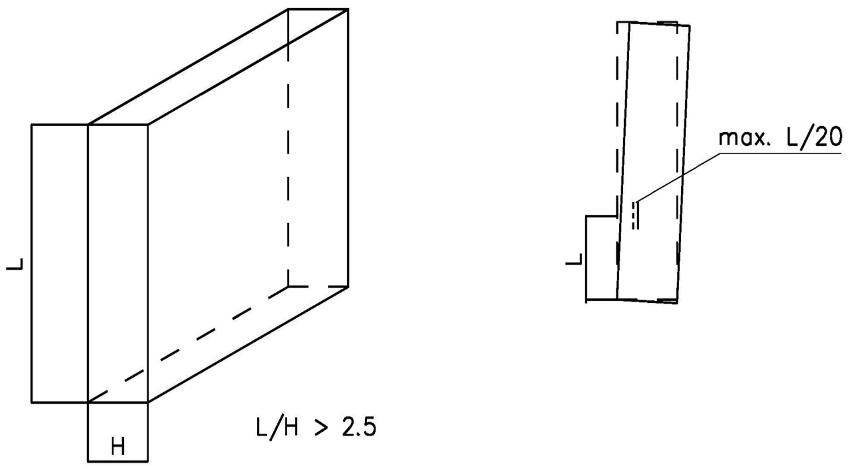


Figure 3. Structural tilting thresholds for snow, ice and slush structures (RIL 2001, 36)

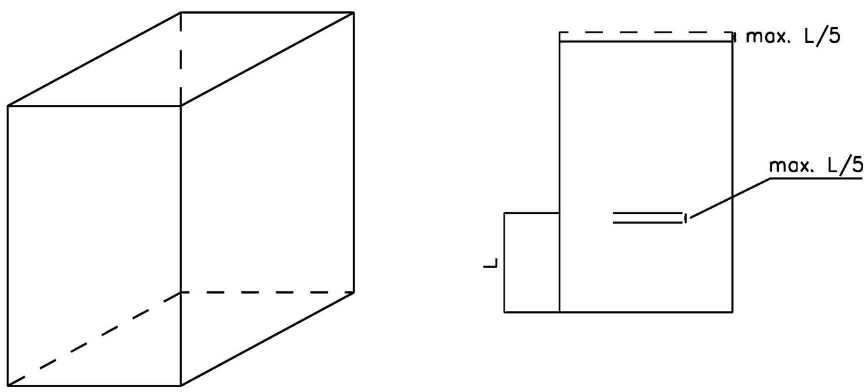


Figure 4. Sagging thresholds for free-standing structures (RIL 2001)

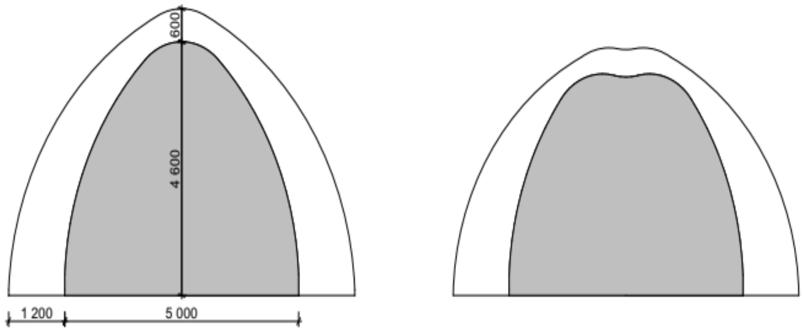


Figure 5. Maintenance of the original structural shape in snow, ice and slush structures (SNOW & ICE METHODS project)

Tip:
The original structural shape must be maintained throughout the period of use.

2.2 Material-specific design principles

Design of snow structures

When building load-bearing structures from snow, the guide published by the Finnish Association of Civil Engineers (RIL) applies to the design of structures: **RIL 218-2001 Snow constructions – General rules for design and construction.**

It is applied in the structural design and construction of load-bearing short-term and seasonal structures (lifecycle less than six months) subject to a licence. The use of the RIL218-2001 guide requires that the density of snow in the load-bearing structure is 400–800 kg/m3 (RIL 2001, 7). If snow structures that are not known in RIL 218-2001 are built, they must always comply with a special design procedure.

In studies related to the design of snow structures, particular attention must be paid to balance, i.e. stability. The probability of a structure falling over increases when the structure is slim or more than 4 m high. In addition, the risks of the breakdown of the upper part usually used in a dome structure must be taken into account.

Stresses and deformations are calculated using a structural model. The structural model must be made using the specific dimensions of the structure. The calculation must be carried out in accordance with RIL 218-2001, taking into account any changes in geometry due to sagging and weather. In the calculation, the service life of the structure is divided into load cycles. In the design, the mutual effects of interconnected structures and the stability of the whole structure must be taken into account.

Tip:

As a rule, the design of snow structures

must comply with the RIL 218-2001 guide.

Design of ice structures

The instructions given in this handbook apply to the design of structures made of ice. In certain respects, the RIL 218-2001 guide can also be applied. The loads of ice structures are calculated according to general design criteria. In calculations, 920 kg/m^3 can be used for the ice density, regardless of whether natural or artificial ice is used. Melting by the sun and wear by the wind must be taken into account when determining structural strengths.

A special feature of ice is its low impact resistance at low temperatures. As the temperature of ice rises, its impact resistance, i.e. toughness, increases. This must be taken into account in design and construction, as well as during the period of use. Ice structures are designed at the temperature of 0 °C when, according to various studies, the material properties of ice are most reliable, helping achieve sufficient safety during the period of use.

The size and shape of ice crystals and the mutual orientation of crystal axes have a very significant impact on the strength and deformation properties. Therefore, ice structures must be designed so that the crystal structure varies as little as possible in different parts of the structure. It must be addressed in the design that, when using pieces of ice, they must be installed with the freezing direction against the compressive force. Loading directed at ice must be planned to be kept as low and constant as possible and constant during the period of use. When the loading is kept constant, three different phases can be identified in time-dependent deformations (Figure 6) (Kilpeläinen & Mäkinen 2003, 52).

Time-dependent deformations in ice include:

- Primary deformation, i.e. the first part of the graph.
- Secondary deformation, when the deformation increases almost at a constant speed.
- Tertiary deformation if loading is sufficiently large. In this case, the ultimate state is achieved.

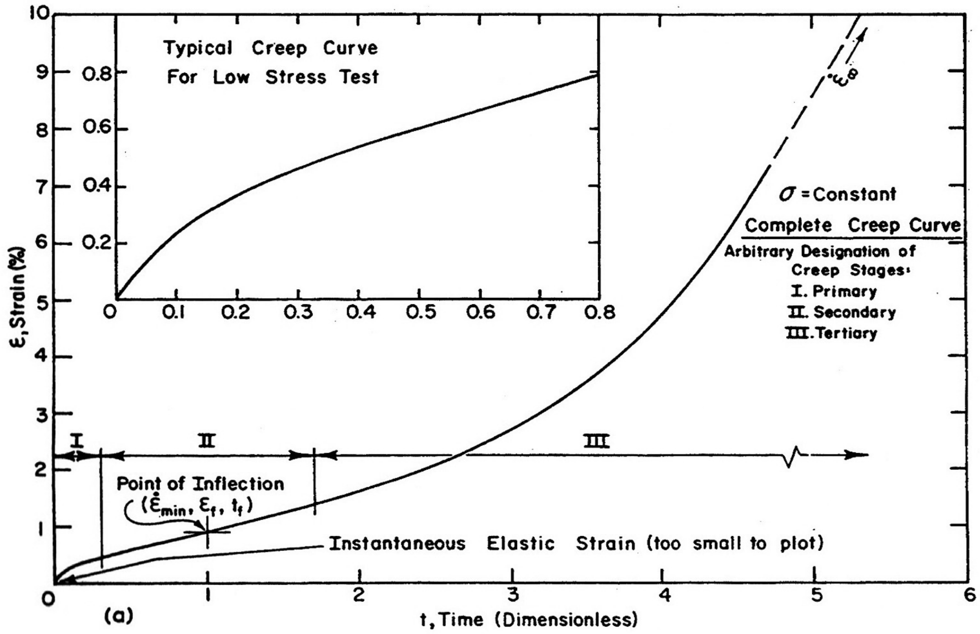


Figure 6. Time-dependent changes in the loading of ice (Kilpeläinen & Mäkinen 2003)

The deformation rate of ice is low. According to the measurements and calculations conducted in the SNOW & ICE METHODS project, the sagging of an ice wall 2 m high during the season remains a few millimetres.

The following criterion must be ensured in the design of ice structures: Compressive strength σ in the service state relative to the temperature of ice T must be achieved (Kilpeläinen & Mäkinen 2003, 62)

$\sigma \leq -0.1 \cdot T + 0.2$ MPa.

For example, when the temperature of ice is -10 °C, the compressive strength should be $\sigma \leq 1.2$ MPa.

In addition to the general design principles, the following are recommended for the design of structures made from **pieces of ice**:

- The structures must be compression structures.

- The slimness and height of the structures can be:
    - Pieces of ice up to 200 mm thick and wide (b × W) with a maximum height of 2 m when unsupported.
    - When supported against the rest of the structure, the height can be up to the height of the supporting structure.
- The overlapping seams of the pieces must overlap by at least the following:
    - Ice blocks and similar shapes with a minimum overlap of half a block.
    - Long pieces of ice with an overlap of at least 1/3 of a piece (Figures 7 & 8).
- If tensile structures such as straight beams in doorways are used:
    - Maximum doorway width is 1,500 mm.
    - The tensile structure is only permitted with long pieces of ice (such as ice logs).
    - The tensile structure's support must be ensured.
- The connection of ice to other structures must be ensured using water or slush in the connections.
- As the material properties of ice vary significantly, a sufficient safety factor must be used in design when determining strengths.

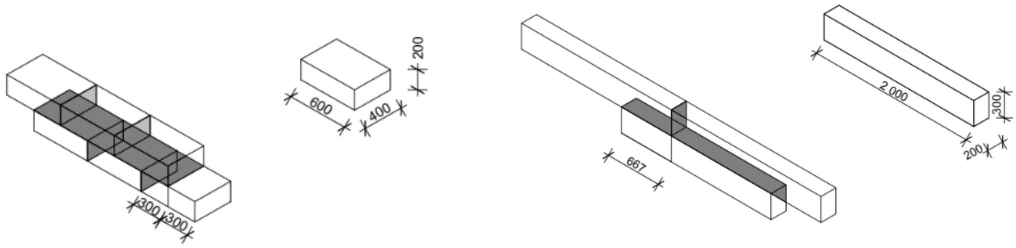


Figure 7 & 8. Recommended overlapping dimensions for pieces of ice in ice structures (SNOW & ICE METHODS project)

In addition to the general design principles, the following are recommended for the design of structures made by **freezing**:

- The compression structure must be used as the structural shape.
- The strength of the structural layer must be at least (Figure 9):
    - 50–100 mm in short-term structures (up to one month of use)
    - 100–200 mm in long term structures (up to six months of use). Strength must be ensured by calculations, e.g. by applying the RIL218-2001 guide, taking into account the effect of melting.
    - The minimum strength also depends on the height and shape of the structure.
- The connection to other structures must be ensured using a sufficient amount of water or slush.
- When using air pressure moulds, the mould pressure must be determined during the design phase. The mould pressure has been found to be sufficient when the pressure carries the mould's weight and the wind load does not move the mould in the initial phase (Kurtakko 2011).

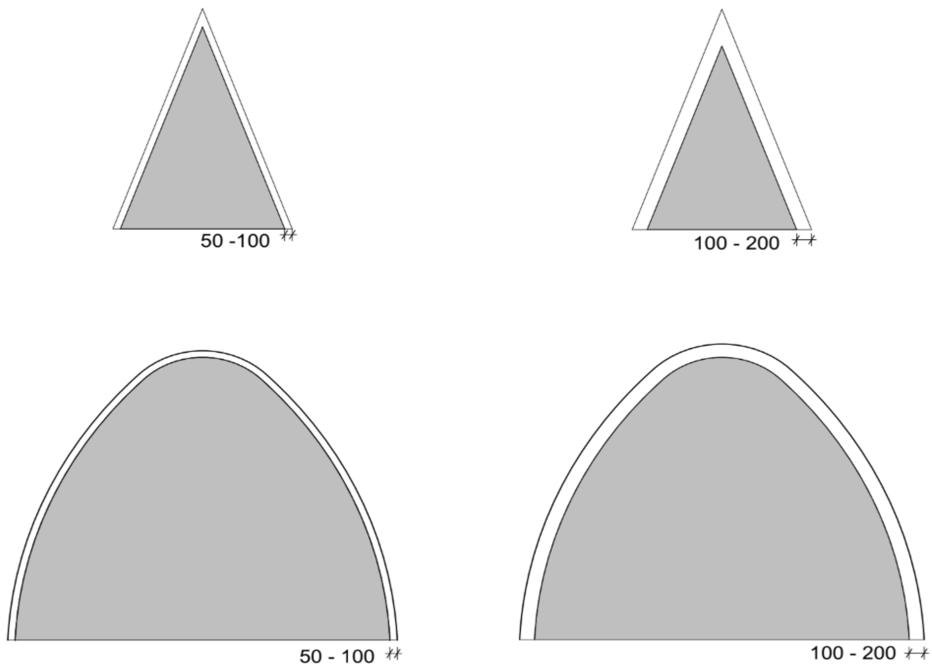


Figure 9. Minimum thickness of the ice layer in an ice structure (SNOW & ICE METHODS project)

Design of slush structures

The instructions given in this handbook apply to structures made of slush. In certain respects, the RIL 218-2001 guide can also be applied. The loads affecting slush structures are calculated as described in the general design principles. The stresses and deformations occurring during the period are calculated according to the RIL 218-2001 guide. Slush structures must be designed so that slush is allowed to freeze completely according to the progress of work. If slush is allowed to freeze throughout the thickness of the material, it will become almost ice-like during use. In this case, the instructions given to ice can be applied to slush. In addition, studies show that deformations and sagging during the use of the structure will be small. According to studies, deformations in slush structures are similar to ice structures. Melting by the sun and wear by the wind must be taken into account when determining structural strengths.

In addition to the general design principles, the following are recommended for the design of structures made from slush:

- Structures must be built as compression structures.
- The thickness of structure must be:
    - at least 300 mm in short-term structures (up to one month of use, Figure 10)
    - in long-term structures of up to six months of use, the strength of the structures during their lifecycle is determined by calculations according to the intended use.
- The connection of structures to other structures must be ensured.
- When using air pressure moulds, the mould pressure must be determined during the design phase.

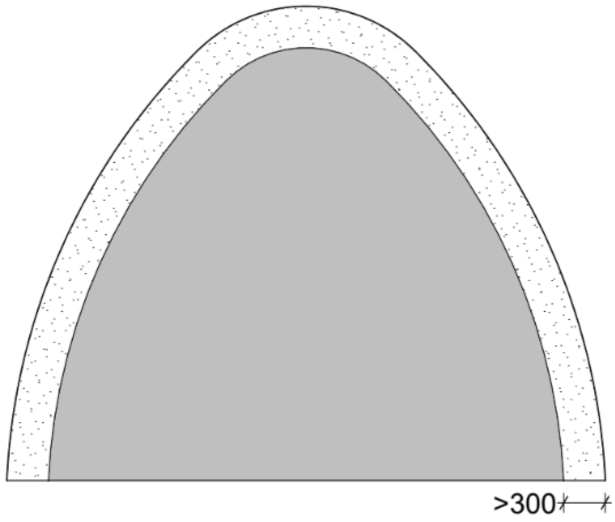


Figure 10. Minimum slush thickness in a short-term structure (SNOW & ICE METHODS project)

2.3 Design of moulds

Moulds give the correct shape to snow, ice and slush structures during the construction phase. Almost any available mould material such as building panels, sheet metal, plastic and wood can be used. The mould to be used must be dimensioned to withstand the mould pressure caused by construction so that the mould remains in place and does not collapse from the material load. The dimensioning method depends on the structural shape and mould material. The RIL 218-2001 guide provides instructions for calculations for wall, arc and dome moulds.

The mould determines the shape and operating principle of the structure, according to which the mould designer should define “critical points” for monitoring the shape and sagging, as well as for the use and filling of the mould during the construction phase.

When using a wall mould, the mould pressure is determined according to Figure 11 (RIL 2001, 55).

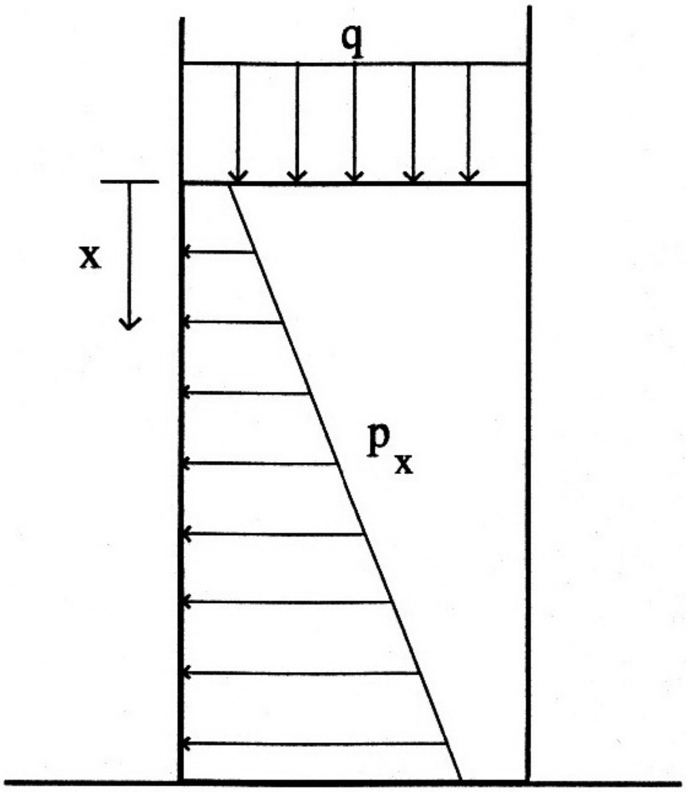


Figure 11. Determination of mould pressure for a wall mould (RIL 2001)

$p_x = (\rho \cdot g \cdot x + q) \cdot K_a$

where

p_x	is the mould pressure for a wall mould	[kN/m^2]
ρ	is the snow/slush/ice density	[kg/m^3]
q	is the temporary surface load, $q \geq 1$ kN/m^2	
K_a	The angle of repose; 0.5 for snow and slush; to be determined separately for ice.	

The mould pressure for arc and dome moulds is determined according to Figure 12 (RIL 2001, 56).

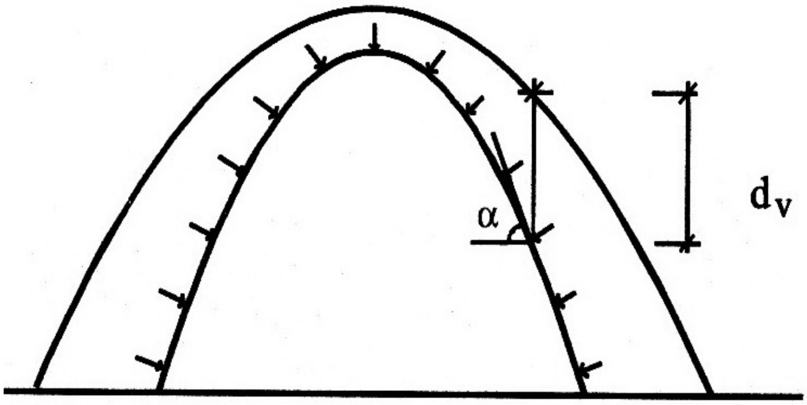


Figure 12. Mould pressure for arc and dome moulds (RIL 2001)

$p_\alpha = \rho \cdot g \cdot d_v \cdot \cos^2 \alpha$

where

p	is the mould pressure	[kN/m²]
ρ	is the snow density	[kg/m³]
d_v	is the vertical thickness of the examined point [m]	

When using arc-shaped moulds, a catenary-shaped arc is the most effective when using snow and slush. A catenary, a hyperbolic cosine equation, can be formed by a flexible chain or rope suspended from two supporting points (Figure 13), (Images 6 & 7). Appendix 1 presents instructions for determining a catenary.

The mathematical formula of a catenary is (Valtanen 2009, 61)

$$y = a \cosh\left(\frac{x}{a}\right) = \frac{a}{2}\left(e^{x/a} + e^{-x/a}\right), \ a>0$$

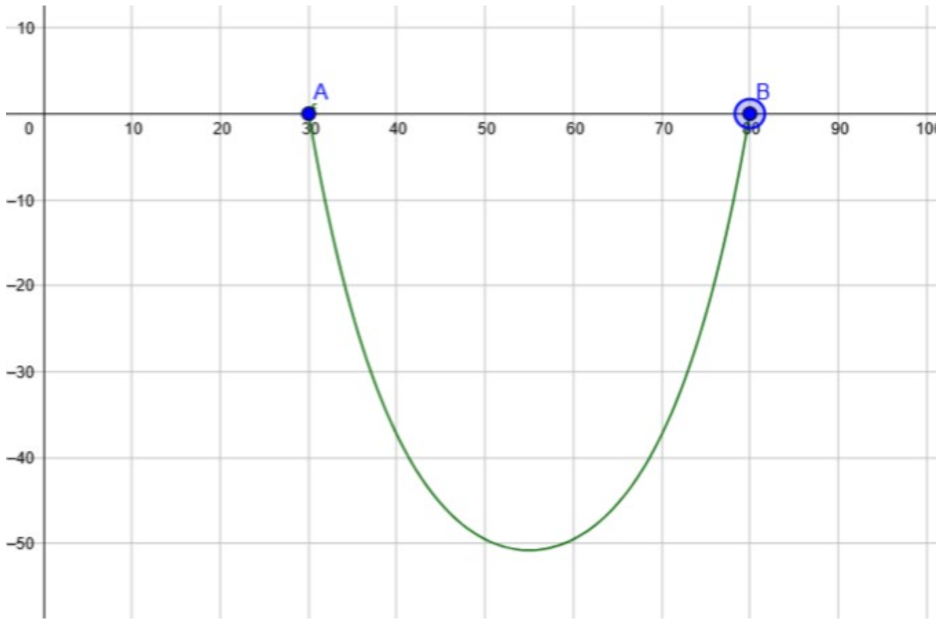


Figure 13. Catenary graph.

Studies have shown that a catenary is also effective in dome shapes made of snow and slush, where the shape of a catenary is realised in each cross-sectional direction of the dome.

Image 6. Steel catenary-shaped vault mould (Ryynänen 2011)

Image 7. A catenary-shaped air pressure mould (Pernu 2022)

2.4 Type structures

Type structures are structural shapes that are proven to be effective when building snow and ice structures. If the instructions presented in this handbook and the RIL 218-2001 guide are followed, more detailed structural design for these structures is generally not required.

The criteria related to the use of type structures are as follows:

- The structural shapes are as presented in the aforementioned instructions.
- The structural strengths are as given in the aforementioned instructions.
- The snow density must be at least 400 kg/m^3 in the construction phase.
- The structures should mainly be compression structures. Tensile structures should only be used in narrow passageways or doorways.
- Snow and slush must be compacted thoroughly in the construction phase.

- In large structures, a three-layer structure can be used, consisting of ice-slush-snow layers.

Walls and towers

Walls (Image 8) and towers can be used as type structures:

- When building from snow and slush or when structures are laid from pieces of ice.
- Structures are vertical and usually free-standing.
- The shape can be evenly thick or thinning upwards evenly or gradually.
- Dimensioning must address the falling over, tilting and sagging of the structure.

Image 8. A free-standing evenly thick snow wall (Pernu 2025)

Arc and vault structures

Arc and vault structures can be used as type structures:

- When building from snow and slush or by freezing (Figure 14, Image 9).
- The main stresses are compressive stresses. The best shape of the structure is a catenary.

- The ratio between the arc and the arrow rise f and the internal span L during the commissioning phase must be at least f/L>0.5.
- The ratio between the thickness of the structural base d_k and the span L must be at least $d_k/L>0.2$ (RIL 2001, 40).
- The ratio between the thickness of the top of the structure dl and the span L must be at least $d_l/L>0.1$ (RIL 2001, 40).

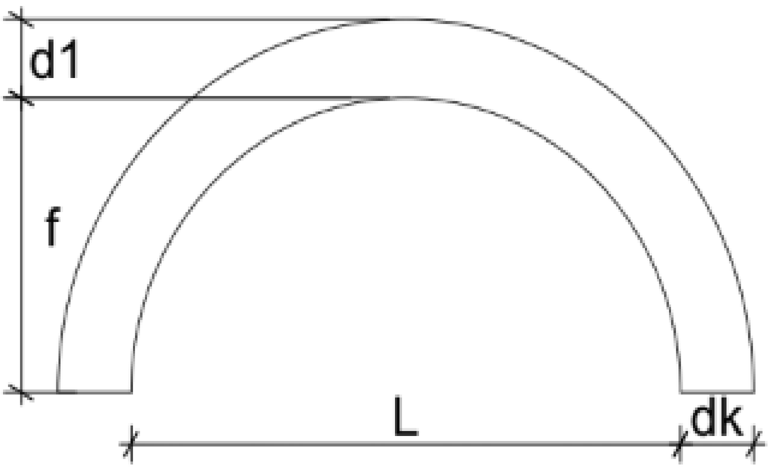


Figure 14. Dimensions and parts in an arc structure (RIL 2001)

Image 9. Arc-shaped snow corridor (Pernu 2024)

Example 1: It must be verified whether the dimensioning criteria are met during the structure's commissioning phase when building an arc corridor with the following dimensions:

- Internal corridor width 3 m
- Height of the interior at the beginning 2.5 m
- Snow thickness at the base 0.8 m
- Snow thickness at the top 0.4 m.

Solution

The ratio between the arc and the arrow rise f and the internal span L

$f / L = 2{,}5 \text{ m} / 3 \text{ m} = 0{,}833 > 0{,}5$ (ok)

The ratio between the base thickness d_k and the span L

$d_k / L = 0{,}8 \text{ m} / 3 \text{ m} = 0{,}266 > 0{,}2$ (ok)

The ratio between the top thickness d_l and the span L

$d_l / L = 0{,}4 \text{ m} / 3 \text{ m} = 0{,}133 > 0{,}1$ (ok)

Dome structures

Dome structures (Image 10) are the most common type structures alongside the arc and vault structure. Significant experience has already been obtained from the use of dome structures. The structure is highly resistant to sagging, as long as the original shape is maintained.

Dome structures can be used as type structures:

- When building from snow and slush or by freezing.
- The ratio between the rise f and the internal diameter L must be at least $f/L>0.5$ during the commissioning phase (Figure 15) (RIL 2001, 44).

- For elliptical structures, the ratio between the rise and the internal diameter f/L is not constant in all directions. Elliptical structures always require an ice layer as a load-bearing layer.

Image 10. Dome structure (Pernu 2022)

3. Permit and building process

3.1 Legislation and official guidance

In Finland, snow and ice construction, similarly to other construction, is governed by the Building Act and the National Building Code of Finland. In addition, municipalities may issue special regulations and guidelines in their building codes.

The construction of professional buildings or structures built from snow, ice or slush, including tourism structures, normally require a building permit. The Building Act, which entered into force in 2025, enables the construction of certain buildings without a building permit. Nevertheless, they must be built in accordance with valid regulations and law. Snow and ice buildings can be made as temporary buildings if the building is intended to be erected for a maximum of ten years. This permit procedure may allow derogations from the

Building Act. In addition to the current legislation, information about building permits and the documents required can be obtained from municipal building control. **The aim is always to ensure the safe use of buildings.**

These guidelines recommend that the construction-related permit procedure be required at least in the following cases:

- If professional accommodation or restaurant activities are carried out in a snow, ice, or slush structure.
    - Rooms for overnight stays.
    - Restaurant facilities, and facilities for serving food or drink.
    - Conference rooms.
- If the shape and size of the structure are such that users go inside the structure or under load-bearing structures.
- If the structure has been built in a public place such as a square and the area is freely accessible to the public.

Permit practices and official requirements may vary by location. Therefore, it is recommended to contact the local authorities at an early stage to address local requirements in addition to general requirements in snow and ice construction projects.

The procedure may require the following information and documents:

1. Site plan
2. Planning drawings
3. Specifications
4. Rescue plans
5. Operating and safety plans
6. The appointment of responsible persons

The construction and use of the snow and ice structures are also governed by other legislation, including the Consumer Safety Act and the Occupational Safety and Health Act, depending on the intended use. In addition to legislation, operations may also be subject to official permits and guidelines, which must be followed in construction and in activities related to the use and operation of the building.

These include:

- The Finnish Safety and Chemicals Agency (Tukes) (Safety instructions for snow and ice structures from 2008). The instructions are attached to this handbook in Appendix 2.
- Rescue services (rescue plan, fireproofing and operational safety).
- National Supervisory Authority for Welfare and Health (Valvira) (e.g. alcohol serving license)

3.2 Drawings to be prepared for snow and ice structures

Architectural and structural drawings must be prepared for snow, ice and slush structures for the building permit procedure and construction process. Rakennustieto (RT) card 103396 is recommended for drawing notes. The drawings must be prepared by a person who is considered to have sufficient professional skills to prepare the drawings. Appendix 3 presents example drawings for snow and ice structures.

The drawings prepared for snow, ice and slush structures must present at least the following:

- The main dimensions of structures and permitted tolerances.
- Nominal dimensions at the time of completion of the structure.
- The required minimum density of snow and slush in different parts of load-bearing structures.
- Other possible materials in the structures, such as steel and wooden supports.
- Doors, windows, other recesses and design solutions that weaken the structure.
- Estimated sagging rates of the structures.
- Permitted angles of tilting for the structures.
- Other information and factors affecting the strength and safety of the structures.

- Changed threshold dimensions resulting in suspended and ended use of the structures.
- Measurement points for deformations in load-bearing structures.
- Location of reference points for the measurement of deformations.

Separate mould drawings must be prepared for the moulds used in construction. The moulds must be dimensioned for the loads caused by the building material and the transfer of the moulds. The mould drawings must be prepared in accordance with the mould material used. If required, a plan for the use of moulds must be prepared. When the same structures are built each year in a different order, the drawings must be updated and checked considering changed locations.

3.3 Specification

The architectural and structural drawings prepared for snow, ice and slush structures can be supplemented with a specification. This defines the construction phases in detail. Appendix 4 presents an example of a snow and ice construction specification. The specification must be prepared if necessary and is mandatory in locations subject to a special procedure.

The specification must include instructions and recommendations for the following:

- The building materials used.
  - Snow (natural/artificial).
  - Ice (pieces of ice/structures made by freezing).
  - Slush (including the amount of water).
  - Other materials (e.g. steel and wooden brackets).
- Material handling in the construction phase.
  - Snow compaction.
  - Adding water to snow in slush construction.
  - Pre-treatment of ice.
- Construction methods.
  - Mould construction.
  - Attaching pieces of ice to each other with slush or water.
- Construction phases.
  - The arrangement of work with different structures.

- The moulds used.
    - Mould rotation.
    - Installation instructions for moulds.
- The machinery and equipment used.
    - The transfer of snow (in the area/to the structures).
    - The transfer of ice.
- Deformation measuring points.
    - The location.
    - Material and construction of reference points.

3.4 Construction site

The construction site is determined by the user's needs. Recommendations for factors affecting the selection of the construction site:

- The area must have sufficient space for construction and structures (Figure 15).
- There must be a water and electricity connection and electricity in the area.
- If artificial snow is made in the area, it will increase the size of the required construction area.
- The area should be protected from the sun to slow down the melting of structures in spring.
- The ground must be as flat as possible.
- There should be a base that can be frozen with water and snow.
- The frozen area should be larger than required by the structures.
- There should be sufficient space for construction machines, depending on their size.
- Construction machines must be able to move around the construction site, especially around structures that snow is blown onto.
- Melting water resulting from the melting of structures and their controlled removal from the area should be considered.
- There should be consideration of ground frost and the effects of frost, especially in the use of ice structures and elements.
- Consideration should be given to the effects of air pollution and pollutants in the area: impurities in snow and accumulating on snow

weaken snow's ability to reflect sunlight and accelerate melting, especially in spring

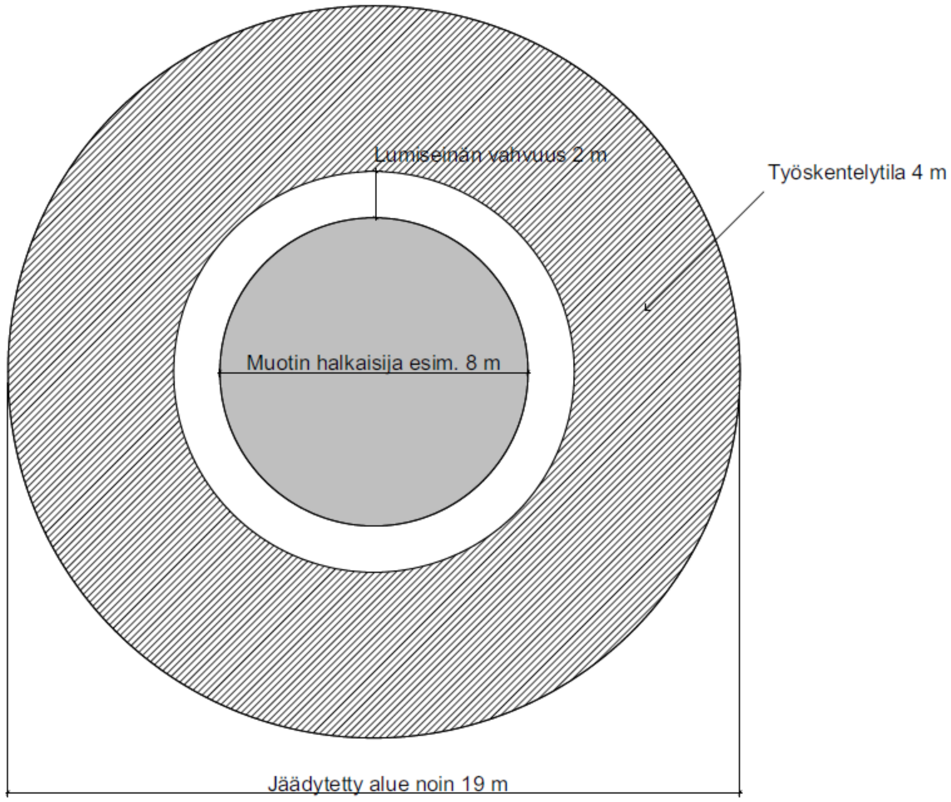


Figure 15. Example of determining the size of the construction area (Riikonen 2009)

4. Safety during construction phase

4.1 Occupational safety in snow and ice construction

Snow and ice construction is demanding in terms of conditions and materials, requiring occupational safety to be addressed in slightly different ways than on regular construction sites. Construction takes place outdoors in winter conditions, where cold, dark and slippery conditions present their challenges to working. On the construction site, safety starts from the comprehensive identification and minimisation of risks. Any hazards must be identified accurately before starting work. On the basis of this, a safety plan must be drawn up, which defines the means of managing work-related risks and provides straightforward instructions for safe operation.

Employee induction is an essential part of safety practices. Induction must cover safety instructions and the special characteristics of the construction site, and guide everyone to work safely on the site. All safety issues must be documented in detail. Written documentation is not merely a formality; it helps ensure that risks have been identified and managed in advance. Good practices, including straightforward instructions and cooperation on the site, support safety and make working smoother.

Occupational safety checklist:

- Identify risks: identify hazards in advance.
- Minimise risks: as a rule, identified risks must be eliminated or, if a risk cannot be eliminated, exposure to risks must be minimised.
- Appropriate protection: protection against identified risks that cannot be eliminated.
- Provide induction for site employees: employees must be provided with comprehensive induction.
- Prepare a safety plan: the plan must include risk management measures and instructions for safe working.
- Provide clear instructions: a good flow of information and straightforward instructions are key to maintaining safety.

Occupational safety equipment

Occupational safety equipment helps prevent risks and protect against them. Helmets, safety shoes, hearing protectors and goggles are basic equipment, but appropriate clothing should also be worn when working outdoors. For example, warm and waterproof high-visibility clothing not only helps prevent frostbite but also ensures that working is comfortable and employees can be seen in frost and snow. Headlamps are required when working in dark conditions to provide visibility both forwards and backwards. In addition to illuminating the working area, headlamps also help operators of machines moving around on the construction site see other employees. On slippery surfaces, it is recommended to use anti-slip devices placed over shoes, including chains or studs, when construction work is in progress.

Recommended protective equipment for snow and ice construction:

- Helmet
- Safety shoes
- Hearing protectors
- Safety goggles
- Warm clothing according to weather conditions
- Headlamp (with illumination forwards and backwards)
- Anti-slip devices for shoes (chains or studs)
- Any accessories when using applicable tools (e.g. chainsaw or fall protection)

4.2 Safety on the construction site

Safety on the construction site must be ensured by thorough planning and high-quality safety measures. Working areas must be fenced and delimited so that outsiders cannot accidentally access the construction site area. In snow and ice construction, work is mainly carried out during the darkest times of the year, which is why the construction site must be illuminated properly to minimise risks. As construction work progresses, slip prevention such as gritting must be ensured on slippery surfaces in the area when this is possible, taking into account future work stages. Fall protection must be implemented in the same way as on regular construction sites if the nature of work requires it in accordance with valid legislation governing occupational safety. When the base is made of snow and ice, special attention must be paid to the stability of scaffolding and other work platforms.

During the mould dismantling phase, the structure may collapse, due to which no-one should go under the structure until the structure has been found to be safe and built correctly in accordance with the designs. Collapsing in the mould dismantling phase may be caused by deviations in the structural layers as a result of work periods or changes in conditions, or insufficient structural strength development before mould removal. Working in pairs is a good safety practice in high-risk situations. For example, when sawing opening to snow wall, work pairs can be used to position the employees participating in the work phase in areas on both sides of the wall structure, thus ensuring that the saw blade coming through one side of the wall does not present a hazard.

In addition, it is good to have a heated maintenance room near work areas, where employees can warm up and take breaks. The importance of a maintenance room in risk management is emphasised especially when the possibility of hypothermia increases. Such situations can arise, for example, when there are no heated buildings nearby, the weather is particularly cold and water is handled while working, making it possible for equipment to get wet.

Selecting and using the correct tools is especially important in ice construction. Not many tools designed specifically for snow and ice construction are available on the market, which is why tools designed for other purposes have to be used. In such situations, not all the required safety equipment, instructions and precautions applied in the context of snow and ice construction may necessarily be available. This requires that supervisors know how to define the precautions and the necessary safety equipment, as well as to provide comprehensive induction. Sharp chisels, power saws and chainsaws, as well as other special tools such as snow files can be useful, but they must be used considering the limitations mentioned in their operating instructions, and appropriate protection is required against associated risks: for example, when using a power saw or chainsaw, safety equipment designed for loggers with protection against saw chains should also be used. Battery-powered saws are especially recommended, as they eliminate the tripping hazard associated with cables.

4.3 Technology and electrical safety in snow and ice buildings

In snow and ice construction, various electrical equipment, technical systems and technology is used for safety, comfort and enjoyment. Buildings can often have electronic warning and guidance devices, including fire alarms and illuminated emergency exit signs (Image 11).

Image 11. An illuminated emergency exit sign (Pernu 2024)

Convenience and entertainment, in turn, are provided by lighting, possible projections, as well as other media and AV systems. In addition, activities carried out in buildings, including restaurant services, may require other electrical equipment to be placed and used in the areas.

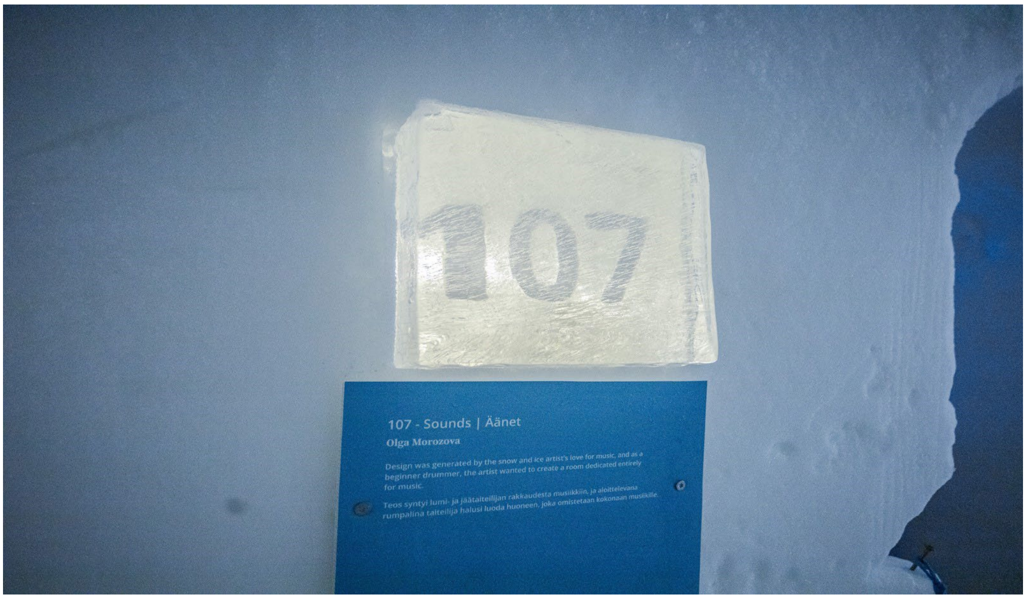
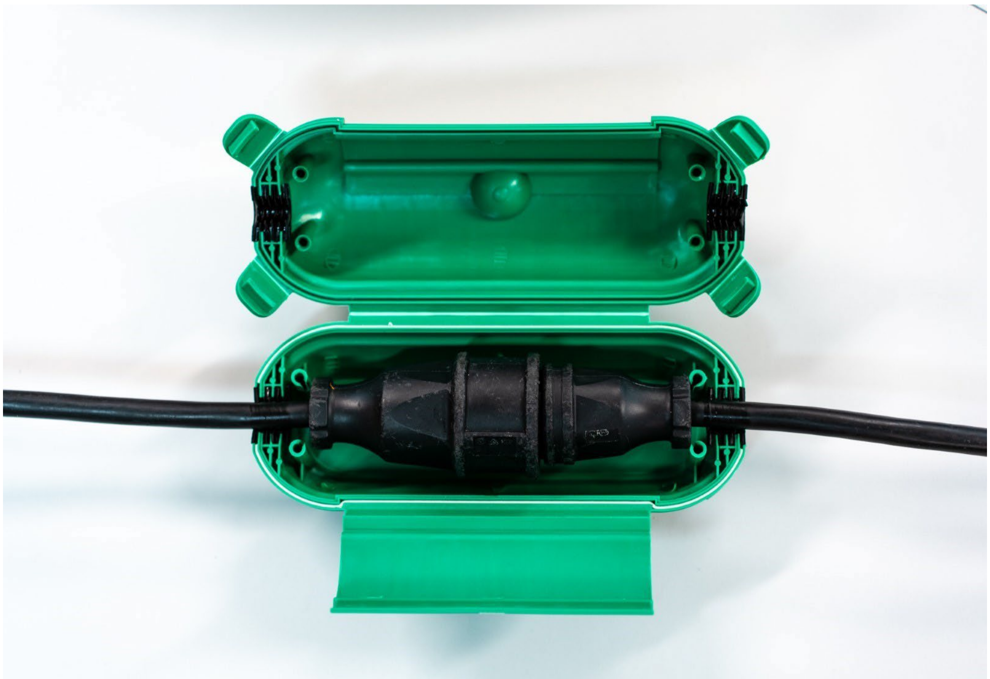


Image 12. Room numbers using LEDs and ice at the Lehtojärvi snow and ice hotel (Pernu 2024)

The equipment, cables and other related accessories used in snow construction must be CE-marked and IP-rated for outdoor use. Where possible, DC devices such as LEDs and media systems should be used. Distribution boards with residual-current devices or similar enclosures designed for outdoor use must be used with AC equipment. If extension cords are used, the connection points must be protected with IP-rated protective enclosures, e.g. as shown in Images 13 and 14. In electrical installations, protection must be carried out in such a way that neither users nor customers can access electrical systems. Cables must be protected during construction and use so that site traffic or maintenance operations cannot damage them. For example, cable trays can be used.



Images 13 and 14. IP-rated protective enclosure to protect cable connections (Pernu 2024)

On larger sites, an electrical designer should be used to manage the system as a whole and make installation easier. For electrical installations, the authorities usually require inspection records. All electrical appliances generate heat, which must be taken into account when placing electrical equipment inside snow. The heat generated by lights will not be a problem if areas are illuminated by spot lights installed farther away as in Image 15. Melting can be minimized and safety can be improved by using low-current systems.

Image 15. Illuminating an ice sculpture from the side at Arctic SnowHotel in Lehtojärvi (Pernu 2025)

Maintenance requirements in snow and ice structures should be taken into account when planning installation locations. Installing other materials inside snow or ice may be challenging if the thermal conductivity of the materials differs significantly from that of snow. Examples include metals that “melt” space around them. In such cases, it is recommended to use non-heat-conductive support structures deeper in the structure. In practice, cracks and fractures in structures may need to be patched with snow during the period of use. If possible, the removal of cables should be taken into account during the design phase so that their removal does not require the snow and ice structure to be melted completely.

5. Manufacturing and storing of building materials

5.1 Making artificial snow

Two types of equipment are commonly used for making artificial snow: snow cannons and snow lances. Different variations of these are also available. Snow cannons can be controlled either manually or automatically according to weather conditions. In addition to snow cannons, snowmaking requires electricity and water, and a booster pump is normally used to increase the water pressure. When planning snowmaking, it is important to consider the capacity of the site's electrical connection and the amount of water available.

In terms of safety, it is important that electrical equipment is suitable for the conditions and furnished with appropriate IPX ratings. As water lines usually contain a pressure of several dozen bars, they cannot be opened when pressurised. In addition, any hose breaks must be taken into account, especially when hoses are used in the terrain. If the equipment used includes a built-in compressed air system, its high pressure must also be addressed in safety practices.

When working outdoors, it must be ensured that work equipment and high-visibility clothing are suitable for the prevailing weather and working conditions. In addition, wind conditions must be taken into account so that snow blown from a cannon remains in the areas designed for it and does not interfere with activities in the nearby area.

Snow blowing near airports

Snowmaking near airports involves significant safety and cost perspectives, which must be taken into account. Ice crystals produced by snow cannons can reach runways up to 10–15 kilometres away under certain conditions. When the crystals adhere to the runway surface, they significantly reduce friction and cause harm to air traffic. Especially in very cold weather (-20 °C or below), removing ice adhered to runways can be very challenging or even impossible, and causes significant costs.

The wind direction is a significant factor in the travel of snow blown from a cannon. In addition to addressing the wind direction, lowering and adjusting the power of snow cannons can help reduce the amount of crystals accessing runways

Checklist for snow blowing near airports:

- Note the wind direction: do not make snow if the wind carries ice crystals in the direction of an airport.
- Adjust the direction and power of snow cannons: point the cannons towards the ground and reduce their power if necessary.
- Cooperate: if required, contact the airport operator and ensure the sufficiency of snowmaking precautions together.

5.2 Storing snow

In snow construction, snow is usually stored both to reduce the need for snowmaking and to manage condition risks. Stored snow is particularly suitable for use in hidden and secondary structures, base structures and the construction of routes requiring snow. Its texture is icier and its crystals are larger, which makes it durable and usable in situations where the cleanliness or appearance of snow is irrelevant. Stored snow can also be used in snow building structures, but it often requires processing, such as grinding using a snow blower, to make the composition of the snow smoother. If fresh snow is added to stored snow, its uses will expand significantly.

Disadvantages of stored snow are related to its coarse and icy texture, as well as impurities, which make it less suitable for use in detailed sculptures or structures where visual design is essential. Stored snow may contain clumps, which complicates its shaping and often requires patching with fresh snow. In sculptures, this may mean that details, including small features in figures, cannot be made accurately.

Image 16. Stored snow and ice (left) and fresh snow (right) in a single structure at the Lehtojärvi snow and ice hotel (Pernu 2025)

For the next season, snow can be stored in two ways. Snow can either be directly blown into a storage pile, or collected from previous structures, slopes or other sites at the end of the season and piled up for storage. For example, snow groomers, excavators or wheel loaders can be used to make snow piles. The shape of the pile is determined by the covering material used, but most commonly they are long and narrow piles shaped in a semicircle.

Cover materials and their use

The most common cover materials include geotextiles, covers with XPS insulation and sawdust, which is, however, used more rarely. Geotextiles are spread overlapping over the pile, either manually or using an excavator, usually two or three layers on top of each other. Seams are taped to keep the covers in place. During installation and removal, the slipperiness of the covers and snow must be taken into account, and protective equipment must be used.

Cover materials with XPS insulation can be spread in the same way either manually or using an excavator. When handling these materials, it is also important to note the slippery surface of the insulation and use appropriate protective equipment. Sawdust is an inexpensive material that is easy to handle because of its small particle size, and when used in the storage of snow, the cover layer is usually a 30-40 centimetres thick. Unlike the previous options, sawdust mixes to some extent with the surface layers of the stored snow during its removal and is easily carried elsewhere in windy conditions, meaning that not all storage sites are suitable for the use of sawdust.

5.3 Construction of ice and slush structures

To be noted in the construction of structures built by freezing

- Water must be sprayed so that it has time to freeze over the previous layer as construction progresses.
- The outdoor temperature must be sufficiently low for ice to be formed using water.
- The water used for freezing must be clean. Any impurities reduce the long-term durability of the material.

To be noted in the construction of structures made of pieces of ice

- Ice pieces and blocks removed from natural waterbodies can be used as pieces of ice (Image 17), as well as pieces frozen using moulds.
- The thickness and size of blocks varies depending on ice and the structure.
- When lifting ice, its freezing direction must be marked.
- Ice must be installed in the structures in the freezing direction to ensure the durability of the material in the compression direction.

Image 17. An ice block wall at Jukkasjärvi (Pernu 2024)

To be noted in slush construction

- Water must be sprayed over snow using a spray nozzle (e.g. Pesukarhu nozzle) during the snow blowing phase (Image 18).
- The amount of water depends on the outdoor temperature, the properties of snow, the power of the snowblower, and the snow blowing method.
- There is no single rule for the amount of water relative to the amount of snow.
- Sufficient structural compaction must be ensured.
- The freezing of the water must be ensured. If too much water is sprayed, it will go under the structure or remain unfrozen in the structure. This may cause the structure to sag.

- Cooling the air inside the structure must be ensured immediately after mould removal so that the slush material can freeze during the construction phase. Freezing reduces the amount of sagging.

Image 18. Spraying water during the snow blowing phase (Pernu 2022)

6. Practical construction instructions

6.1 Domes

Snow blowing using an air pressure mould

Phases related to construction using an air pressure mould:

1. Snow must first be blown to the bottom of the air pressure mould. Snow falls to the base of the mould. The snow must be compacted by trampling it between the plywood mould and the air pressure mould. The walls of the doorways and tunnels are important. Snow must not be compacted too close to the air pressure mould to ensure that the mould is not pushed inwards.
2. Pressure must be adjusted suitably for snow blowing, depending on the size of the mould being used.

3. The blower unit must be protected so that water or snow cannot enter the blower inlet. If this happens, the mould pressure drops.
4. A power supply must be ensured throughout the construction phase.
5. Snow must be blown directly at the mould so that it falls along the surface of the mould. This way any snow pieces fly away from the surface of the mould and the inner surface becomes smooth.
6. Snow must be blown with a long lance directly from the top down. As a result, the snow is compacted properly in the structure. The snow must be compacted as the work progresses.
7. The plywood mould must be lifted after it has been filled.
8. If water is mixed with the snow, it must be sprayed throughout the snow blowing process.
9. When snow blowing is interrupted, no slanted surfaces must be left in place, from which snow may later start to slide. Compacting snow by trampling helps because the surface of snow becomes uneven.
10. Water must be sprayed on the walls of entrance tunnels so that they are almost like slush, and the walls must be compacted properly. As a result, the shape of doorways can be maintained during the use of the structure.

A snow mould for round structures (slip casting)

The following are required to build a slip casting mould (Figure 16):

- Film faced plywood of 6 mm, size 1.5 m × 3 m. Plywood is required for the length of the circumference. 250 mm of plywood must be added for each joint.
- One wire pulley per plywood joint is required.
- Three cotter pins are required for each plywood panel.
- The mould can be lifted using, for example, a 1½-inch water pipe as 3-m-long rods with extensions enabled.
- In addition, plastic rope is needed between the plywood and the wire pulley for plywood lifting.

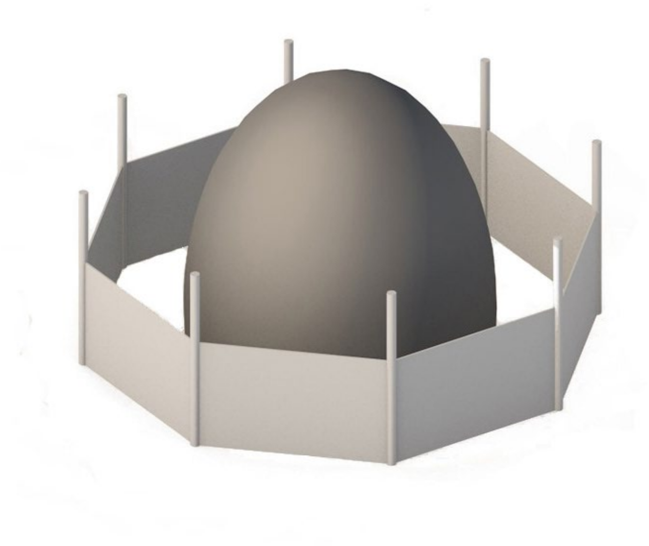


Figure 16. Slip casting mould parts (Riikonen 2009)

Blowing artificial snow directly over the structure

Artificial snow made on the construction site can be blown directly over the mould using a snow cannon during the construction phase. To be noted in the direct blowing method:

- Snow must be blown starting from the bottom of the mould.
- The snow cannon must be moved around the structure. Snow must be blown evenly around the mould.
- Snow must be compacted during blowing as the work progresses.
- Any snow accumulating at the top of the mould must be removed at the beginning.
- The snow layers must be sufficiently thin. The layers must be allowed to freeze after each layer has been completed.
- In tall structures, a high-pressure cannon can be used (Image 19), whose nozzle can be raised over the structure being built.

- In direct snow blowing, the removal of excess water from the structure must be planned and enabled.

Direct snow blowing makes the structure durable and achieves a clean and smooth inner surface. At the same time, fewer work stages are required and machine costs are lower. In addition, the need for artificial snow decreases.

Image 19. A high-pressure lance suitable for direct blowing in Ounasvaara (Pernu 2025)

Slush structure for large structures

Large air pressure moulds are also suitable for slush structures (Figure 17). In this case, the following must be considered in construction:

- The mould must be pressurised and its pressure must be kept constant throughout the construction process, e.g. 2 kPa.
- Snow must be blown against the mould from all sides.
- Snow must be compacted by trampling, and the structure must be watered properly at the same time.
- The formed slush layer must be frozen.

- During the next phase, water must be sprayed over the mould until a layer of ice of about 60–100 mm, i.e. the load-bearing layer, has been accumulated.
- When the load-bearing layer is strong enough, a layer of snow of at least 150 mm must be blown over the water layer.
- A plywood mould must be installed around the outer circumference.
- The plywood mould must be lifted upwards as needed.

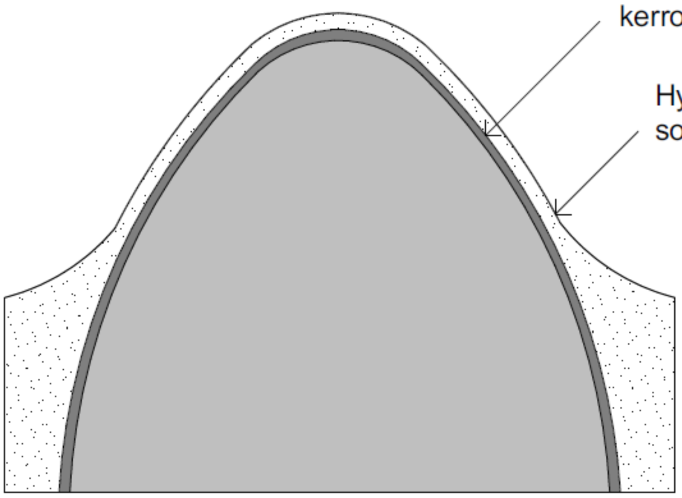


Figure 17. Example of the structural strengths of a large slush structure (Riikonen 2009)

Oval three-layer structure

When building large structures, a three-layer structure is technically the most effective. A three-layer structure from the inside consists of: an ice layer, a slush layer and a snow layer.

The following layer thicknesses are most common in a three-layer structure (Figure 18):

- Ice layer: approx. 50 mm
- Slush layer: approx. 150 mm
- Snow layer: approx. 400 mm.

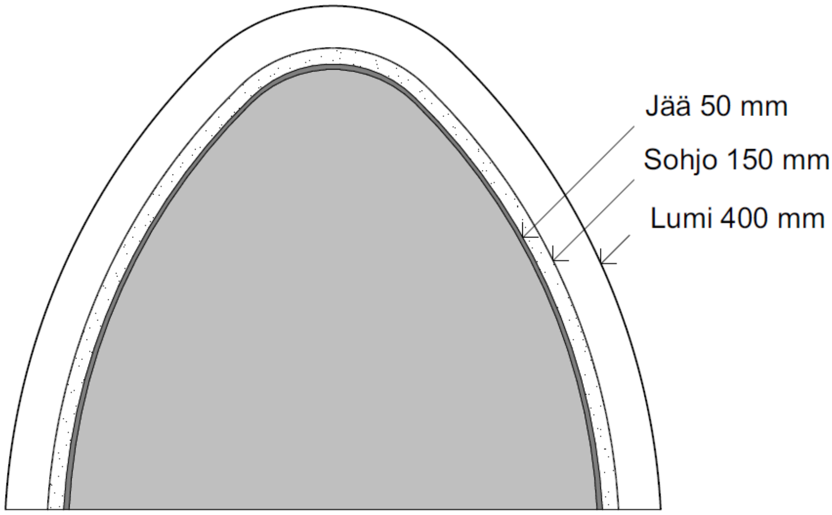


Figure 18. Layer thicknesses in a three-layer structure (SNOW & ICE METHODS project)

For example, when using a prefabricated oval mould of 10 × 15 × 4.9 m, the construction phases are:

1. The bottomless prefabricated oval mould is attached to the ice by freezing on a flat base which has been raised with wet snow.
2. Raising is required to prevent surface water from entering the structure in the spring.
3. The mould is attached to a groove about 10 mm wide and 80 mm deep by freezing.
4. After the mould has been attached, it is pressurised at a low pressure.
5. The mould is entered through the zipper door. Slush is placed inside the mould.
6. The mould is pressurised to roughly 1.3–2.0 kPa.
7. Water is sprayed to freeze an ice layer of about 50–60 mm.
8. At the end of the ice layer, snow is mixed with water and a layer of about 150 mm of slush is made.
9. Once the total thickness of the ice and slush layer is about 200 mm, only snow can be added.
10. The layers are compacted properly together.
    The thickness of the snow layer cannot exceed 500 mm.

Igloos for overnight stays

The wall thickness of an igloo for an overnight stay must be sufficiently high due to heat inside the structure and light permeability (Figure 23). Igloos for overnight stays are usually designed according to a dome structure. The structural strength recommendations given here are based on structures that have been proven to work in practice. For ventilation, igloos for overnight stays must have a hole at the top of the structure as shown in Figure 19. Replacement air is easiest to supply through the doorway. When using a door, an air gap should be left below or above the door for replacement air, or the supply of replacement air should be arranged from the bottom parts of the structure.

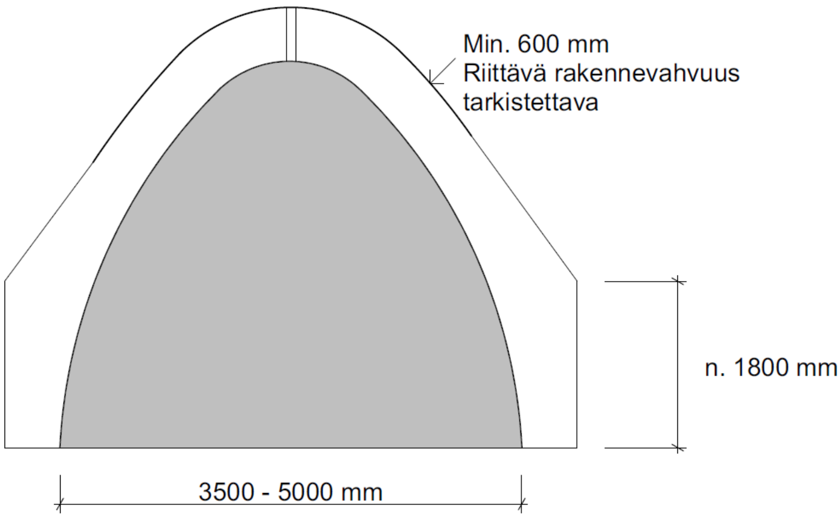


Figure 19. Recommended structural strengths and strength checkpoints in igloos for overnight stays made from snow (Riikonen 2009)

Building a stage from snow

Building a stage from snow or slush using an air pressure mould includes the following steps (Image 20):

1. An air pressure mould is erected (e.g. a mould with a diameter of 5 m).
2. A door mould is placed to the back of the stage for climbing onto the stage.
3. A plywood mould is installed in the outer circumference.

4. Snow is blown between the moulds. Large amounts of water are sprayed over the snow, especially at the top of the stage, but not over the part to be cut.
5. The plywood mould is lifted as the work progresses.
6. Slush must be allowed to freeze before removing the mould.
7. The stage is shaped by cutting any excess snow.

Image 20. A snow stage in the Kemi snow castle (Riikonen 2011)

In practice, it has been found that half of the snow dome structure can be cut off. A stage can also be built as a tunnel structure, where the stage is at the mouth of the tunnel structure.

6.2 Arcs and corridors

Construction using a fixed arc mould (catenary)

When building from natural snow, snow must be blown at least twice and water must be mixed with snow during the blowing phase. The snow spray must be directed at the previously blown layer (Figure 20).

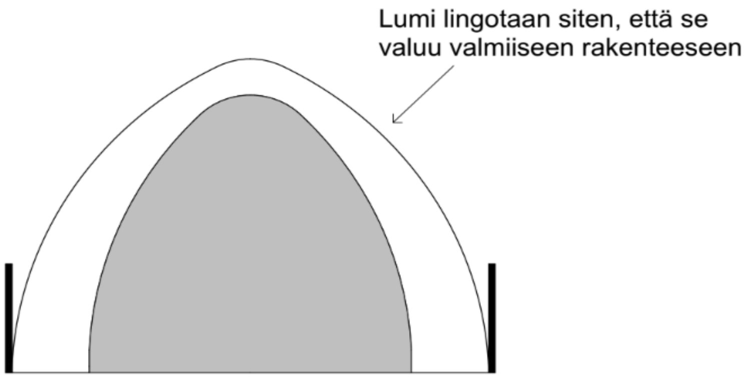


Figure 20. Snow blowing using a fixed arc mould (Riikonen 2009)

Phases and important steps related to fixed mould construction:

- If snow settles and forms a crack during construction, the crack must be compressed before the mould is lowered.
- The crystalline structure of snow must be broken by blowing the snow twice before blowing it over the mould.
- The snow must be blown so that the snow spray is directed at the previously blown snow layer.
- The snow must be compacted continuously during snow blowing and at least after every 300–500 mm layer.
- When moving the mould, no-one may go immediately under the built arc due to the collapse risk.
- The thickness of the snow layer must be identical on both sides of the mould.

Building a corridor using a plastic film mould

Steps in building a raised corridor (Figure 21):

1. Short strips are frozen to the side of the frozen base roughly every 1 m.
2. A 15-m-wide plastic film is spread so that one edge of the film goes approximately 30 mm over the mounting plank.
3. Mounting planks are installed over the film on both sides.

4. A beam to raise the film is installed over the film.
5. The plastic film is wrapped over the beam and the edges of the film are taped together over one of the mounting planks.
6. The mould is pressurised at a sufficiently high pressure.
7. An ice layer of approximately 50 mm is frozen.
8. A slush layer is built over the ice layer using snow and water. The structural thickness of the slush layer is about 100 mm at the top, about 600 mm on the walls.

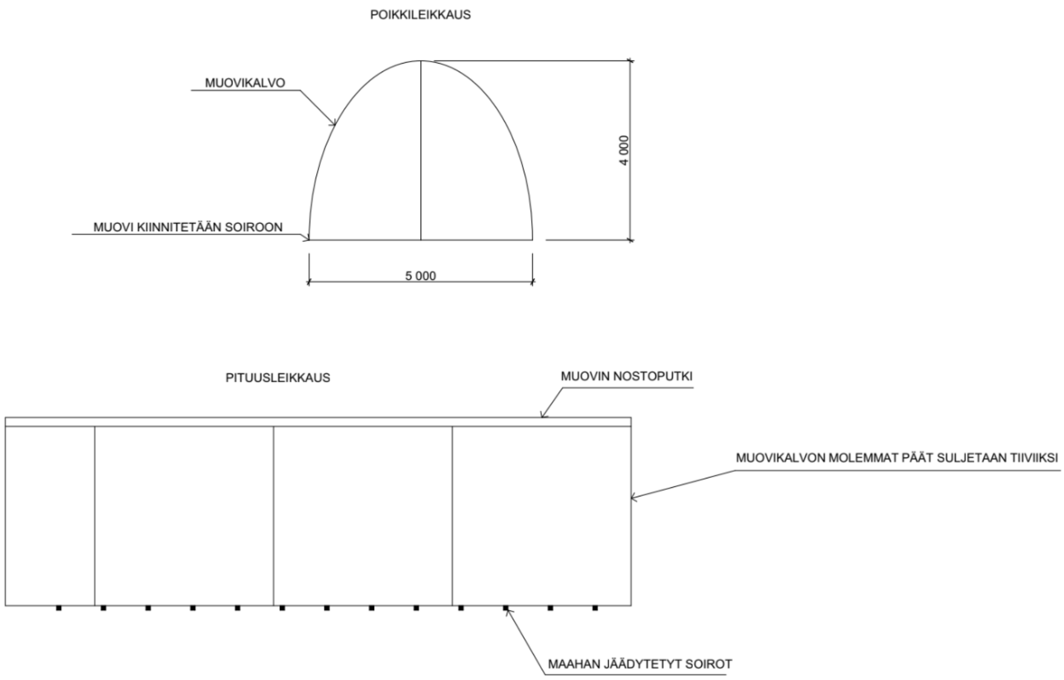


Figure 21. Basic drawing of a corridor mould (Riikonen 2009)

Prefabricated door moulds

Prefabricated doorway moulds can be used in construction (Image 21).

To be noted in the use of door moulds:

- A catenary is the best shape for door moulds and doorways. In this case, the structure will settle evenly in doorways.

- The mould must be shaped so that the end of the actual structure placed against the mould is slightly narrower.
- To remove the mould, it must lowered by about 50–100 mm.
- When using water, a plastic film must be installed over the door mould to prevent freezing.
- When using snow, the edges of the moulds must be carefully compacted.
- If a door mould is used in a structure, the blower can be installed inside the mould.

The sagging of the structure must be taken into account in the design of the doorway and door mould, and either the doorway must be made sufficiently large so that any sagging has no adverse impact on the use of the structure, or sagging must be taken into account in maintenance by enlarging doorways as required. To install a door, wood or ice can be placed in the structure, to which the door can easily be screwed.

Image 21. Door mould (Ryynänen 2011)

Snow sauna

A snow sauna offers a unique sauna experience, the design and use of which must take into account the heat and moisture loads that are directed at it and that are higher than in a regular snow building. The use of a sauna consumes its structures: during a single use, the wall thickness may decrease by as much as 3–5 mm. Changes in wall strength are case-specific and depend on the output of the sauna stove and the duration of use. This should be taken into account in the structural thickness designed for the sauna structure so that the wall structure of the sauna can withstand the number of intended uses and the structural thickness remains sufficiently high despite the use of the sauna. The internal surface of the sauna structure is usually built with an ice cover, as ice can withstand steam better than snow (Haavikko 2025).

In snow saunas, an ever-ready sauna stove can be used, enabling the use of the sauna quickly and effortlessly without significant heat loads being directed at the sauna when it is not used. The areas around the stove should be protected from the heat of the stove. Considering the durability of the structures, it is important that the sauna has sufficiently large openings for ventilation, the operation of the stove, as well as access, as warm air flowing from small openings can melt the structures very quickly (Haavikko 2025).

The volume of the sauna is a key factor, as it has a significant impact on its operation and user experience. During use, visibility is poor, which is why special attention must be paid to ventilation safety in lighting and the guided use of the sauna (Haavikko 2025).

Image 22. The interior of a snow sauna at the Lehtojärvi snow and ice hotel (Pernu 2025)

6.3 Cones

Steps in building a cone-shaped mould:

1. The mould is first cut from plastic film. The mould is shaped as shown in Figure 22.
2. Straight mould sides are taped together using tape suitable for the plastic used. Points A and B are taped together until point O. The tape is applied on both sides of the plastic.
3. A piece is cut from the top of the mould to make a 100 mm hole for ventilation.
4. Plastic rope of about 6 mm thick is taped to the bottom so that the edge of the plastic is turned inwards by about 20 mm. The rope helps ensure that the mould remains in place during construction.

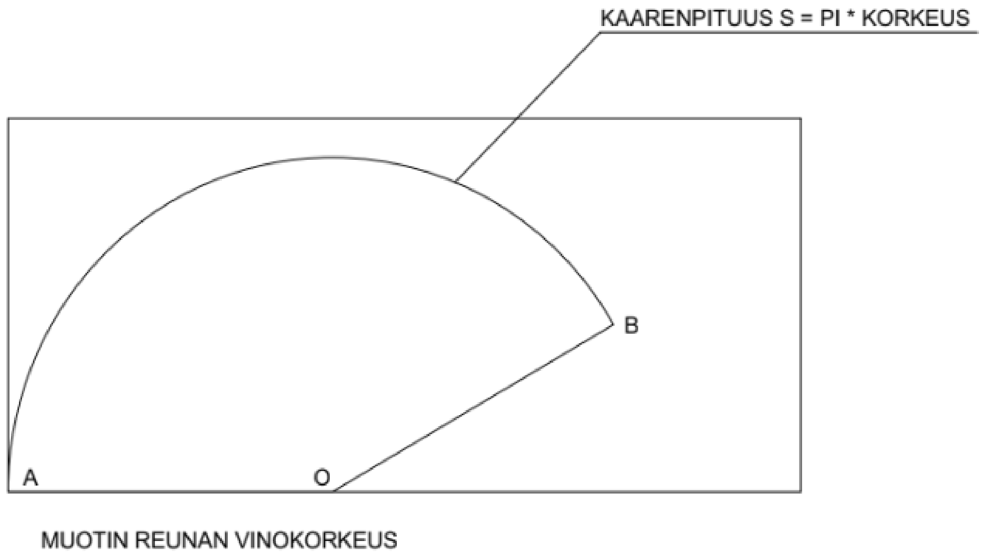


Figure 22. Basic drawing of cutting a cone-shaped mould (Riikonen 2009)

Steps in building a cone-shaped structure:

1. A layer of approximately 150 mm of snow is compacted in the building location. The layer can be watered and allowed to freeze. Freezing ensures that the mould remains in place during construction.
2. The cone-shaped mould is placed on the base. A circle equalling the size of the bottom of the mould is drawn on the base.
3. The mould is installed in a groove of about 50 mm deep. The mould is attached using slush, which is frozen.
4. A hole is made in the mould for the blower tube. The hole is made at the height of approximately 300 mm.
5. The blower tube is taped to the mould. A 110 mm drain pipe can be used as a tool.
6. Air is blown inside the mould. In the blowing stage, it must be ensured that the mould does not come off its base.
7. The mould air pressure can be about 0.6–1.2 kPa, depending on the size of the cone structure and the blower.
8. Cold water is sprayed over the mould. Water at network pressure or a sufficiently powerful high-pressure cleaner can be used to spray water.

9. When spraying water, it must be ensured that the air pressure does not blow water off the mould surface or that the sprayed water does not melt the already frozen layer.
10. The surface of the ice structure must be frozen before spraying the next layer.
11. The thickness of the ice layer should be at least 20–30 mm, depending on the size of the mould.
12. In the next stage, snow can be blown over water.
13. A layer of about 250–300 mm of slush formed by water and snow is built over the structure. At the top of the structure, the layer thickness can be half of the bottom thickness, about 100–150 mm.

Ice and slush layers must always be built in the internal surface of a conical structure to ensure the load-bearing capacity of the structure. At the end of construction, the structure can be reinforced with snow, especially if the structure is used for a long period.

Image 23. Ice cone (Ryynänen 2011)

Other structures shaped like a cone include:

- A tourist hut as a slush structure.
    - They can be built sealed or open at the top.
    - With a large number of users, a structure open at the top will remain cooler.
- Light towers built using normal water supply network pressure.
    - Ice is clear and light can easily penetrate the structures.
    - This type of structure cannot withstand sunlight.
    - Natural snow can be mixed with the structure during the construction phase. In this case, the light permeability of the structure decreases, and the material is slightly tougher than in a structure made only of ice.

6.4 Snow wall

Snow walls are among the most difficult shapes in snow construction. In practice, it has been found that a snow wall should be made wider at the bottom.

To be noted when building a snow wall:

- Snow must be blown from the bottom up over the entire mould distance, not from back to front.
- Snow must first be blown against the mould sides, then in the middle.
- It will be easier to move the mould if it can be opened before moving it.
- When building from natural snow, snow must be watered and compacted by trampling throughout the snow blowing process.
- Spraying water over a plywood mould should be avoided due to the risk of freezing.

- Smaller walls can also be built using separate plywood panels installed at a suitable distance from each other, after which snow will be blown over them.

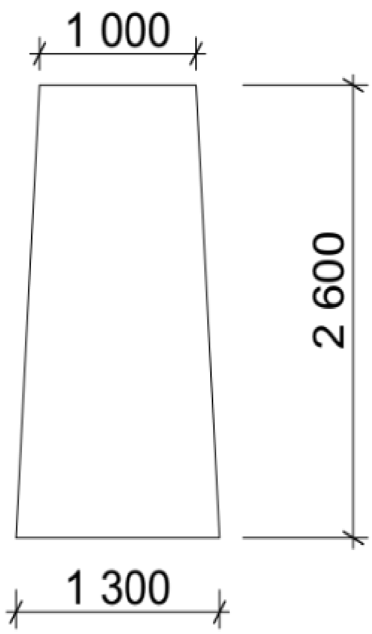


Figure 23. Basic drawing of a snow wall structure (Riikonen 2009)

7. Monitoring and dismantling of structures

Snow, ice and slush structures must be monitored during their use. Monitoring consists of daily maintenance inspections as well as long-term monitoring, including deformation measurements. Persons responsible for monitoring the structures during their use must be appointed. This refers to those who must monitor the operational safety of the structures and are responsible for the use of the structures during their lifecycle.

A separate operating and safety plan must be prepared for each snow and ice construction site as part of the construction process. The operating and safety plan must be approved at the kick-off meeting of the construction project at the latest. The operating and safety plan must be prepared by the party engaged in the construction project or their representative. Appendix 5 presents an example of an operating and safety plan for a snow and ice structure.

The operating and safety plan must define at least the following:

- The permitted deformations in load-bearing structures.
- The deformation measurements for load-bearing structures.
- The permitted temperatures for load-bearing structures.
- The strength and density of structures, depending on the material.
- Factors leading to the dismantling of the structures.

7.1 Structural deformations

Deformations in snow and ice structures must be monitored throughout the use of the structures. In the construction drawings and any specifications, the measurement points and the measuring interval for deformations must be defined for each load-bearing structure. The methods for carrying out measurements must be defined as part of the operating and safety plan. A measurement plan must be prepared by a structural engineer or builder. The measurement plan must be signed by the party engaged in the construction project or their representative, the user of the structure if they are other than the party engaged in the construction project, the party responsible for deformations, and the building authority.

Sufficiently reliable measurement methods must be used to monitor deformations, depending on the size and shape of the structure. This includes manual and electronic measurement methods. Deformation measurement results must be recorded in a measurement report and attached to the structure’s operating and safety reports. In addition to the measurements, monitoring should also focus on maintaining the original shape. Sagging is characteristic to snow structures and takes place during both construction and use. In structures with ice and slush layers, sagging is significantly less notable.

Measurement points must be selected in areas critical for the functioning of snow and ice structures. The measurement points must be marked in the drawings during the design phase. Critical areas include:

- The tallest point in structures.
- Boundaries between different materials.
- Doorways and window openings, as well as other solutions that weaken load-bearing structures.
- The top of curved structural parts; the centre and base of arc structures.
- The top and centre of free-standing structures.

It must be ensured that measurement points attached to the structures remain attached to the material. Measuring points must be made of a material that adheres to snow and ice, including wooden and plastic rods. As a rule, the values given in the section “General design principles” of this handbook must be used as threshold values for sagging and deformations, or the values can be determined on a case-by-case basis.

When using electronic measurement methods, drawings can be made for sagging monitoring, which can be used to reliably observe deformations in the structures over time (Figures 24 and 25). Appendix 6 presents an example of the results of electronic deformation measurements conducted for the snow and ice structure in the SNOW & ICE METHODS project.

In addition to the measurement points, it is also important for the safety of the structures to maintain the designed shape, despite any sagging. The original shape of the structure must be maintained to ensure the safe use of the structure. In dome and tunnel structures that follow the shape of a catenary, for example, losing the original shape will invariably lead to the suspended use of the structure.

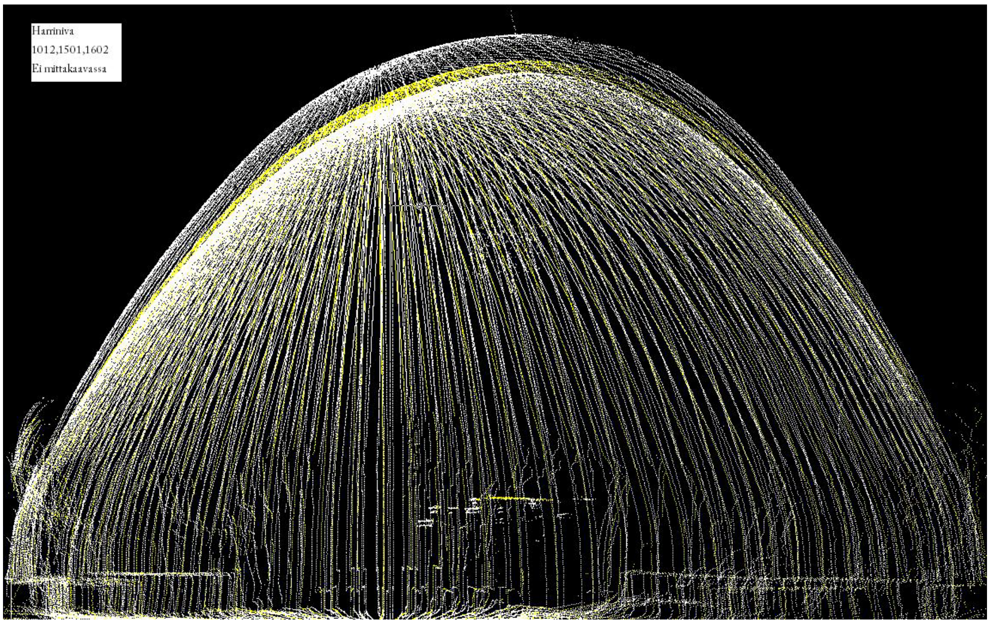


Figure 24. Sagging in a snow structure as a laser scanning drawing (SNOW & ICE METHODS project)

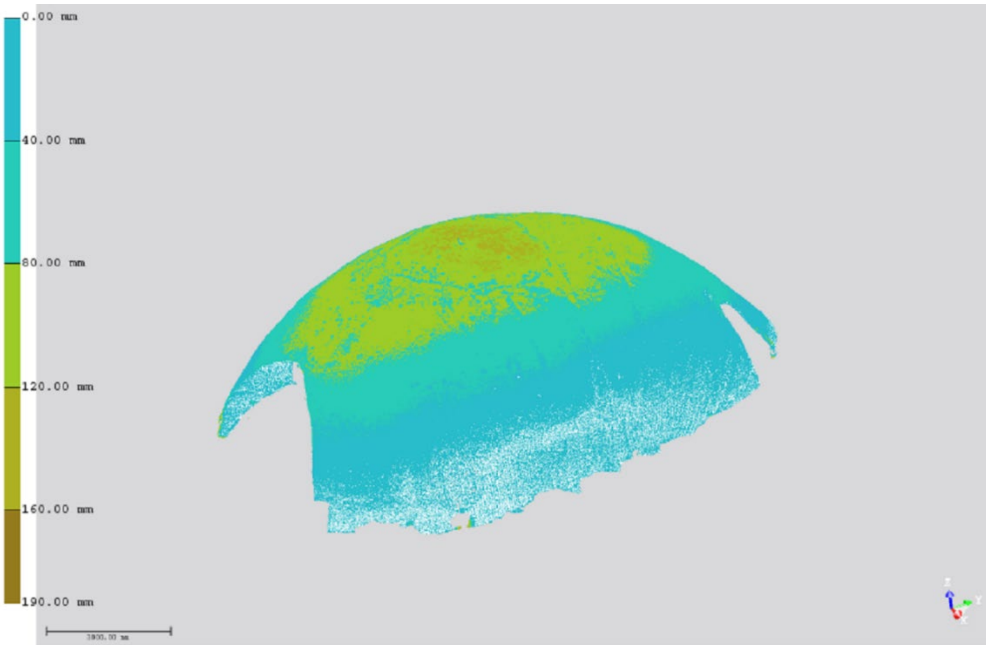


Figure 25. Laser scanning measurement results as a sagging chart (SNOW & ICE METHODS project)

Various measurement methods and measuring instruments such as visual inspections, measuring rods, total stations, electronic rangefinders or laser scanners can be used to monitor deformations in snow, ice and slush structures. Visual observations and inspections are suitable to observe the maintenance of the original shape and the accessibility of doorways, and to monitor any cracks and material compression. A measuring or level rod can be used to monitor sagging and lateral movements. While this measurement method is easy and cost-effective, it requires a systematic measurement method and the definition of measurement points to avoid errors.

When measuring using a total station (Image 24), the total station must measure from the surface of the structure, but no separate prisms are required for the measurement. The measuring accuracy of the method is high, and it is also suitable for measuring small structures. A total station requires reference points that do not move during the season. An electronic rangefinder can be used to monitor sagging and lateral movements. The advantages of the method include measuring accuracy, speed and the suitability of the device for cold conditions. While a laser scanner can achieve very accurate measurement results (Image 25), the device's purchase price is high. Laser scanning is a method of measuring the surface of the structure, requiring reference points and prismatic sights. In addition, a total station is required to measure prismatic sights. The method is also well-suited for measuring small structures.

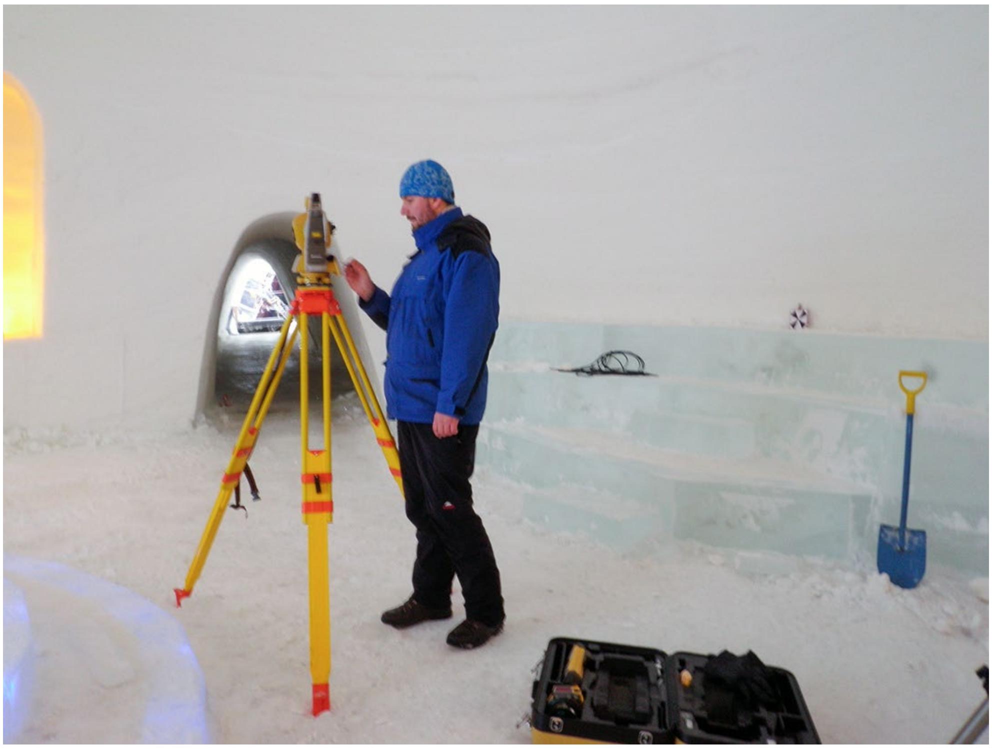


Image 24. A total station used for snow structure measurements (Ryynänen 2011)

Image 25. A laser scanner's prismatic sights in snow structure measurement (Ryynänen 2011)

7.2 Temperature of structures

During use, the internal temperature of the snow, slush and ice structure must be low enough to ensure the functioning of the material. The RIL 218-2001 guide provides recommendations for measuring the temperature of snow structures. If no other assessment is made, the recommendation given in the aforementioned guide can be followed in monitoring the temperature of large snow structures with a structural thickness of 1.5 m or more. Temperature monitoring results must be attached to operating and safety reports.

According to RIL 218-2001 (RIL 2001, 67):

> *"The temperature of snow structures must be measured when the indoor or outdoor temperature has been continuously above zero for more than two days. The measurement must be made in the structure at the depth of at least 20 cm from the surface of the structure. Measurements must be made in structures where snow is used as the roof structure."*

In addition:

> “Records must be maintained of the measurements to determine increases in structural temperatures and to calculate any melting and softening. When the internal temperature of the structure rises higher than -1.0 °C, the strength of the structure must be monitored.”

In the SNOW & ICE METHODS project, the temperatures of snow, slush and ice structures were monitored at different locations during two winter seasons. According to the study, the internal temperature of the snow and slush structure follows the outdoor temperature with a certain delay. The internal temperature of the structure is never constant, despite the strength of the structure (Figure 26).

The structural strength of ice structures is usually so thin that the monitoring of the internal temperature of the structure is irrelevant considering the use of the structure. The reason for this is that, when the internal temperature of ice rises, the ice has almost always lost its load-bearing capacity and solid state.

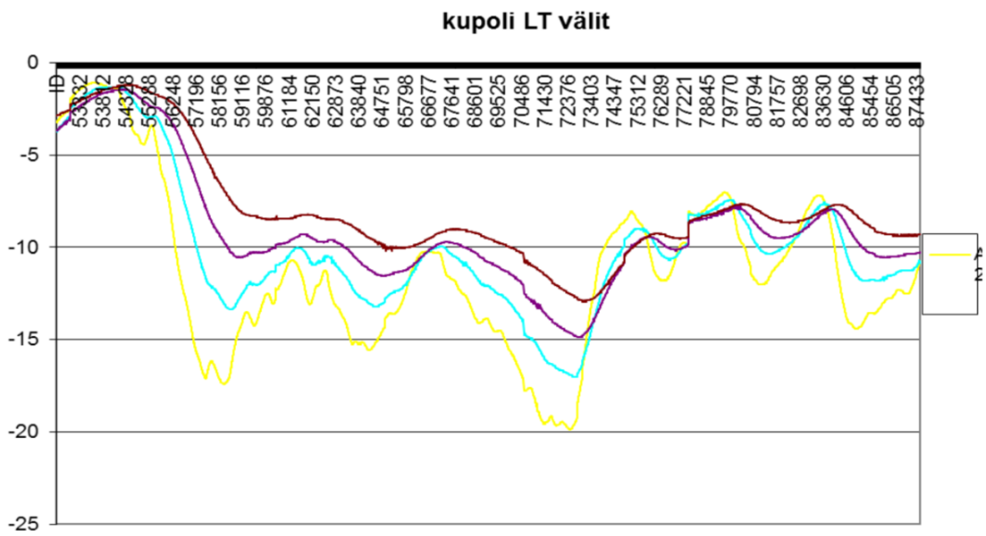


Figure 26. Example of changes in the internal temperature of a snow structure during the use of the structure (SNOW & ICE METHODS project)

The internal temperature of the material in a snow, ice and slush structure can be monitored using various measurement methods. Modern wireless temperature sensors (Image 26) can be installed inside the structure, from where they transmit data from the measuring point wirelessly to a server or smart device. Sensors are often inexpensive and easy to install during the construction phase, but installing them in an existing structure is difficult.

Another option is to measure the temperature using temperature sensors installed inside an electrical conduit and a data collection system. In practice, this requires an electrical conduit, data collection unit, as well as a computer and/or a network connection, in addition to sensors. The measurement method enables the creation of accurate and reliable temperature profiles, but requires special expertise and a customised solution. In addition, the system has a high purchase price.

The third option is to measure the temperature using a multimeter and an embedded temperature sensor. While this measures the current temperature reliably, it is not suitable for long-term monitoring, and the purchase price of the equipment is fairly high.

Image 26. A wireless temperature sensor for installation in a snow structure (Pernu 2025)

7.3 Structural hardness and density

The hardness of the structure must be monitored during use through regular measurements. Hardness monitoring must be carried out visually in addition to measurements. The RIL 218-2001 guide includes a recommendation for monitoring the hardness of snow structures (RIL 2001, 68):

> *"Determining the hardness of roof structures made of snow must be started once the snow structure can soften due to the effect of melting --- the air temperature rises above +0 °C. As long as the structure is hard, it can be considered usable."*

The density measurements conducted in the SNOW & ICE METHODS project show that the density of snow and slush increases during the use of the structure, i.e. strength develops.

This handbook recommends: **The density of snow and slush must be ensured during the construction phase. Reliable deformation and hardness monitoring can ensure the development of structural strength during use.** The density must be measured if there is a specific reason for it. Such reasons include an unexpected warm period during the use of the structure. The density values for different materials are listed in in Tables 1 and 3. According to studies, the density of ice structures does not change during the use of the structure.

Once the melting phase starts, the crystalline structure of the snow, ice and slush material changes both internally and externally. As a result of the sun and wind, the structure starts to soften on the surface, and the state of the material changes from solid to water and water vapour. During the melting process, the material melts during the day and freezes during the night when the air temperature drops. This melting and freezing phase partially improves the strength of the snow and ice structure.

A steel rod can be used to measure the hardness of snow and slush. The RIL218-2001 guide provides instructions for measuring the hardness of snow using a steel rod. In snow and slush strength measurements, the heterogeneity of the material must be taken into account by carrying out the measurement in several different parts of the structure. Affordability is one of the method's advantages.

Either the hydrostatic weighing method or drill sampling can be used to measure the density of snow, slush and ice. When using the hydrostatic weighing method, a sample of approximately three litres must be taken from the structure, the density of which can be determined in accordance with Appendix 7. The advantages of the hydrostatic weighing method include its suitability for various shapes of samples, as well as its affordability. Density can also be determined using drill samples (Image 27) in which a snow sample is taken with a drill prepared for ice sampling. To determine the density of snow, the sample is weighed and its weight is determined relative to its volume. While the method enables quick and accurate measurements of thick structures, it has a high purchase price.

Image 27. Measuring snow density using an ice drill (Pernu 2022)

7.4 Operational safety

Fire safety and rescue

Safety planning for snow and ice buildings involves various special characteristics that have an impact on the safety of building users. In addition to the safety of the actual structures, the building's floor plan is an essential part of operational safety. Exits and evacuation must be planned in the case of emergencies in accordance with law and regulations valid at the time, including the Rescue Act and the decrees of the Ministry of the Environment, and they must be marked clearly and appropriately. Passageways and routes must remain large enough, regardless of sagging in the structures. Normally, it is required that the building can be exited using at least two different routes, and the exits reserved for this purpose must be kept free of any movable property. In addition, it is recommended to address the accessibility of different parts of the building or buildings along rescue routes in the planning of the area.

The fire safety of snow buildings is high as a result of the building material and cold indoor conditions, as a fire requires flammable material and a fire or heat source to start. A short-lived fire usually does not present any risk of collapse, especially in thick snow structures, and visibility stays high in indoor areas for a long time, making evacuation easier.

Snow and ice buildings are often located far away from residential areas, due to which the arrival of emergency services may take a long time. In very rare, but possible, collapse situations, the parties' readiness for rescue from a collapsed building is emphasised. Rescue from collapsed snow and ice structures is often challenging, as the persons to be rescued are likely to be under or inside very dense snow or ice. In rescue situations, it is important for rescuers that there are good rescue routes and a floor plan and information about the people inside are available.

The authorities that supervise snow and ice construction and its safety usually conduct inspections at sites and ensure that safety aspects have been addressed in the building and its use. Official requirements for the safety of snow and ice buildings are specified in more detail in Appendix 2.

Slip prevention

In snow and ice constructions and buildings, slipperiness is a significant safety factor that requires constant attention. A broad range of methods can be used to prevent slipperiness, and should be selected according to the situation and conditions. Mechanical roughening is one of the most commonly used methods. Accordingly, mechanical tools or machines roughen the surface of snow or ice, making a slippery surface rougher. Clean snow can also be added to reduce slipperiness, as a fresh coarse snow surface often provides better friction than older snow packed as ice. When the number of visitors increases on normally snow-based surfaces, the need for slip prevention also increases.

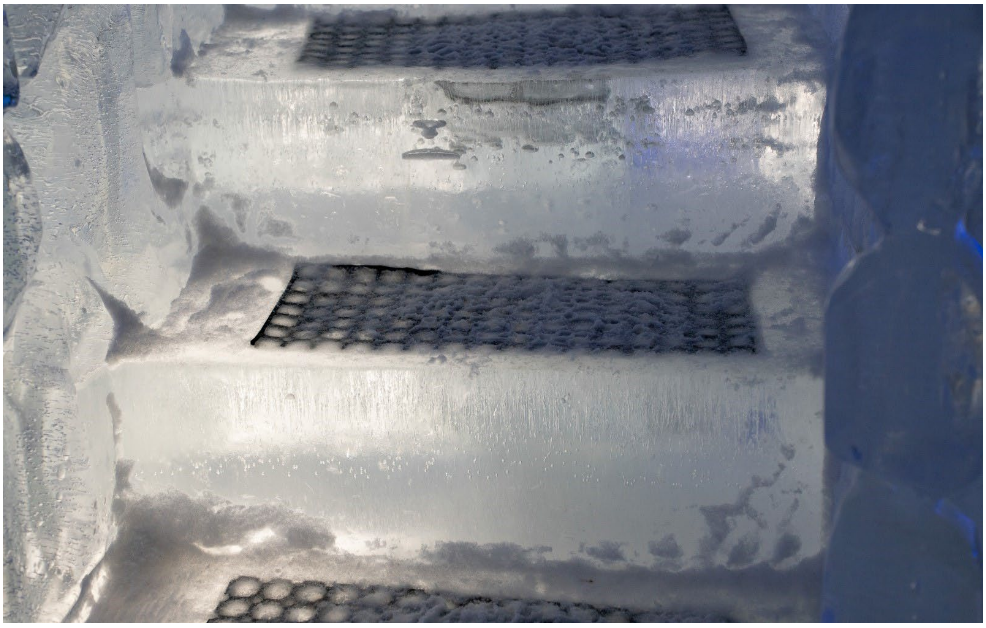


Image 28. Slip prevention using rubber mats on ice steps (Pernu 2024)

Various friction-increasing elements and materials are also suitable for slip prevention in snow and ice buildings. Friction can be increased by placing various grated sheets and textile or rubber mats on snow or ice surfaces as shown in Image 28. Sand (Image 29) or sawdust also acts as a quick solution on slippery surfaces. Sand is also available in a light colour, which is often preferred over regular sand due to aesthetics.

Image 29. Gritted stairs (Pernu 2024)

In the construction phase, slip prevention by the aforementioned means is not always possible, in which case the management of the risks caused by slipperiness may be easier to implement by wearing studded shoes or placing chains over regular shoes. In addition, proper induction regarding the characteristics of a snow and ice construction site, as well as the clearing of work platforms such as scaffolding from snow can significantly prevent slipping hazard.

In slip prevention and management, regular monitoring and maintenance of friction in areas is emphasised. Any slippery floor surfaces require quick responses so that the areas can be used safely.

Common slip prevention methods:

- Mechanical roughening (e.g. roughening tools and machines).
- Adding snow to improve friction.
- Gritting.
- Use of sawdust.
- Studded shoes or other appropriate footwear
- Placing mats on slippery surfaces.

Functional elements

Functional elements are often placed in and around snow and ice structures, the most common of which is a slide made of snow or ice. Functional elements increase unusual movements and activities in the areas, which should be taken into account especially from the point of view of safety.

In the safety of slides, particular attention must be paid to the prevention of slips, collisions and falls. Both snowy and icy slide structures and the stairs leading to them may become slippery as a result of abundant use, due to which friction must be increased by the means described in the previous section, for example. There can be no obstacles or protrusions on the slide with which users could collide.

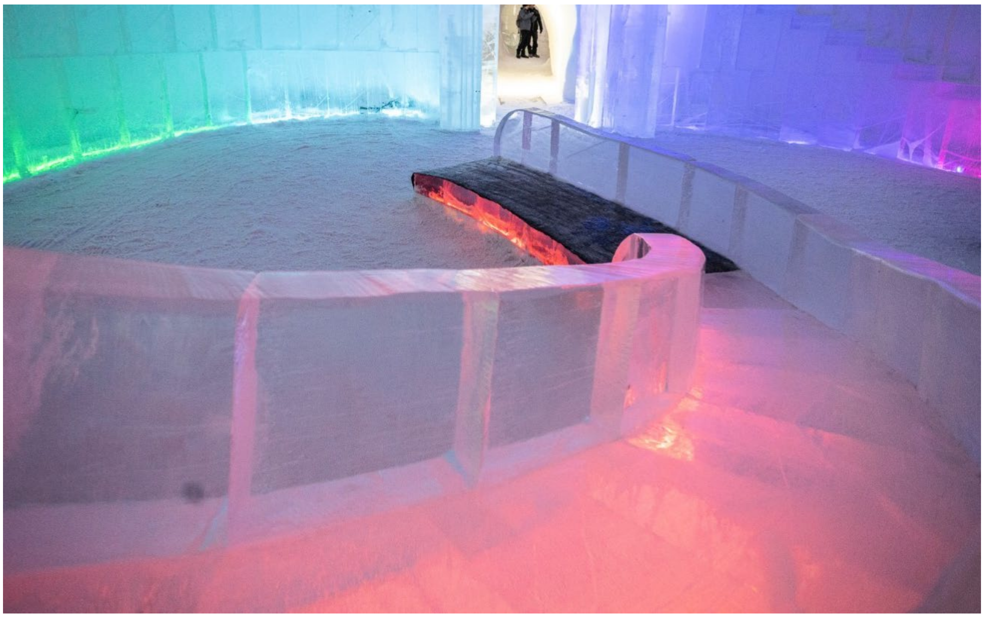


Image 30. An ice slide and railing structure (Pernu 2024)

The slope of the slide must be planned so that the speed of users cannot become too high. When in use and when conditions change, the slide's friction may change significantly, which is why slides require regular monitoring and reactions to any identified irregularities in addition to planning. Various decelerating surface materials can be installed at the end of the slide (Image 31) such as rubber or felt mats so that users stop in a controlled and safe manner. In slide structures, users are often at the height of several meters, due to which railing structures of sufficient height and strength are necessary.

Image 31. A rubber mat placed at the end of a slide to stop users (Pernu 2024)

Decorations, sculptures and delimitation of areas

In snow and ice construction, visual design is a key attractive factor alongside building materials. The aesthetics of buildings, structures and sculptures is typically manifested in carved wall and pillar surfaces, designed furniture and separate works of art. However, visual attractiveness can arouse curiosity in users and inspire them to climb on structures and sculptures, which is why it is important to minimize elements that encourage climbing such as crevices and protrusions to ensure safety already during the design and construction phases. In addition, clear boundaries of areas and information signs help prevent any unwanted activities by users.

Free-standing sculptures must be designed and anchored to ensure stability throughout their intended period of use. In addition to use, external forces may be directed at the sculptures as a result of ground frost, which may tilt sculptures and other icy structures. In addition, to prevent climbing and protect sculptures, it may often be necessary to delimit areas, especially around sensitive and large sculptures. For large protrusions, the durability and functionality of the structures must be proven by strength calculations, and for safety reasons it is recommended to exclude areas under large protrusions from general use.

In the carving of structures, regardless of the structure, attention must be paid to the maintenance of the planned structural strength and shape, as well as the cross-section of pillars. Particularly in large, multidimensional sculptures, perceiving depths and structural thicknesses can be challenging without additional measurements.

7.5 Dismantling structures

If any of the following threshold values are reached during the use of snow, ice and slush structures, the use of the structure must be suspended. If the suspension is prolonged or its cause cannot be eliminated, the dismantling of the structure must be considered.

The following must be used as thresholds for dismantling:

- With regard to snow, the guidelines given in section 8.3 of the RIL218-2001 guide apply.
- If a load-bearing structure has settled or tilted over the permitted threshold limit.

- If the shape of a load-bearing structure has not remained as planned.
- If a load-bearing structure has become fractured/collapsed.
- If the internal temperature of the material used rises above the given limit.
- If the material properties have changed so that they no longer meet the properties of slush, for example.

The party responsible for the snow and ice structure must determine when the structure needs to be dismantled. It is recommended that all parties to the construction project define the dismantling of the building in the operating and safety instructions. The authorities may also assign an external party to determine the prerequisites for dismantling the structure, including areas subject to special procedures.

When dismantling, the snow and ice structure must be broken down so completely that it can no longer be used for its original purpose, and it is no longer possible to enter the building. Load-bearing structures must be completely dismantled.

Dismantling must be documented using photos, and a written notification of the terminated use of the structure and its dismantling must be submitted to the authorities. Normally, the reason for terminating the use of snow and ice structures is that the aesthetics and usability of the structures decrease significantly due to melting and water, as well as the end of the season, rather than factors related to the load-bearing capacity of the structures.

Summary

This handbook aims to provide instructions for the safe construction, design and use of ice and slush structures. Ice as a building material is so heterogenous that unambiguous threshold values and guidelines cannot be provided for it, unlike for snow. Therefore, sufficiently large material and load safety factors must be set for ice to ensure the safe use of structures.

This handbook presents type structures with material thicknesses for snow and ice structures. These type structures are based on shapes with a building history of almost thirty years and observations made regarding them during different years of construction. When building these types of structures under the conditions mentioned in this handbook, the structures are reliable during operation. According to guidelines, no separate structural design is presented for type structures.

In summary, key factors related to snow and ice construction include:

- The shape of the load-bearing structure must be a compression structure.
- Snow must be handled according to snow quality and the ambient temperature.
  - Natural snow must be blown several times before being blown over the structure.
  - Water must be mixed with natural snow if the outdoor temperature is -15 to -20 °C.
  - Previously piled artificial snow can be used as it is.
  - Water must be mixed with artificial snow if necessary, but at discretion.
  - Frozen snow can be used as it is.
- Snow and slush must always be compacted properly mechanically.
- Ice piece structures.
  - The impact resistance of ice is low.
  - Ice must be handled with care during the construction phase.
  - The overlap distance defined in instructions must be used between layers of ice pieces.
  - The connection of ice to other structures must be ensured using water or slush in the connections.
- Structures made by freezing

    - A sufficient layer of ice must be made in the structure.
- The freezing rate depends on the outdoor temperature and the freezing of water.
- Monitoring during the period of use
    - The monitoring of sagging and deformations must be carried out according to plans and implemented carefully.
    - The original shape of the structure must be maintained during the period of use.
    - A responsible person or persons must be appointed for the use of structures.
    - Straightforward thresholds must be defined for terminating the use of the structure and dismantling the structure.
- Dismantling of structures
    - Load-bearing structures must be dismantled completely.
    - The dismantling phase must be documented.

More professionals are required for the structural design of snow and ice structures and for the supervision of construction. Therefore, separate certification training should be prepared for those operating in the industry. After completing it, everyone entering the industry could demonstrate their professional competence in snow and ice construction. Even without such certification, everyone operating currently in the industry is a top professional.

The construction instructions given in this handbook are based on structural shapes that have been built several times in practice. The instructions are not, nor seek to be, exhaustive in the relatively young and rapidly developing industry. Parties operating in the industry should maintain a creative mindset to achieve new sought-after structural shapes and changes.

At the time of the original publication of this handbook, it was stated that “we have only scraped the surface of the ice”. After the revision made in 2025, we can safely say that the industry has taken various steps forwards over the course of a decade, but especially compared to conventional construction, we are still in the early stages of the journey – there is still much to learn and try, but there are also new challenges in sight due to climate change, for example. We believe that, with the innovativeness of those operating in the industry and RDI cooperation, new solutions to the challenges can constantly be found.

Other literature related to the industry

Below, we have listed a few more texts that discuss the properties of snow and ice, their use, as well as structural and physical phenomena. The texts below provide more information about the basic principles of snow and ice, as well as their practical applications, including construction and artistic design. With the help of these sources, the reader can learn more about the behaviour and use of winter materials in different contexts, as well as the making and storing of snow.

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Appendix 1. Instructions for determining a catenary in a snow structure.

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APPENDIX 1.
Instructions for determining a catenary in a snow structure

The catenary is a shape which also appears in nature. One of its special characteristics is that it works as a compression structure in every direction. In a compression structure, the tension of an object tends to push the structure downwards due to the structure's weight, loading and gravity. The catenary is a shape that was already known during Galileo's time. Old stone bridges and vaulted ceilings of stone churches are the best-known structures in the shape of a catenary.

In mathematics, the catenary is a hyperbolic cosine equation. Its name comes from an idealised chain or rope suspended from two anchor points always assuming the shape of a catenary.

In mathematics, the equation of a catenary is

$$y = a\cosh\left(\frac{x}{a}\right) = \frac{a}{2}\left(e^{x/a} + e^{-x/a}\right),$$ is

where cosh is the hyperbolic cosine function. When the catenary represents the shape of a chain or rope, the parameter *a* represents the ratio between the horizontal component of the chain tension and the weight of the chain per length unit.

In practical snow and ice construction, the catenary can be determined, for example, as follows (Riikonen 2009):

- Two nails are struck on the wall of a building at the same height at the distance from each other that is to be the width of a mould.

- The desired height of the mould is measured from the centre of the upper edge of the nails. A nail is hit at that point.

- A dog's leash, for example, is suspended from the nails at the upper edge, and it is adjusted until it touches the nail that indicates height.

- A plate is placed under the suspended leash, and the resulting catenary is drawn.

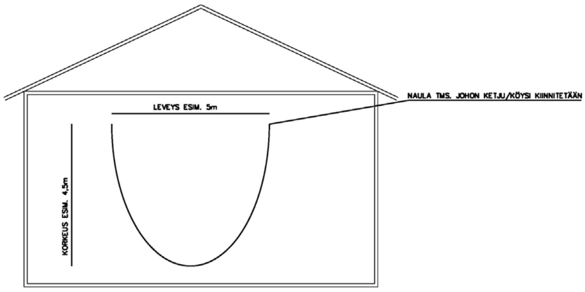

Figure 1. Determining a catenary of a building's wall (according to Riikonen)

APPENDIX 2.

The Finnish Competition and Consumer Authority's safety instructions for product safety supervision in snow and ice structures

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Kuluttajavirasto / Tuoteturvallisuusvalvonta **20.3.2008**

LUMI- JA JÄÄRAKENNELMIEN TURVALLISUUS

1. Yleistä lumi- ja jäärakentamisesta

Talviaikaan etenkin Pohjois-Suomessa tarjotaan kuluttajille erilaisia lumesta ja jäästä tehtyihin rakennelmiin liittyviä palveluita. Tarjolla on niin majoitustiloja, kuten lumihotelleja ja igluja kuin lumesta rakennettuja ravintoloita ja lasten leikkeihin tarkoitettuja lumilinnojakin. Näitä kaikkia on pidettävä kulutustavaroiden ja kuluttajapalvelusten turvallisuudesta annetussa laissa (75/2004) tarkoitettuina kuluttajapalveluksina riippumatta siitä, peritäänkö niiden käyttämisestä maksua. Lain 3
§:n nojalla kuluttajapalvelun turvallisuudesta vastaa aina palvelun tarjoaja. Lumi- ja jäärakentamisen kyseessä ollessa lain mukainen vastuutaho voi olla esimerkiksi rakennelman rakentaja, haltija tai ylläpitäjä.

Rakennuslainsäädäntö tai rakentamista koskevat viranomaisten antamat yleisohjeet eivät sisällä lumi- tai jäärakentamista nimenomaisesti koskevia normeja. Lumi ja jää ovat kuitenkin erityisen haastavia rakennusmateriaaleja, sillä niistä tehtyjen rakenteiden ominaisuudet muuttuvat olennaisesti ympäristötekijöiden ja ajan vaikutuksesta. Lumen ja jään sulamisen ohella huomioon on otettava muun muassa materiaalin tiivistymisestä johtuva rakenteiden muodon muuttuminen.

Seuraavassa esitettyjä lumi- ja jäärakentamisen turvallisuuteen liittyviä huomioita voidaan hyödyntää niin rakennelmien suunnittelussa, rakentamisessa ja ylläpitämisessä kuin viranomaisten suorittamassa valvonnassakin.

2. Kaikessa lumi- ja jäärakentamisessa huomioon otettavaa

Alalla toimii yrittäjiä, jotka ovat erikoistuneet lumi- ja jäärakentamiseen, mutta osa rakennelmista tehdään täysin amatöörivoimin. Ollakseen turvallisia on etenkin suuret ja lumella tai jäällä katetut oleskelutiloja sisältävät rakennelmat suunniteltava ja toteutettava huolellisesti. Käytännössä ainakin suurimpien rakennelmien osalta on tehtävä kirjallista rakennesuunnittelua lujuuslaskelmineen.

Lumen ja jään ominaisuuksiin vaikuttaa merkittävästi se, millaisissa ilmastollisissa olosuhteissa niiden kiderakenteet ovat syntyneet. Rakentamisvaiheessa vallinneet olosuhteet vaikuttavat lumi- ja jäärakenteiden ominaisuuksiin koko niiden elinkaaren ajan. Näin ollen rakennelmissa käytettävän lumi- tai jäämateriaalin ominaisuudet voivat vaihdella vuosittain. Käytännössä lumen tai jään teko- tai keräämispaikka vaikuttaa myös merkittävästi materiaalin ominaisuuksiin. Lumi- tai jäärakenteiden ominaisuuksista hankittua tietoa ei siten voida välttämättä hyödyntää sellaisenaan keskenään erilaisilla alueilla, kuten meren rannikolla tai sisämaassa toteutettavan rakentamisen suunnittelussa.

Kaikkien lumi- ja jäärakenteiden kuntoa on valvottava päivittäin. Lumi- ja jäärakenteiden muodon jatkuvasta muuttumisesta johtuen on hyvin tärkeätä, että tällaisten rakenteiden turvallisuus ja käyttökelpoisuus tarkastetaan säännönmukaisesti myös silloin, kun sääolosuhteet ovat pysyneet pitkään tämän kaltaiselle rakentamiselle suotuisina. Palvelun tarjoajan on määritettävä sekä se, kenen vastuulle rakenteiden kunnon tarkkailu kuuluu että se, mihin seikkoihin tarkkailussa on erityisesti kiinnitettävä huomiota. Palvelun tarjoajan on määritettävä myös se, miten rakenteiden kunnon tarkkailussa tehdyt havainnot kirjataan käyttöpäiväkirjaan tai vastaavaan asiakirjaan. Rakenteiden kunnon tarkkailussa hyväksi käytännöksi on osoittautunut rakenteiden säännönmukainen valokuvaaminen. Kuvia vertailemalla rakenteiden muodonmuutokset rakennelman elinkaaren aikana ovat helposti havaittavissa.

Lumesta ja jäästä tehtyjä rakennelmia suunniteltaessa ja huollettaessa on kiinnittävä huomiota käyttöturvallisuusnäkökohtiin. Huomioon on otettava niin portaiden turvallisuus kuin käsijohteiden ja kaiteiden tarve samoin kuin liukkauden torjunta. Sähkölaitteiden ja -johtojen osalta on muistettava, että kaikkien lumi- ja jäärakennelmissa käytettävien sähkölaitteiden ja kytkentöjen on oltava ulkotiloihin soveltuvia. Käytettävien sähkölaitteiden on aina oltava suojaeristettyjä, suojamaadoitettuja tai suojajännitteellä toimivia. Pitkäaikaiseen ulkokäyttöön tarkoitetun sähkölaitteen koteloinnin on oltava niin tiivis, ettei sen sisään pääse vettä. Vikavirtasuojakytkin tuo lisäturvaa ulkopistorasioissa.

Palvelun tarjoajan tulee riskinarviointiin perustuen arvioida, tuleeko palvelua samanaikaisesti käyttäville henkilöille asettaa enimmäismäärä. Jos enimmäiskäyttäjämäärän määrittely katsotaan tarpeelliseksi, on määritettävä myös se, miten käyttäjämäärää seurataan ja tarvittaessa rajoitetaan.

Palvelun tarjoajan on määritettävä myös se, millaisissa olosuhteissa rakennelma poistetaan käytöstä tai sen käyttöä rajoitetaan. Samoin on määritettävä se, miten rakennelman käytöstä poistaminen tapahtuu, jotta heikentyvästä tai sulavasta rakennelmasta ei aiheutuisi vaaraa. Tältä osin on otettava huomioon se, että tällaiset rakennelmat saattavat houkutella ihmisiä myös siinä tapauksessa, että palvelun käyttäminen olisi nimenomaisesti kielletty. Turvallisuuden varmistamiseksi hyvä käytäntö on esimerkiksi rakennelman kertakaikkinen hajottaminen käytöstä poistamisen yhteydessä.

Tarkempaa tietoa lumesta tehtävien kantavien rakenteiden suunnittelusta, rakentamisesta ja käytöstä saa muun muassa Suomen Rakennusinsinöörien Liiton julkaisusta Lumirakenteiden suunnittelu- ja rakentamisohjeet (RIL 218-2001).

3. Majoitustiloina käytettävät rakennelmat

Majoittumiseen tarkoitetut lumesta tai jäästä tehdyt rakennelmat ovat myös pelastuslainsäädännön soveltamisalalla. Majoitustilat ovat erityiskohteita, joissa pelastusviranomainen tekee palotarkastuksen. Palovaroitinten ja palontorjuntakaluston asianmukaisuuden ohella poistumisturvallisuus on keskeinen majoitustilojen turvallisuuteen vaikuttava tekijä. Erityistä huomiota tulee kiinnittää siihen, että rakennelmissa ovat esteettömät poistumistiet, jotka on osoitettu selvästi myös pimeässä ja mahdollisen sähkökatkon aikana erottuvin merkinnöin.

Majoitustiloina käytettäviin lumesta tai jäästä tehtyihin rakennelmiin saattaa liittyä myös muista rakennusmateriaaleista tehtyjä tiloja, kuten wc- ja peseytymistiloja. Näiden tilojen paloturvallisuus on otettava huomioon lumi- tai jäärakennelmien kokonaispaloturvallisuutta arvioitaessa, sillä esimerkiksi puurakenteiden palamisesta syntyvät kaasut voivat vaikuttaa merkittävästi myös lumi- tai jäärakenteisissa tiloissa oleskelevien henkilöiden turvallisuuteen.

Majoittuville asiakkaille tulee antaa tupakointia koskevat ohjeet. Ohjeistuksessa tulee ottaa huomioon myös käytettävien vuodevaatteiden ja patjojen sekä makuupussien paloturvallisuus. Makuupussit eivät aina vastaa paloturvallisuusominaisuuksiltaan kaupallisiin majoitustiloihin tarkoitettuja vuodevaatteita.

Koska lumi- ja jäärakenteet tiivistyvät eli käytännössä painuvat ajan kuluessa huomattavasti kasaan, täytyy poistumistiet käytännössä mitoittaa rakennusvaiheessa huomattavasti vähimmäisvaatimuksia suuremmiksi, jotta ne täyttäisivät kooltaan niille asetetut vaatimukset myös elinkaarensa loppupäässä.

Lumesta tai jäästä tehtyjä majoitustiloja suunniteltaessa ja rakennettaessa täytyy ottaa huomioon kohteen luokse päästävyys ennen kaikkea pelastustoimen näkökulmasta. Hälytysajoneuvoille tarkoitettujen ajoteiden ja muiden kulkuyhteyksien (pelastustiet) on oltava aina ajokelpoisia, esteettömiä ja asianmukaisesti merkittyjä.
Palvelun tarjoajan tulee järjestää tarpeellinen päivystys siten, että majoittuvilla asiakkailla on mahdollisuus saada yhteys palvelun tarjoajan henkilökuntaan kaikkina vuorokaudenaikoina. Palvelun tarjoajan tule varautua myös tilanteisiin, joissa majoittuva asiakas haluaa jostakin syystä siirtyä majoittumaan pois lumi- tai

jäärakenteisista tiloista. Myös asiakkaiden turvallisuuden valvontaan tulee kiinnittää huomiota. Lumi- tai jäärakenteisissa majoitustiloissa ei yleensä ole lukittavia ovia, mistä johtuen ulkopuolisten henkilöiden liikkuminen tulee ehkäistä riittävällä valvonnalla.

Mahdollisen evakuointi- tai onnettomuustilanteen varalta palvelun tarjoajalla tulee olla onnettomuustilanteessa nopeasti saatavilla oleva ajantasainen luettelo siitä, kuinka monta majoittunutta henkilöä rakennelmassa on, ja missä huoneissa tai muissa tiloissa he ovat. Pelastus- ja evakuointitoiminnan tehokkuuden takaamiseksi nämä tiedot tulisi pystyä esittämään kohdetta havainnollisesti kuvaavan pohjapiirroksen avulla.

Jos majoitustilat sijaitsevat etäällä vakinaisesta asutuksesta tai muista lämmitetyistä luokse päästävistä sisätiloista, on palvelun tarjoajan suunniteltava etukäteen myös se, mihin ja miten majoittuvat asiakkaat mahdollisessa evakuointitilanteessa siirretään.

4. Erityisesti lasten leikkeihin tarkoitetut lumirakennelmat

Suunniteltaessa ja rakennettaessa erityisesti lasten käyttöön tarkoitettuja lumesta tai jäästä tehtyjä rakennelmia voidaan soveltuvin osin soveltaa leikkikenttävälineitä koskevia standardeja (SFS-EN 1176 ja SFS-EN 1177) ja Kuluttajaviraston internetsivuilla olevia leikkikenttien turvallisuutta koskevia lähtökohtia. Turvallisuuden kannalta keskeisiä tekijöitä näissä saattavat olla esimerkiksi putoamisvaaran sisältävät paikat. Huomioon tulee siten ottaa muun muassa mahdollinen putoamiskorkeus, tarve kaiderakenteille sekä liukumäkien turvallisuus.

Erityisesti lasten käyttöön tarkoitetuissa rakennelmissa tulee ottaa huomioon myös rakennelman käytön valvonta. Huolimatta siitä, että lapsen huoltajalla on aina vastuu lapsesta, on palvelun tarjoajalla kulutustavaroiden ja kuluttajapalvelusten turvallisuudesta annetun lain mukainen vastuu rakennelman ja sen käytön turvallisuudesta.

5. Palvelun tarjoajan turvallisuussuunnittelu ja henkilökunnan hätätilannevalmius

Edellä tarkoitetut palvelun tarjoajan turvallisuussuunnitteluvelvollisuuden piiriin kuuluvat seikat on otettava huomioon palvelun tarjoajan turvallisuusasiakirjassa tai muussa turvallisuussuunnitteluasiakirjassa (esimerkiksi pelastuslainsäädännön mukaisessa pelastussuunnitelmassa).

Erityisesti Pohjois-Suomessa pelastustoimen ja sairaanhoidon resurssit ovat varsin rajalliset alueella vilkkaimman matkailukauden aikana oleskelevien henkilöiden määrään nähden. Tämä korostaa palvelun tarjoajan velvollisuutta varautua erilaisten poikkeustilanteiden hoitamiseen itsenäisesti. Lisäksi erityisesti majoitustiloina käytettävät lumi- ja jäärakennelmat sijaitsevat usein etäällä asutuskeskuksista, mistä johtuen pelastushenkilökunnan saapuminen onnettomuuspaikalle saattaa kestää huomattavan pitkään. Palvelun tarjoajan henkilökunnan onkin kyettävä aloittamaan tarvittavat pelastustoimet itsenäisesti ja opastamaan pelastustoimen edustajia tilan- teen hoitamisessa.

Palvelun tarjoajan on varmistettava henkilökuntansa hätätilanneosaaminen. Henkilökunnalle on annettava tarvittavaa koulutusta ainakin tavanomaisimpien hätätilanteiden varalle. Kyseeseen saattavat tulla esimerkiksi alkusammutus- ja ensiapukoulutus sekä rakenteiden sortumistilanteissa noudatettavien toimintamallien opettaminen.

Lumi- ja jäärakennelmiin liittyvien palveluiden turvallisuuden kehittämisessä ja arvioimisessa voidaan soveltuvin osin käyttää hyväksi myös Kuluttajaviraston ohjetta ohjelmapalveluiden turvallisuuden edistämiseksi (Kuluttajaviraston julkaisusarja 9/2003).

6. Lumi- ja jäärakentamista valvovat viranomaiset

Kuntien tuoteturvallisuusvalvontaviranomaisten ohella lumirakentamista valvovat myös pelastusviranomaiset ja rakennusvalvontaviranomaiset.

Kuluttajapalveluksi katsottavan lumi- tai jäärakennelman rakentamista suunnittelevan on syytä olla yhteydessä paikalliseen rakennusvalvontaviranomaiseen sen selvittämiseksi, miten kyseisen kunnan rakennusvalvonnassa suhtaudutaan tämän kaltaiseen rakentamiseen.

Joissakin kunnissa etenkin suurimpien lumirakennelmien on katsottu olevan maankäyttö- ja rakennuslain (132/1999) 18 luvussa tarkoitettuja rakennus- tai toimenpidelupaa edellyttäviä tilapäisiä rakennuksia tai rakennelmia.

Harkittaessa luvan myöntämisen edellytyksiä, tulee maankäyttö- ja rakennuslain 176.2 §:n nojalla ottaa huomioon rakennelman tarkoitus sekä lujuuden, terveellisyyden, liikenteen, paloturvallisuuden ja ympäristöön sopeutuvuuden vaatimukset. Rakennus-valvontaviranomainen voi asettaa luvan myöntämisen ehdoksi rakennelman ominaisuuksiin ja käyttämiseen liittyviä ehtoja.

Ennen lumi- tai jäärakennelman rakentamista ja käyttöön ottamista on syytä olla yhteydessä myös pelastusviranomaiseen etenkin, jos kyse on myös majoitustilana käytettävästä rakennelmasta. Muun muassa pelastuslaissa (468/2003) ja pelastustoimesta annetussa valtioneuvoston asetuksessa (787/2003) on lumi- ja jäärakentamiseen soveltuvia rakennuksen tai rakennelman omistajaa ja haltijaa velvoittavia säännöksiä.

Valvontaviranomaiset valvovat lumi- ja jäärakennelmien turvallisuutta sekä rakennelmien suunnitteluvaiheessa että käyttöönottotarkastuksin ja pistokokeenomaisia tarkastuksia tekemällä.

APPENDIX 3.

Planning drawings for snow and ice building

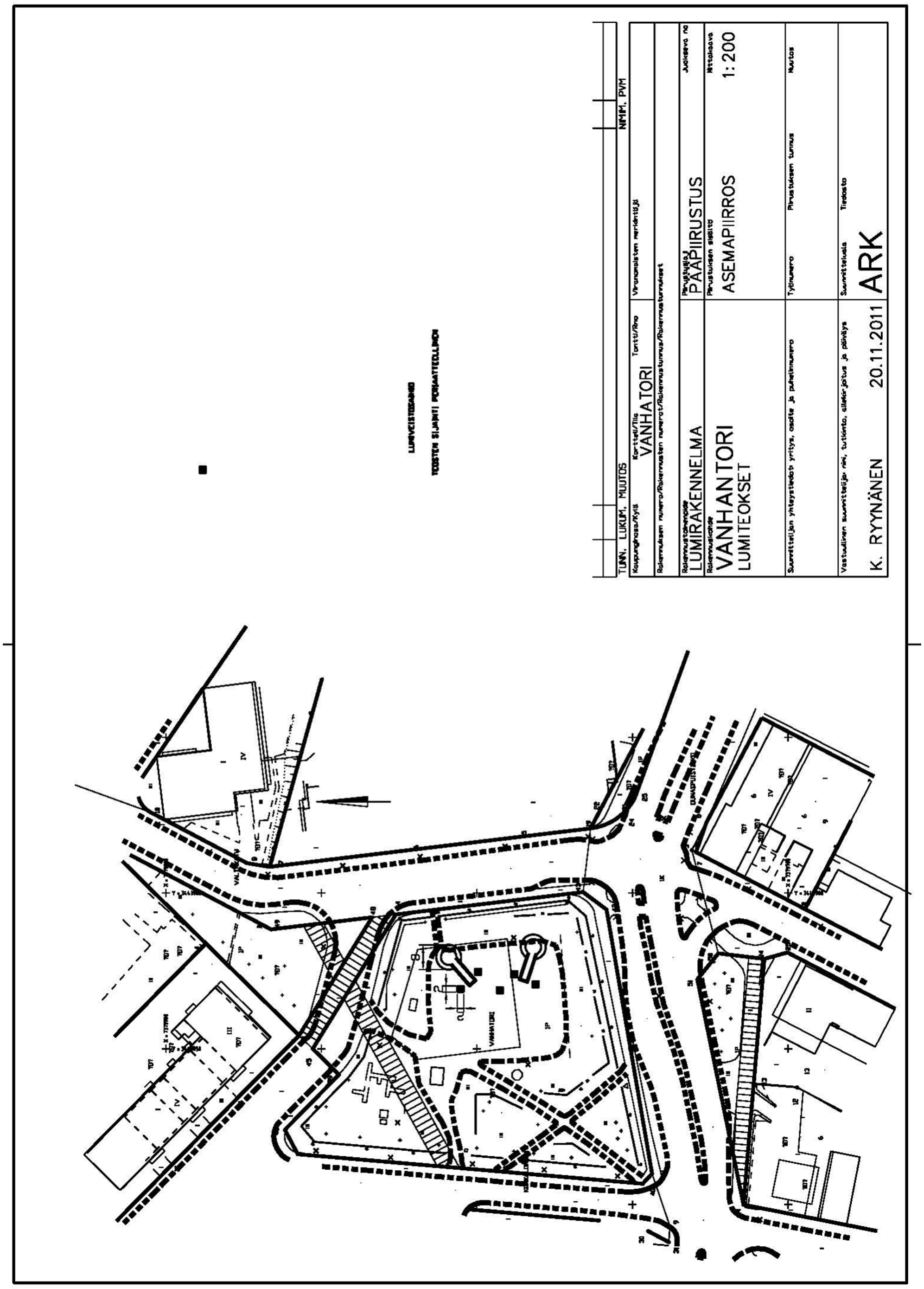


Figure 1. Site plan (Ryynänen 2011)

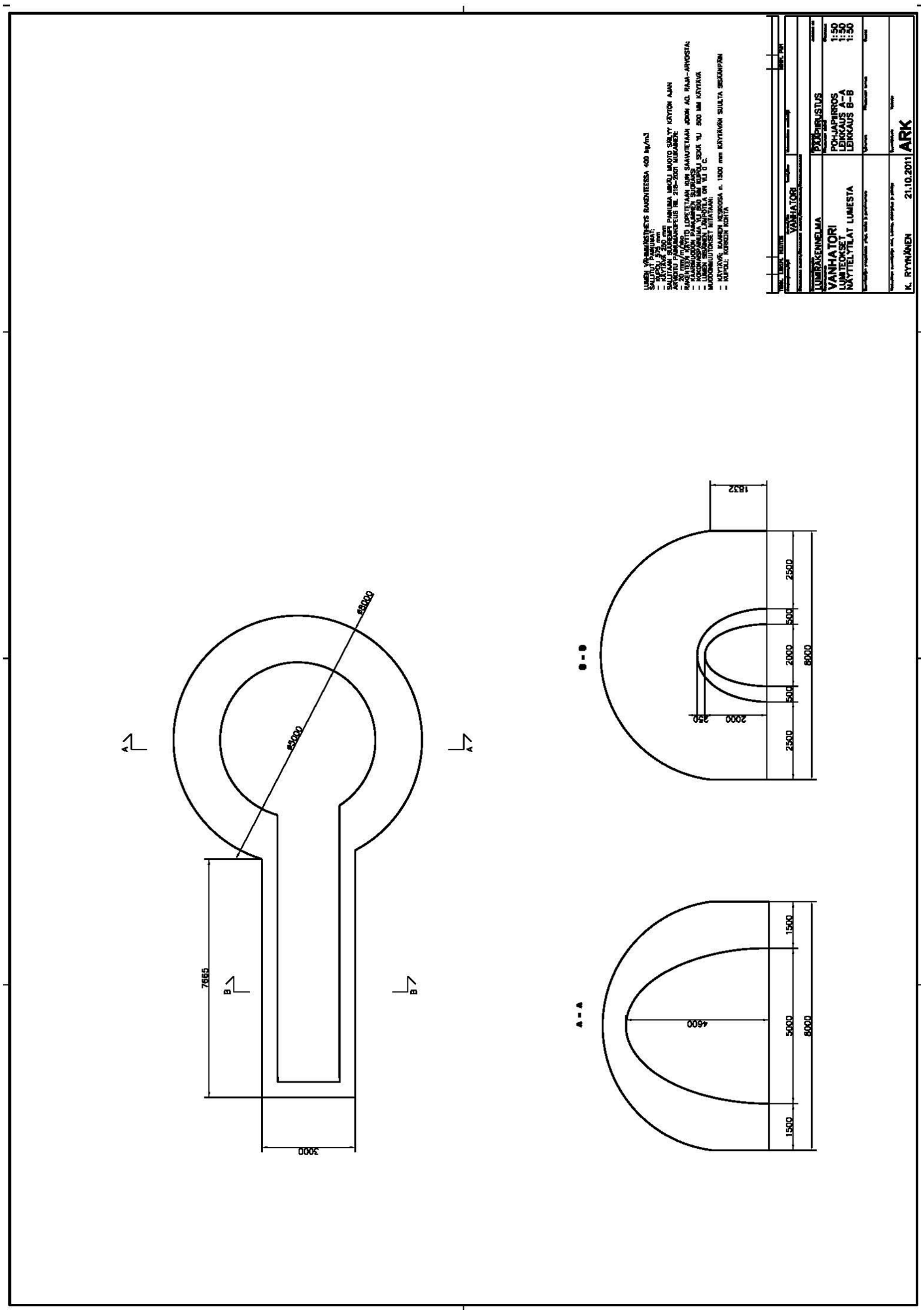


Figure 2. Exhibition space drawing (Ryynänen 2011)

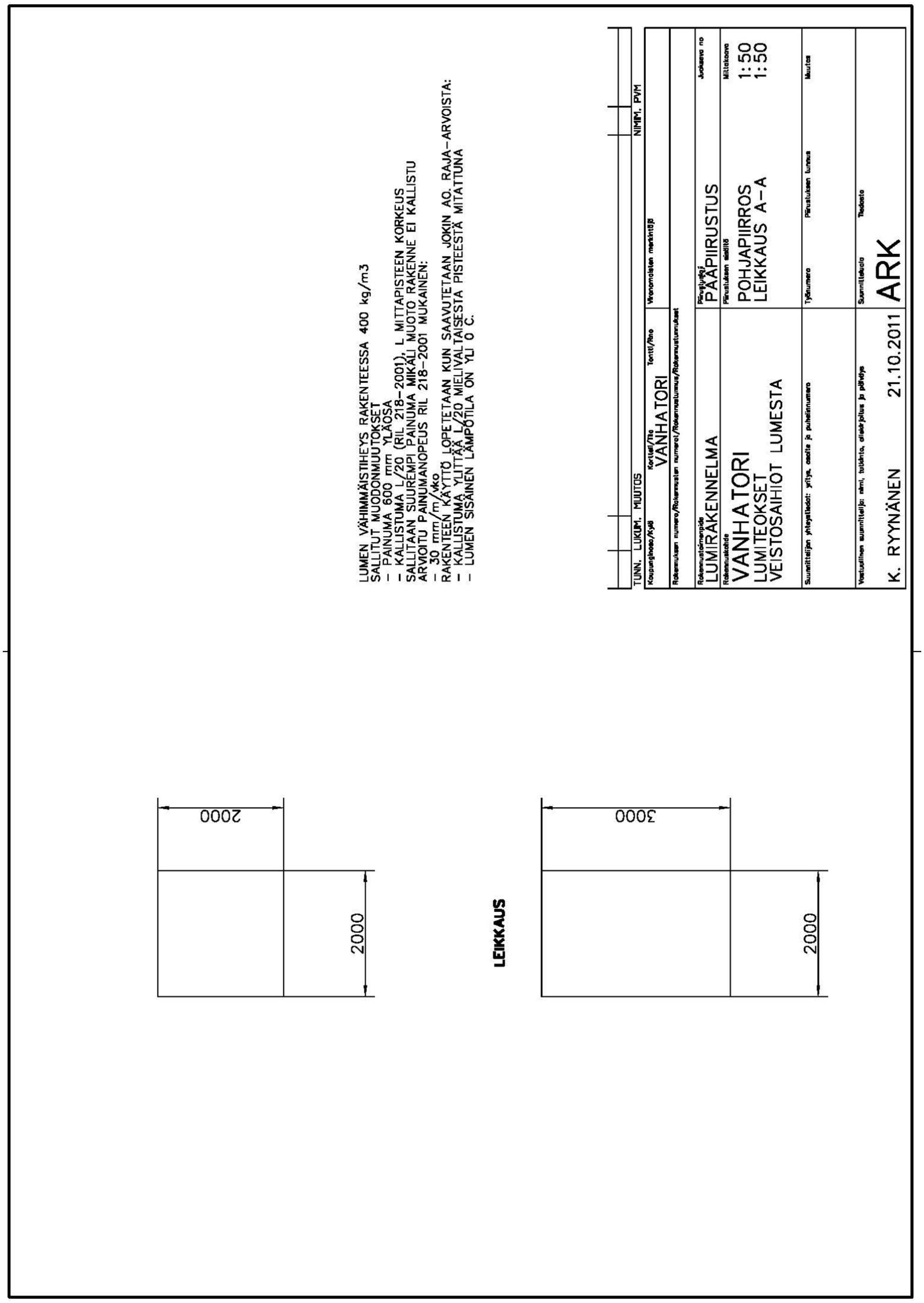


Figure 3. Snow sculpture draft (Ryynänen 2011)

APPENDIX 4.

Example of a snow and ice construction specifications

Lapland University of Applied Sciences, Rantavitikka Campus
Jokiväylä 11

SPECIFICATIONS
Snow structure in the old square

Kai Ryynänen
Rovaniemi 2011

CONTENTS

1. Site

This is a fictional site.

The site is a construction of two snow domes and an interconnecting snow corridor to be built in the old square of Rovaniemi. In addition, the site consists of two snow sculpture blocks, as well as ice sculptures to be built inside the snow domes.

According to the attached drawings, two snow domes with a snow wall will be built in the area. The nominal inner dimensions of the domes after the completion of the building: width 5 m, and height 4.6 m. The thickness of the snow wall will be 1.5 m from the lower edge. The snow wall will be built 1.5 m thick up to the height of 2 m. The thickness of snow at the top of the dome will be 0.6 m.

In the construction phase, the thickness of the upper snow layer will be measured at the top of the structure before removing the moulds. Structural strengths cannot deviate by more than ±10% (according to RIL218-2001).

Two snow corridors will be built. The dimensions of a single snow corridor are: height 2 m, width 1.2 m, and length 10 m.

The dimensions of each snow sculpture block are: height 3 m, width and length 2 m.

2. Building materials used

2.1 Snow

Artificial snow will be used in construction, with the minimum density in the construction phase being 400 kg per m^3. Snow will be made in a storage pile at least one week before the snow construction.

The density of snow will be verified using the hydrostatic weighing method, for example. The snow density will be measured randomly from snow transported to the construction site. At least five density tests per dome will be conducted. Measurement documents will be drawn up for the density tests, which will be attached to the construction documents.

2.2 Ice

Pieces of ice removed from natural waterbodies will be used in the sculpture blocks. The minimum thickness of the ice to be used will be 200 mm.

3. Material handling in the building phase

3.1 Snow compaction and grinding

Snow will be compacted mechanically by stomping. The snow will be compacted in layers of at most 400 mm. Particular caution will be observed when compacting snow along the edges of the mould. In the compaction phase, care must be taken not to stomp on the air pressure mould.

No frozen pieces of snow that would weaken the structure can remain in the snow. If they do not break mechanically, they must be removed from the structure. The snow will be processed at least twice before installation in the structure. Snow will be ground with a wheel loader before snow blowing.

3.2 Adding water to snow in slush construction

Depending on the outdoor temperature at the time of construction, snow can be processed by adding water to it for better strength. The amount of water to be added depends on the ambient temperature as well as the density of snow. No water will be added if the outdoor temperature is between 0 °C and -5 °C or below -20 °C.

3.3 Pre-treatment of ice

Pieces of ice will be shaped during the construction phase. The pieces of ice brought to the construction site will be protected and stored so that they are not moved unnecessarily during construction.

4. Construction methods

4.1 Mould construction

The snow domes will be built using air pressure and plywood moulds. A mould with a diameter of 5 m and a height of 4.6 m will be used as an air pressure mould. The outer circumference of the snow structure will be built using 6 mm film faced plywood.

The mould will be pressurised at full pressure, 2–3 kPa depending on the blower used. The mould pressure will be kept constant throughout the construction phase.

4.2 Attaching pieces of ice to each other

The pieces of ice will be attached to each other using water or slush, depending on the outdoor temperature. If the outdoor temperature is below -20 °C, the pieces of ice will be attached using water.

5. Construction phases

The snow structures will be built in the following order:

1. The snow dome on the right (when viewed from the front) will be built first.
2. The left-hand side snow dome will be built next.
3. The snow corridors will be built from right to left.
4. The snow sculpture blocks will be built from right to left.

Ice will be installed inside the snow domes before building the snow corridors. The snow domes will be built as follows:

- The dome mould will be installed supported by brackets.
- The external plywood mould and the lifting brackets for the mould will be installed.
- The diameter of the outer circumference will be measured. The snow wall thickness must be 1.5 m.
- Snow will be applied between the moulds by going around the moulds. Snow will be applied using a tractor-driven snow blower. Snow will be compacted in layers of at most 400 mm.
- Once the plywood mould has been filled, it will be raised so that at least 500 mm of plywood remains above the completed snow layer.
- Snow blowing will be continued until the height of the snow layer is 2 m.
- Snow will be blown to the top of the dome until the thickness of the snow layer is 600 mm at the top of the dome.

6. Machinery and equipment used

With regard to non-road machinery, the cleanliness of vehicles must be ensured. There can be no leaking hoses or connections. Ice and snow will be moved in the construction area using a wheel loader or tractor. Snow will be applied to the structures with a sufficiently powerful tractor-driven snow blower.
u

7. Deformation measuring points

Deformations will be measured using a tachymeter and laser scanner. For the measurements, sufficient reference points will be built in the area to make measurement observations. Measuring points for structural deformations will be placed as specified in the drawings. Measuring points:

- edges of the vent hole at the top of the domes; sagging measurement
- centre point at the top of the dome inlet; sagging measurement
- centre point of the top and in the middle at the end of the snow walls; sagging and tilting measurement

Iron bars struck into the ground will be used as fixed points: length 600 mm and Ø25 mm. A measuring point will be struck on the head of the iron bar using a stamp. Alternatively, another fixed winter-proof reference point can be used such as a sticker stapled to a tree. The reference points must be placed taking into account their permanence and visibility during winter. In addition, the maintenance of the area must be taken into account.

APPENDIX 5.

Example of an operating and safety plan for a snow and ice structure

Lapland University of Applied Sciences, Rantavitikka Campus

Jokiväylä 11

OPERATING AND SAFETY PLAN

Snow structure in the old square

Kai Ryynänen
Rovaniemi 2011

CONTENTS

1. Site

This is a fictional site.

The site is a construction of two snow domes and an interconnecting snow corridor to be built in the old square of Rovaniemi. There are snow sculptures in the area and ice sculptures inside the snow domes.

The snow domes and corridors have been made of artificial snow. The density in the construction phase was at least 400 kg per m3. The nominal inner dimensions of the snow domes after the completion of the building: width 5 m, and height 4.6 m. The thickness of the snow wall is 1.5 m from the lower edge up to a height of roughly 2 m. The thickness of the snow decreases towards the top of the wall so that the thickness at the top of the dome is 0.6 m.

Nominal inner dimensions of the snow domes after the completion of the building: width 2 m at the lower edge, and height 2 m. The thickness of the snow wall is 0.6 m at the bottom and 0.25 m at the top.

The dimensions of each snow sculpture block are: height 3 m, width and length 2 m.

2. Monitoring the structures during use

The snow structures are monitored by means of daily and weekly monitoring measurements. Monitoring is reported in writing using a monitoring form at the end of the plan, for example. The observations and measurements made are recorded in the monitoring form. Observations are acknowledged with dates and signatures.

3. Permitted deformations

Deformation monitoring and threshold values are based on the RIL 218-2001 guide for the design and construction of snow structures.

Deformation thresholds permitted at the site:

Sagging

The sagging of the snow dome cannot exceed 600 mm when measured from the centre of the interior of the dome. An excess of 10% is permitted, provided that the structure does not lose its original shape during use.

The sagging of the snow corridor cannot exceed 250 mm when measured from the middle of the structure. An excess of 10% is permitted, provided that the structure does not lose its original shape during use.

The sagging of the snow sculptures cannot exceed 600 mm. The sagging can be greater if the shape of the sculpture permits it, and the sagging is not considered to present any risk to users.

Sagging is measured from the highest point of the structure, from the points marked on the drawings. Sagging is measured using a total station and laser scanner. Sagging measurements are recorded in the monitoring plan attached to the plan or otherwise saved reliably.

Tilting

The permitted amount of tilting of the snow sculpture blocks is L/20, where L is an arbitrary height from the bottom of the sculpture. The tilting can be higher if it does not present any risk or hazard to users.

Deformation measurements

Deformations will be measured using a total station and laser scanner. For the measurements, reference points will be built in the area to make measurement observations. Fixed points will be built during the construction phase.

Iron bars struck into the ground will be used as fixed points: with a length of 600 mm and Ø25 mm. A measuring point will be struck on the head of the iron bar using a stamp. Alternatively, another fixed reference point remaining in place throughout winter can be used such as a sticker stapled to a tree. The reference points must be placed taking into account their permanence and visibility during winter. In addition, the maintenance of the area must be taken into account.

Measuring points for structural deformations will be placed as specified in the

drawings. These are:

- edges of the vent hole at the top of the domes; sagging measurement
- centre point at the top of the dome inlet; sagging measurement
- roughly 1,500 mm inwards from the end of the snow corridors, centre point of the top and the middle point, sagging and tilting measurement
- the tilting and sagging of the snow sculptures will be measured at the highest point

4. Temperature of the structures

The temperature measurement points are:

- snow domes: the connection between the snow corridor and the dome, as well as the side facing Koskikatu (south side), the height of the measuring point is 1,500 mm from the lower edge
- snow corridors: centre of the snow corridor at a height of 1,500 mm.

The indoor temperature will be monitored at the end of the use of the structures. When the indoor temperature rises to 0 °C and above, the structures will be monitored continuously.

If the outdoor temperature is more than 0 °C for more than two days, the snow structures will be closed. When the outdoor temperature decreases, the structures can be taken into use, provided that the warm period has not caused too significant deformations in the structures. The reuse of the structures will be decided after a separate inspection.

5. Density and strength of the structures

The density and strength of the snow structures will be monitored weekly during use. The density will be determined from the external surfaces of the structure using test piece measurements conducted in different parts of the structure. The density will be measured using the hydrostatic weighing method. The results will be recorded in the monitoring form.

The strength will be measured according to RIL 218-2001. The strength will be measured using a 16 mm iron bar. The bar will be pushed by hand into the snow structure at random points. If the iron bar sinks into the structure more than 100 mm without hitting it, the use of the structure must be stopped. If there is a hard layer of ice in the structure, the bar must be hit through it.

6. Dismantling the structures

All load-bearing snow structures, snow corridors and snow domes, as well as snow sculptures, will be dismantled if:

- sagging exceeds the permitted threshold values
- the structures soften quickly
- the structures lose their original shape
- the temperature of the snow structure rises above 0 °C
- the use of the structure is stopped for reasons other than deformations.

When dismantling, the load-bearing structures must be dismantled so that they do not present any risks to passers-by. All structures containing indoor areas must be dismantled by pressing the roof structures down.

7. Repairing the structures

If any places requiring minor repairs are detected during use, they can be repaired if a sufficient structural strength can be ensured and the structural shapes can be maintained. The given minimum structural strengths must be followed.

Repairs can be made in doorways and snow sculptures, for example. The minimum width of the doorway is 1,200 mm measured at the height of 1,500 mm. The height of an access opening must be at least 1,800 mm.

8. Inspecting the structures

The structures must be inspected at sufficient frequencies using reliable methods.

The following must be inspected daily:

- slipperiness of routes
- anti-slip treatment or de-icing of routes mechanically

- gritting using white gravel, if required
- condition of snow structures
- any cracks and fractures, visual inspection
- tilting and sagging
- cleanliness and structures of snow sculptures
- operation of doors
- dimensions of doorways
- condition and operation of lights
- temperature of structures and interiors (final stage)
- accumulation of water inside the structure (final stage).

The following must be inspected weekly:

- density of snow using the hydrostatic weighing method
- deformation measurements for load-bearing structures
- temperature of the snow structure (daily at the final stage)
- cleanliness of outdoor areas (daily in parts).

Rovaniemen ammattikorkeakoulu

SEURANTALOMAKE

Rakennuskohde: ______________________

Osoite: ______________________

Yhdyshenkilö: ______________________ Puh. __________

Rakenteen käytöstä vastaava: ______________________ Puh. __________

Rakenne: ______________________

pvm	klo	tarkastuksen suorittaja	ulkolämpötila	rakenteen sisälämpötila	painumat, murtumat yms.	lumen tiheys	lumen kovuus	tehdyt korjaukset	muut havainnot
			[°C]	[°C]		[kg/m^3]			

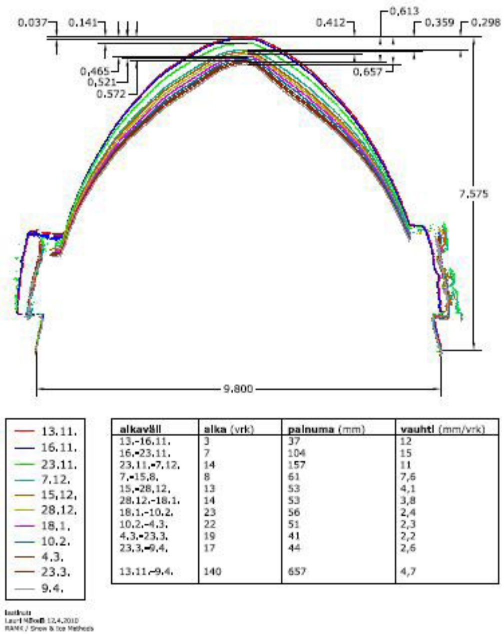
Tätä lomaketta käytetään lumi- ja jäärakenteen seurantaan. Jokaisesta lumirakenteesta tehdään oma lomake.

APPENDIX 6.

Example of the results of deformation measurements conducted for the snow and ice structure in the SNOW & ICE METHODS project.

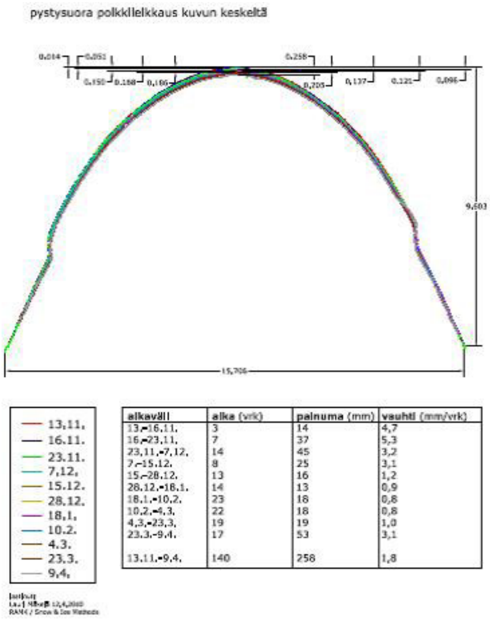
SNOW & ICE METHODS. In the research and guidance project for snow and ice construction, deformations in snow and ice structures were measured in different locations during two winters. The measurements were conducted using laser scanners. For the measurements, a reference point network was built in the structures, using which the results of different measurements were linked.

The figures below show a summary of the measurement results of different sites during the winter season in a single measurement line, usually drawn concerning the centre of the structure. The figures show the sagging of the structures, as well as the sagging rate.



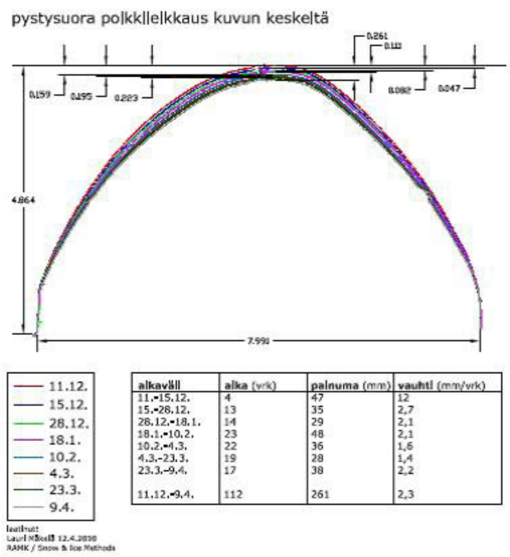
alkaväli	aika (vrk)	painuma (mm)	vauhti (mm/vrk)
13.-16.11.	3	37	12
16.-23.11.	7	104	15
23.11.-7.12.	14	157	11
7.-15.8.	8	61	7,6
15.-28.12.	13	53	4,1
28.12.-18.1.	14	53	3,8
18.1.-10.2.	23	56	2,4
10.2.-4.3.	22	51	2,3
4.3.-23.3.	19	41	2,2
23.3.-9.4.	17	44	2,6
13.11.-9.4.	140	657	4,7

Figure 1. Deformation measurement drawing of a snow structure (Mäkelä 2010)



alkaväli	aika (vrk)	painuma (mm)	vauhti (mm/vrk)
13.-16.11.	3	14	4,7
16.-23.11.	7	37	5,3
23.11.-7.12.	14	45	3,2
7.-15.12.	8	25	3,1
15.-28.12.	13	16	1,2
28.12.-18.1.	14	13	0,9
18.1.-10.2.	23	18	0,8
10.2.-4.3.	22	18	0,8
4.3.-23.3.	19	19	1,0
23.3.-9.4.	17	53	3,1
13.11.-9.4.	140	258	1,8

Figure 2. Deformation drawing of a snow and ice structure (Mäkelä 2010)



alkaväli	aika (vrk)	painuma (mm)	vauhti (mm/vrk)
11.-15.12.	4	47	12
15.-28.12.	13	35	2,7
28.12.-18.1.	14	29	2,1
18.1.-10.2.	23	48	2,1
10.2.-4.3.	22	36	1,6
4.3.-23.3.	19	28	1,4
23.3.-9.4.	17	38	2,2
11.12.-9.4.	112	261	2,3

Figure 3. Deformation drawing of a snow structure (Mäkelä 2010)

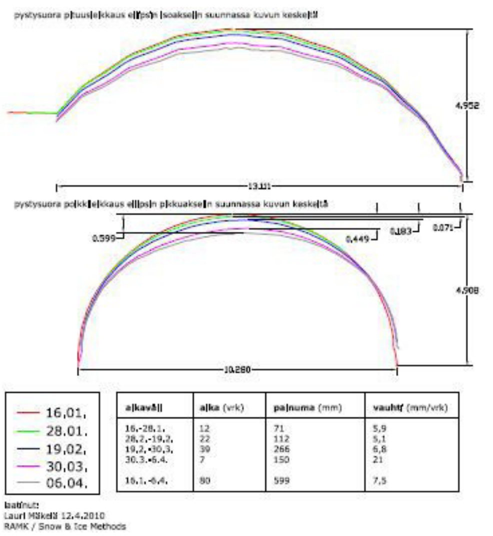


Figure 4. Deformation drawing of a three-layer structure (Mäkelä 2010)

APPENDIX 7.

Instructions for determining snow density

The density of snow in "field conditions" can be determined by various methods. When determining the density, as natural a snow sample as possible should be taken. The sample's density is calculated by dividing its mass by its volume (kg/m^3).

Several different methods can be used. The two most common options are presented here.

1. Determining the density of snow using the hydrostatic weighing method.

The hydrostatic weighing method is based on Archimedes' principle. In the method developed by Archimedes, the volume of a body can be determined by weighing the volume of the water it displaces.

Steps for determining the density of snow:

- A 4–7 litre piece is cut from snow.
- The test piece is shaped to be as round as possible.
- The piece is placed in a sealed plastic bag.
- The test piece is weighed using a sufficiently accurate scale. The measured weight of $_{snow}$ (kg) is recorded.
- The volume of the piece is determined by immersing it in bag in a container of cold water with an overflow connection/tube.
- A vessel and scale are placed under the overflow tube.
- The test piece is completely immersed in water.
- The amount of water displaced is weighed.
- After immersion, the piece is weighed again to ensure that it has not absorbed any water.

The weight of water displaced by the piece (in kg) is the volume of the piece (in m^3), as the density of water is 1,000 kg/m^3 (i.e. the volume of 1 kg of water volume is 0.001 m^3).

Example. Determining the density of snow using the hydrostatic weighing method.

A sample cut from snow weighs 3 kg in a sealed bag. The weight of water displaced by the piece is 6 kg. The volume of the piece is obtained when it is known that the weight of water by volume is 1,000 kg/m^3 => the volume of the sample in question is 0.00600 m^3.

The density ϱ can be calculated as follows:

$$\rho = \frac{3\ kg}{0{,}006\ \mathrm{m}^3} = 500\ kg/m^3$$

The accuracy of the weighing immersion method is affected by sample handling and the accuracy of the water measurement. It is important in this method that the sample bag is sufficiently sealed so that snow cannot mix with water. According to the measurements made, the method achieves an accuracy of ± 5 kg/m3. The method is suitable for density measurements carried out during the construction phase. Suitable water containers and a reliable scale must be used in the method.

2. Determining the density of snow using a sample drill

For example, a metal tube with a diameter of 72 mm and with a serrated edge at one end and a turning handle at the other can be used as a sample drill. A sample is taken by drilling the tube into a snow wall at the depth of 150–230 mm, after which the tube and the sample it contains are weighed. The weight of the pipe is subtracted from the result. The depth (h) of the hole left by the sample taken from the wall is measured to calculate the volume (V) of the sample using the inner diameter of the tube. The density of snow (kg/m^3) is calculated by dividing the weight by the volume.

Example. A sample drill is used to drill a 170-mm-deep hole (h) in a snow wall. The weight of snow left in the drill is 1.442 kg.

The inner diameter of the

sample drill is $A = \pi r^2 = \pi \times$

$(0.072\ m)^2 = 0.0163\ m^2$

The volume of the sample is

$V = h\pi r^2 = h \times A = 0.170\ m \times 0.0163\ m^2 = 0.0028\ m^3$

The density is calculated by dividing the sample volume by its weight.

$$\rho = \frac{1{,}442\ kg}{0{,}0028\ \mathrm{m}^3} = 515\ kg/m^3$$

According to the measurements made in the SNOW & ICE METHODS project, factors that affect the measurement accuracy include the estimated volume of the sample taken, as well as weighing errors, when using a sample drill. The estimated volume, i.e. the accuracy of measuring the sample depth, affects the density by +/- 5 kg for every 10 ml. When measuring the weight of snow, an error of 10 g causes a variation of roughly +/- 5 kg in density. The accuracy can be improved by taking samples of larger volumes.